The WaterStrategyMan DSS
A Comprehensive Decision Support System for the Development of Sustainable Water Management Strategies

Preface

This work presents the concepts, the philosophy and the implementation of the WaterStrategyMan Decision Support System. The package has been developed within the *WaterStrategyMan Project* “*Developing Strategies fir Regulating and Managing Water Resources and Demand in Water Deficient Regions*” - EVK1-CT-2001-00098, a project supported by the European Commission under the Fifth Framework Programme, contributing to the implementation of the Key Action *Sustainable Management and Quality of Water* within the *Energy, Environment and Sustainable Development*.

The main objective of the work undertaken was the formulation of improved resource and demand management strategies, being appropriate for arid and semi-arid regions in the Mediterranean in the context of implementing the European Water Framework Directive 2000/60/EC. The directive has introduced a new model of water management and planning, which aims at accomplishing Integrated Water Resources Management and at maintaining or improving the environmental integrity of aquatic systems. Special emphasis is given to the use of management practices that account for cost recovery of water services and for a sustainable exploitation of water resources, and that concern non-structural solutions and strategies. The European Community is enforcing the passage from a Dominant Paradigm of water management, characterized by massive engineering projects for finding new sources of supply to meet new demand, towards a New Shifting Paradigm that incorporates ecological values into water policy and considers the environmental costs a society has to pay for ecosystem degradation and water resources contamination.

Six case studies were selected, representing typologies of arid or semi-arid regions with respect to natural conditions and infrastructure, economic and social system and the Decision Making Process. These are: the island of Paros (Greece), the region of Algarve (Portugal), the area of Limassol (Cyprus), the island of Tenerife (Spain), the areas of Tel Aviv and Arava (Israel), and the area of the Belice River Basin (Italy). Dominant Paradigms and Shifting Paradigms were respectively identified and proposed for them, with the help of the DPSIR framework of indicators defined by the European Environment Agency (Smeets *et al.,1999*): Driving Forces, Pressures, Impacts on the Status were recognized and the related existing traditional Responses, i.e. Dominant Paradigm and the new alternative Responses, i.e. Shifting Paradigm, were formalised in terms of strategic policy options.

The development of the Decision Support System was functional to the analysis of the dominant and shifting paradigm options and of their quantitative, qualitative and economic impacts in the selected regional water resource systems. The primary intent was to develop a tool, able to simulate the behaviour of water resource systems under different scenarios of water availability and demand, and including a module for simulating and evaluating the alternative water strategies. Its implementation was preceded by a comprehensive review of existing suitable methodologies and models for water resources and an analysis of their strong and weak points led to the definition of the present architecture of the DSS. For the sake of clarity, the developed WSM DSS applicable to the Paradigms of Water Deficient Regions in Southern Europe is presented in the Part I of this volume, while the review of tools is outlined in Part II. More specifically, Part I consists of ten chapters, each presenting a specific characteristic or module of the WSM DSS. Chapter 1 introduces the objectives of the dss and the use of the DPSIR framework. Chapter 2 illustrates the main components of the graphical user interface, which represent the working environment for the water resource analyses. Chapter 3 describes the schematisation adopted for studying water resource systems within the DSS, and how required data and information have been organised into a geodatabase. Then Chapters 4 to 10 present the steps the DSS user has to go through in order to simulate a water system. These are: the creation of climatic and demographic scenarios (Chapters 4 and

5), the application of strategic options with the scope of improving the state of the system and mitigate the impact of driving forces and pressures (Chapter 6), the setting of initial and boundary conditions for water quality scenarios (Chapter 7), and finally the simulation and the evaluation of results, including economic indicators (Chapters 8 to 10). In Part II, a chapter is assigned to each reviewed tool.

The WaterStrategyMan Project partners who have been actively and directly involved in the DSS formulation, development and finalisation are: the National Technical University of Athens, the Ruhr-University Bochum and ProGEA S.r.l.. Nonetheless, invaluable support was offered from all project partners, who either contributed to the methodology definition or applied and tested the software to their own case study. Those are: Office International de l'Eau, Hebrew University of Jerusalem, Water Development Department (Governmental Department – Cyprus), INSULA (International Scientific Council for Island Development), Aeoliki Ltd, and Faculdade de Engenharia da Universidade do Porto. They are all gratefully acknowledged.

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ProGEA S.r.l.

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Part I

The WaterStrategyMan Decision Support System (WSM DSS)

Chapter 1 Introduction to the WSM DSS

Basics

The GIS-based Decision Support System developed for the WaterStrategyMan Project (WSM DSS) aims to assess the state of a water resource system in terms of sources, usage, water cycles (pathways) and environmental quality. In addition, it evaluates the effects of actions, on the basis of different scenarios, alternatives and policies. Water allocation is performed according to a set of demand and supply priorities reflecting the pricing system, social preferences, environmental constraints and development priorities. Among the many ways of classifying implementation approaches or policy options, social system responses are of particular importance for the WSM DSS, being conceived as four types of management options:

- **Supply enhancement options**, intended to increase available water quantities during drought; they concern structural interventions which attempt to enhance water supply;
- **Demand management options**, aiming at decreasing water demands through various conservation techniques and use limitation;
- **Socio-economic measures** needed to mitigate impacts, also by means of socio-economic instruments, such as pricing and changes in the regional development priorities;
- Methods able to produce management strategies through **combinations** of control measures seeking optimum and efficient solutions.

The WSM DSS can model water conditions in a given area and be used to estimate how much water is needed to meet the existing and projected demand, to determine what interventions are necessary, as well as when and where, and their cost. It can provide indicators of performance for selected actions under potential availability and demand scenarios, and use them to rank the scenarios. The DSS supports the user to assess the functionality and performance of the water system within the entire region of application as well as individual points of interest.

Key words in the WSM modelling approach are: *Description, Assessment, Strategy, Forecasting* and *Evaluation*. They reflect the main functions of the DSS, which, through the assistance of Geographical Information Systems (GIS) and properly customised databases, aim at:

- **Describing** the existing situation in a case study area, in terms of hydraulic and environmental characteristics of manufactured and natural water systems;
- **Assessing** the state of a water system addressing different aspects such as available water sources, actual usage practices, water cycles (paths), environmental quality and economic issues;
- **Defining and applying** alternative strategies for an integrated water resource management, built on technical management options/actions;
- **Forecasting** the behaviour of the water system state, on the basis of assumed or envisaged scenarios of water availability, and water demands for different types of uses;
- **Evaluating** the impacts of the actions, by observing and analysing the results of forecasted scenarios, alternative options and policies, through a multi-criteria evaluation approach and consideration of local, national or international legal constraints and directives.

The DPSIR Framework in the WSM DSS

In order to facilitate regional case study analyses, pinpoint any water related problems and identify a list of possible solutions, the main functions of the WSM DSS have been framed under the Driving Forces-Pressures-State-Impacts-Responses (DPSIR) structure of indicators as adopted at the European level by the European Environmental Agency.

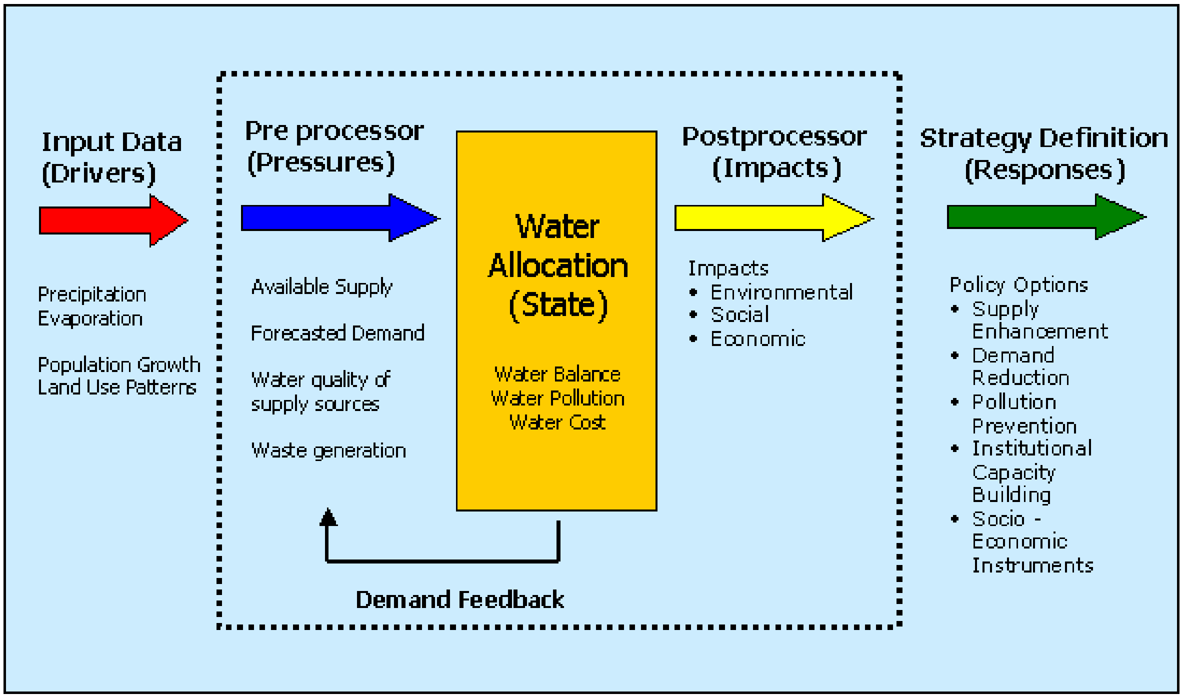


Figure 1 The framework of the WSM Decision Support System

Driving Forces are defined as natural phenomena and anthropogenic activities that are not easily manipulated (Walmsley, 2002). In the WSM DSS they are represented by climate changes, demographic growth and change of land use patterns. The first implies variations of precipitation, evapotranspiration and temperature that, along with land use patterns, influence the surface and groundwater balance of the region, thus increasing or decreasing available water resources. The second, relating population growth over time, is one of the leading factors in determining domestic water demand. The analysis of Driving Forces, and the definition of Pressures they exert on a water resource system, is performed by the pre-processors of the WSM DSS, the *Water Availability* and the *Water Demand Modules*.

Pressures, such as water quality of supply sources and pollutant loads generated by human activities are computed before simulating a water resource system. The *State* of the system is described in terms of water allocated over the amount requested, of water quality changes at the water sources, uses and treatment plants, and as an economic analysis of water services and uses.

The **State** is based on results of the *Water Allocation Module* which is the Kernel of the WSM package. Water is allocated through the system, from water sources, such as lakes, aquifers and river reaches, to water demanding uses, such as irrigation sites, settlements, animal breeding facilities etc. The allocation is based on priority rules, assigned to both demand sites and supply elements. Supply allocation rules can express cost, quality or conservation preferences, whereas demand rules reflect social objectives or regional development priorities.

The post-processor of the DSS is the Evaluation module, whose main function is the computation and presentation of indicators regarding environmental and socio-economic **Impacts**, such as high direct costs, insufficient cost recovery, user-conflicts under shortage conditions. Through a multi-criteria evaluation of indicators, Decision Makers can draw their conclusions and start formulating **Responses**, here standing for alternative policy options which may alleviate impacts and confront the water-related problems.

Water management schemes

The WSM DSS depicts water resource systems supported by GIS software and by Geodatabases. Available water resources, water users and treatment plants are geo-referenced and loaded on the graphical interface as point geographic features into the ESRI shape file format. The water paths in the system are identified by line features, which connect water sources to users. This water network is the subject of all the operations the DSS user can put into practice with the WSM DSS: from the creation of water availability and water demand scenarios, to the water allocation and the computation of indicators, from the definition of water strategies to economic analysis and the comparisons of alternative water management schemes. The nodes and the links of the water network are described in Chapter 3.

Chapter 2 Architecture and Operational Aspects

This chapter describes the main characteristics of the graphical user interface of the WSM package and introduces the schematisation of water resource systems and their simulation.

Opening windows and Operating Interface

The Decision Support System starts with a Splash Screen (Figure 2), followed by a *Region Selection* window that shows the countries under which a new case study can be defined. Because initially the software package was developed with the purpose of simulating case study regions within the WaterStrategyMan Project, the window contains entries for the six countries involved, Greece, Portugal, Israel, Spain, Italy, and Cyprus. Definition and loading of a region requires the respective ArcINFO Geodatabase, containing all information needed by the DSS to run properly, and a folder containing a set of maps in raster and shape file format, including the Digital Elevation Model (DEM), climatic data and soil data. The ArcINFO geodatabase used by the WSM DSS is a relational database, developed by ESRI in the ArcGIS software (2001) that contains geographic information organised as feature classes and tables. Details about data requirements and structure for the WSM DSS are given in Chapter 3.

Figure 2 The Splash Screen Image of the WSM DSS

After the selection of a case study region, the main Graphical User Interface opens, with the *Navigation Panel* on the left. The Navigation Panel is always loaded, whatever functionality or sub-module is running, and presents the **Base Case** and the list of **Water Management Schemes** associated with it. The Base Case represents the case study region as it was when the region was registered in the DSS. Therefore, its geodatabase contains all recently measured data that characterise the actual current water management of the case study. The Base Case is not simulated within the DSS tool; however, it can be edited to update available information on the conceptual network of nodes and links that schematise the water resource system. Data entry and network modifications can be performed in the relevant windows accessed through the *Edit Base Case Data* menu of the Base Case, in the **Navigation panel**.

Once update operations on the Base Case are complete, one or more **Water Management Schemes** (WMS) can be created as its copies; water management schemes are the actual object of the DSS analysis. For each WMS, the water allocation from sources to demand sites can be simulated under user-generated scenarios of water availability and/or demand, and strategic options selected and applied to particular time periods. Each WMS, when created, works with the data of the base case at the beginning; however both data and water network can be modified, thus customizing the scheme according to the type of analysis and objectives of the Decision Maker.

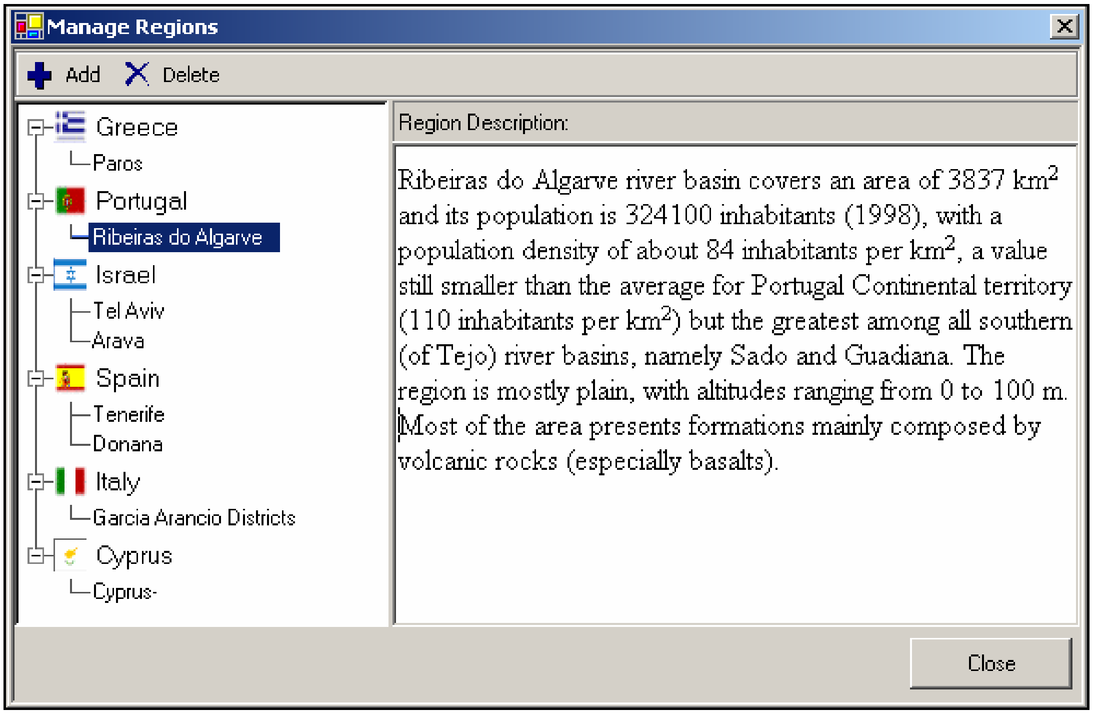


Figure 3 The Window for managing the case study regions loaded on the DSS

Generated water management schemes appear listed in the Navigation panel, just under the Base Case. The selection of one of them provokes the opening of the related geodatabase and the loading of all network maps and information needed for running the simulation. Then a tree view expands under the scheme name, presenting the menus that will support the user throughout modelling and evaluation. There are three broad categories of submenus: *Create Scenario*, divided into *Availability* and *Demand* sub-menus, *Create WMS*, including the *Modify Map*, *Modify Data* and *Apply Strategy*, and *Analysis*, with the *Overview*, *Economic Analysis* and *Detailed Results*. Each functionality and the related DSS module are presented in the corresponding sections of this volume. In this section the Modify menus are discussed, since they incorporate three important and useful parts of the interface, the **Object Manager**, the **Data Editor** and the **Map Editor**.

The **Object Manager** is a tree view form, opening next to the Navigation Panel. It presents the nodes and the links of the schematised water resource system, classified by type, firstly according to their role with respect to the allocation (e.g. demand nodes, supply nodes or treatment nodes) and secondly according to their specific water use or resource type (e.g. industrial, domestic, aquifers, storage reservoirs etc). Categories can be expanded to the desired level of detail while each object type is marked with its own coloured symbol. This symbol characterises all the elements on the regional map that displays the water network (see Map Editor section), and other geographic layers. Each network object is identified by a user-defined name, and the unique identifier (ID) appearing in brackets next to the name. The Object Manager is used for navigating through network elements, in order to get node or link-specific information when used in combination with the Data and Map Editors of the WSM DSS.

Data Editor

The Data Editor (DE) of the WSM DSS gives access to data characterising the analysed region. The DE has two functions:

- ❖ It **shows** the data that already exist in the regional geodatabase, and have previously been prepared by the user, and
- ❖ It allows to **edit** the data or simply to enter the information for the first time, directly from within the DSS.

The user opens the DE from the Navigation Panel, on the left in the GUI, by clicking on the *Data Editor* or *Modify Data* options, according to whether Base Case or Water Management Scheme editing is active. The DE comprises of a series of tabs, grouped together in a dedicated resizable panel in the top-right of the GUI.

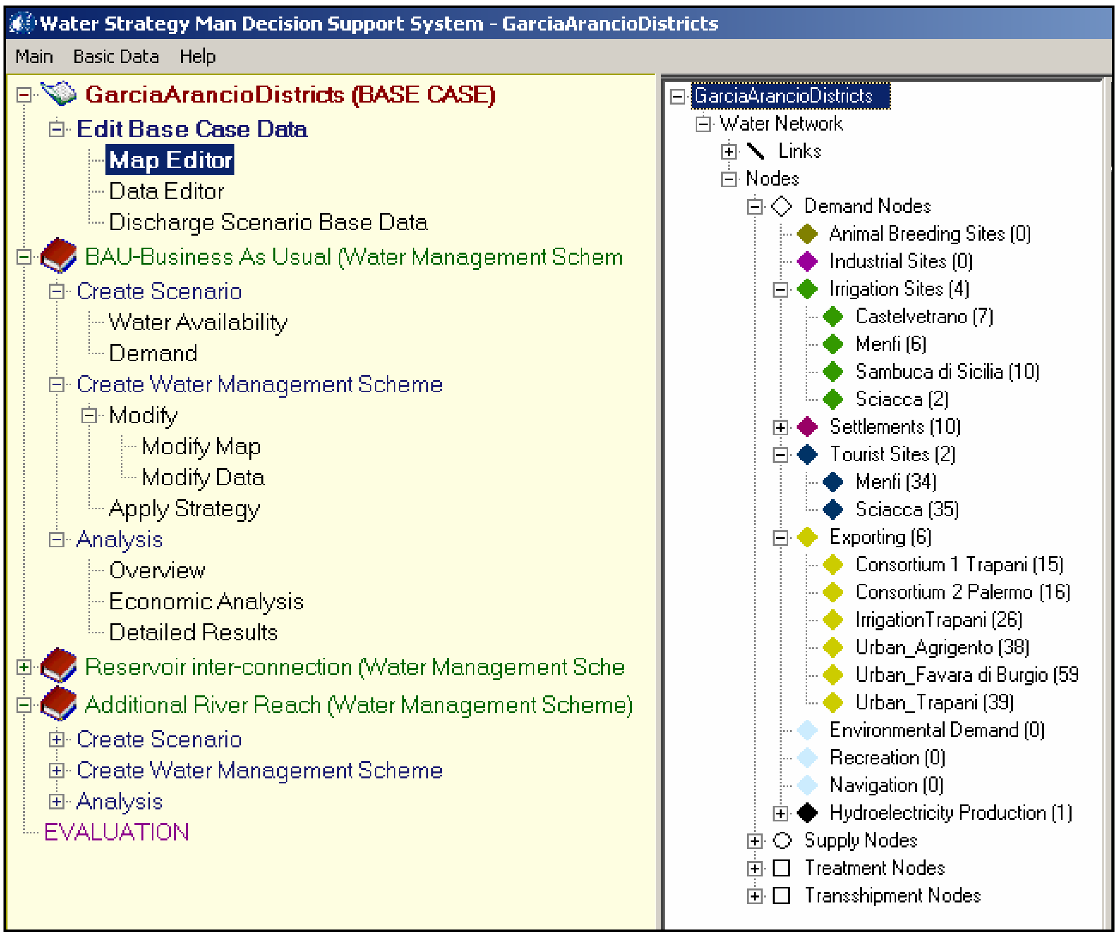


Figure 4 The Navigation Panel (left) and the Object Manager Panel (right) of the DSS

Each tab consists of a list of information addressing specific aspects of the network element accessed. For example, the first tab, *General,* contains basic information, such as identifier, name and allocation priority. Generally, information is organised under three different columns: the first presents name and type of information, the second presents the value that can be edited and the third provides a short explanation of the attribute. The classification of information in other tabs is presented in more detail throughout this volume. They mainly concern irrigation activities and methods, permanent and seasonal population, water distribution losses and costs, water resources quality, and more.

As already said in the Navigation Panel description, the Data Editor presents data characterising the elements of the water resource network in the analysed region. Those network elements represent: 1) available **water resources**, such as groundwater, river reaches and reservoirs, 2) **water uses**, among which settlements, irrigation sites and animal breeders, 3) **treatment and transhipment** plants and structures, and 4) their inter**connections** such as canals and pipelines that link them all conceptually and physically. All water network elements are schematically represented in the DSS in terms of coloured spots and links placed on the region map.

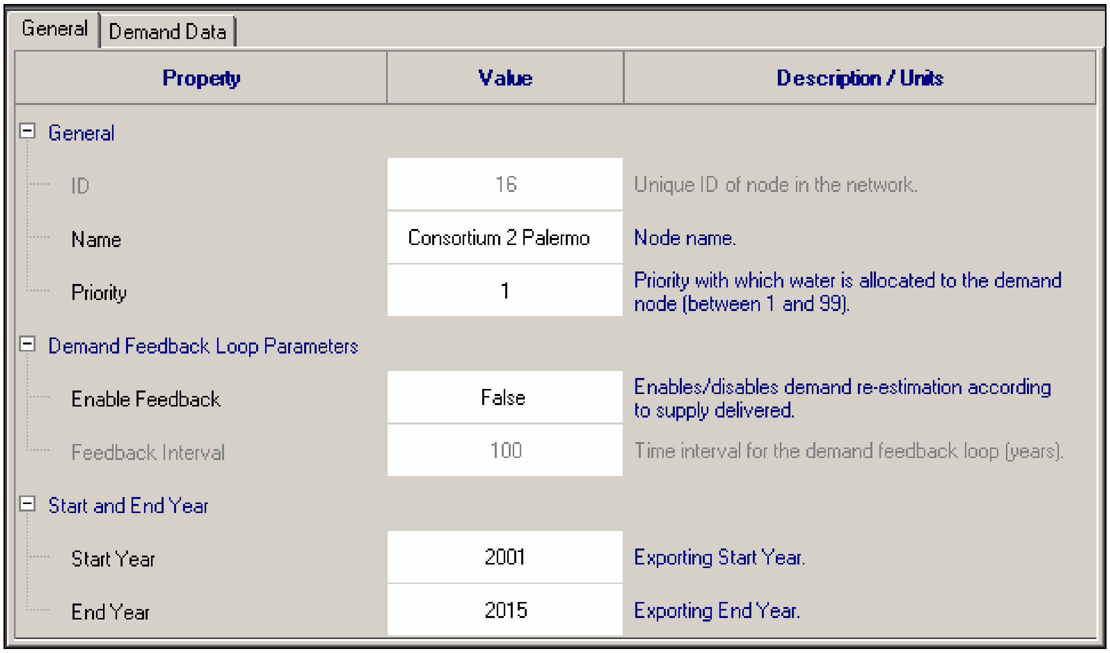


Figure 5 The General tab of the Data Editor for exporting nodes

In order to enter the DE of a network element, the DSS user can do two things: select the object from the Object Manager panel, which lists the nodes and links of the network in a tree view form, or select the object from the Map window, which displays them on the region map. Both functionalities enable the user to view and manipulate data associated with the network features. For example, through the Object Manager, the user can navigate through all list items and left-click on those he wants to see data for. The name of the item is highlighted on the Object Manager, and the corresponding feature is selected on the Map. The Data Editor panel is recalled with all the data loaded on it. On the other hand, if the user is looking at the map and the target item is visible in front of him, it will be much easier to double-click on it directly, rather than navigate to it from the Object Manager. The click on the map element provokes the DE opening in the same way as it opens from the Object Manager panel. The advantage of doing that from the Map View is evident in case the user is well aware of the geographical location of the target elements. On the contrary, opening the DE from the tree list may be helpful in case the user needs to edit or compare data related to many items of the same category, e.g. all pipelines, since they are all placed in the list one below the other, and not scattered on the map.

The two options are interrelated. The water network element that is selected by the user from the Object Manager is also automatically selected on the region map. Vice versa, when the user left-clicks on a node or link in the map the item is also automatically highlighted in the tree view.

When running the DE, either from the Base Case or from a Water Management Scheme, the panel opens with a preloaded table, showing the priorities by default associated with the different demand node categories. Demand priorities are used by the allocation algorithm of the WSM DSS for distributing water from water sources to uses. They establish the rank of each demand node, assigning each one the right to receive water before all others with lower priorities. Demand priorities are a sort of discriminating factor, being useful and determinant when handling water shortage situations and conflicts between competing uses. A demand node can have a priority ranging from 1, the highest, to 99, the lowest.

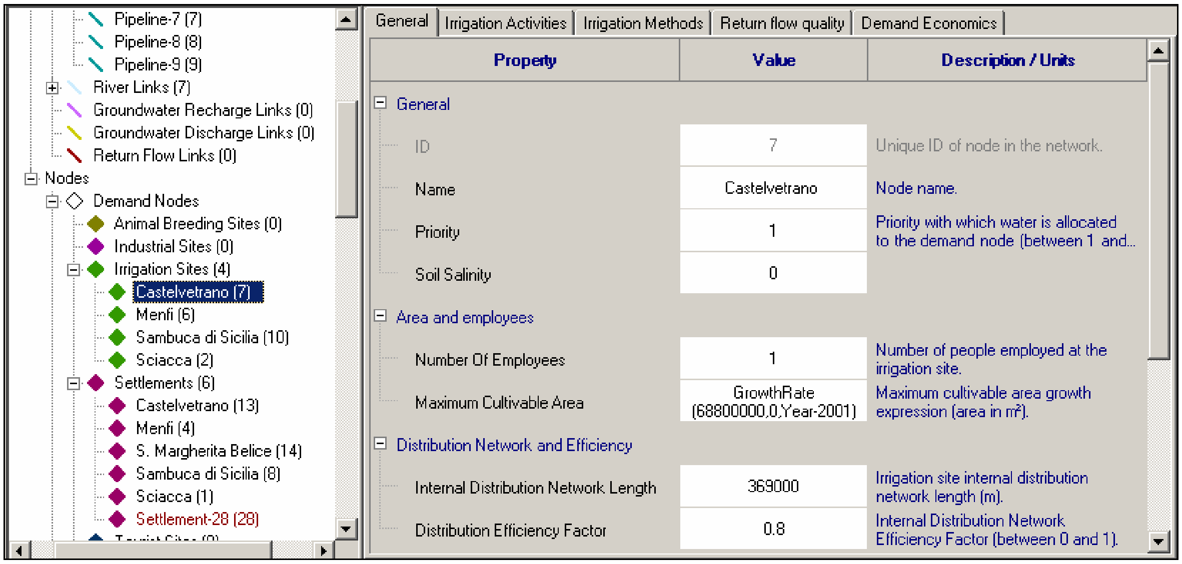


Figure 6 Opening the DE editor for irrigation site Castelvetrano (on the right) from the Object Manager Panel (on the left)

The default priorities are associated with categories of nodes according to the demand type: the maximum, 1, is attributed to domestic uses, i.e. settlements and tourist site nodes, a value of 2 is attached to irrigation and animal breeding, a value of 3 to industries and hydroelectricity plants, while values of 4 and 5 are by default assigned to minimum flow requirements in river reaches, either for aquatic life protection and preservation, or for recreation and navigation purposes. A default priority of 6 is given to export nodes that account for water transfers for meeting water needs in neighbouring regions.

Default priority values can be changed for one or more single demand nodes through the *General* data editor tab of the node. Demand priorities can also be modified through the Map Editor: the selection of a demand node either on the map or in the Object Manager panel invokes the opening of a small *Properties window* at the bottom of the Object Manager panel. Here the user can find the name, the identifier (ID), geographic coordinates and priority of the node. All information, except the ID (which is locked for editing), can also be edited. Every property modification can be verified on the map, through the labeling values appearing in square brackets next to the name of the node.

In case that many demand nodes have been assigned new priorities, and the user would like to roll back to the original default priority assignments, default priority values for each node category can be restored using the *Apply To All* button of the preloaded data editor table. This table is reachable from the Manager Panel, *Modify Data* or *Data Editor* menus, but also from the node navigator, by selecting the name of current water management scheme, placed at the top of the tree view of the Object Manager panel, just above *Water Network.*

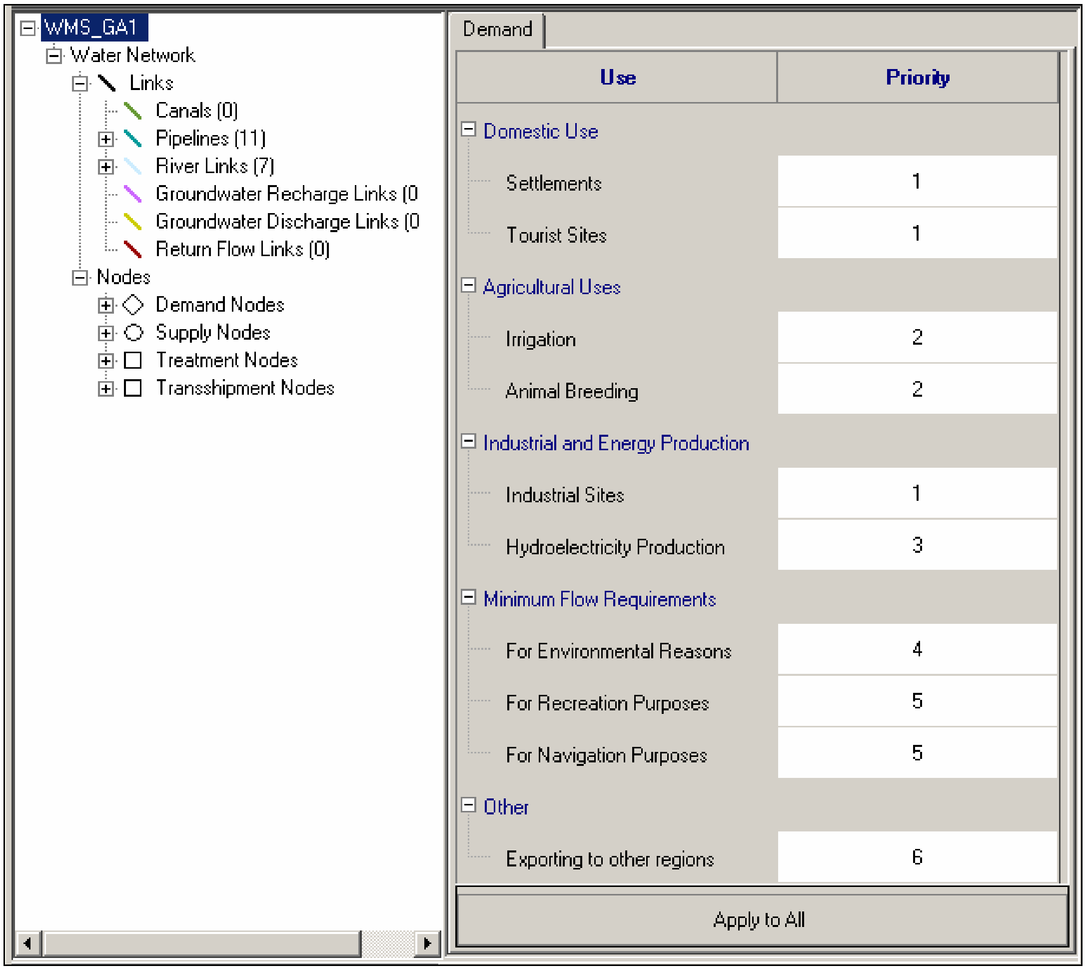


Figure 7 The Default Priority Window of the Data Editor

In addition to the demand priorities that rank the demand nodes with respect to each other, a rule for the use of alternative available water sources is also considered, the **Supply Priorities**. This information is attached to every supply link connecting a water source node to a demand node and, similarly to demand priorities, values range from 1 (highest), that is usually the default value, to 99 (lowest). Supply priorities are used to define a preference or a constraint of use for a demand node that is supplied from multiple water sources. The supply node whose link has the higher priority will be exploited first, i.e. water will be abstracted and allocated to the connected demand node prior to the use of others with lower supply priorities. The DSS user can change the default values that are assigned to links in the corresponding *General* tabs of the Data Editor.

Map Editor

Some functionalities of the Map Editor have already been presented. The **Map Editor** (ME) is launched for a Water Management Scheme from the Navigation Panel, *Modify Map* menu. The map window embeds a GIS control, and two toolbars. The *Network Editing* toolbar is located at the top of the Map Editor View and can be used to place new geo-referenced elements on the network. It contains four drop-down buttons each referring to a category of node/link, which permit the user to select a type of node/link within the category and to position it on the map on the desired geographical location. The four buttons are: *Supply Node*, *Demand Node*, *Treatment Node* and *Link*. The new element is highlighted on the map with a red spot/polyline and the small *Properties Window* is loaded in the interface under the Object Manager, showing the geographical coordinates (or the length) and the default allocation priority. Network links have to be drawn between two nodes following the direction of the water flow: if a new pipeline must be placed, connecting a water source to a demand node, the user has to click the former and then end the geographical feature polyline with click on the latter.

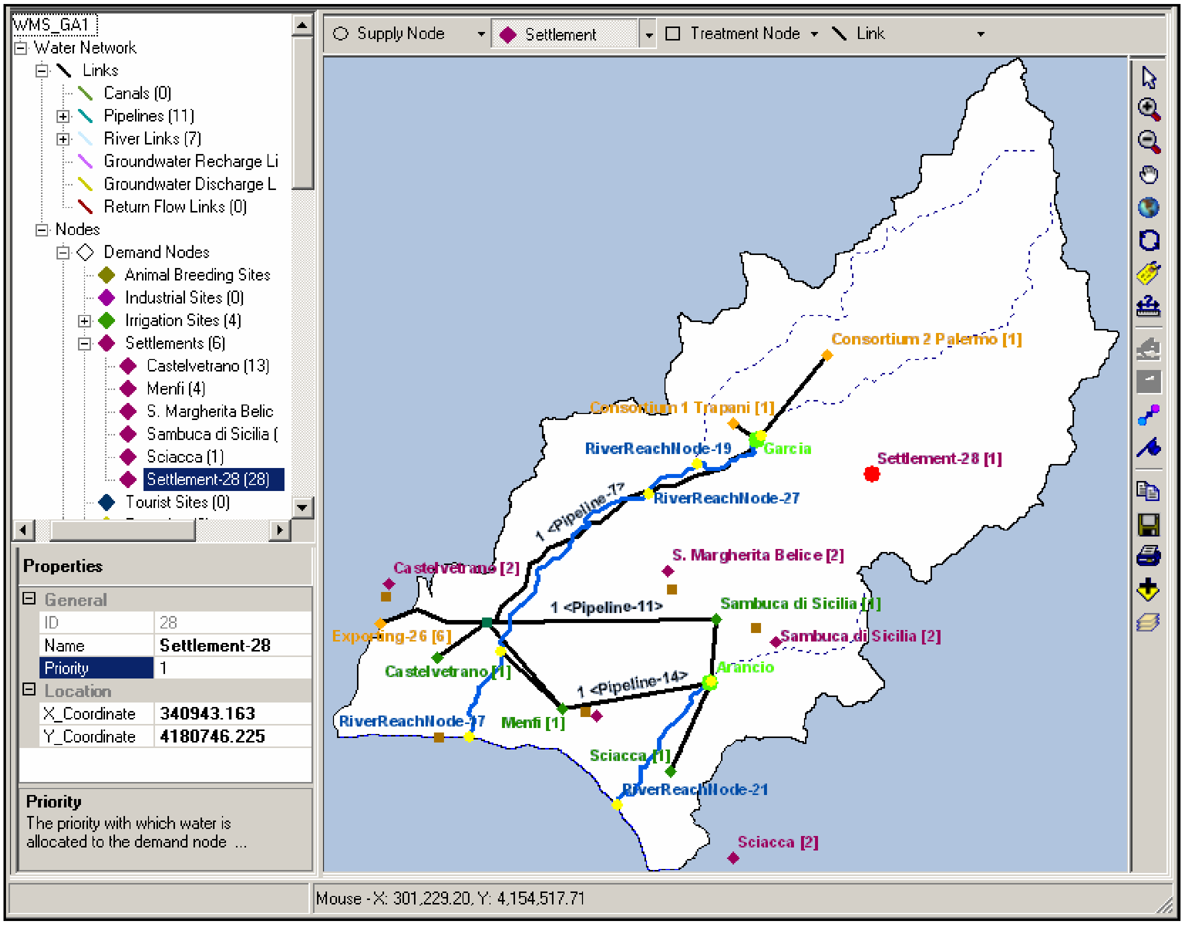


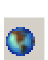
Figure 8 Creating a new settlement (28) with the Map Editor

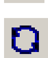
The toolbar on the right of the map window makes available a number of GIS functionalities that are necessary to work with the map. They range from common ones, such as the Zoom, Pan and Labelling to more advanced ones, such as the Flip Tool and the Move Point Tool, and are summarised below.

 **Select**: selects a network element on the map and loads properties or data table;

 **Zoom**: enlarges or reduces a portion of a geographic dataset to display greater or smaller detail;

 **Pan**: moves the viewing window up, down, or sideways to display areas in a geographic dataset that, are not visible at the current viewing scale;

 **View Full Extent**: zooms to the full extent of the data in the map;

 **Refresh Map**: redraws the map

 **Labels**: customises annotation on a map that provides information on the network nodes and links;

Measure Distance: measures a distance on the map;

Add/Edit Links Vertices: adds or moves vertices on a polyline (link);

Flip (Reverse Link Orientation): reverses the direction of a polyline so that the last vertex of the sketch becomes the first, if such an operation is permitted by network connectivity rules;

Move Point: moves a point (node) and its attached links on the network;

Clear Unconnected Network Junctions: deletes all unconnected network junctions[1];

Add layer (map): used to load additional geographic data in shapefile format or from the regional geodatabase;

Table of contents: lists the layers/maps loaded in the Map window. Each of them can be switched on /off in order to make it visible or not in the map;

Copy: copies the map to the Windows clipboard;

Save: saves a picture of the map in different formats (jpeg, emf, bmp, eps);

Print: prints the map.

[1] Network junctions are created by default when links are split. They have no modelling functionality but are used to maintain the network connectivity.

Chapter 3 Water Network Structure and Database structure

This chapter describes the schematisation of water resource systems in the WSM DSS in terms of nodes and links of a water network, as well as the structure of data in the relational geographic database that stores all information characterising the geographic network elements.

Categories and types of water network elements

As mentioned in Chapter 2, the elements modelling a water resource system appear in the Map Editor window of the DSS as points connected by arcs. The former symbolise physical entities such as settlements, lakes and treatment plants that receive, treat or supply water, and the latter stand for artificial conduits or natural water paths, such as pipelines, canals and river reaches, which carry water throughout the system. The DSS user builds the water network structure by placing the nodes and the connections on the map according to their geographical locations and relationships in the water resource system.

The nodes of the schematic water network are classified into three broad categories:

- **Supply** nodes,
- **Demand** nodes, and
- **Transhipment** nodes.

Supply Nodes conceptually provide water to demanding users through outgoing links, thus having the role of a water source. Some of them may have also ingoing links, functioning as water accumulators or final receptor body. They are:

- *Renewable Groundwater*, representing shallow, free groundwater that is continuously recharged by the hydrological cycle. A renewable groundwater is a water source with the further roles of accumulator and receptor body of return flows (end node);
- *Coastal Zone*, conceptualising a coastal area where seawater is abstracted for desalination, or quality status such as eutrophication is monitored. A coastal zone is a water source and also an end node. As a receptor body, it can receive the return flows from consumptive uses and recharges from aquifers;
- *River Reach*. For the modelling purposes of the DSS a river and its tributaries are divided into “river reaches” by a certain number of cross sections. Each river reach is characterised by a physical branch of the river and by its downstream section. A river reach is schematically represented by one river node;
- *Reservoir (Storage + Small + Natural Lake)*, conceptualising three types of reservoirs: an artificial storage reservoir fed either by a natural watercourse or by pipelines, a small artificial reservoir built to collect rainfall or run-off from a catchment area, or a natural surface lake. A reservoir is a water source with the further roles of accumulator and receptor body;
- *Importing*, standing for water transfers from a neighbouring area. As a supply node it has the role of water source;

- *Fossil Groundwater*, conceptualising deep, confined groundwater that is not recharged by the hydrological cycle. Fossil groundwater is a water source but not an accumulator or an end node because it has a no recharge.

Demand nodes are used for modelling water uses and flow requirements in the water system. They are:

- *Settlement*, conceptualising the civil urban population and infrastructures of a defined area, i.e. a city, a town or a village;
- *Tourist site*, representing a tourist community exerting a seasonal water demand;
- *Irrigation Site*, standing for the activity of cultivating land either for the survival of land-owners or for commercial purposes;
- *Industrial Site*, representing a productive site producing or supplying goods, services etc. An Industrial Site can be public or private, and is also characterised by its field of application: Petrochemical, Electronics, Aerospace, Food and Beverage, Pulp and Paper, Textile etc;
- *Animal Breeding*, describing the activities of livestock breeding;
- *Exporting*, representing the amount of water to be exported to a neighbouring area;
- *Hydro-electricity production*, which takes into account the amount of water requested by a single plant or a group of plants to generate electricity from falling or fast-flowing water;
- *Environmental, Recreation and Navigation Requirements*, representing non-consumptive demand nodes aiming to address the minimum water requirements of rivers, or the water needs for recreational purposes and navigation.

The category of **Transhipment** Nodes includes Water Treatment Plants and Network Reservoirs. The former treat water abstracted from the water sources and allocated to demand nodes, or water that originates from the demand nodes as return flow. The network reservoir is an element that does not influence the water distribution in the network but whose construction and operating costs must be considered in the computation of direct (financial) costs. In more detail, transhipment node types are the following:

- *Drinking Water Treatment Plant*, standing for a plant treating water in order to make it safe and acceptable for human consumption;
- *Wastewater Treatment Plant*, describing a plant treating water in order to remove or at least abate pollutant concentrations before water is re-used or discharged into a body of surface water;
- *.Desalination*, conceptualising a plant removing dissolved salts from seawater, brackish water or highly mineralized groundwater;
- *Network Reservoir*, representing a physical reservoir of very small capacity, which is used to serve the needs of settlements, tourist sites etc. Its contribution in the water allocation is not significant at the monthly time scale used within the WSM simulations. However, as a part of the infrastructure, it has costs for construction, operation etc that can be accounted for.

Water links of the conceptual water network have two main characteristic variables: a) the link capacity, which represents the maximum monthly flows allowed, and b) the monthly flow rate, that is the decision variable of the water allocation algorithm. Water link objects are classified in four categories based on the connectivity rules of the network and the particular modeling requirements of the DSS:

- *Supply Links (pipelines and canals)* conveying water from supply sources to demand nodes;
- *River Links*, representing the natural course of a river water body;
- *Groundwater Interaction Links*, representing the natural interaction between surface and groundwater bodies;
- *Return Flow Links*, conveying return flows from consumptive demand uses to receptor bodies (surface or groundwater) or wastewater treatment plants.

Water Network and Geodatabase

The water network element types have been modelled in the Geodatabase as **feature classes**, all grouped in the feature dataset named *WaterNetwork*. A feature class is the conceptual representation of a geographic object, *Feature*, as a point, a polygon, or a polyline/line. A feature class has specific **attributes** and **relationships** to other classes. For example, the *StorageReservoir* Feature Class has been conceptualized with attributes such as identifier ID, capacity, dead volume, and the functions height-volume and height-stage area. All the reservoirs of the water resource system belong to this class, thus having the same type of attributes, while their information is stored in the same **database table**. All feature classes corresponding to network elements are part of an ArcINFO geometric utility network, implemented in the *Water Network* feature dataset. An Arc Info geometric utility network was used, in order to store information and connectivity rules between nodes and links, i.e. what classes of links can connect to a particular class of node or at what type of node two classes of links must connect.

Furthermore, as the structure of the water resources system in terms of available resources and demand can only in part be adequately described by the spatial data of the Water Network Dataset, additional data were used that are stored in tabular form. They are non-spatial data but are related with the spatial objects of the geometric network with one-to-one, one-to-many and many-to-many database relationships. According to the ArcINFO Data Model used for the WaterStrategyMan Geodatabase, they are modelled as "*simple*" data inheriting from the general abstract class called *Object*. These data include for example the *Quality Variables*, related to supply nodes and treatment nodes mostly, *Activity* levels of consumptive demands and distribution/sewage network, related to the urban use of water, *AppliedIrrigationMethods*, *Crop Types* and *Livestock Types* related to the agricultural users, and other.

The set of feature classes defining the Water Network have been organized in **classes** and **subclasses** where the latter inherit the attributes of the former and have their own specific as well. At the top of this structure, there are the general abstract classes of *WaterNode* and *WaterLink* classes, whose attributes are simply an ID and a name. Subclasses of the WaterNode are the *SupplyNode*, representing natural and artificial water resources, the *DemandNode*, representing consumptive and non-consumptive uses and activities, and the *TranshipmentNode*, representing treatment processes or spatial objects used to maintain network connectivity (simple junctions).

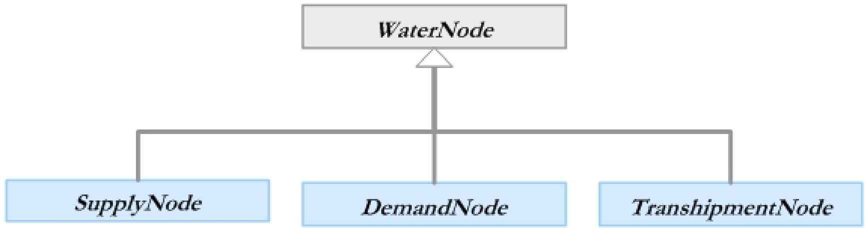


Figure 9 The Water Node class and its subclasses

The attributes of the *SupplyNode* class describe a water source from an infrastructure point of view and do not refer to a particular type such as reservoir or aquifer. The type of data considered pertain: 1) the construction year and the Start/End years of operation, 2) data for economic analysis.

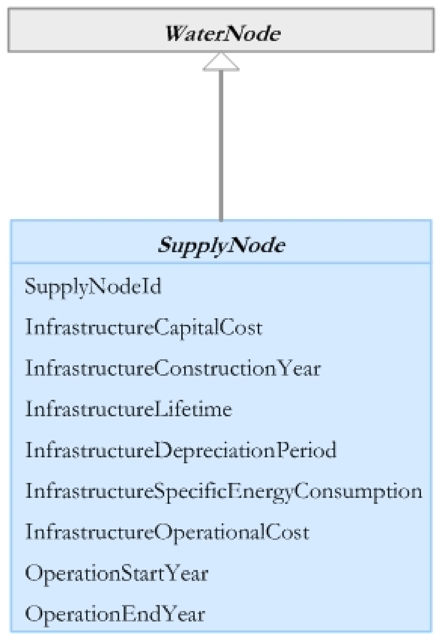


Figure 10 Attributes of the SupplyNode class

To account for the different available water resources, the *SupplyNode* class is further divided into different subclasses conceptualising aquifers, fossil groundwater, surface water bodies in terms of reservoirs and river reaches, and water transfer from neighbouring areas.

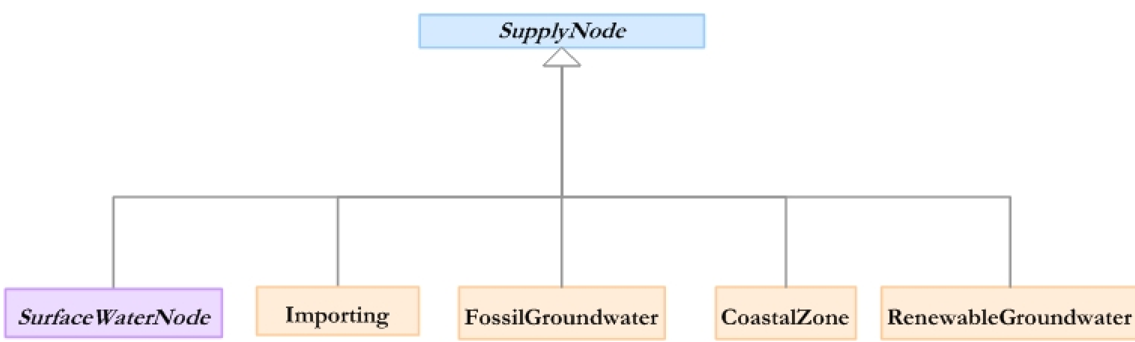


Figure 11 The subclasses of the SupplyNode class

Each one of these subclasses inherits the general attributes of the *SupplyNode* class, and completes them with its own set of attributes. For instance, the *RenewableGroundwater Class* is characterized by capacity, number of wells, catchment area, and factor for sustainable production, while *Importing* has the further attributes of the maximum volume of water that can be imported in the region.

Similarly to the *SupplyNode*, the *DemandNode* abstract class inherits from the *WaterNode* class and additionally defines the attributes ID and DemandPriority. The subclasses of the DemandNode class are *ConsumptiveDemand* and *NonConsumptiveDemand.*

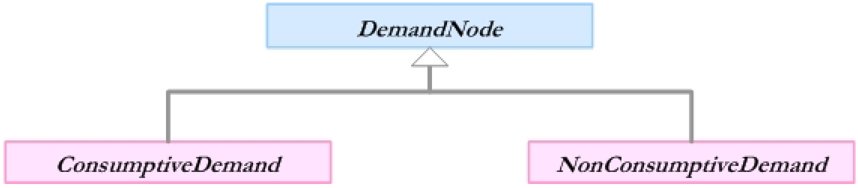


Figure 12 The subclasses of the DemandNode class

The *NonConsumptiveDemand* class is used to model demands that are non-consumptive, therefore characterised by null return flows and inflows equal to outflows. The class does not define any additional attributes with respect to the *DemandNode* Class. The *ConsumptiveDemand* class models consumptive water uses such as irrigation, domestic use, animal breeding activities and industrial production. This subclass defines the following additional attributes: 1) type of pricing method, namely volumetric, per area, output pricing, tiered pricing, 2) water selling price as a function of consumption and/or demand elasticity, and 3) the potential limit (quota) to be allocated for a particular water use, as a function of time and/or previous yearly or monthly demands.

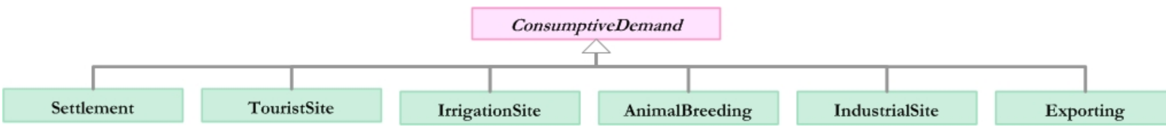


Figure 13 The subclasses of the Consumptive Demand abstract class

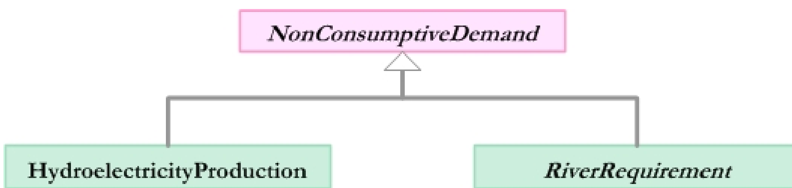


Figure 14 The subclasses of the NonConsumptive Demand class

In addition to being characterized by their own attributes, the six subclasses of consumptive demand are associated with the Activity non-spatial class. The aim of those attributed relationships is to model data regarding the particular water consuming activities encountered within the demand node objects (e.g. washing for domestic use, cooling in industries etc). The activity level and the consumption rate of those activities actually determine the demand of each particular node class, while the pollutant generation per activity unit is used for the estimation of the respective pollution loads of return flows.

The third subclass of *WaterNode* is the *TranshipmentNode* that is used to characterize points in the water system that act neither as supply sources nor as water demanding activities, and comprises the classes of *NetworkReservoir* and *TreatmentNode.* This latter in particular is used to model treatment plants, i.e. points in the network where water quality is modified through a precise treatment process. The three types of treatment nodes, which are represented by the relevant classes, are the *DrinkingWaterTreatmentPlant*, the *WastewaterTreatmentPlant* and the *Desalination* feature classes. Each one has specific attributes that describe the type of treatment process, such as Reverse Osmosis etc. for desalination, or Primary, Secondary and Tertiary for wastewater treatment. The treatment plant classes are also associated with a many-to-many attributed relationship with the *QualityVariables* non-spatial class. The relationship is used to describe the particular details of the treatment process, such as pollutant removal rates and required concentrations for drinking water or effluent disposal in case of wastewater treatment plants.

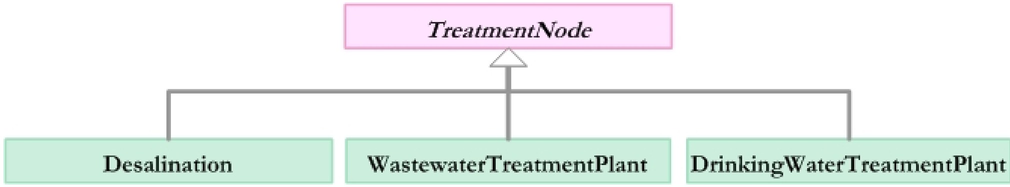


Figure 15 The subclasses of the Treatment Node class

The *WaterLink* abstract class stands for any connection in the water network between water nodes. It inherits from the *SimpleEdgeFeature* of the Arc Info Object Model. Edges logically are defined as network features that have a length through which commodity flows. Consequently, all water nodes occur at the intersection of two or more edges. An edge should always start and end at network junctions (water nodes). Water link objects are classified in four categories according to the connectivity rules of the network and the particular modelling requirements of the DSS. They are: 1) *Supply Links*, conveying water from supply sources to demand nodes, 2) *Groundwater Interaction Links*, representing the natural interaction between surface and groundwater bodies, 3) *Return Flow Links*, conveying return flows from consumptive demand uses to receptor bodies (surface or groundwater) or wastewater treatment plants, and 4) *River Links*, representing the natural course of a river water body, interconnecting river reach nodes, storage reservoirs and minimum flow requirement objects.

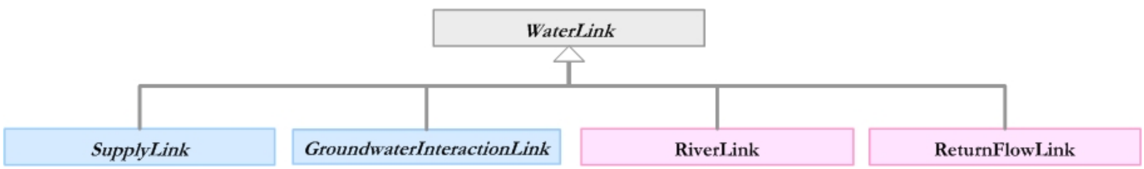


Figure 16 The subclasses of WaterLink

The *SupplyLink* class represents edges transferring water (either fresh or treated wastewater) intended to be used by consumptive demand node objects. Among the fundamental attributes are the *FlowCapacity* of the link, which represents the maximum monthly flows allowed, and the *SupplyPriority* that determines the priority with which water is allocated from the start node of the link to the end node. In addition to the *WaterLink ID* attribute inherited by the parent *WaterLink* feature class, the class further defines fields for construction and operating cost, lifetime, depreciation period, and the *ConveyanceLoss*, expressing the share of inflow that is lost due to leakages. From the DSS point of view, the *SupplyLink* class defines the attributes that are common to all the pipelines and canals that the DSS user places on the region map with the Map Editor.

The *Groundwater Interaction Links* class comprises the subtypes of *Groundwater RechargeLinks* and *Groundwater DischargeLinks*. They do not have specific attributes, but are conceptually important, since they represent the water paths between groundwater and surface resources of the. Groundwater recharge links are used to model the natural process of aquifer recharge from surface water bodies, such as lakes, storage reservoirs and rivers, whereas groundwater discharge links are used to model the natural process of aquifer discharge to surface water bodies and the sea.

The *ReturnFlowLink* class conceptualises edges that transfer return flows from demand sites either at wastewater treatment plants or at water bodies, who act as effluent receptors. The share of return flow is the only additional attribute of this feature class, which determines the amount of water to be allocated to each return flow link outgoing the same demand site.

The fourth type of WaterLink is the *RiverLink*, whose specific attribute is the ID of the river it belongs to. Since the particular river segments are modelled as points, namely river reach nodes, the only modelling functionality of *RiverLink* Feature class is to maintain network connectivity along the natural course of a river.

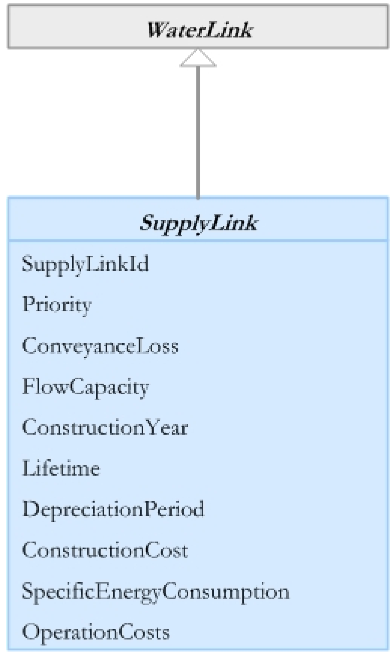


Figure 17 Attributes of the SupplyLink Class

The features classes of Water Nodes and Water Links described here above define the **geometric water network** and the relevant features. In order to complete the conceptualisation of the water network, a set of **rules of connectivity** between nodes and links was studied. The maintenance of appropriate connectivity rules, which specify what types of junctions (water nodes) can be connected to each other and with which type of edge (water link), is a fundamental concept in a water resource network, as with every type of utility network. The Data Model of the WaterStrategyMan Geodatabase specifies a number of connectivity rules, in order to ensure the proper modelling of a water resource system and its correct simulation by the WSM Decision Support System. Modelling requires that some types of edges (water links) have a specific type of start or end junction or both. For example, groundwater recharge links can only originate from surface water nodes (reservoirs and river reaches) and should end only at renewable groundwater nodes. Additionally, junctions modelling particular types of water sources, such as non-renewable (fossil groundwater) or importing from neighbouring regions, cannot have incoming edges of any type. To ensure therefore the integrity of network data within the database, network connectivity is modelled within the WSM Decision Support System, with a set of rules that specify which type of junction can be connected to which other junction type and with what type of edge. Those rules are outlined in the following tables.

Table 1 Node connectivity restrictions

Node Type	Restriction for Incoming Links	Restriction for Outgoing Links
Fossil Groundwater	None	Canal Pipeline
Importing	None	Canal Pipeline
Renewable groundwater	No restriction	Canal Pipeline Groundwater discharge link

Reservoir	No restriction	Canal Pipeline Groundwater recharge link
Coastal zone	Return flow link Groundwater discharge link	None
Settlement Tourist Site Industrial Site Irrigation Site Animal Breeding	Canal Pipeline	Return flow link
Wastewater Treatment Plant	Return flow link	Return flow link Canal/pipeline if the end node is an irrigation site object
Drinking water treatment plant	Canal Pipeline	Canal Pipeline
Desalination	Canal Pipeline	Canal Pipeline

Table 2 Link connectivity restrictions

Link Type	**Start Node**	**End Node**
Groundwater Recharge Links	Storage Reservoir Small Reservoir Lake	Renewable groundwater node
Groundwater Discharge Link	Renewable groundwater	Storage Reservoir Small Reservoir Lake Renewable groundwater Coastal Zone
River Links	River Reach Node Storage reservoir Hydroelectricity River requirement	River Reach Node, Storage reservoir Hydroelectricity River requirement

Regional Data

The core data of the WaterStrategyMan Geodatabase is defined by the feature classes of the Water Network, but the DSS is also designed to store some supplementary information describing the region in general. They are divided into *Basic Data*, *Water bodies and Monitoring Stations*, and *Administrative Structure*.

The basic regional information is defined by the *Physical Data* feature dataset, which includes the feature classes of: 1) boundary of the case study area, 2) elevation, 3) shoreline, 4) road infrastructure (national, national country etc.), 5) towns and agglomerations, and 6) land use and soil patterns, according to the USGS and FAO classifications.

Modelling of water bodies and monitoring stations is performed in accordance to the *"Guidance Document on Implementing the GIS Elements of the Water Framework Directive"* (Working Group GIS, 2002), implementing the requirements for the definition of water bodies from the European **Water Framework Directive 2000/60** (European Parliament, 2000). Although the purpose of the modelling of the WSM Geodatabase, as well as that of the

Decision Support System, was not to satisfy the reporting requirements of the Water Framework Directive, it has been considered fundamental to incorporate some of the required elements for future use, in order to enhance the capabilities of the database and to allow for further improvements of the DSS towards this direction. Spatial objects are included in the *WaterBodies* feature dataset, whose basic object is the *WaterBody* abstract class that is the parent for all surface and groundwater bodies included in the model.

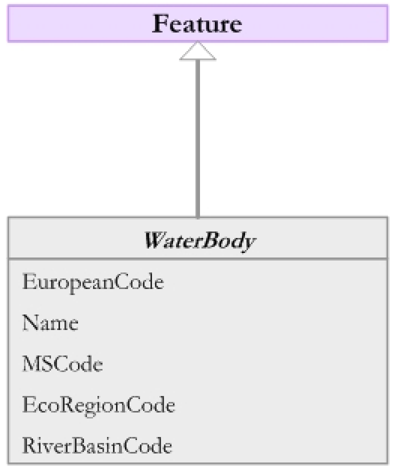


Figure 18 Attributes of the WaterBody Class

Attributes of this class are the *Codes* that identify each water body both at the European level, in terms of European code and Ecoregion the water body belongs to, and at the national scale, in terms of Member state code (MScode) and code of the related river basin.

The two main subclasses of *WaterBody* are *GroundwaterBody* and *SurfaceWaterBody*. The latter is further classified into the abstract classes *FreshWaterBody* and *SalineWaterBody*, both having a different set of attributes. The *SurfaceWaterBody* feature class defines three logical-type (true or false) attributes: 1) *HeavilyModified*, which denotes a water body substantially changed in character as a result of physical alterations by human activity, 2) *Artificial*, i.e. whether the water body was created by a human activity, and 3) *System*, which refers to the *System A* and *System B* types of surface water body, as indicated in Annex II of the WFD. According to the Directive the A/B System are defined for each one of the four category of surface water body: rivers, lakes, transitional waters and coastal waters. The two tables for rivers from Annex II of the Directive are shown below.

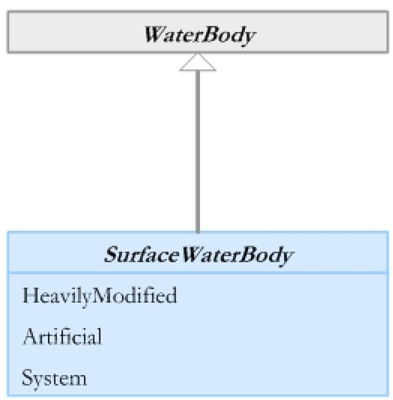


Figure 19 Attributes of the SurfaceWaterBody Class

Table 3 System A for River characterization (Annex II of the WFD)

Fixed typology	Descriptors
Ecoregion	Ecoregions shown on map A in Annex XI of the Directive
Type	Altitude typology • high: >800 m • mid-altitude: 200 to 800 m • lowland: <200 m Size typology based on catchment area • small: 10 to 100 km2 • medium: >100 to 1 000 km2 • large: >1 000 to 10 000 km2 • very large: >10 000 km2 Geology • calcareous • siliceous • organic

Table 4 System B for River characterization (Annex II of the WFD)

Alternative characterisation	Physical and chemical factors that determine the characteristics of the river or part of the river and hence the biological population structure and composition
Obligatory factors	altitude latitude longitude geology size
Optional factors	distance from river source energy of flow (function of flow and slope) mean water width & depth mean water slope form and shape of main river bed river discharge (flow) category valley shape transport of solids acid neutralising capacity mean substratum composition chloride air temperature range mean air temperature precipitation

Fresh water bodies are the *RiverWaterBody* and the *LakeWaterBody* feature classes, which are defined within the WFD as follows. *RiverWaterBody* means "*a body of inland water flowing for the most part on the surface of the land but which may flow underground for part of its course", and Lake means "a body of standing inland surface water*". In the Geodatabase a river water body is connected with a one-to-many relationship with the *RiverLink* feature class of the Water Network Feature Dataset that models the particular river segments. From a geometric point of view, lakes are modelled within the Water Bodies Dataset as polygons and at the Water Network Dataset as points. This double approach allows for:

- ❖ The representation of individual lakes as distinct bodies and the estimation of their water balance;
- ❖ The modelling of lakes as supply sources and a part of a water network.

For this purpose, the polygon *LakeWaterBody* feature class is associated with the point *Lake* feature class of the *Water Network* Dataset with a one-to-one relationship through the *WaterNodeId* attribute.

The characteristic attribute for the *SalineWaterBody* class is the *MeanSalinity*, which is inherited by the subtypes *TransitionalWaters* and *CoastalWaters*. Transitional waters are defined as *"bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows"*. Transitional waters are typically estuaries and are modelled as polygon features. Coastal waters means *"surface water on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters"*.

The counterpart of *SurfaceWaterBody* is the class of *GroundwaterBody*. Body of groundwater means a distinct volume of groundwater within an aquifer or aquifers. Aquifers are modelled within the *Water Bodies* Dataset as polygons and within the Water Network Dataset as points, analogously to the Lakes. The two feature classes are associated with a one-to-one relationship through the *WaterNodeId* field.

Other feature datasets that have been designed in the WSM Geodatabase within the *Water bodies and Monitoring Stations* category concern *River Basins*, *Protected areas* and *Monitoring Stations*.

River basin means "*the area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta*". In accordance to the Guidance Document on the implementation of the GIS Elements of the WFD the attributes of this class concern unique codes that identify the basin both within the Member State, *MSCode*, and at European Level, *EuropeanCode*.

Protected areas are referred to in the Annex V of the WFD where it is stated that a river management plan "*shall include maps indicating the location of each protected area and a description of the Community, national or local legislation under which they have been designated*". The GIS Guidance Document on the Water Framework Directive specifies the following subclasses for the feature class of protected areas:

- Areas designated for the abstraction of water intended for human consumption;
- Areas designated for the protection of economically significant aquatic species;
- Bodies of water designated as recreational waters, including areas designated as bathing waters under Directive 76/160/EEC;
- Nutrient-sensitive areas, including areas designated as vulnerable zones under Directive 91/676/EEC (Nitrates Directive);
- Areas designated as sensitive under Directive 91/271/EEC (Urban Waste Water Treatment Directive);
- Areas designated for the protection of habitats or species where the maintenance or improvement of the status of water is an important factor in their protection, including relevant Natura 2000 sites designated under Directive 92/43/EEC (habitats) and Directive79/409/EEC (Birds).

Within the WaterStrategyMan Geodatabase these categories have not been modelled by subclasses, because such a classification has been considered to be out of scope for the purposes of the project. Therefore, the object is modelled as a single polygon feature class, providing a *Description* attribute, to be used for a more detailed representation.

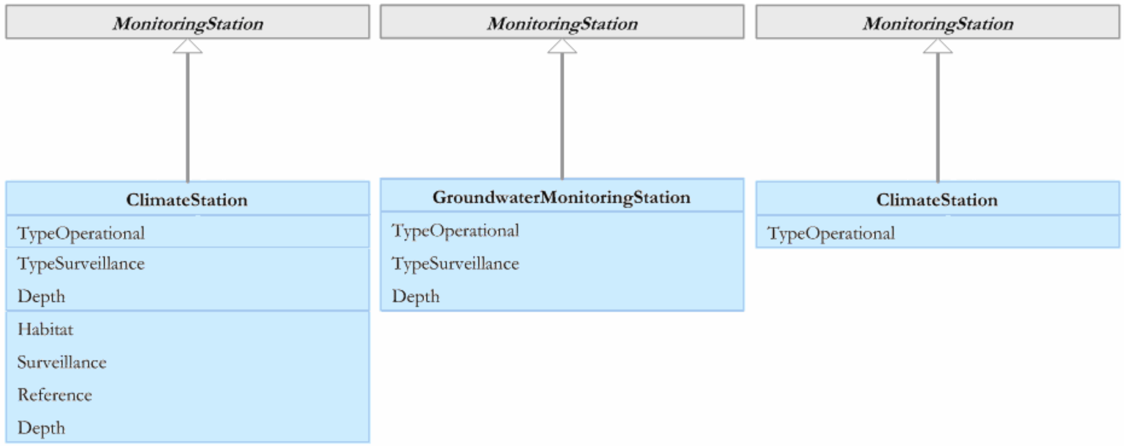


Figure 20 Feature classes for Monitoring stations and their attributes

As far as the monitoring stations are concerned, they form the basis of the monitoring of water status, and consequently are the basis for the classification of water bodies. Monitoring stations are defined in the WSM DSS as a single feature class, further subdivided into *SurfaceMonitoringStation* and *GroundwaterMonitoringStation*, according to the Water Framework Directive. In fact, Annex V, Article 1.3 states that *"Member States shall provide a map or maps showing the surface water monitoring network in the river basin management plan"*. Similarly, Article 2.2.1 states that *"the groundwater monitoring network should also be provided as a map or maps"*. The additional subclass of *ClimateStation* has been defined for considering the stations that monitor only meteorological conditions and not the status of one or more water bodies. The attributes of the *MonitoringStation* abstract class relate the National and European codes of the stations, which are inherited by the three subclasses.

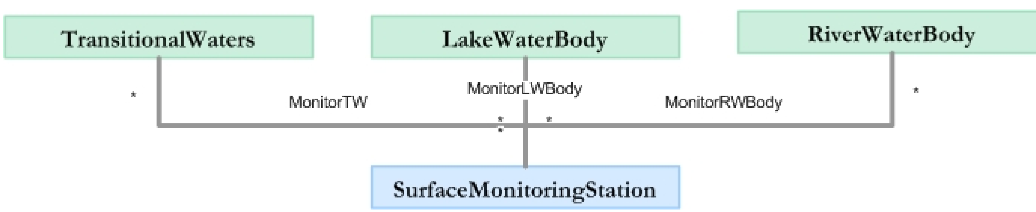


Figure 21 Relationships between the SurfaceMonitoringStation class and the WaterBodies

With respect to the relationships with other information in the Geodatabase, the feature classes are associated with many-to-many relationships with subtypes of the *WaterBodies* class: *GroundwaterMonitoringStation* is associated with the *GroundwaterBody*, whereas *SurfaceMonitoringStation* is associated to *TransitionalWaters*, *RiverWaterBody* and *LakeWaterBody*. The attributes featuring the monitoring stations in water resource systems relate their activity status, i.e. whether they are operational, and their role according to different monitoring purposes, such as investigative or surveillance. Furthermore, there are attributes denoting the type of site that is under observation such as sites for drinking water abstractions, or sites with biological reference conditions.

Another type of information included in the regional data of the WSM Geodatabase relates the first and second level of governmental authorities, i.e. regions or prefectures and municipalities, as well as the Districts of Water Competent Authorities and the River Basin Districts. These data are modelled as polygon features within the *Administrative Structures* feature dataset, whose attributes are Identifier, Name and Description. River basin districts are identified under Articles 3(1) and 13(1) of the Water Framework Directive as the main unit for management of river basins: *"Member States shall identify the individual river basins lying within their national territory and, for the purposes of this Directive, shall assign them to individual river basin districts"*, and *"Member States shall ensure that a river basin management plan is produced for each river basin district"*. A river basin district is defined under Article 2(15) as *"the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters"*. Therefore, despite the duplication of some geometry from the *Water Features* Dataset, where river basins, groundwaters and coastal waters are represented each by its own feature class, River Basin Districts are defined within the WSM Geodatabase as a separate polygon feature class. Attributes of this class are the National and European Codes of the districts as well as the code of the water competent authority that is responsible for applying the rules of the Directive to the district. Because in some cases it is not possible to aggregate River Basin District objects to form the boundary of the Competent Authority, the latter are defined as a separate polygon feature class.

Chapter 4 Water Availability Scenarios

The idea behind the creation of scenarios of water availability and of water demand for water resource systems in the WSM DSS reflects the general need of Decision Makers and Water Planners to account for potential future DPSIR - Pressures in the preparation of management plans. The knowledge of the up-to-date climatic and demographic characteristics of a water resource system and of their forecasted evolution is a fundamental prerequisite to the formulation of whatever strategy for handling water scarcity conditions, impacts of human activities on water quality and recovery of costs for water services. Therefore, two pre-processors have been designed in the WaterStrategyMan package, whose task is to estimate the future behaviour of identified Driving Forces, here climate changes and population growth, and consequently of the Pressures exerted on the system in terms of available supply, forecasted demand, water quality of supply sources and waste generation. The scenarios produced by the *Water Availability Module* and by the *Water Demand Module* are the main input to the simulations of the water resource system within the DSS, which is performed by the *Water Allocation Module* to be analysed under Chapter 8.

This chapter presents the methodology used within the first of the two pre-processors, the **Water Availability Module**, for generating the Water Availability Scenarios, and its implementation in the graphical user interface.

Methodology Outline

The objective of the Water Availability Module of the WSM Decision Support System is to estimate the amount of water that is available in a water resource system, to be allocated to the existing demand users. The water sources considered in the WSM package comprise surface water, such as artificial or natural lakes and the river network system, and of groundwater, both renewable and fossil.

The availability module, reads the topologic water resource network and generates monthly time series of forecasted available water for each water source node in the network. These availability scenarios, along with the demand scenarios generated by the demand module represent the basic information entering the allocation module of the package.

Time series output of the module concern natural recharge for renewable groundwater and surface runoff for reservoirs and river reaches. The results can be obtained in the following two ways:

1) By **defining** a set of customized years to be repeated in time, based upon the real observations at existing monitoring stations, and
2) By **estimating** runoff and natural recharge from a surface water balance performed on a monthly time step.

In the first case, *Discharge Scenarios* within the DSS, the user has to go through the list of reservoirs, river reaches and renewable groundwater nodes that exist on the case study map, and respectively define a *Normal Year (Average)* of runoff and recharge (twelve monthly values), which can be obtained from existing recorded data. Given the normal year, the user can create and customise new years, by editing monthly positive or negative rates with respect to the normal one. Then the availability scenario is constructed by customising the sequence of previously created water years for the entire duration of the simulation. Recorded data for the normal year description can be easily imported from text files or excel spreadsheets.

The alternative way for building availability scenarios is based on a lumped water balance at the watershed scale, performed by the Soil Moisture Balance Module of the ARNO rainfall-runoff model (Todini, 1996). Time series of available runoff and infiltration are computed for selected river reach nodes, lakes and aquifers, entered by the DSS user in the Map Editor Window. The user, in this case, must prepare a set of required maps, among which are those of hydro-geological catchments relevant to aquifers and lakes and the Digital Elevation Model (DEM) of the area under study. Given the DEM and the geographical position of the river reaches, the availability module formulates the maps of the corresponding upstream subbasins, through the use of common GIS functions. Once watersheds maps are ready for all the water source elements, mean values of climatic and pedologic information are calculated for each one. As far as meteorological data is concerned, twelve maps of precipitation, reference evapotranspiration and temperature, containing monthly data for the average year are used as input.

The user can visualise the average water year of precipitation, reference evapotranspiration and temperature from the Graphic Interface of the module. Additional functionalities are available, such as building customised water years (**Base Years)**, to be repeated or assigned a trend within the scenario generation. Once time series of meteorological data for the entire duration of the scenario have been produced, the surface water balance is run, resulting in the time series of runoff and natural recharge.

In order to create Base Years, the user is allowed to change the mean monthly values of climatic data by operating directly on the average year graph with a drag and drop of the graph bars, or to edit the new values under each month bar. Once the base year has been saved, the user has three ways to build scenarios:

a) To **repeat the base year** as it is for the entire duration of the scenario,

b) To **define a total increment** over the entire period, either annual or monthly, thus defining an yearly or monthly trend, or

c) To **build up a sequence** of previously created base years, as he does for the Normal year approach.

With respect to the generation of meteorological time series, the user can choose to work with reference ETP or temperature maps, according to data available. Since water balance estimations receive evapotranspiration as input, when temperature scenarios are selected, an intermediate calculation is necessary. Since temperature values are not independent from the height above the sea level (a six Celsius degrees per a hundred metres gradient exists), the altitude distribution of the case study region area has to be calculated before estimating ETP from temperature. For this purpose, the DEM of the region is divided in a number of classes, each one ranging for a hundred metres, and mean temperature values are referred to each class according to the above six degree gradient. Mean values of evapotranspiration for each class are then obtained from the mean corresponding temperature values by the Thornthwaite formula for ETP.

A **stochastic option** has been recently added to the water availability module, and is currently under validation by the WaterStrategyMan Methodology Team. The idea consists of generating a certain number of forecasted discharge time series based on a statistical analysis of historical discharge data series: the trend of historical data is kept in the forecast and fluctuations up and down the trend are produced in the generated series trying to maintain as much as possible the statistics of the historical fluctuations, such as mean, standard deviation and skewness. The user-defined number of discharge scenarios coming out the stochastic function, have to be all simulated by the water allocation model, and results have to be compared, thus leading to and permitting an analysis and classification of strategies under uncertain conditions.

The maps and information required by the availability module are the following:

- ❖ Digital Elevation Model in a proper scale with respect to the basin area
- ❖ Map of hydraulic conductivity of soils;
- ❖ Map of soil moisture capacity as a function of soil types;
- ❖ Map of land use;
- ❖ River reach nodes, created from the Map Editor Window, to be used as closing sections in watershed creations;
- ❖ Maps of the river network;
- ❖ Map of hydro-geological catchments relevant to the aquifers in the areas under study. They are the water-collecting areas of water infiltrating to aquifers;
- ❖ Catchment areas for natural lakes and artificial small reservoirs;
- ❖ Maps of the average years of precipitation, temperature and evapotranspiration.

The equations used by the availability module to perform the surface water balance are here presented. The water balance equation updates soil moisture at each monthly time step, taking into account current moisture state, precipitation, evaporation, rapid subsurface flow, water percolating to the aquifers water table and the water volume originating surface runoff. The latter is the actual output of the model. The **balance** equation is:

$$W_{t+1} = W_t + P_{t,t+1} - I_{t,t+1} - E_{t,t+1} - R_{t,t+1} - D_{t,t+1} \quad (1)$$

where:

W = soil moisture storage

P = precipitation

I = groundwater recharge

E = actual evapotranspiration

R = runoff

D = rapid subsurface flow

Precipitation is obtained from the mean values computed at the watershed level according to the average monthly data maps. **Actual evapotranspiration** is computed from average monthly maps of reference ETP, crop factors according to the land use of the region, and the soil moisture state:

$$E = \gamma \cdot k_c \cdot E_{T0} \quad (2)$$

where:

E = actual evapotranspiration

E_{T0} = reference potential evapotranspiration

k_c = crop factor

The γ term is the reduction of soil moisture saturation and is defined as follows:

$$\begin{aligned} \gamma &= \frac{W}{\beta \cdot W_{\max}} && if \quad W < \beta \cdot W_{\max} \\ \gamma &= 1 && if \quad W \geq \beta \cdot W_{\max} \end{aligned} \quad (3)$$

with $W_{\max}$ being the maximum soil moisture content given by the average soil depth multiplied by the soil porosity (saturated soil moisture less residual soil moisture): $W_{max} = L \cdot (\vartheta_S - \vartheta_r)$.

The **surface runoff** R is computed based on the effective meteorological input M_e (the difference between precipitation and potential evapotranspiration), and the cumulative distribution for the elementary area soil moisture distribution:

$$R = M_e - \left\{ \left(W_{\max} - W\right) - W_{\max} \cdot \left[\left(1 - \frac{W}{W_{\max}}\right)^{\frac{1}{b+1}} - \frac{M_e}{(b+1) \cdot W_{\max}} \right]^{b+1} \right\}$$
$$if \;\; 0 < M_e < (b+1) \cdot W_{\max} \cdot \left(1 - \frac{W}{W_{\max}}\right)^{\frac{1}{b+1}} \qquad (4)$$

$$R = M_e - \left(W_{\max} - W\right)$$
$$if \;\; M_e > (b+1) \cdot W_{\max} \cdot \left(1 - \frac{W}{W_{\max}}\right)^{\frac{1}{b+1}} \qquad (5)$$

The **aquifer recharge** is calculated based on the vertical hydraulic conductivity of bedrocks, $k_{s,vert}$ and the percentage of soil moisture saturation α :

$$I = \alpha \cdot k_{s,vert} \qquad (6)$$

with:

$$\alpha = 0 \qquad if \;\; W < W_{\min}$$
$$\alpha = \frac{\left(W - W_{\min}\right)}{\left(W_{\max} - W_{\min}\right)} \qquad if \;\; W_{\min} < W < W_{\max} \qquad (7)$$
$$\alpha = 1 \qquad W > W_{\max}$$

Finally, the **rapid subsurface flow** is calculated as:

$$D = k_{s,hor} \cdot SD \cdot 2 \cdot \frac{L}{A} \cdot \alpha^{2.5} \qquad (8)$$

with:

$k_{s,hor}$	=	horizontal hydraulic conductivity of soil
SD	=	mean soil depth
L	=	length of the drainage network
A	=	area of the watershed
α	=	percentage of soil moisture saturation (as for aquifer recharge)

Implementation in the WSM DSS

This section presents the overall implementation of the availability module of the WSM DSS. As explained in the methodology part, time series output of the module concern natural recharge for renewable groundwater and surface runoff for reservoirs and river reaches. They can be computed in two ways, according to observations at existing monitoring stations or through the estimation of a water balance based upon monthly meteorological data and soil characteristics of the region. The first approach, *Discharge Scenarios*, is based on historical observations and implies the definition of Average (Normal) Years of discharge and recharge. Scenarios are formulated through the creation of customized new years which have a monthly positive or negative rate with respect to the normal one. The second algorithm starts from the generation of rainfall, temperature and evapotranspiration scenarios and performs a water balance at watershed level for each sub-basin identified by the river reach nodes of the Water Management Scheme.

The interface windows of the two approaches are loaded from the same menu, the *Water Availability*, accessible from the *Create Scenario* menu of a Water management Scheme, in the Navigation Panel.

The *Discharge Scenarios* interface includes a tree view with the menus for Water Year Definitions and Sequence, and a second window showing the relevant data according to the selected node.

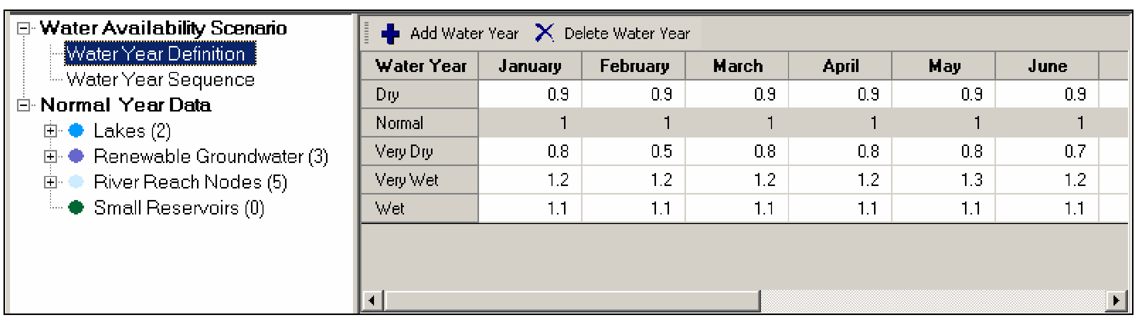


Figure 22 Defining Water Years based on Average (Normal) years)

The **Water Year Definition** menu loads a table where new water years can be defined by editing the monthly rates with respect to the normal year. A coefficient of 0.9 for the January-Wet means that all the values of river discharge and natural groundwater recharge are supposed to be at the 90% of the historical measured data that characterise the first month of the normal year.

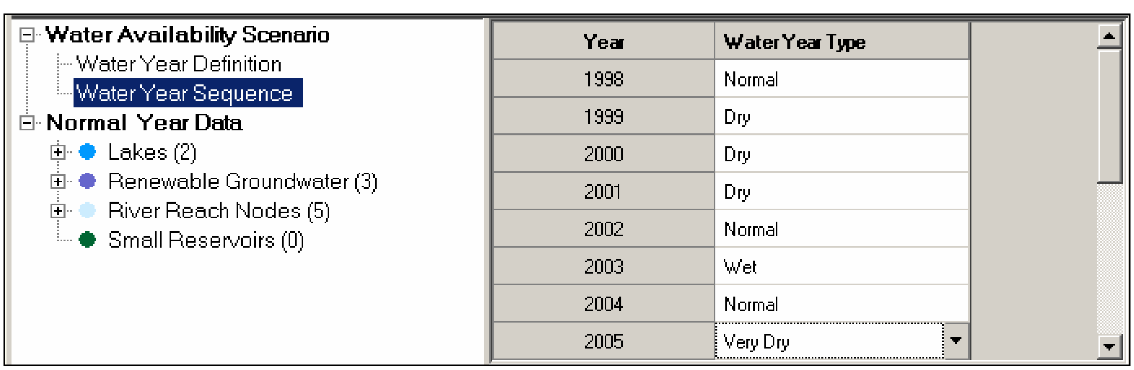


Figure 23 Building the Availability Scenario

Once the user has generated the types of water years that best approximate the possible regional conditions of water availability, for example dry, very dry or wet conditions, he can build up the sequence of water years, which represents the availability scenario, by choosing the type of water year for each simulation year through dedicated drop down buttons.

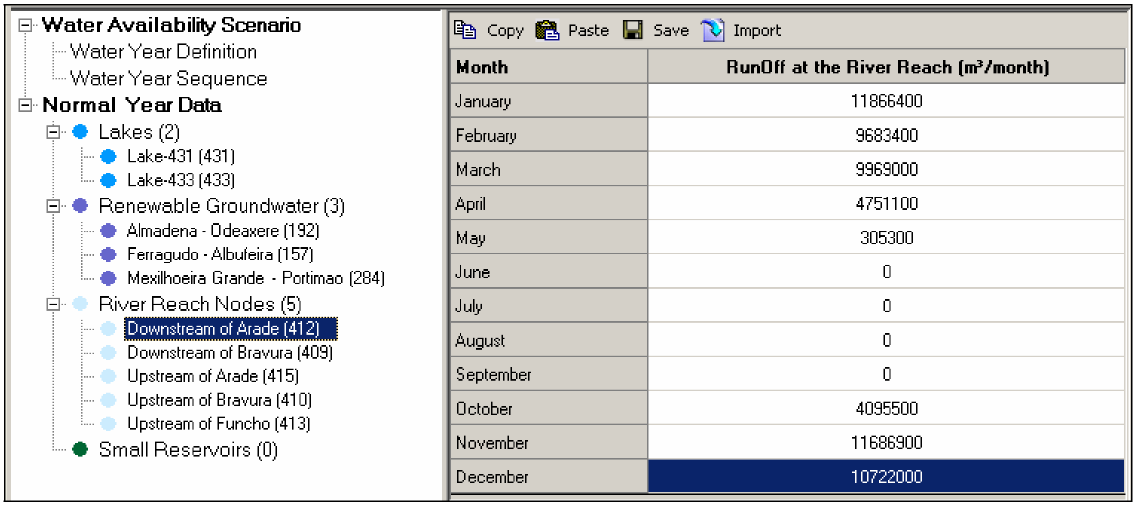


Figure 24 Entering Normal Year Data for river reaches

The historical Normal year data can be imported from text files in the table of the GUI for each lake, renewable groundwater, small reservoir and river reach node of the water supply system. If some imported data have been modified by hand, the node-related table can be copied or saved as a text file.

The graphical interface of the second approach includes a map window and a number of menus guiding and assisting the user in the generation of Weather Scenarios first and in the water balance then.

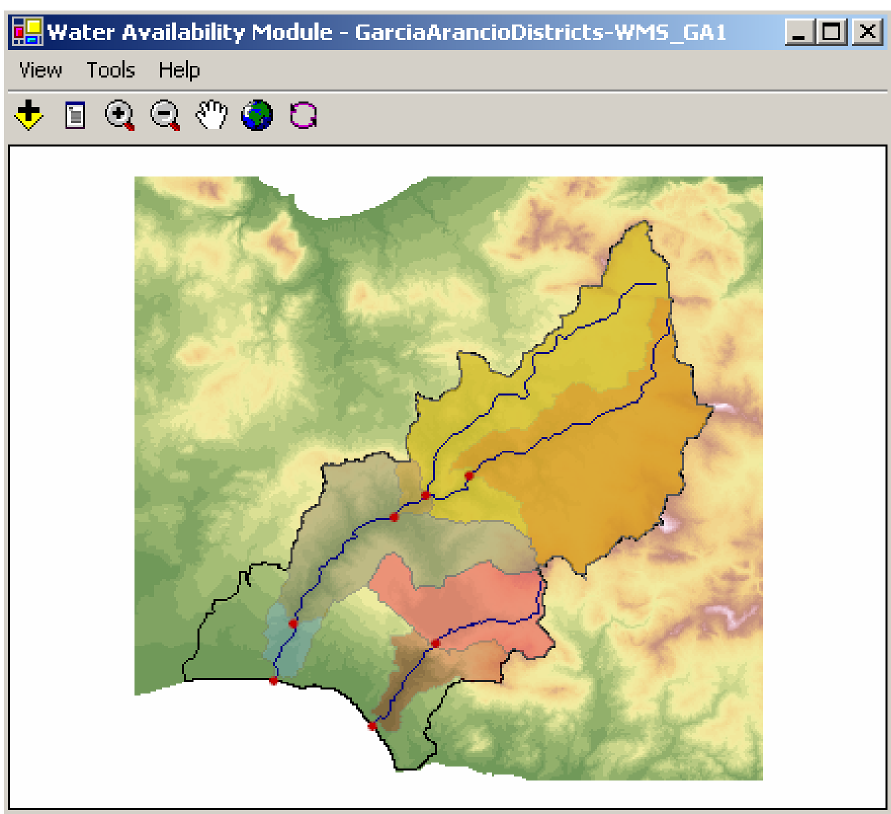


Figure 25 The sub-basins generated by the pro-processor of the availability module using climatic data

The module has a pre-processor, running during the loading phase, which reads the river water bodies and the cross sections in the region, located by the river reach nodes. Then the module generates the maps of the corresponding upstream sub-basins according to the Digital Elevation Model. Statistics on the input raster maps and aggregation of these data to the watershed level are also performed at this stage. The opening view of the module shows the generated river basins over the DEM (Figure 25).

Data maps involved in the calculation are: twelve monthly maps of rainfall, temperature and reference evapotranspiration (ET_o), which represent the Average Years, maps of the soil moisture capacity, hydraulic conductivity and land use. They can be loaded and visualized from the *View* menu.

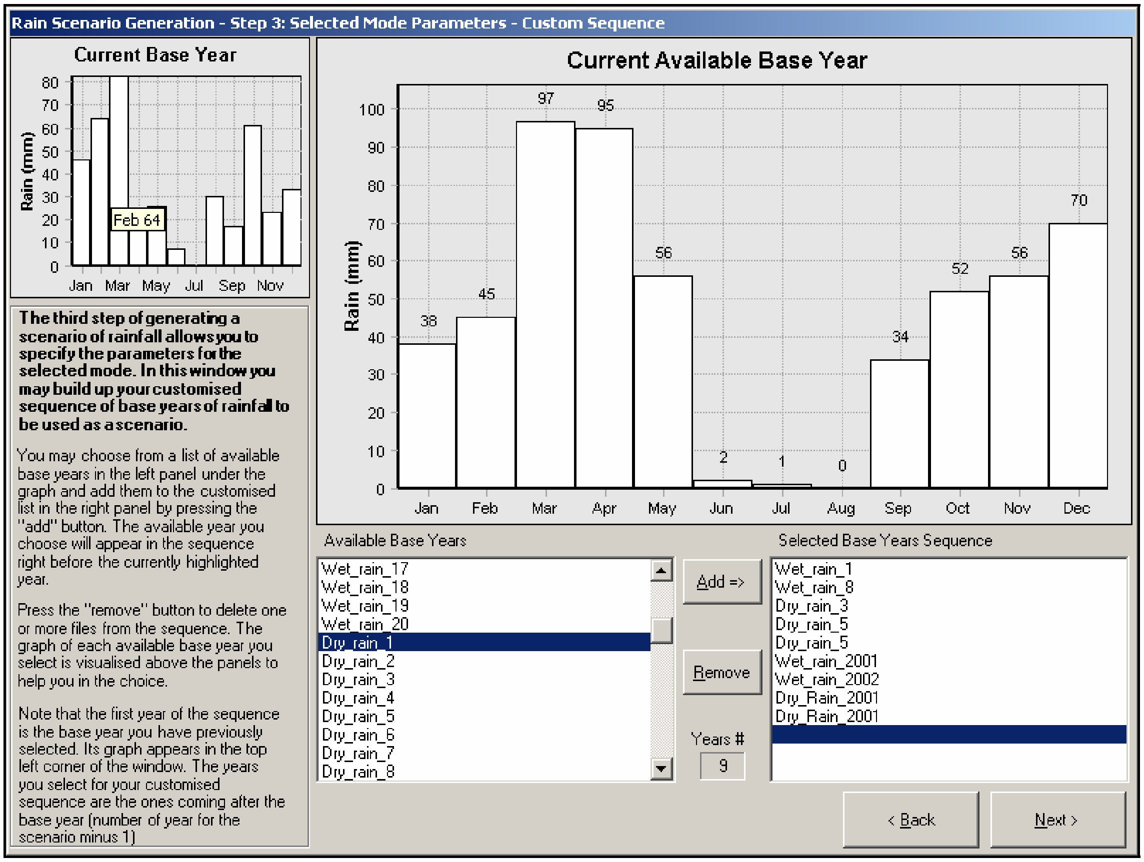


Figure 26 Displaying available base years to be selected and added to the scenario sequence

Based on the average years of climatic data, already aggregated at watershed level, the user is prompted to build weather scenarios. First of all, he can use an average year or define a new year, Base Year, by increasing or decreasing the monthly average values. In this latter case, he can create dry, very dry or wet years, as with *Discharge Scenarios*. This operation is carried out in the Base Year Window. Then a dedicated wizard , allows him (a) to build the sequence of years one by one, (b) to assign a yearly or monthly trend to the customised starting Base Year, or (c) to repeat it as it is for the entire duration of the scenario. These operations are performed through the *Custom Sequence* and the *Trend Definition* windows (Figure 27)

After the rainfall and ET_o scenarios have been generated, they are read by the water balance routine and time series of discharge are computed for each cross section identified in river water bodies. Time series of natural recharge for aquifers are also produced.

The window that presents the resulting water availability scenarios that will be used by the allocation module of the DSS comprises of:

- a drop-down menu where the type of network element can be chosen, either a lake, a river reach or an aquifer;
- a list of available elements of the type selected by the user;
- a chart where the corresponding discharge or recharge time series are plotted.

The interface menus of the availability module are the *View* and the *Tools*. The *Tools* menu includes the sub-menus for creating the weather scenarios and for running the water balance, whereas the *View* loads the maps and the base years or scenarios that have already been produced and are available for the water balance.

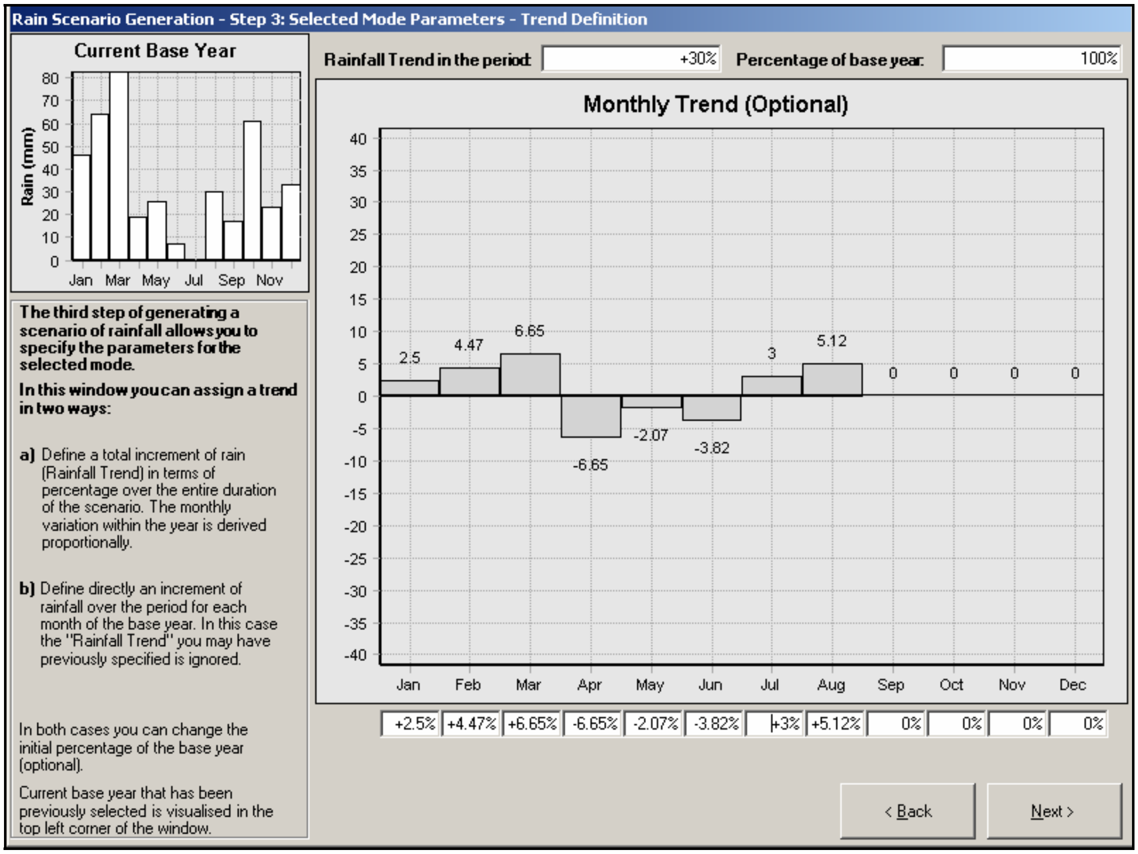


Figure 27 The Trend Definition window of the wizard for rain scenario generation

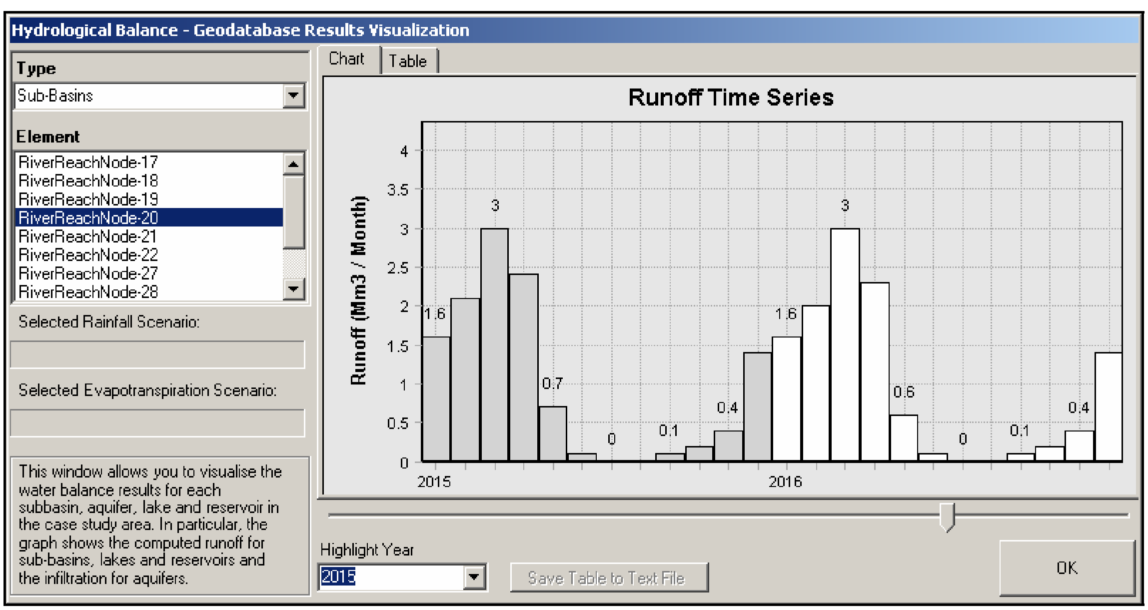


Figure 28 Displaying Results for river reaches

Chapter 5 Water Demand Scenarios

This chapter presents the *Water Demand Module* of the WaterStrategyMan DSS, a pre-processor responsible for generating Water Demand Scenarios for every demand node in the water network, according to its type, e.g. settlement, irrigation site, industry etc. The formulation of water demands is mainly described in the methodology part of the chapter, which presents the key variables involved. The second part of the chapter presents the implementation of that methodology in the DSS, focusing on the access of demand data and the assignment of growth rates or functions to the key variables driving the demands.

Methodology Outline

The analysis of water demand in the WSM DSS is strictly functional to the water allocation performed by the kernel of the tool. The water demand module has been developed to generate hypothetical demand scenarios, which constitute, along with availability scenarios, the basic and discriminating factor in the distribution of water from sources to the uses.

Within the water demand methodology, a specific formulation for scenario building has been adopted for each type of activity and water use, considered to be part of a water resource system:

- Permanent and tourist population, representing the domestic use of water,
- Farmers and breeders, needing water for land cultivation and animals, and
- Industries of various types.

In addition to the activities related to **consumptive** water demands, as those above, the WSM DSS also addresses **non-consumptive** uses, such as hydropower-generation, navigation and protection of aquatic life in rivers (environmental demand). Consumptive demands describe water needs within a particular region the tool is applied to; however it is not necessary that available water resources are entirely used to meet home requirements only. In many areas of the world, inter-basin water transfers are a usual and sometimes the only way to get water. In order to consider also this practice, an additional water demand, *Exporting Demand*, has been introduced in the WSM DSS, describing the amount of water to be allocated outside the analysed region.

In the following paragraphs the approach to estimate water needs for each demand type is presented, emphasising on the dominant domestic and agricultural uses.

Domestic Demand

Domestic water requirements are forecasted on estimations of population growth, both permanent and seasonal.

Domestic users are represented in the Map Editor View of the DSS in terms of Settlements or Tourist Sites, according to whether they stand for inhabitants who live permanently in that region or for tourist arrivals and departures over the year. Regarding *Settlements*, the permanent population is the leading factor for water demand estimation; however the presence of people visiting the agglomeration annually is not excluded a priori. To cope with that, growth rates for seasonal population are also considered. Water demand for domestic use in year y and month m is computed as follows:

$$\begin{aligned} &SettleDemand_{y,m} = \\ &(PermPop_{y,m} \cdot ConsRatePerm_{y} \cdot 30 + SeasonPop_{y,m} \cdot ConsRateSeas_{y}) \cdot \\ &\cdot (1 + DistributionLosses_{y}) \end{aligned} \tag{9}$$

where:

PermPop	=	permanent population (inhabitants per month)
SeasonPop	=	seasonal population (overnight stays per month)
ConsRatePerm	=	consumption rate for permanent population (l/capita/d)
ConsRateSeas	=	consumption rate for seasonal population (l/capita/d)
DistributionLosses	=	water losses due to network inefficiency

The required data are specified by the DSS end user in the Data Editor Panel, together with the related trends, or behaviours in time.

Permanent and seasonal population are monthly variables; the annual number of people in the location is projected in time by assigning a yearly trend, and a monthly variation within every year of the projection can also be specified. Consumption rates and loss variables are defined on a yearly basis.

Domestic demand estimations are based on the following assumptions:

- Residential and tourist per capita demand are largely different; therefore they are treated as two separate factors, governed by different parameters (i.e. consumption rates);
- Losses in the distribution network and unaccounted for water are constant throughout the simulation year, and are given as a share of the total amount of water delivered;
- The monthly variation of tourist population indicates a seasonal pattern of arrivals and departures, which remain constant for the entire simulation period.

Agricultural Demand

The term "agricultural" refers here to the estimation of water needs for irrigation purposes. This demand depends on meteorological factors such as reference evapotranspiration and precipitation, as well as on cultivated crop types, characterised by crop factors and leaching requirements. The net irrigation water requirement per unit area of crop *i* is estimated on a monthly timescale according to the FAO crop coefficient method:

$$IRRnet_i = (Kc_i * ET_0 - P) \qquad (10)$$

where:

IRRnet	=	net irrigation requirement (mm/month)
Kc_i	=	crop *i* coefficient
ET_0	=	Reference evapotranspiration (mm/month)
P	=	Precipitation (mm/month)

Precipitation and reference evapotranspiration are expressed in mm/month and are derived from availability scenarios. The ET_0 term is defined as the evapotranspiration from an extensive surface of covered by green grass of 12 cm height adequately watered. The Kc coefficient accounts for crop characteristics, rate of crop development and length of growing season, and is used to get the particular ETP for the specific crop type from the reference one. The Kc crop coefficient is different for the four stages of crop development, which usually appear during the growing season. They comprise:

- The **initial stage**, running from planting date to approximately 10% ground cover;

- The **development stage**, from 10% ground cover to effective full cover (where effective full cover for many crops occurs at the initiation of flowering);
- The **mid-season stage**, from effective full cover to the start of maturity, which is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit; and
- The **late season stage**, running from the start of maturity to harvest or full senescence.

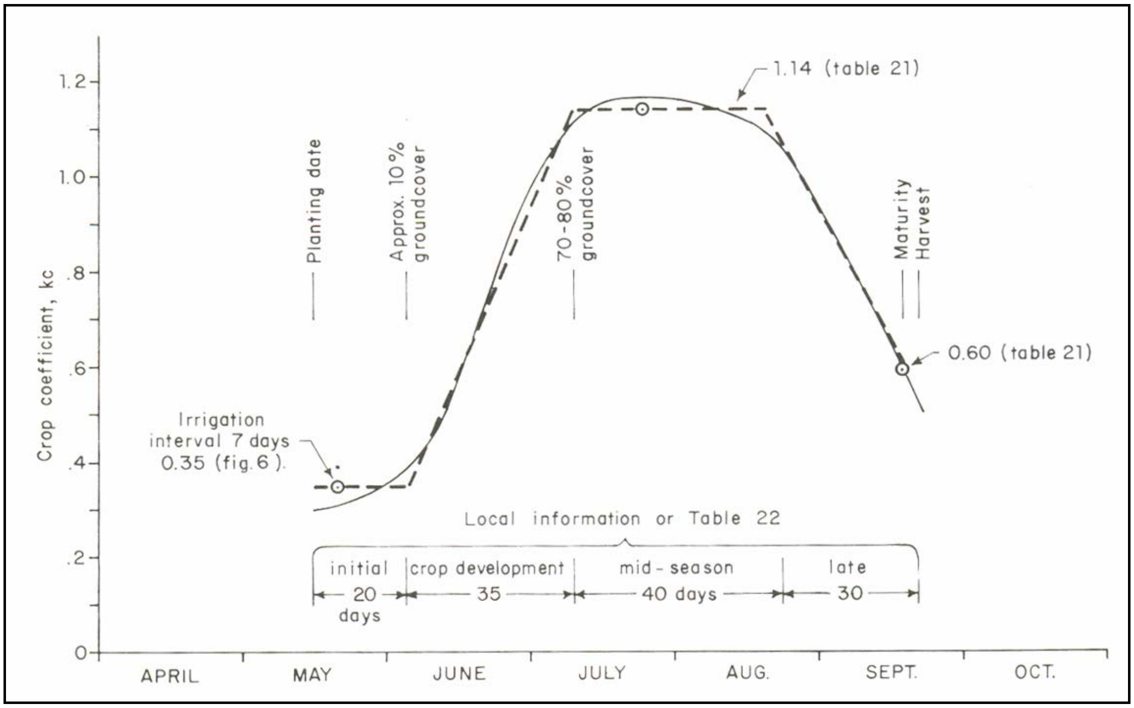


Figure 29 Example of Crop coefficient curve (from FAO, 1977)

The required crop information, including the crop coefficient curve defining the stage periods, can be entered by the user from the DSS interface, in a particular crop table. When computing the net water requirements for crop *i* in month *m*, the Demand Module of the DSS retrieves the proper monthly values of meteorological data and of *Kc* from the database, by accessing it with the current month index.

In order to compute the *Gross Irrigation Water requirement*, defined as the amount of water to be applied to an irrigation scheme, the net irrigation amount has to be multiplied by the crop area. Leaching requirements and the global efficiency of the irrigation system must also be accounted for:

$$GrossIRR = \frac{10}{Eff} \sum_{crops} \left[\frac{AreaCrop \cdot IRRnet}{1 - LR} \right] \tag{11}$$

where:

GrossIRR	=	Gross Irrigation Water requirement (m3/month)
AreaCrop	=	area cultivated with the generic crop (ha)
IRRnet	=	net irrigation requirement (mm/month)
LR	=	leaching requirement factor
Eff	=	global efficiency

The global efficiency of an irrigation system is defined as the ratio of abstracted water that actually reaches the plant and is disaggregated in three different factors:

- Conveyance efficiency, relating the path from the abstraction to the network,
- Distribution efficiency, referring to the losses in the distribution network, and
- Application efficiency, representing the amount of water that actually reaches the fields.

On a global level, irrigation efficiency is estimated to be around 40 %.

Leaching requirement is the amount of water that is needed for leaching of accumulated salts from the root zone, in order to control the soil salinity at the given specific level. It is determined according to irrigation methods and electrical conductivities of irrigation water and saturated soil (FAO, 1977):

For surface irrigation and sprinkler:

$$LR = \frac{EC_W}{5EC_e - EC_W} \qquad (12)$$

For drip and high frequency sprinkler:

$$LR = \frac{EC_W}{MaxEC_e} \qquad (13)$$

where:

EC_W	=	electrical conductivity of irrigation water
EC_e	=	electrical conductivity of the soil salt saturation extract for a given crop, appropriate to the tolerable degree of yield reduction.
$MaxEC_e$	=	maximum tolerable electrical conductivity of the soil salt saturation extract for a given crop

As an alternative to the above water requirements estimation based on meteorological and crop-specific data, which is also regarded as *Complex model* within the tool, the WSM DSS also considers the possibility that the user may already have the data for the average amount of water requirement for each cultivated crop type and for each month (mm/month). In this case, the data can be directly edited in the *Demand Database Form – Simplified Model Tab*, from the main interface window. According to the available data, the complex or simplified model can be chosen.

Animal Breeding Demand

The computation of water demand for animal breeding activities is based on the monthly demand per head of livestock type, such as cows, goats, pigs, sheep etc., multiplied by the number of animals. These data are defined by the user both in the Data Editor and in the *Livestock Types* form, together with the growth rates expression for the number of animals, which define the animal breeding demand scenarios.

Industrial Site Demand

Industrial demand scenarios follow the same activity level approach as the breeding sites: a consumption rate, in terms of cubic metres needed per unit production, drives the demand calculation upon a total production growth and the share of consumptive demand over the total. This latter term takes into account the nature of industrial use of water, which is consumptive when referred to as processing water, and non-consumptive when used for cooling, steam generation, cleaning, conditioning, etc.

Hydropower Demand

The water demand for hydropower facilities connected to a reservoir structure is non-consumptive and is estimated given the amount of energy to be produced. This amount is specified by the DSS user in the *Data Editor Panel*, where he also defines trends of produced energy.

The amount of energy that is converted by a hydraulic turbine using the energy of water is computed by integrating the power produced by the turbine over time:

$$E = \int_{t=0}^{T} Q \cdot H \cdot g \cdot e \cdot dt \qquad (14)$$

where:

E	=	energy produced
H	=	net available head
Q	=	flow
e	=	overall efficiency which includes turbine and generator efficiency

Exporting Demand

Exporting demand represents the amount of water that is transferred out of the region. It is defined by the maximum monthly volume that can be allocated for the purpose, and is subject to a demand growth expression and a related annual variation (Data Editor).

Environmental – Navigation – Recreational Demands

The river reach-related water demands consist of minimum monthly flow requirements aiming to guarantee navigation, recreational activities (e.g. fishing), and the preservation of physical and geomorphologic regime of the river, in order to sustain the ecologic value of the aquatic ecosystem. For these three types of requirements, demand scenarios are assumed to be annually stable over the simulation period and only a monthly distribution should be provided.

Implementation in the WSM DSS

The Demand Scenarios Module of the DSS produces forecasted time-series of water demand for all the *demand nodes* that are placed on the map of the region, both *site*-type, such as settlements, tourist sites, irrigation, animal breeding and industrial sites, and others such as hydropower plants, exporting and river demands.

Scenarios are generated by specifying appropriate **growth rates** to the key variables (Drivers) that govern the water demand of the nodes, such as population for the domestic use, cultivable area and livestock for agricultural practices, production growth and energy requirements for industries and hydropower plants respectively. This specification can be performed in two ways:

- **At once** for all the nodes belonging to the same demand category, by activating the Create Scenarios/Demand option in the Navigation Panel, or
- **Node by node** going through the list on nodes in the Navigation Panel and editing growth rates from the Data Editor Panel.

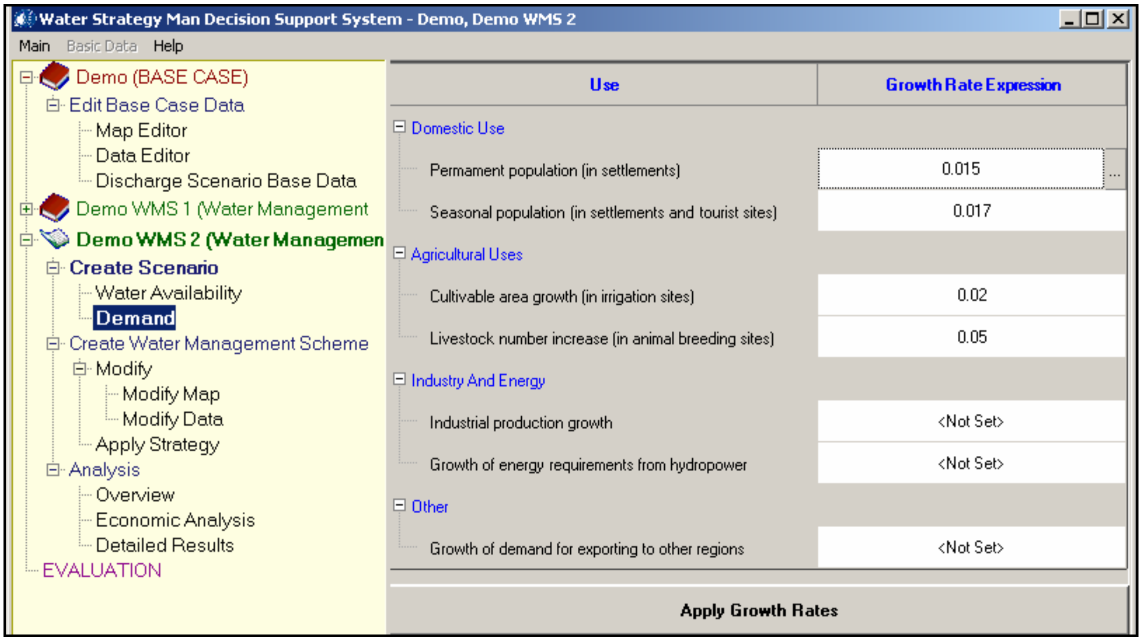


Figure 30 Definition of growth rates from the Create Scenario\Demand Panel (on the right)

In order to assign the same growth rate number or expression to all the nodes of the same water sector, e.g. to all settlement nodes, the user of the DSS activates the Demand Scenarios Panel from the Navigation window and double clicks the *<Not Set>* field corresponding to *Permanent population (in settlements)*. This procedure opens a table where time variant (yearly) or constant rates can be entered. With the *Add* and *Delete* buttons new entries are defined or erased, each one related to a year of the simulation period. The growth rate assigned to a year is implicitly assigned to all the years that follow, which do not have an explicit rate, until another year with a different rate is entered.

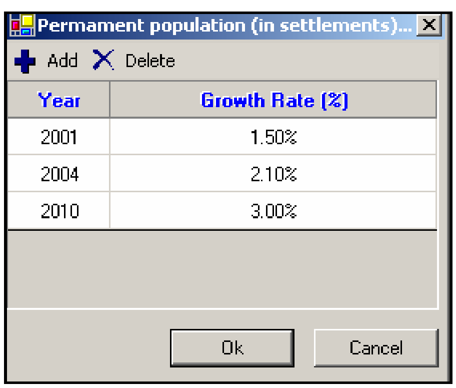


Figure 31 Growth rate form with time-variant rates.

For example, if growth rates of 1.5, 2.1 and 3% are entered for years 2001, 2004 and 2010 respectively, this means that for the period 2001-2003 the permanent population growth rate will be 1.5%, for the period 2004-2009 it will be 2.1% and from year 2010 up to the end of the scenario horizon, it will be set equal to 3%. With the *Apply Growth Rate* button (located at the bottom of the Demand Panel) the user can apply the growth rate to all the nodes of the sector. The operation overwrites any custom value the user may have previously entered, even this has been assigned to a particular node.

Having confirmed the application of the desired values, it is possible to see graphically the influence and effect of any choice over the total water demand of the domestic sector during the simulation period. The yearly sums are displayed in a graph below the Demand Scenario Panel. A tab allows the user to pass from the graph to a table format of the visualised data.

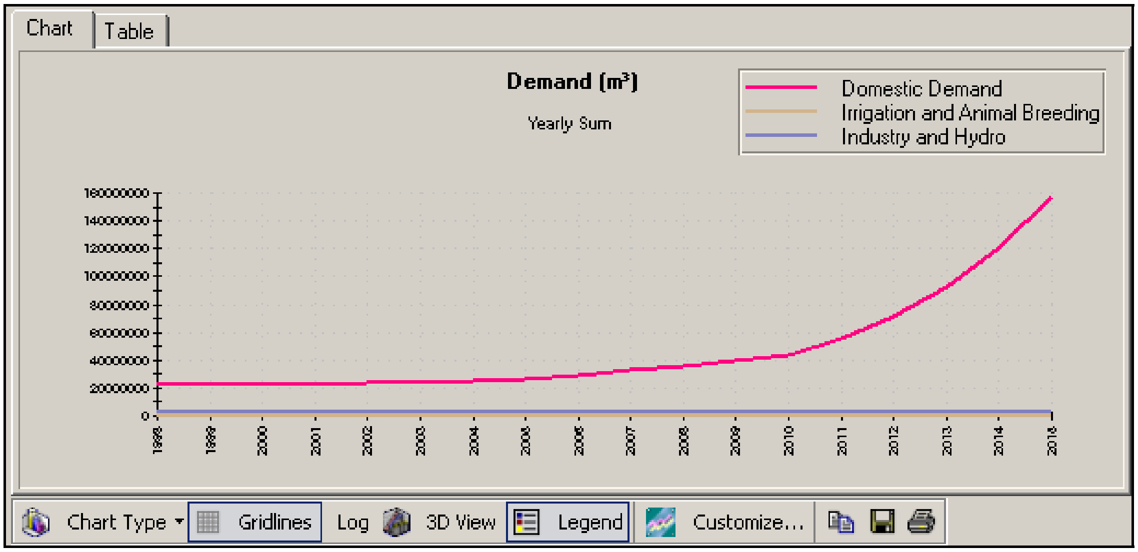


Figure 32 The chart below the Demand Panel displays the Demand Scenarios for each water sectors. Here the effect of three different growth rates for years 2001, 2004 and 2010 is visible.

Alternatively, growth rates for the demand drivers can be entered node-by-node. Data are edited directly in the Data Editor Panel, after having accessed the specific nodes through the Object Manager panel of the DSS. Node by node definition of data overwrites the one by sector. Table 5 shows for node type, the variables where a growth factor (or another type of customized expression) can be assigned and their location in the Data Editor table of attributes.

Table 5 Attributes for building Demand Scenarios on a node level

Node Type	Variables	Data Editor Tab
Animal Breeding Site	Number of Animals	Animal Breeding Activities
Industrial Site	Production	Demand Data
	Consumption Rate	Demand Data
	Share of Consumptive Demand	Demand Data
Irrigation Site	Maximum Cultivable Area	General
	Crop Area Share	Irrigation Activities
Settlement	Residential & Tourist Population	Population Data
	Population Month Variation (optional)	Population Data
	Residential & Tourist Consumption Rate	Demand Data
Tourist Site	Tourist Population	Population Data
	Month Variation (optional)	Population Data
	Tourist Consumption Rate	Demand Data
Exporting	Demand	Demand Data
	Month Variation (optional)	Demand Data

Node Type	Variables	Data Editor Tab
Hydroelectricity	Energy Requirements	Demand Data
	Month Variation (optional)	Demand Data

The *Month Variation* variable, identified in Table 5 as optional, represents the yearly distribution of the increment set by the user to the demand key variable. If not used, the yearly growth is allocated monthly with the same percentage. The month variation entry is supported by a separate window of the DSS, which allows for direct editing of the percentages in a grid or for setting them graphically through a drag and drop operation on a chart. The *Set All Equal to Zero* button helps for a quick reset of variation values.

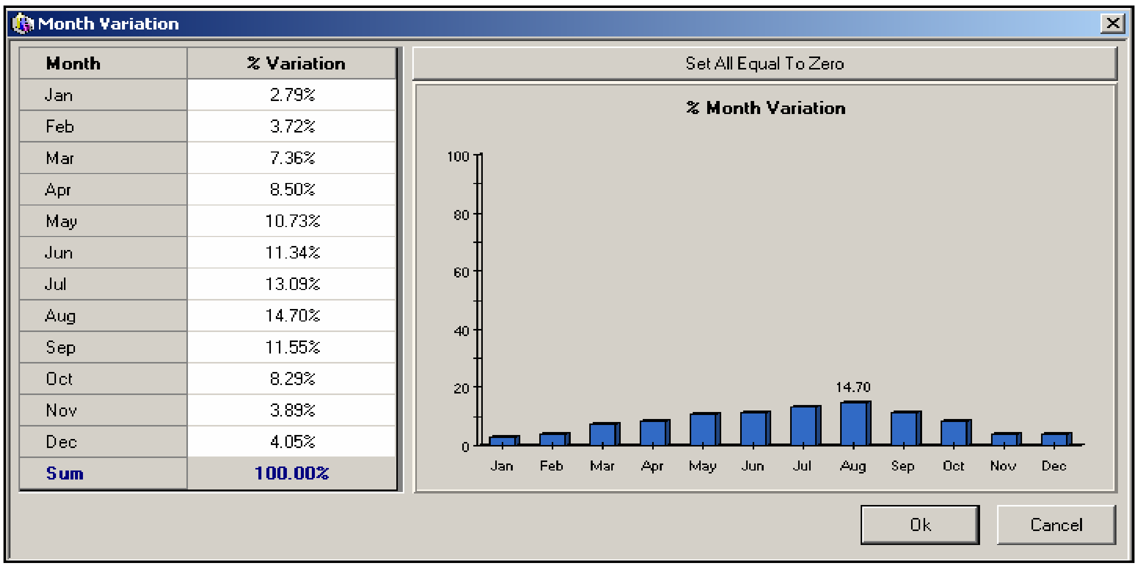


Figure 33 The Month Variation Window

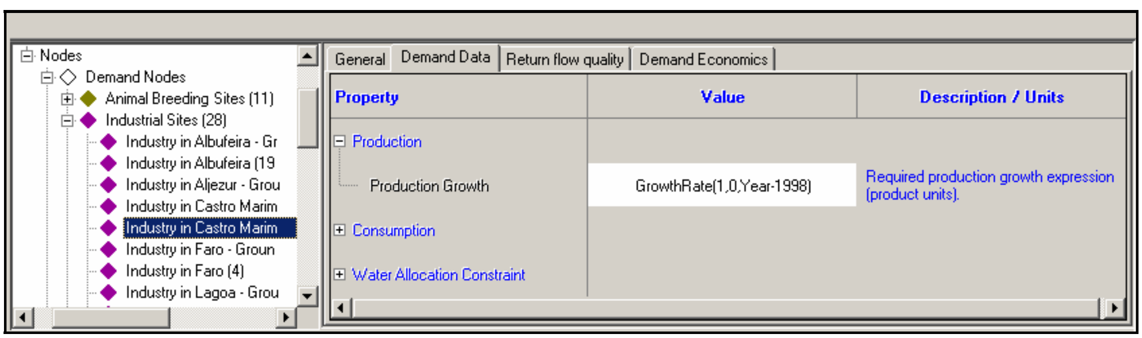


Figure 34 Editing growth rate for a single Industrial Site

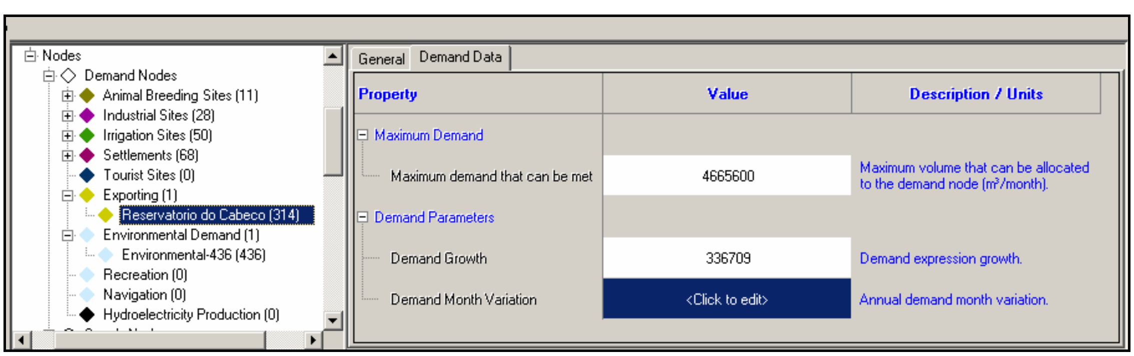


Figure 35 Editing growth rate for a single Export node

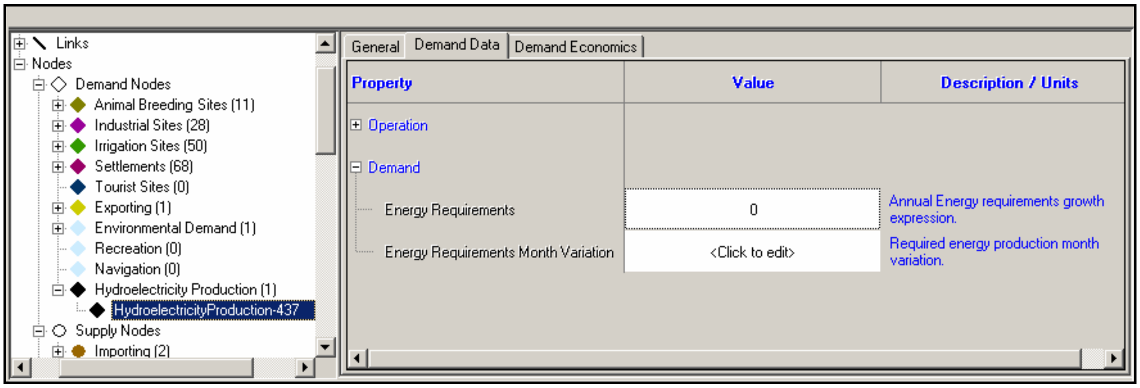


Figure 36 Editing growth rate for a single Hydroelectric Plant

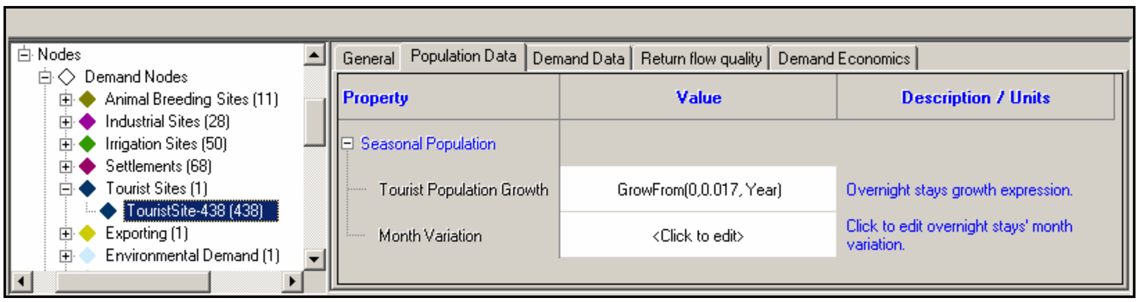


Figure 37 Editing growth rate for a single Tourist Site

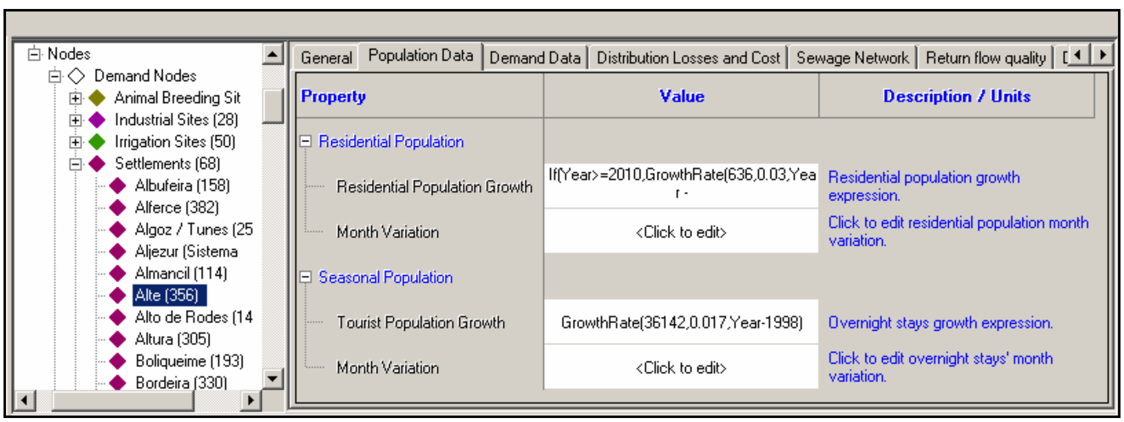


Figure 38 Editing growth rate for a single Settlement

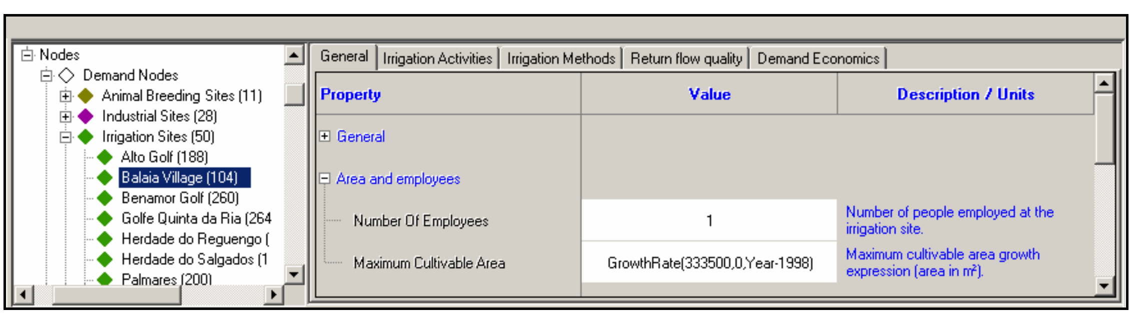


Figure 39 Editing growth rate for a single Irrigation Site

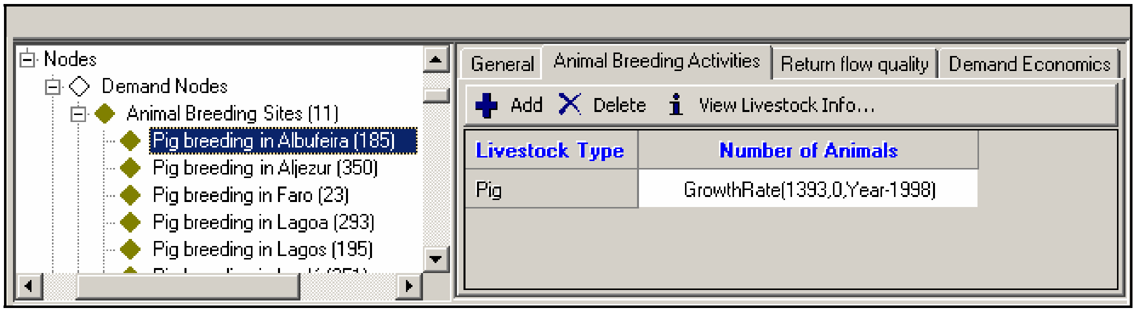


Figure 40 Editing growth rate for a single Animal Breeding Site

The definition and management of data related to agricultural and animal breeding modelling is based on dedicated entry forms. Information about the list of the different crops cultivated in the region and their characteristics is placed in the *Crop Database*, accessed from the interface by the *Basic Data/Demand Database* menu, while the list of animals and their market values are placed in the *Livestock Types Form*, accessed by the *Basic Data/Livestock Types* menu.

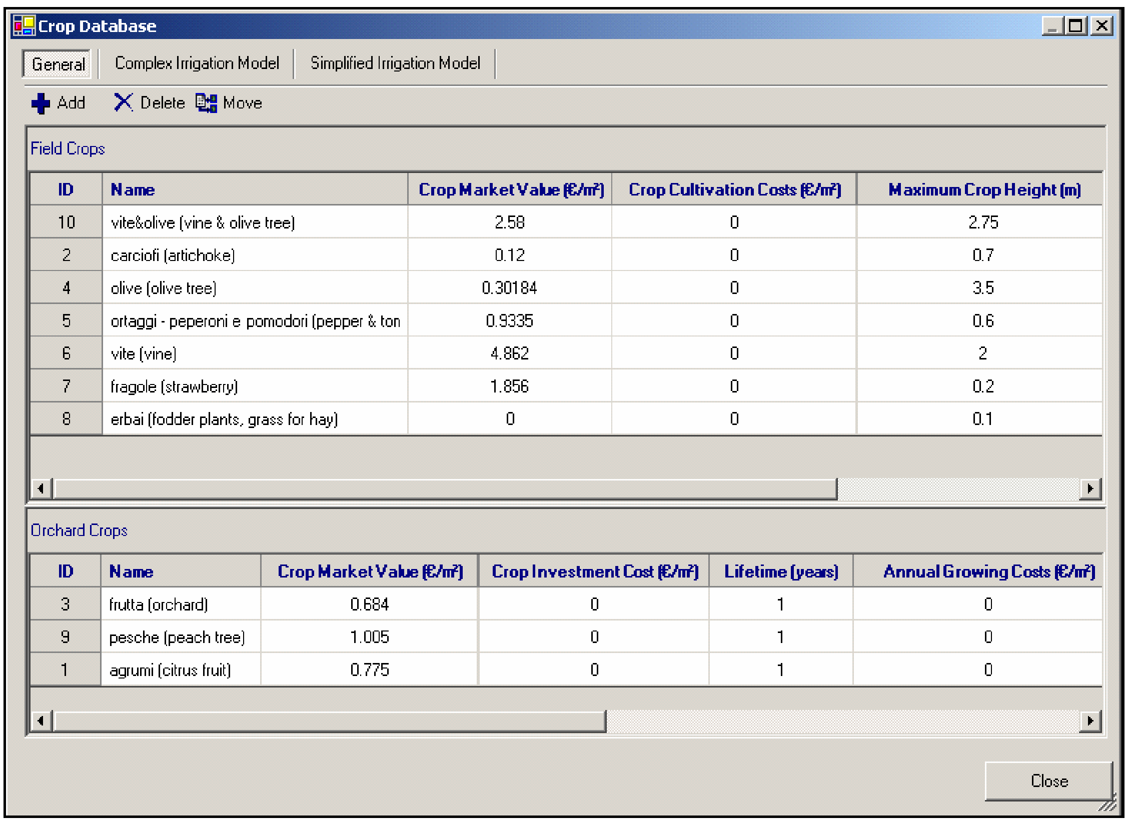
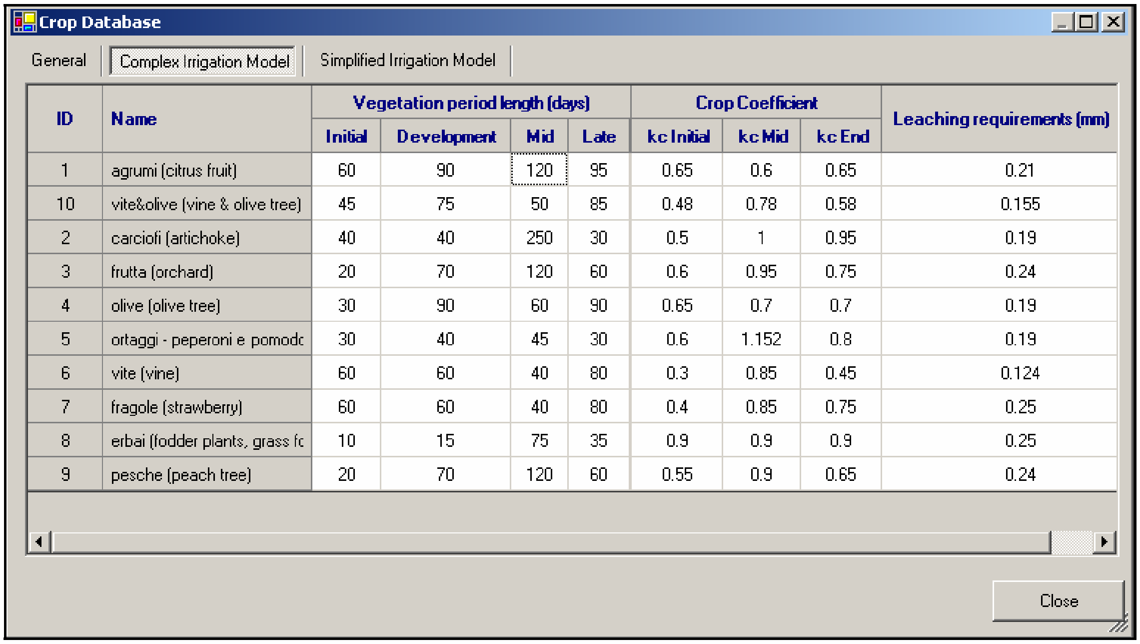


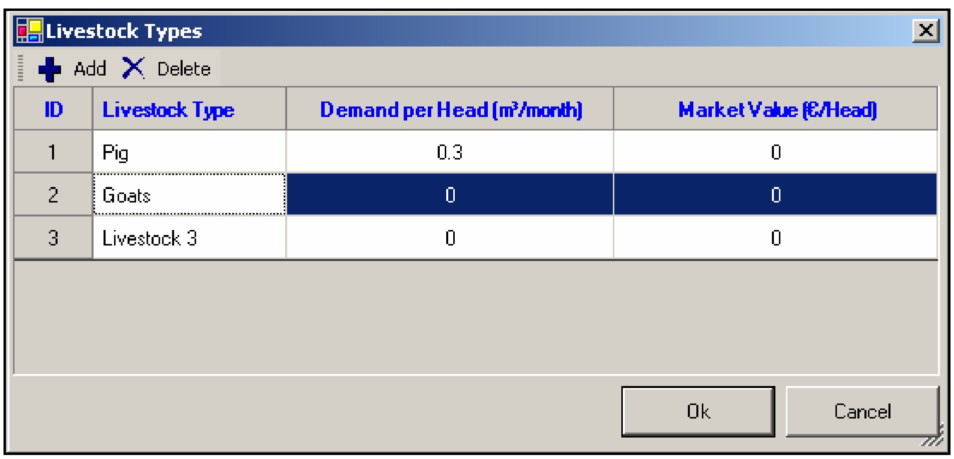
Figure 41 The General Section of the Crop Database

In particular, the Crop Database Form presents crop data classified in three sections: the *General,* the *Complex Irrigation Model* and the *Simplified Irrigation Model*. In the General section two tables show a number of crop type economic data for field and orchard crops respectively. Among the economic information for field crops there are Crop Gross Added Value and Cultivation Costs, whereas maximum crop height and planting date are the crop characteristics. Orchard crops also have some exclusive information, such as Investment Cost, Lifetime, Growth period and Cost. The DSS user can customize his own list of crops by adding new ones or deleting some through the *Add* and *Delete* buttons, and he can move the crops from the field crop table to the orchard and vice versa by selecting the crop and clicking the *Move* button. The Complex and Simplified sections of the Crop Database Form contain the modelling information that is described in the *methodology outline* section of this document: vegetation periods, crop factors and leaching, for the complex model, and monthly water requirements for the simplified one.



ID	Name	Vegetation period length (days)				Crop Coefficient			Leaching requirements (mm)
		Initial	Development	Mid	Late	kc Initial	kc Mid	kc End	
1	agrumi (citrus fruit)	60	90	120	95	0.65	0.6	0.65	0.21
10	vite&olive (vine & olive tree)	45	75	50	85	0.48	0.78	0.58	0.155
2	carciofi (artichoke)	40	40	250	30	0.5	1	0.95	0.19
3	frutta (orchard)	20	70	120	60	0.6	0.95	0.75	0.24
4	olive (olive tree)	30	90	60	90	0.65	0.7	0.7	0.19
5	ortaggi - peperoni e pomodc	30	40	45	30	0.6	1.152	0.8	0.19
6	vite (vine)	60	60	40	80	0.3	0.85	0.45	0.124
7	fragole (strawberry)	60	60	40	80	0.4	0.85	0.75	0.25
8	erbai (fodder plants, grass fc	10	15	75	35	0.9	0.9	0.9	0.25
9	pesche (peach tree)	20	70	120	60	0.55	0.9	0.65	0.24

Figure 42 The Complex Irrigation Model Section of the Crop Database



ID	Livestock Type	Demand per Head (m³/month)	Market Value (€/Head)
1	Pig	0.3	0
2	Goats	0	0
3	Livestock 3	0	0

Figure 43 The entry form for livestock data

An additional DSS functionality that characterises the demand scenarios is the **Demand Feedback Loop**. When enabled by the DSS user in the General Tab of the Data Editor, this option allows for modifying the demand scenarios on the fly, during the simulated water allocation. The variables that drive the scenarios behaviour, such as population for settlements or cultivable area for irrigation sites, are changed according to the demand deficits occurring in a user-defined number of previous years. Such a modelling approach can be used to simulate the demand node reaction and adaptation to deficit conditions. The demand feedback loop option can be activated for every single node, by setting the *Enable* parameter in the General Data Tab of the node equal to *True*. At the same section, the DSS user has to specify the interval of years to be considered in the feedback analysis. The feedback option is currently implemented for Irrigation Sites, Settlements and Animal Breeding and is under development for Tourist, Industrial Sites and Export Nodes.

The irrigation site loop works as follows: the DSS during the feedback interval estimates the actual water that is received by each crop cultivated in the irrigation site (according to the total supply delivered to the irrigation site and the user-defined priority for each crop) and from that the actually irrigated area. In case that the total volume of water received by the crop is less than the theoretical irrigation water requirements during the feedback interval, the DSS estimates the median of actually irrigated area during the interval and uses it to specify an upper limit for the area that can be cultivated with the specific crop.

In the case of settlements, if supply delivered to the settlement is zero during the feedback interval, then permanent and seasonal populations are set to zero for the remaining simulation period; if the total volume of water received is not equal to zero, then the DSS estimates for each month of the interval, an upper limit of overnight stays (seasonal population) that can be sustained with the volume of water delivered. This is performed through the calculation of the median value of overnight stays for that month of the interval that can be sustained with the volume of water delivered.

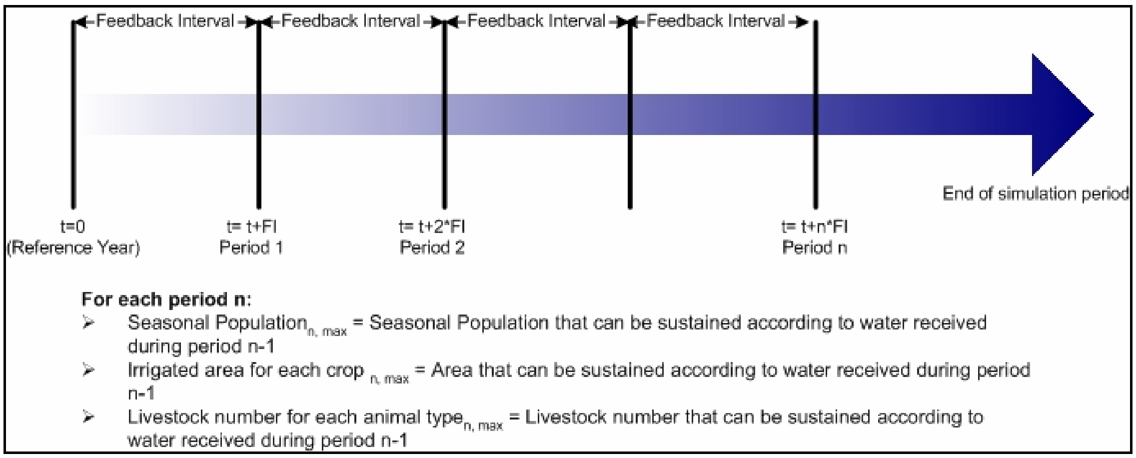


Figure 44 Feedback loop runs every feedback interval in the simulation period

For animal breeding activities the procedure is similar to that applied for irrigation sites. For the Demand Feedback Interval the DSS estimates the actual water that is received by each livestock type specified for the animal breeding site according to the total supply delivered to the site and the value for the livestock type. In case that the total volume of water received by the animal type during the demand feedback interval is less than the total water requirements, the DSS estimates the median of the number of animals that can be sustained, and uses it to specify an upper limit for livestock number of the particular type at the specific site.

Chapter 6 Strategic Options for Integrated Water Resource Management

This chapter describes the strategic options currently available within the WSM DSS. They are grouped under four categories:

- Measures related with **Supply Enhancement**, introducing new structural interventions to increase water availability;
- Measures of **Demand Management**, aiming to control and limit water demands;
- **Regional Development** measures, affecting the socio-economic preferences given to certain types of water use with respect to others and finally,
- **Institutional policies**, such as water pricing policy changes.

Table 6 Summary Table of Policy Options and related Actions

Policy Options	Actions
A. Supply Enhancement	Unconventional/untapped resources Surface Waters and precipitation (direct abstraction, dams, reservoirs) Groundwater (drillings, wells) Desalination Importing Water Reuse
B. Demand Management	Quotas, Regulated supply Irrigation method improvements (drip irrigation, enclosures) Conservation measures in the home (water saving plumbing systems) Recycling in industry and domestic use Improved infrastructure to reduce losses (networks, storage facilities) Raw material substitution and process changes in industry
C. Social-Developmental Policy	Change in agricultural practices (low irrigation crops, genetic improvement) Change of regional development policy (tourism/agriculture limitation)
D. Institutional Policies	Institutional Capacity Building (Education and awareness campaigns, Use of standards, Public participation, Stakeholder involvement, Conflict resolution, Contingency planning) Economic Policies (Water pricing, Cost recovery, Incentives) Environmental Policies (Enforcement of environmental standards and legislation, Monitoring, Penalties and fines, Impact and risk assessment)

Within the Water Strategy Man Project, a **strategy** is intended as the employment of all the policies/options available in the case study region for mitigating water stress conditions and accomplishing the objectives of an Integrated Water Resource Management, based on principles such as economic efficiency, environmental sustainability and social equity. Equity relates actions for minimising water shortage and for distributing costs equitably among domestic, tourist, agricultural and industrial uses. Environmental protection is connected to regulation enforcement and impact mitigation whereas economic efficiency is founded on cost recovery of direct, opportunity and environmental costs and their minimisation during the formulation of water management plans.

According to the definition of a strategy as above, the DSS user is supported to apply and evaluate the effects of every single strategic option by itself; however the real objective of the DSS Strategy Module is to assist in building a combination of management measures in a timeframe into a strategy.

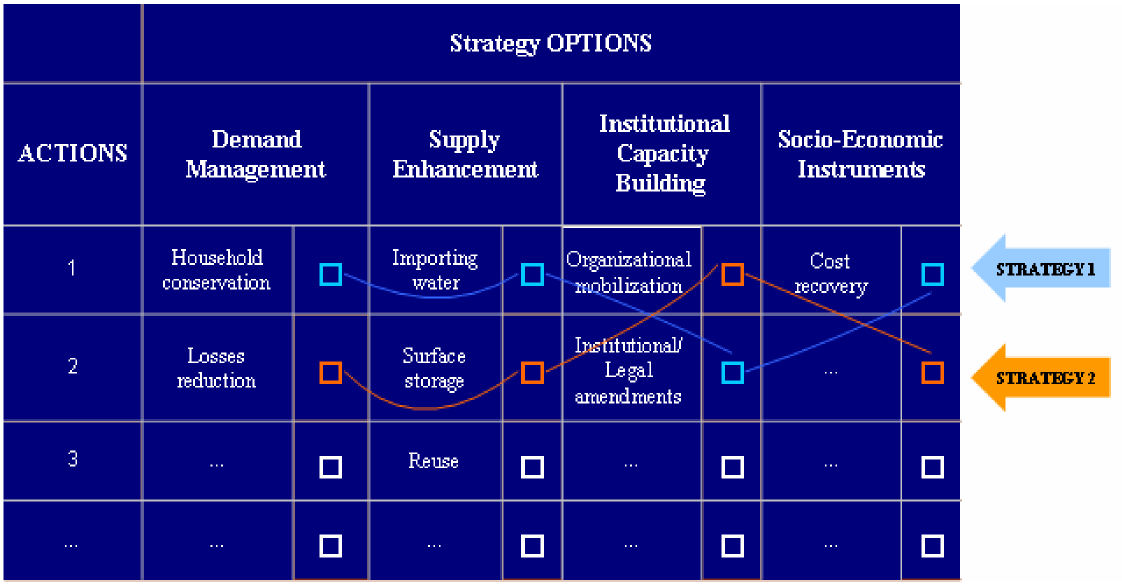


Figure 45 Combining options into strategies

The *Strategy Panel* of the WSM DSS is reachable from the *Apply Strategy* menu of every Water Management Scheme in the Manager Panel. The window is split in three sections:

1) The **Action Tree View**, listing the pending or the already applied actions;
2) The **Action Form** containing descriptive detailed information for each action, that is used for its definition, and
3) The **Map Window** with the region and the water resource network system.

At the top of the window there are four drop-down buttons, listing the types of actions that can be implemented for each policy option category included in the current version of the DSS. By selecting an option from a list, the form with all the data fields and information specific to the action is loaded and the selected action appears in the tree view under *Pending Actions.* At the bottom of each action form there is the *Apply Action* button that allows for applying the selected action to the water management scheme under analysis: in this way the option moves from the list of *Pending Actions* to the *Already Applied Actions* one. It should be noted that every action can also be applied through proper modification of the attributes of the network nodes/links or through network editing using the Modify Map and Modify Data options. However, the Apply Strategy module provides an easy-to-use interface that permits the successive implementation of actions and their systematic organisation in both space and time.

The **Supply Enhancement** options currently implemented in the DSS are:

- ❖ Desalination Unit construction,
- ❖ Water Reuse and
- ❖ Importing.

The *Desalination Unit Construction* form permits the construction of a new plant (desalting sea or brackish water) to provide some settlements or tourist sites with potable water. Regarding the simulation of the water system, this implies that those demand nodes will count on more available potable water from a certain time step on in the simulation period. The amount of water supplied to demand nodes depends on the capacity of the plant and the rate of distribution losses of the pipelines connecting the nodes. The time at which the new network node becomes active is set in the *Construction Year* field of the form whereas the *Operating Lifetime* field implicitly sets the year in the simulation the node stops working.

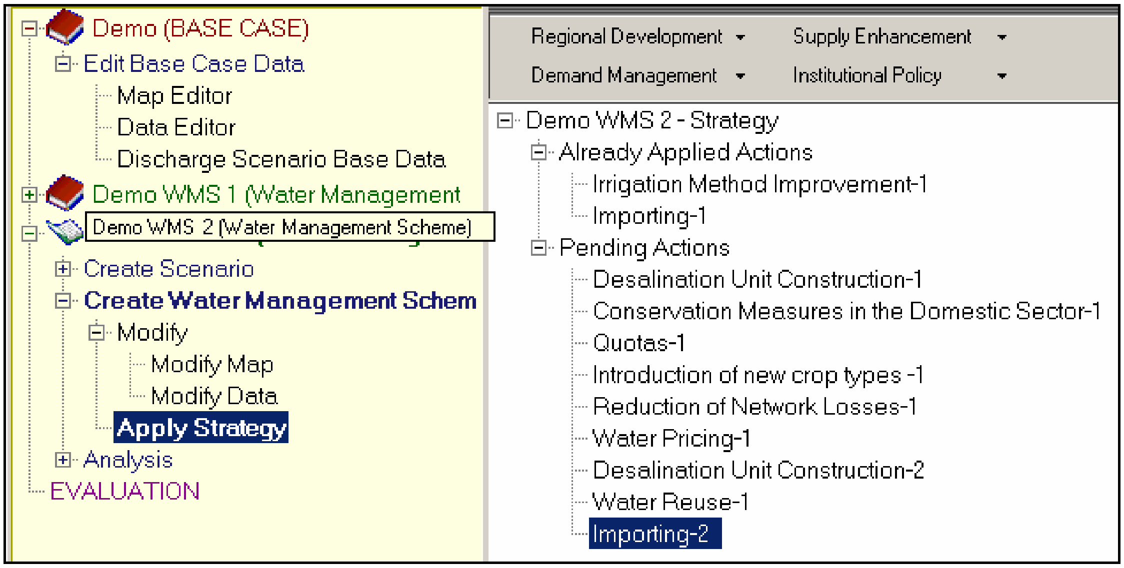


Figure 46 Running the Strategy Options Panel from the Navigation Panel (left), and the tree view of pending and applied actions (right)

The form also presents Unit and Process type of the desalination plant, cost figures related to construction, operation and maintenance costs and energy consumption. Part of the form lists the settlements and tourist sites of the network that can be connected to the new treatment plant. The connection is conceptually established by ticking in the dedicated field, while a supply priority of the link can also be assigned. The desalination unit is finally sited on the region according to a user-selected distance from the source of sea or brackish water and the distance from the settlements.

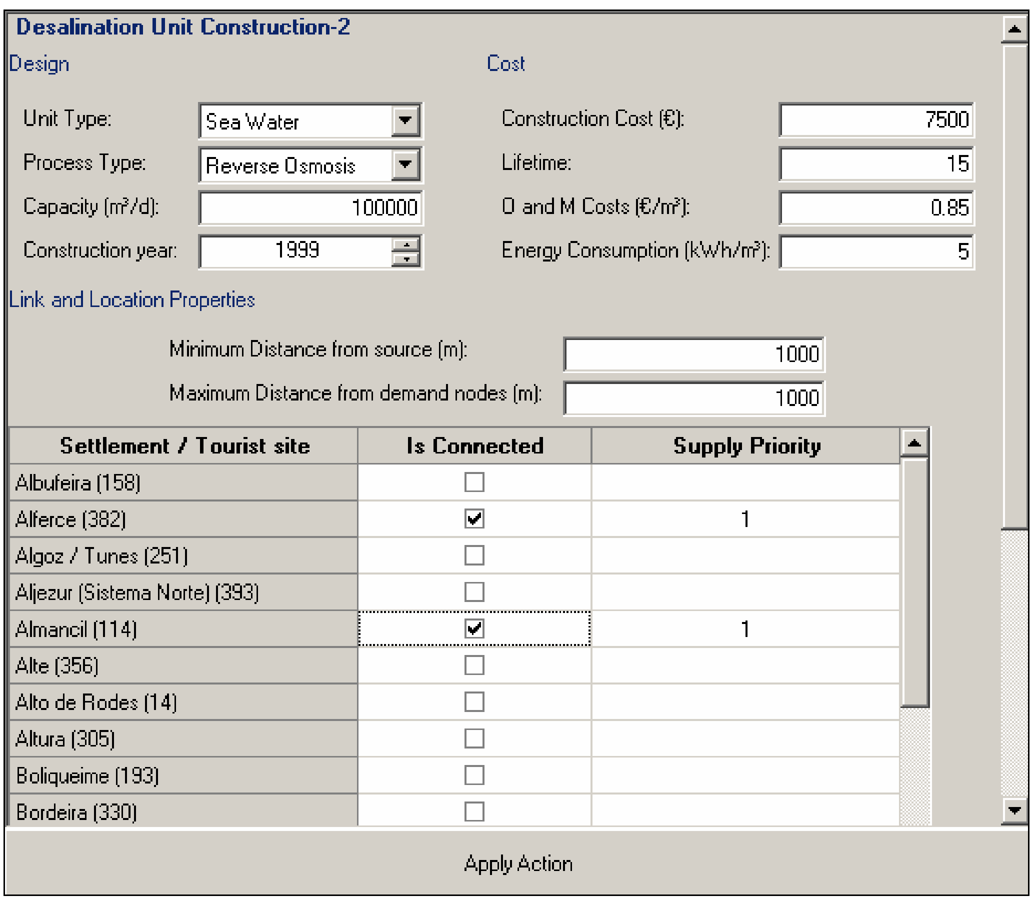


Figure 47 Supply Enhancement – Desalination Policy Form

The *Water Reuse* measure of the Supply Enhancement category permits to connect existing waste water treatment plants to irrigation sites, in order to reuse urban return flows for agricultural purposes. Similarly to the desalination form, it presents economic and process type details about the plants, and a field setting the implementation year for the action. The DSS user has to go through the list of irrigation sites of the network and choose the ones to be provided with treated wastewater effluents. Once a site has been ticked properly, the supplying treatment plant is to be selected from the drop-down box at the top of the form and a supply priority has to be defined. While selecting the plants, the corresponding removal rates for all quality variables are displayed in the specific table. These data are those edited in the Data Editor and can be modified there.

The *Importing* action concerns the activation of a new node standing for the importing of water from outside the studied area for meeting high water requirements either in settlements, animal breeding sites, irrigated districts or industries. The operation period of time of the new importing transfers are determined by the information in the *Implementation Year* and *Infrastructure Lifetime* fields of the form. A maximum amount of water to be distributed each month among the selected demands can be defined in the *Maximum Quantity* entry. The resulting import node is situated on the map according to restrictions concerning the maximum distance from the boundary of the region and the distance from the demand nodes to be served. The form also allows for the assignment of water transfer costs (per cubic meter of water actually imported in the region).

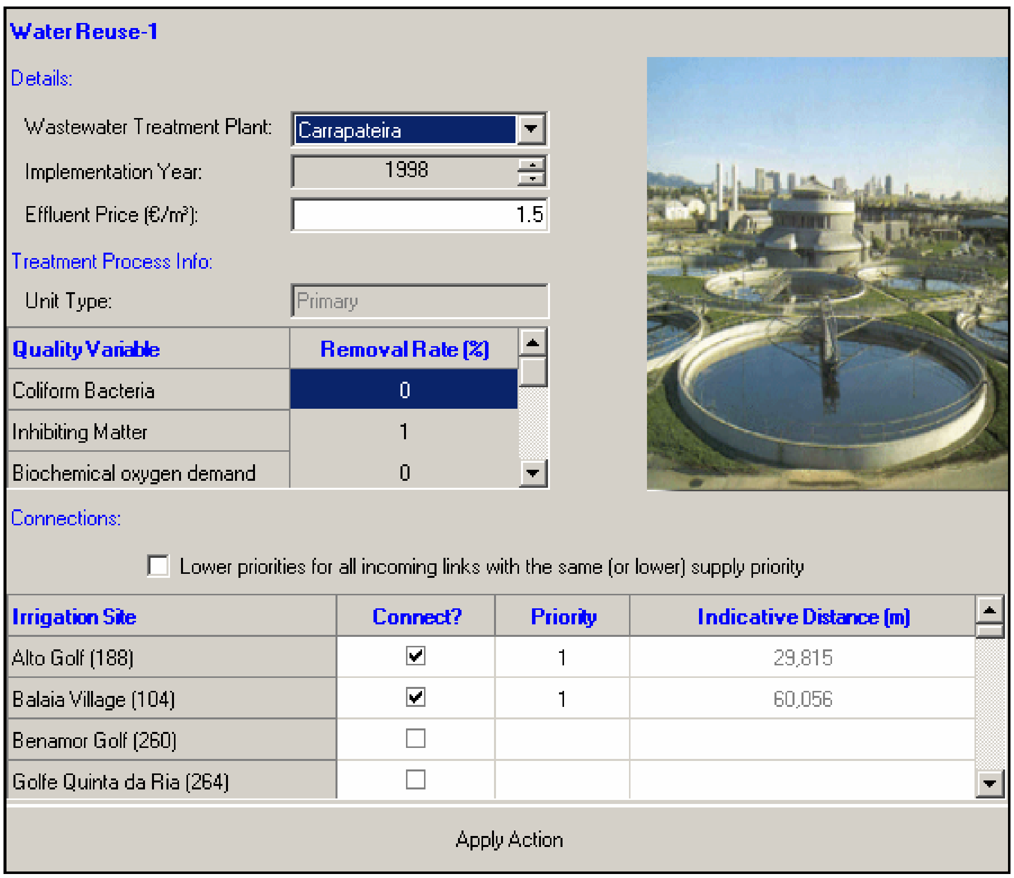


Figure 48 Supply Enhancement – Water Reuse Policy Form

The Demand Management options currently implemented in the DSS are:

- Conservation measures in domestic sector;
- Limitation to water use in terms of quotas;
- Irrigation method improvements;

- Process change in industry;
- Introduction of new crop types, and
- Reduction of network losses.

Conservation measures address a reduction of the daily per capita consumption in settlements to be applied from the implementation year of the option to the end of the simulation horizon. The consumption rates to be reduced are those entered by the DSS user in the *Data Editor* for each settlement node in the water network. The decrease is a percentage of the rate and can affect either residential or tourist consumptions. A cost per cubic metre of water conserved helps defining the economic sustainability of this action.

Another action aiming to decrease the water demands from a certain time step in the simulation is that of establishing *Quotas* of water use. Limitations to water volume allocated can be defined in terms of intensity and period of time the option will be applied to. From the quantity point of view, quotas are represented by a maximum volume per month allocated or by a rule that limits the volume supplied to a percentage of the previous year demand. Quotas can be activated: a) always throughout the year, b) only during summer months or 3) only the peak month of August.

In order to modify the demand pattern of irrigation sites, an option for improving current irrigation methods can also be implemented. The window relevant to this type of action displays the list of irrigated districts in the case study region, each one with the percentages of irrigation methods originally used in management scheme. New methods and corresponding irrigation efficiencies can be set, starting from the *Year of Implementation* of the action.

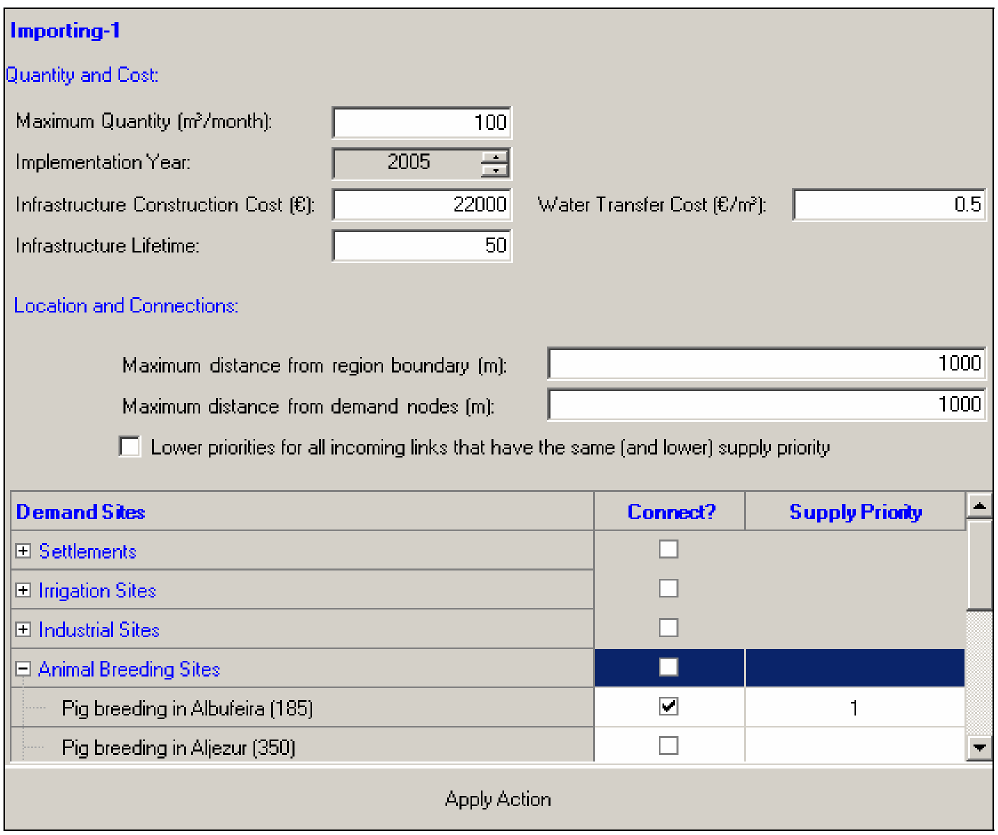


Figure 49 Supply Enhancement – Importing Policy Form

Another action that addresses the agricultural use of water concerns in particular the cropping pattern. The action name is *Introduction of New Crop Types* and allows for the partial or complete replacement of a crop with another on the basis of the cropping factor and value:

arrangements have to be accepted between cultivating crops that require less water and those which have a higher net value.

Demand management actions can also affect the industrial use of water: the DSS user is enabled to modify the consumption rates per production unit and the ratio of consumptive demand over the total, in the window of the *Process Change in Industry* action. The procedure to build the action is similar to the one of *Conservation Measures*: the industrial site nodes, which are the target of the demand reduction measure, are selected from a list and new values are set. Then, by pressing the *Apply Action* button, the action is implemented.

The last strategic option for demand management that is here described aims at reducing the distribution losses in the urban network of aqueducts. It works either on settlement nodes, by considering a replacement or maintenance of their internal distribution networks, or on the pipelines and canals that connect the resource nodes to the demand nodes. In both cases, the list of settlements or pipelines can be filtered, according to a targeted loss coefficient: by entering the target value in the relevant field of the action window, the number of network elements displayed is updated to those having a loss value greater or equal to the targeted one. Then the new losses rate can be assigned to all the resulting elements or just some of them. Selection is made by ticking the node or link, as it is for all the options in general. Replacement costs can also be specified.

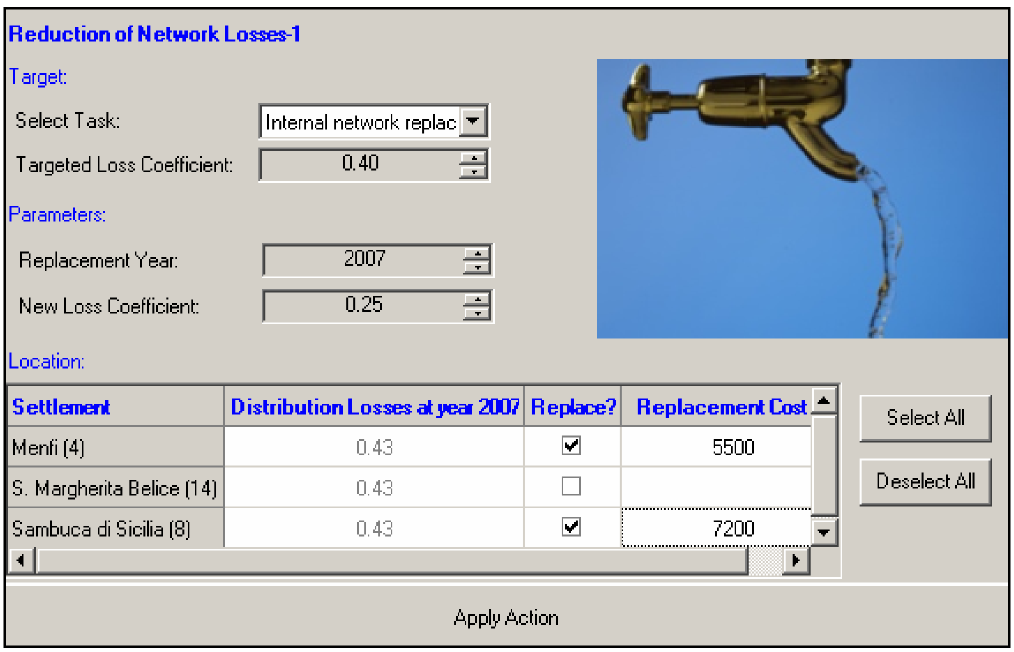


Figure 50 Demand Management – Reduction of Losses Form

From the side of the *Institutional Policy Options* category, the WSM Decision Support System currently includes a *Water Pricing* measure, which affects and influences the water demand of whatever use by setting information about demand elasticity and applying a new pricing scheme. Demand or price elasticity can be defined as the proportionate change in demand, when a change in price occurs, and it is given by the change in demand divided by the change in price. As it is for all the actions, the *Water Pricing* interface prompts the DSS user with the lists of settlements, irrigation sites, breeders and industries that exist in the case study, each one having the water-selling price that has been attached in the Data Editor and that would originally be used during the simulation. By changing demand elasticity for selected demand nodes, and thus implementing the water pricing option, the DSS simulates an external institutional intervention to become active at a certain time - the *Implementation Year* - during the water allocation simulation.

Chapter 7 Water Quality

The concept behind the inclusion of a simple water quality algorithm within the WSM DSS is to provide the Decision Makers with an estimation of how the concentration of selected quality parameters may evolve during the simulation period under specific water demands, meteorological conditions and allocation rules (priorities). In particular, the key concentrations addressed are those at the water resource nodes of the network: groundwater, river reaches, artificial and natural lakes. It is evident that water quality at the source nodes directly influences the one at the demand nodes they supply water to, and therefore at every location of the case study region.

Quality estimations are currently based on the assumption that water flowing in the water links (computed at each time step by the Water Allocation Model) has the same concentration as at the water source (supply nodes) it originates from, and it does not change during the transfer towards the demand sites (if of course the path does not intersect any treatment plants). Only mixing rules are applied on network intersections. The strict connection between water quantity and quality is evident: by distributing water volumes throughout the system, the Kernel of the DSS also distributes the concentrations of the monitored quality parameters, according to the paths traced by the network links.

The set of quality variables simulated comprises:

- Salinity,
- Chlorophyll alpha,
- Ammonia nitrogen,
- Nitrate nitrogen,
- Coliform bacteria,
- Total phosphorus,
- Heavy metals in general,
- Biochemical Oxygen Demand and
- Dissolved Oxygen.

New parameters are currently being introduced, such as suspended and inhibiting matters and adsorbable organic halogens.

Methodology Outline

The concentration of each quality parameter is updated at each time step and for each supply node using two different algorithms, according to the quality parameter type. For some the **continuity equation on the loads** is applied: the variation of load in the volume stored in the supply node (where load is concentration multiplied by the water volume) equals the difference between the incoming load and the outgoing load. The incoming load is equal to the sum of loads of the links carrying water to the supply node, while the outgoing load is computed from the current concentration at the supply node. Concentration is estimated at each time step by the equation. In these equations, additional terms are added to take into consideration the generation or decay of load i.e. the presence of algae and the nitrogen cycle. Moreover, some of the water quality variables, such as Chlorophyll alpha, ammonia nitrogen and nitrate nitrogen are strictly inter-related and their equations are solved following a computation sequence or iterations. This approach requires the user to specify the initial concentrations of the quality variables (referring to the first month in the simulation period).

Then, from the second month on, the quality equations use the concentrations updated at the previous time step.

The differential continuity equation, applied for each quality variable is the following:

$$\frac{di}{dt} = -A \cdot i + B \tag{15}$$

with an analytical solution of the type:

$$i = i_0 \cdot e^{-A \cdot t} + \frac{B}{A} \cdot (1 - e^{-A \cdot t}) \tag{16}$$

The specific equations for each quality variable are presented below.

Volume V of the water body:

$$\frac{dV}{dt} = I - O \tag{17}$$

where:

I = water flow entering the water body;

O = water flow exiting the water body.

Salinity S:

$$\frac{d(S \cdot V)}{dt} = Load(S)_{in} - O \cdot S \tag{18}$$

where:

S = salinity (amount of salt per cubic metre) ;

O = water flow exiting the water body;

$Load(S)_{in}$ = salinity load entering water body;

V = water volume (for the river reach it is the water volume flowing in it).

Chlorophyll alpha:

Chlorophyll alpha is directly proportional to the concentration of algal biomass A through the α_0 conversion factor.

$$Chl\alpha = \alpha_0 * A \tag{19}$$

The equation used to model the behaviour of algal biomass in time is the following:

$$\frac{d(A \cdot V)}{dt} = Load(A)_{in} - O \cdot A + V \cdot \left[(\mu - \rho - \sigma_1) \cdot A\right] \tag{20}$$

where:

$Load(A)_{in}$ = algal biomass load entering the water body;

O = water outflow;

A = concentration of algal biomass;

V	=	water volume;
μ	=	algal growth rate;
ρ	=	algal respiration rate;
σ_1	=	algal settling rate.

Ammonia N_1:

$$\frac{d(N_1 \cdot V)}{dt} = Load(N_1)_{in} - O \cdot N_1 + V \cdot \left[-\beta_1 N_1 \text{-} F_1\ \alpha_1 \mu A \right] \tag{21}$$

with

$$F_1 = \frac{P_N N_1}{P_N N_1 + \left(1 - P_N\right) \cdot N_3} \tag{22}$$

where:

$Load(N_1)_{in}$	=	ammonia nitrogen load entering the water body;
O	=	water outflow;
N_1	=	concentration of ammonia nitrogen;
V	=	water volume;
F_1	=	fraction of algal nitrogen uptake from ammonia pool;
α_1	=	fraction of algal biomass that is nitrogen;
A	=	concentration of algal biomass;
β_3	=	rate constant for hydrolysis of organic nitrogen to ammonia nitrogen;
β_1	=	rate constant for the biological oxidation of ammonia nitrogen;
μ	=	algal growth rate;
P_N	=	preference factor for ammonia nitrogen.

Nitrates:

$$\frac{d(N_3 \cdot V)}{dt} = Load(N_3)_{in} - O \cdot N_3 + V \cdot \left[\beta_1 N_1 \text{-} \left(1 - F_1\right) \alpha_1 \mu A \right] \tag{23}$$

with

$$F_1 = \frac{P_N \cdot N_1}{P_N \cdot N_1 + \left(1 - P_N\right) \cdot N_3} \tag{24}$$

where:

$Load(N_1)_{in}$	=	nitrate nitrogen load entering the water body;
O	=	water outflow;
N_3	=	concentration of nitrate nitrogen;
N_1	=	concentration of ammonia nitrogen;

V = water volume;

F_1 = fraction of algal nitrogen uptake from ammonia pool;

α_1 = fraction of algal biomass that is nitrogen;

A = concentration of algal biomass;

β_1 = rate constant for the biological oxidation of ammonia nitrogen;

μ = algal growth rate;

P_N = preference factor for ammonia nitrogen.

Coliform bacteria:

$$\frac{d(E \cdot V)}{dt} = Load(E)_{in} - O \cdot E + V \cdot \left[-k_5 \cdot E \right] \qquad (25)$$

where:

$Load(E)_{in}$ = coliform load entering the water body;

O = water outflow;

E = concentration of coliform bacteria;

V = water volume;

k_5 = coliform die-off rate.

Biochemical Oxygen Demand (BOD):

$$\frac{d(BOD \cdot V)}{dt} = Load(BOD)_{in} - O \cdot BOD + V \cdot \left[-\left(k_1 + k_3\right) \cdot BOD \right] \qquad (26)$$

where:

$Load(BOD)_{in}$ = Biochemical Oxygen Demand load entering the water body;

O = water outflow;

BOD = concentration of Biochemical Oxygen Demand;

V = water volume;

k_1 = deoxigenation rate coefficient;

k_3 = rate of BOD loss due to settling.

Dissolved Oxygen (DO):

$$\frac{d(DO \cdot V)}{dt} = Load(DO)_{in} - O \cdot DO + V \cdot \left[k_2 \left(DO^* - DO \right) + \left(\alpha_3 \mu - \alpha_4 \rho \right) \cdot A - k_1 \cdot BOD - \alpha_5 \beta_1 \cdot N_1 \right] \qquad (27)$$

where:

$Load(DO)_{in}$ = Dissolved Oxygen load entering the water body;

DO	=	concentration of Dissolved Oxygen;
$DO*$	=	saturation concentration of Dissolved Oxygen;
O	=	water outflow;
BOD	=	concentration of Biochemical Oxygen Demand;
V	=	water volume;
N_1	=	concentration of ammonia nitrogen;
A	=	concentration of algal biomass;
k_1	=	deoxigenation rate coefficient;
k_2	=	reareation rate;
μ	=	algal growth rate;
ρ	=	algal respiration rate;
α_3	=	rate of oxygen production per unit of algal photo-synthesis;
α_4	=	rate of oxygen uptake per unit of algae respired;
α_5	=	rate of oxygen uptake per unit of ammonia nitrogen oxidation.

Table 7 Water quality parameters involved for the differential continuity equations

Definition	Notation	Range of values	Units
Algal growth rate	μ	1.0 - 3.0	day^{-1}
Algal respiration rate	ρ	0.05 - 0.5	day^{-1}
Algal settling rate	σ_1	0.5 - 6.0	day^{-1}
Fraction of algal biomass that is nitrogen	α_1	0.07 - 0.09	dimensionless
Preference factor for ammonia nitrogen	P_N	0.0 - 1.0	dimensionless
Rate constant for the biological oxidation of ammonia nitrogen	β_1	0.1 - 1.0	day^{-1}
Coliform die-off rate	k_5	0.05 - 4	day^{-1}
Deoxigenation rate coefficient	k_1	0.02 - 3.4	day^{-1}
Rate of BOD loss due to settling	k_3	-0.36 - 0.36	day^{-1}
Reareation rate	k_2	0.0 - 100	day^{-1}
Rate of oxygen production per unit of algal photo-synthesis	α_3	1.4 - 1.8	dimensionless

Definition	Notation	Range of values	Units
Rate of oxygen uptake per unit of algae respired	α_4	1.6 - 2.3	dimensionless
Rate of oxygen uptake per unit of ammonia nitrogen oxidation	α_5	3.0 - 4.0	dimensionless
Ratio of chlorophyll alpha to algal biomass	α_0	10 - 100	µg-Chla/mg-A
Saturation concentration of Dissolved Oxygen	$DO*$	-	mg/l

The continuity equation algorithm is applied to river reach nodes and reservoirs nodes (lakes, storage reservoirs and small reservoirs). The formulation described above is based on the following assumptions:

- *For Dissolved Oxygen*: the rate of oxygen involved in oxidation of ammonia to nitrite has been disregarded, since nitrification-oxidation of ammonia to nitrate in one-stage process has been considered. Benthic oxygen uptake has not been considered.
- *For Ammonia Nitrogen*: benthos source rates have been disregarded.
- *For Nitrate Nitrogen*: nitrification-oxidation of ammonia to nitrate has been considered a one-stage process. Contribution of organic nitrogen has not been considered.

For quality variables such as heavy metals, total phosphorus, suspended and inhibiting matters and adsorbable organic halogens, the DSS applies a **heuristic proportionality approach**, which updates the concentration as a function of incoming load and of reference concentrations and loads. Water quality is assumed constant if the corresponding load is equal to the reference one, it worsens if the load increases, and it improves in the opposite case. In other words, the behaviour of the quality parameter at the supply node is in this case simulated according to the load received, by making the very rough approximation that the water body behaves in the same way as when reference concentrations and loads were measured. The reference concentrations and loads can be the ones entered for the beginning of the simulation period, equal to the initial concentrations, and should be the *Most Recently Measured* (MRM) values. The model uses twelve reference values, one for each month to consider the different monitored conditions over a one-year period.

The equation used is the following:

$$X_{t+1} = X^0{}_{t+1} \cdot (Load(X)_t / Load(X)^0{}_t) \quad (28)$$

where:

X	=	Concentration of the quality variable;
X^o	=	Reference concentration of the quality variable;
$Load(X)$	=	Load of the quality variable;
$Load(X^o)$	=	Reference Load of the quality variable.

In case of groundwater, this heuristic proportionality approach is used for all quality variables.

Water quality at supply nodes changes at each time step due to incoming loads from return flows generated by demand nodes and treatment plants. The loads at the exit of each wastewater treatment plant are computed according to removal rates assigned to each quality variable. The same stands for drinking treatment plants. However, in this case instead of removal rates, concentrations after process are set. The loads generated from demand nodes are also user-defined: a rate per unit of activity level is specified for each quality variable (Table 8).

Table 8 Generated Load Units for each consumptive use

Demand Node	Generated Load Units
Animal Breeding	kg/(m^3 of return flow)
Industry	kg/(unit production)
Irrigation	kg/(m^2 irrigated area)
Permanent & Seasonal Population	g/capita*day

Implementation in the WSM DSS

According to the outlined methodology, a minimum set of data is required in order to simulate the time evolution of water quality within the WaterStrategyMan DSS, in order to get a minimum set of results. These data include:

- **Initial water quality status**, to be used at the beginning of the simulation. Initial concentrations of quality variables must be defined for all the supply nodes of the water network. They can be average values of historic measurements or values monitored during the year before the simulation period;
- **Reference concentrations** and loads for all supply nodes. They are monthly values denoting a quality status that can be assumed as reference for estimating improvements or a worsening variation. They can be the *Most Recently Measured* concentrations of water variables;
- **Quality parameters** as in Table 7 that are involved in the analytical formulation. They must be defined for all surface water nodes (river reaches and reservoirs).

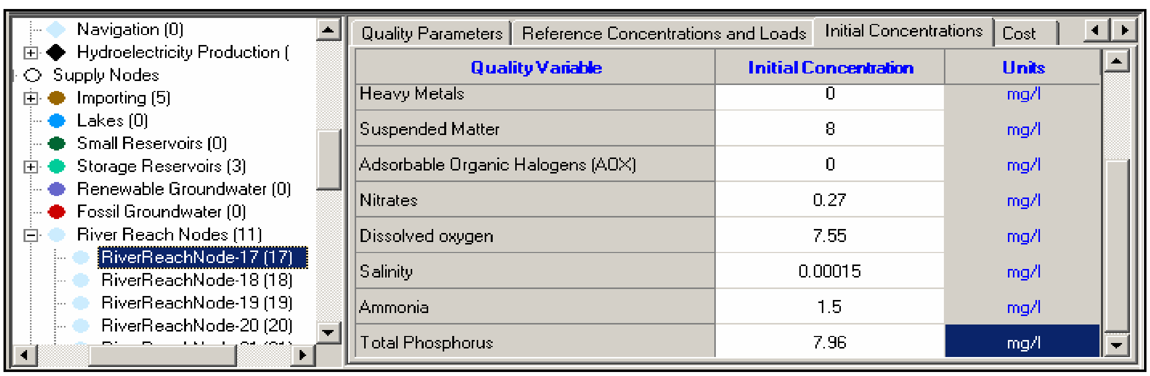


Figure 51 Initial concentrations in the Data Editor Window for river reach

As these data are part of the variables characterising supply nodes, they can be entered or changed from the Data Editor window of each reservoir, river reach and aquifer included in the modelled water resource system.

The water quality model updates the status of supply nodes according to the quality of incoming flows. This latter is influenced by the pollutant loads generated by water uses as well as by the treatment process at drinking, wastewater and desalination plants. Data for these nodes is located in the data editor of the DSS, similarly to the supply nodes. With respect to demand nodes, the *Return Flow Quality* tab presents:

- Concentrations per unit volume of return flows, for animal breeding sites;
- Loads generated per unit production, for industries;
- Loads generated per unit irrigated area, for irrigation sites;
- Loads generated per capita and per day, different for permanent and seasonal population, for settlement nodes;

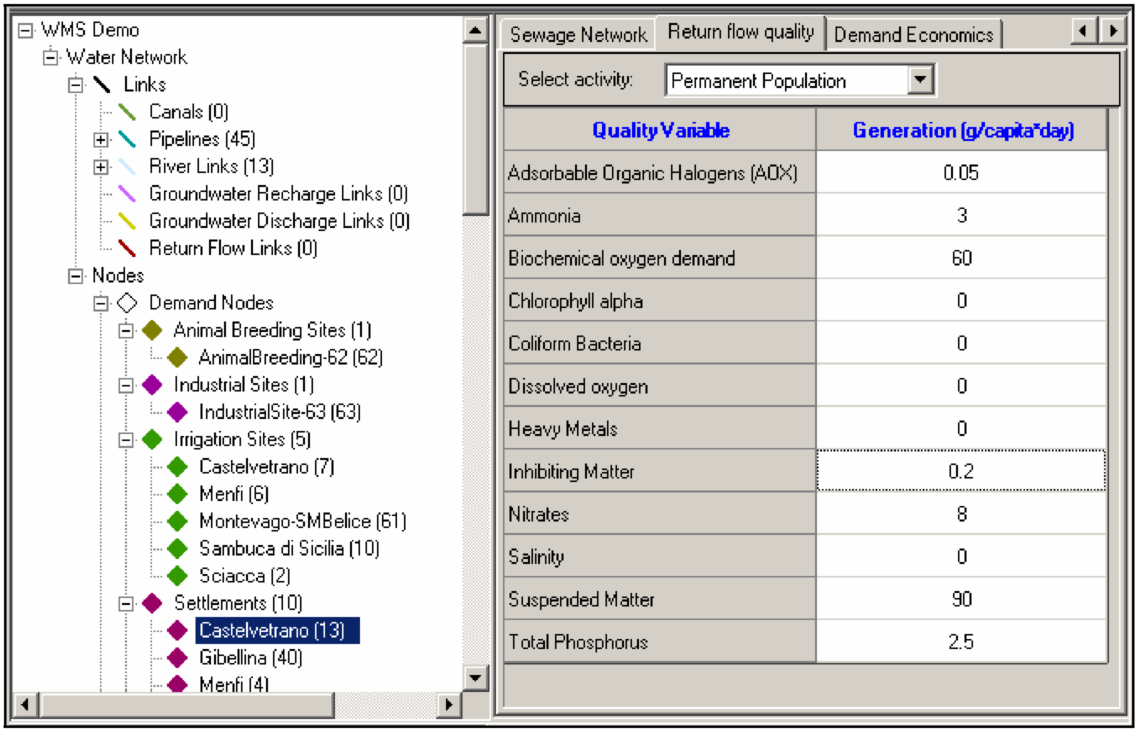


Figure 52 Return flow quality for settlements sites

Outflow Quality tabs of the plants concern mostly the concentrations of treated effluents. In the case of wastewater, the removal rates of treatment as well as the bonus annual coefficients involved in the calculation of environmental costs (see Chapter 9) can also be specified for each pollutant.

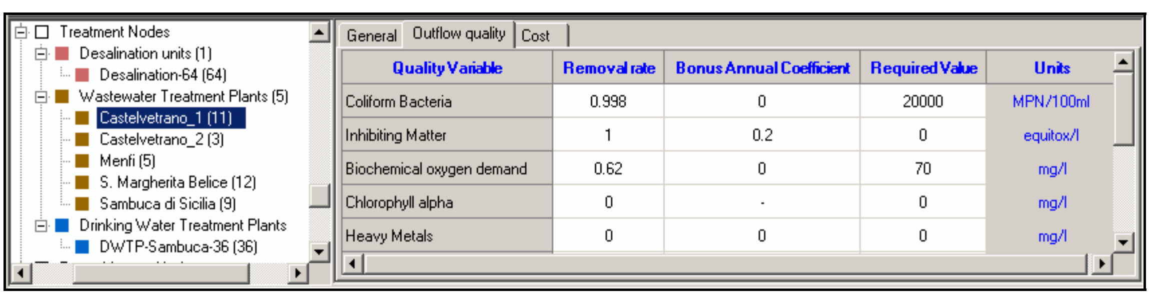


Figure 53 Quality parameters for wastewater treatment plants

Chapter 8 Water Allocation and Simulation Results

Water Allocation Module

The Water Allocation Module is the Kernel of the Water Strategy Man package, having as a primary objective the simulation of water distribution in the water resource system.

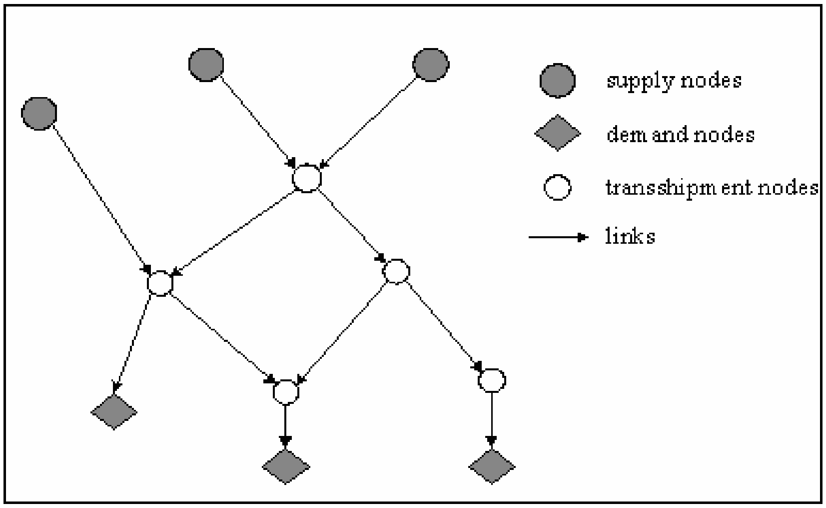


Figure 54 Network representation of a water resource system

For the purposes of the model, network nodes are classified into three categories:

- Supply Nodes,
- Demand Nodes, and
- Transhipment Nodes.

Supply nodes are mainly characterized by a positive monthly supply rate s_i, whereas demand nodes are characterized by a monthly demand rate d_i. These monthly demand and supply rates attached to the respective nodes come from the monthly demand and availability scenarios calculated in the pre-processor of the DSS and are the input to the water allocation module.

The allocation is governed by a system of priority rules, namely **Demand priorities** and **Supply priorities**. Demand priorities are used to treat competing demand sites. Each demand site is characterized by a priority, ranged from 1 (highest priority) to 99 (lowest priority). During a water shortage, higher priority demand sites are satisfied as fully as possible. A default priority of 1 is usually assigned to each demand node. Supply priorities are used when a demand site is connected to more than one supply nodes. These priorities are attached to the supply links (canals and pipelines) and are useful in ranking the choices of a demand site for obtaining water. Supply priorities can range from 1 (highest priority) to 99 (lowest priority). Then, the network is solved as follows.

For each time step, the problem is to find the flow on the network (a set of link flows) that minimizes the water shortage on all demand nodes under four types of constraints: supply, demand, flow conservation and capacity. In the notation below, *i* are nodes, s_i are the positive monthly supply rates of supply nodes, d_i the monthly demand rate of demand nodes, *j* are the links, *f* the monthly flow rates of links and *c* are the link capacities.

$$\text{minimize} \sum_{all\,demand\,nodes\,i} \left(d_i - \sum_{all\,incoming\,links\,j} f_j \right) \qquad (29)$$

Supply constraints associated with all supply nodes:

$$\sum_{\text{all outcoming links } j} f_j - \sum_{\text{all incoming links } j} f_j \le s_i \tag{30}$$

Demand constraints associated with all demand nodes:

$$\sum_{\text{all incoming links } j} f_j - \sum_{\text{all outcoming links } j} f_j \le d_i \tag{31}$$

Flow conservation constraints associated with all transhipment nodes:

$$\sum_{\text{all outcoming links } j} f_j - \sum_{\text{all incoming links } j} f_j = 0 \tag{32}$$

Capacity constraints associated with all links:

$$0 \le f_j \le c_j \tag{33}$$

The model is solved by first constructing a reduction to a standard **MaxFlow problem** (Ford and Fulkerson, 1962) 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 non-negative link flows, satisfying the conditions that no link's flow is greater than the link's capacity, Eq. (33), and that the total flow into each internal node is equal to the total flow out of that node, Eq. (32),. 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 (find a flow such as no other flow from s to t has larger value).

In order to reduce the WSM allocation model to a maxflow problem a transformation of the network is used, as follows:

- ❖ 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

Then the maxflow problem is solved using the Ford-Fulkerson method (1962), also known as the *Augmenting-Path Maxflow* algorithm.

Before proceeding with the water allocation, at each time step, this module sweeps the water resource network and updates the water available at water supply nodes, according to the previous time step status and to the related scenarios of monthly water availability and monthly water abstractions computed by the DSS pre-processor. Return flows computed at the end of previous time step by the water allocation module itself are considered as well. The water balance equations and all the parameters involved in the update of resource nodes such as storage reservoirs, river reaches and renewable groundwater are shown next.

Storage Reservoir node

The storage reservoir equation updates the volume of a reservoir created artificially through construction of a dam on a river. The man made reservoir is schematised in the DSS by the storage reservoir node that must be placed between two river nodes: the reservoir receives water from the upstream river reach and releases water to the downstream one.

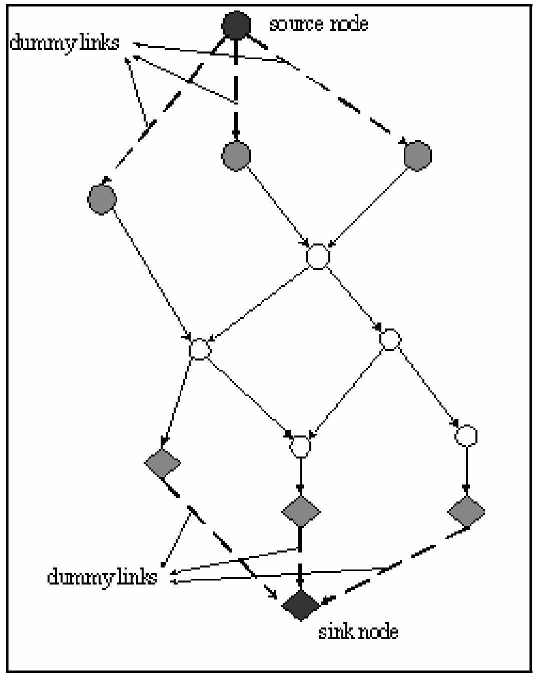


Figure 55 Network transformations

The water balance of the reservoir is computed based on volume, spillage, releases to users, return flows, inflows, rainfall, release due to management rules and evaporation:

$$V_t = V_{t\text{-}1} + U_t + RF + R - REL - E - S - RuleREL \qquad (34)$$

The spillage occurs when the updated volume V_t is greater than the $StorageCapacity$ of the reservoir. In this case the spillage is calculated as the volume of water exceeding the capacity, and the updated volume is set equal to the capacity:

$$\begin{aligned} SPIL &= V_t - StorageCapacity \\ V_t &= StorageCapacity \end{aligned} \qquad (35)$$

Therefore the total volume released downstream D is the summation of the release for operation and the spillage:

$$D = RuleREL + SPIL \qquad (36)$$

The notation used in the formulas is the following:

V_t	=	Volume at current time step (at the end of the time interval);
V_{t-1}	=	Volume at previous time step (it is the volume at the beginning of the time interval);
U_t	=	Inflow: Water from the upstream river reach, computed by the Water Allocation Module;
RF	=	Inflow: Water volume originated from rainfall, computed as: $RF = Rainfall * A$;
R	=	Inflow: Return Flows, computed by the Water Allocation Module;
REL	=	Outflow: Abstractions that is summation of water volumes feeding users, computed by the Water Allocation Module;
E	=	Outflow: Evaporation, computed as: $E = z * A$ or $E = k * ET_o * A$; Evaporation is output of the model.

S = Outflow: Seepage losses to the connected aquifer, computed as a function of volume $S = S(V)$;

$RuleRel$ = Outflow: release governed by a reservoir management rule;

$Spil$ = Outflow: Uncontrolled Spillage flowing downstream naturally;

D = Outflow: Flow to downstream river reach;

$Rainfall$ = Input: (average) rainfall over the surface area of the reservoir;

z = Parameter: Evaporation rate at current month per unit surface area of the reservoir;

A = Surface area of the reservoir $A = A(V)$;

k = Parameter: Conversion factor from Reference Evapotranspiration to open water Evaporation;

ET_o = Reference Evapotranspiration.

River reach node

The river reach node equation updates the stream flow along the river at each time step, given the natural water volume originated by rainfall, water flows exchanged with users or other water sources and losses. The amount of water feeding the downstream river reach is obtained from that balance as follows:

$$D = U + R + GWF + SR - Abs - GWT \quad (37)$$

where:

U = Inflow: Water from the upstream river reaches, computed by the upstream River Reach Node Model;

R = Inflow: Return Flows, computed by the Water Allocation Module;

GWF = Inflow: Water volume originated from the connected aquifer as its natural discharge. It is the monthly base flow of the river reach computed by the Renewable groundwater node model;

SR = Inflow: Surface runoff originated from rainfall and entering the river reach along its length. This is computed by the Water Availability Module as difference of the natural monthly runoff flowing at current river reach (Q_R) and at the upstream ones ($Q_{R_{UP}}$) originated by rainfall on the competing sub-basins;

Abs = Outflow: Abstractions, computed by the Water Allocation Module;

GWT = Outflow: Water volume lost from the river reach (seepage losses). It contributes to the natural recharge of the connected aquifer. It is computed as a fraction of water available in the river reach: $GWT = w*(U + R + GWF + SR - Abs)$

Note: factor "w" is a parameter specified by the user of the DSS. It is output of the model;

D = Outflow: Water feeding the downstream river reach. It is output of the model.

It should be noted that evaporation losses from the river reach were considered not significant with respect to the other terms of the water balance.

Renewable Groundwater node

The renewable groundwater equation updates the volume of water in aquifers. A water balance of each aquifer is computed according to current water volume, pumping to feed water users, natural recharge due to infiltration originated by rainfall or inflows from connected river reach, and natural discharge to river reaches or the sea.

$$V_t = V_{t\text{-}1} + INF + IRR + GWT + AGWT - P - B \qquad (38)$$

where:

V_t	=	Volume at current time step (at the end of the time interval)
V_{t-1}	=	Volume at previous time step (it is the volume at the beginning of the time interval)
Inf	=	Inflow: Infiltration of rainwater towards the aquifer, computed by the Water Availability Module;
Irr	=	Inflow: Infiltration of water used for irrigation towards the aquifer
GWT	=	Inflow: Flow from river reaches and/or by lakes or reservoirs computed by the Water Allocation Module;
AGWT	=	Inflow: artificial recharge from river reaches, lakes or reservoirs.
P	=	Outflow: Pumpings feeding the water users, computed by the Water Allocation Module;
B	=	Outflow: Natural discharge of aquifer to river reaches or the sea, defined by the DSS user.

A *suggested maximum water volume to be abstracted next time step* (BS) is computed as percentage of total recharge:

$$BS = w * \left(INF + IRR + GWT\right) \qquad (39)$$

with :

w	=	Percentage of total recharge to be abstracted next (value given by the user).

At this point, two simplified examples of water allocation are presented. In the first example (Figure 56) there are two supply nodes A and B having an amount of 500 and 800 of available water resource respectively, and two demand nodes C and D with demands of 1000 and 700. Demand node C has a higher priority than the D node (priorities range from 1 the highest to 99 the lowest), and is connected to both the supply nodes with different supply priorities. The allocation works as follows: since C has the higher priority, its demand is met first and, according to the supply priorities on the links, the water from the A node is the first to be allocated with respect to B. In this case node A and B have a sufficient amount of resource to cover the demand of the C node but only 300 over 700 is what remains for the D node. Thus, a deficit of 400 occurs for the demand node D. In the second example of water allocation (Figure 57), there are three supply nodes A, B and C connected to three demand nodes D, E, F and the K node that can represent a network reservoir node, another water source or a treatment plant.

According to the network connections and the allocation priority system, the demand of E is partially covered by the supply from C which leaves nothing to the demand of F. Water from C is allocated to E first with respect to F because E has a higher demand priority (1 against 2). A deficit equal to the demand occurs in the node F, while node E asks node K for 500. On the other hand, node D asks node K for his entire demand 1500. Supply nodes A and B have enough water resource to satisfy the requirement imposed on K, so demands at nodes D and E are fully covered. Supply node A is completely exploited because the supply priority of the A-K link is higher than the B-K, and consequently the resource at A has to be allocated first.

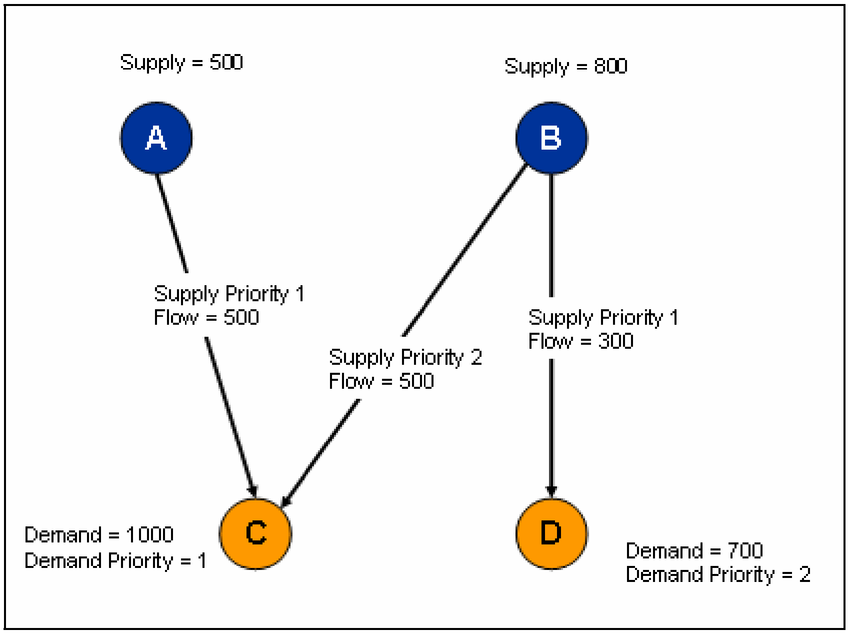


Figure 56 Example 1 of water allocation

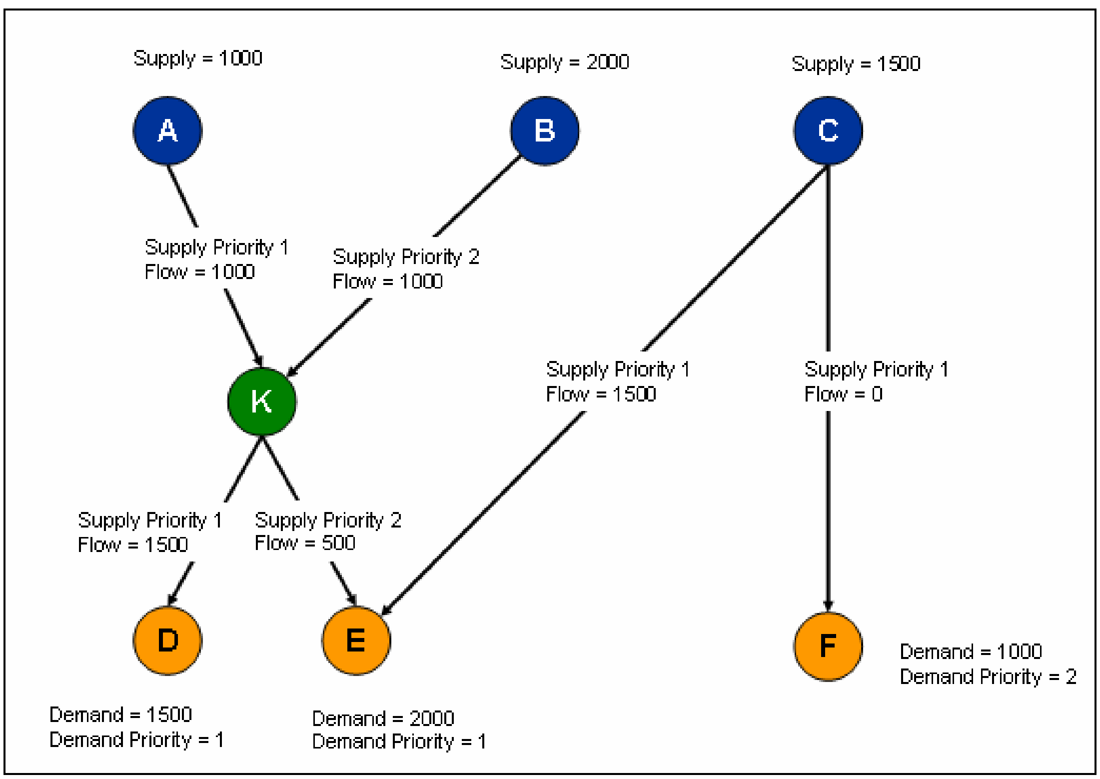


Figure 57 Example 2 of water allocation

Simulation Results

The *Analysis* menu in the tree view of water management schemes, in the Manager Panel, is made up of three sub-menus: *Overview*, *Economic Analysis* and *Detailed Results*. By clicking on one of them, the simulation of the WSM DSS runs, thus allocating available water from resources to connected demand nodes. Then, according to the selected menu, a different simulation window opens.

The **Detailed Results** menu opens a window showing the results of the allocation in terms of indicators, specific for each type of node or link. Indicators are plotted and presented in tabular form. The Detailed Results window comprises four panels that allow the DSS user to navigate among results and network elements: 1) the navigation panel, 2) the map of the region, 3) the list of indicators and 4) the graphical and tabular view where results are presented.

Since the simulation runs on a monthly time step, most indicators are computed on a monthly basis. However, for many network elements they can be displayed either as monthly time series or as yearly aggregated values.

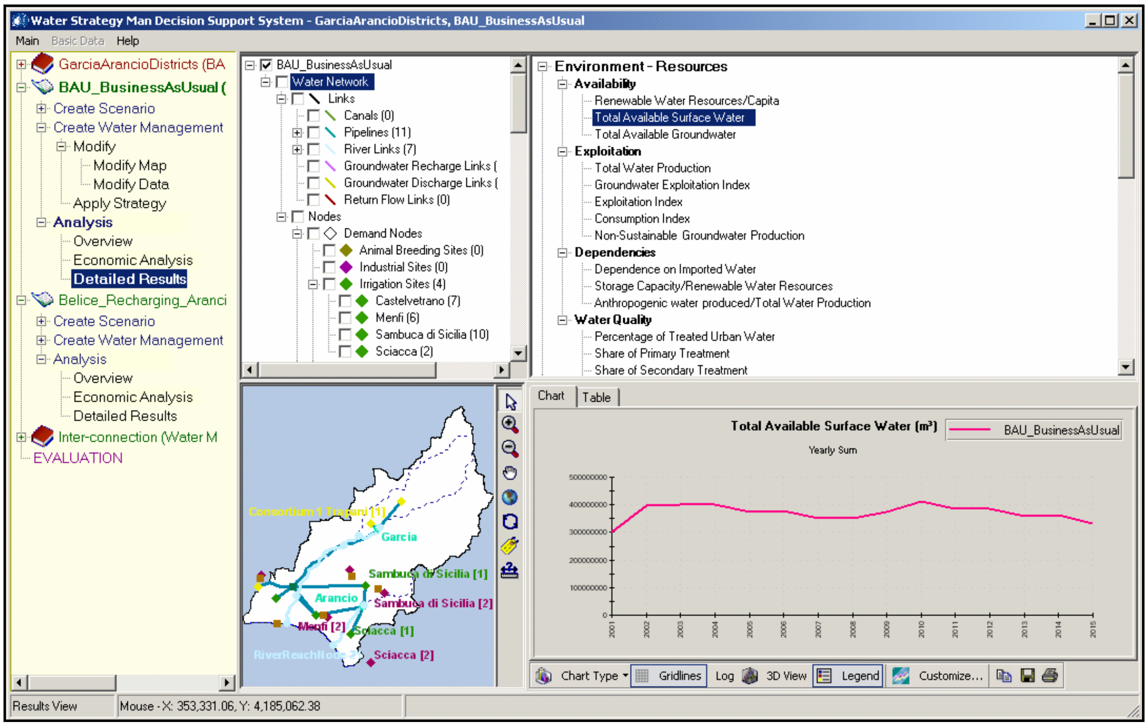


Figure 58 Opening the Detailed Results View

The list of indicators that are associated to a specific node or link is shown once the element has been checked on the Object Manager panel. Each indicator in the list can be plotted just for one node at a time, for some, or for all the nodes of the same type that exist in the simulated water system. This is useful for comparing the same simulation output for different demand nodes of same category; for instance the time series of unmet demands for all the irrigation sites, or BOD concentrations in some subsequent river reaches.

A list of indicators aggregated yearly and at regional level is also available, by checking the name of the current water management scheme at the top of the Object Manager panel. These regional indicators are divided into three main groups. *Environment and Resources* includes indicators about water availability, exploitation, dependencies on imported water and water quality, *Demand Indicators* refer to consumption indices or abstractions per capita (being the pressures over the system), and to deficits, and finally the *Cost-Revenues* section address the economic results, such as direct and environmental costs, benefits on water use and rate of cost recovery. As far as the node-specific indicators are concerned, they are usually divided into the three classes of Water Quantity, Quality and Cost.

The **Chart Panel** of the Result View has some useful functionalities that permit the customisation of the plot of indicators: it is possible to change the graph type, from lines to bars, to use a logarithmic scale, or a 3D view, and the legend and gridlines of the graph can be put to visible or not. The *Customise* button has an important role since it modifies the time steps plotted: the DSS user can decide to show the detailed simulation output, monthly time series, or visualise only yearly aggregated values. In case he is making an analysis for a particular season or for one-two months only, he can select them in the "*Customize*" dialog box and decide also to view this information for the entire duration of the scenario or for preferred years only.

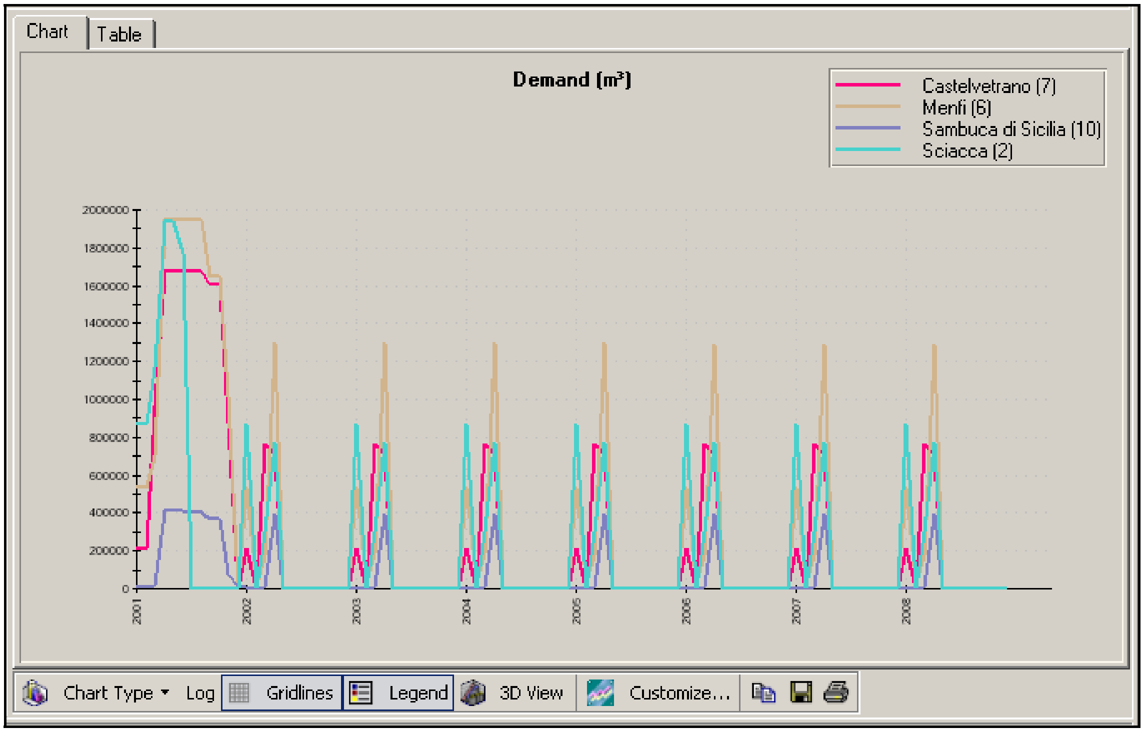


Figure 59 The Chart Panel displaying indicators

At the right side of plotting tools, three buttons allow to copy the graph to the Windows clipboard, to save it as a JPEG image or to print it. These copy, save and print options can be useful in the analysis of the case study, mostly when there is the need to investigate results for many network users, to find inter-relations and causal effects, and when it is important to look simultaneously at the behaviour of many indicators.

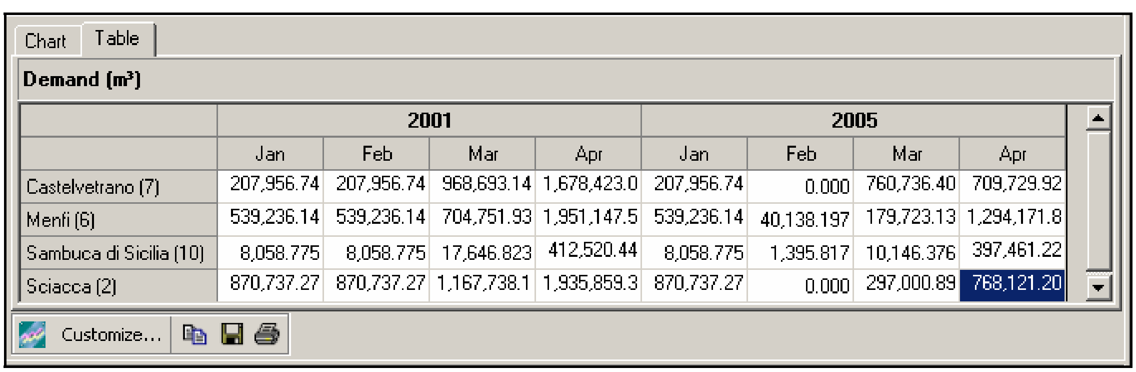


Chart | Table

Demand (m³)

	2001				2005			
	Jan	Feb	Mar	Apr	Jan	Feb	Mar	Apr
Castelvetrano (7)	207,956.74	207,956.74	968,693.14	1,678,423.0	207,956.74	0.000	760,736.40	709,729.92
Menfi (6)	539,236.14	539,236.14	704,751.93	1,951,147.5	539,236.14	40,138.197	179,723.13	1,294,171.8
Sambuca di Sicilia (10)	8,058.775	8,058.775	17,646.823	412,520.44	8,058.775	1,395.817	10,146.376	397,461.22
Sciacca (2)	870,737.27	870,737.27	1,167,738.1	1,935,859.3	870,737.27	0.000	297,000.89	768,121.20

Customize...

Figure 60 The Table Panel shows the data that are plotted in the Chart View

The **Table Panel** of the Result View displays in a table the data plotted in the Chart View. Time steps are the columns of the table and the selected nodes are the rows. The two Chart and Table views are loaded as tabs in the same interface block and the DSS user can pass from one to the other by selecting the *Chart* or *Table* tab. The Customise option operates also on the tabular data.

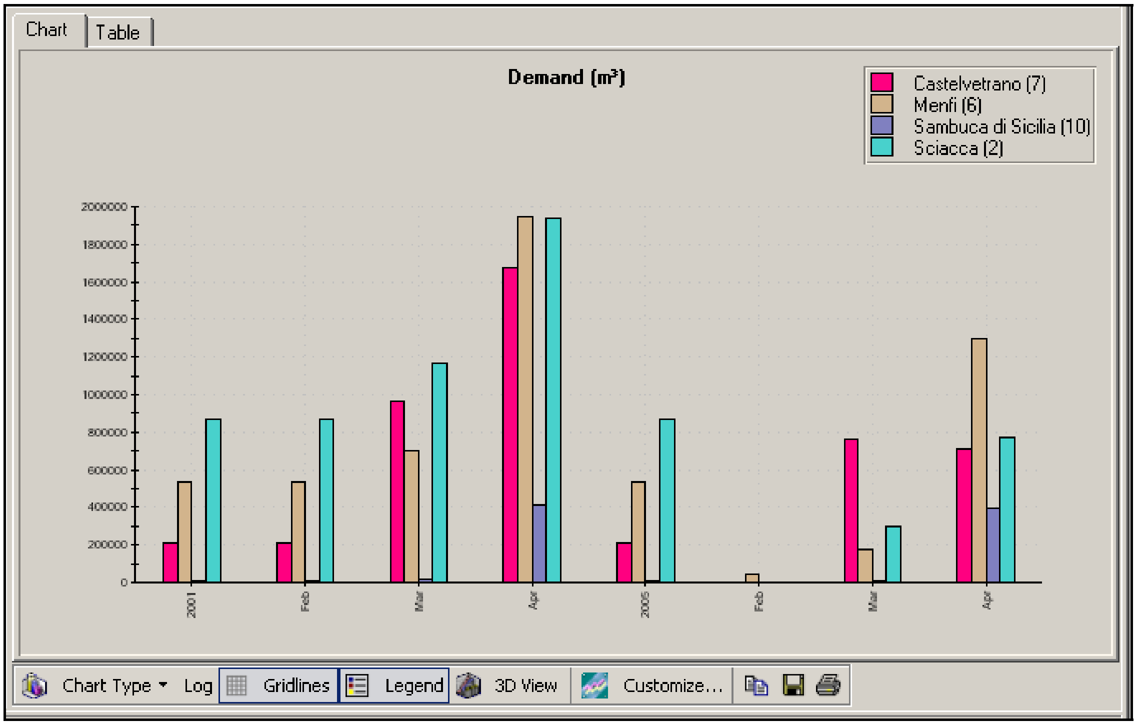


Figure 61 The Customize functionality: comparing results for January-April seasons of years 2001 and 2005

Once the chart and table have been customized, the format remains the same while the Result View is open, whatever indicator is loaded, so that an overall analysis of a targeted period can easily be performed just by selecting the different simulation outputs.

The **Analysis-Overview** menu of WSM DSS interface displays in the same window the four graphs relating water demands, unmet demands, freshwater abstractions and cost/benefits data, aggregated yearly and over water uses or water resource types in the region. The yearly water demands and the unmet demands are both displayed aggregated on domestic use, summing over all the settlement nodes, on irrigation and animal breeding, and on industries and hydropower facilities. Freshwater abstractions are aggregated over all surface or groundwater resources. Finally the Costs and Benefits graph shows aggregated direct costs, benefits from water use and environmental costs.

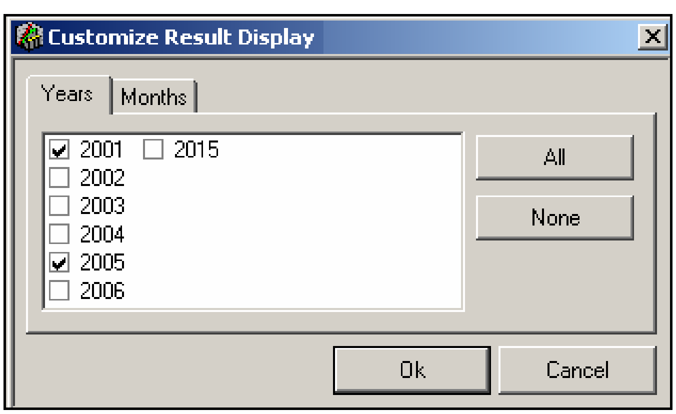


Figure 62 The Customize Dialog Box

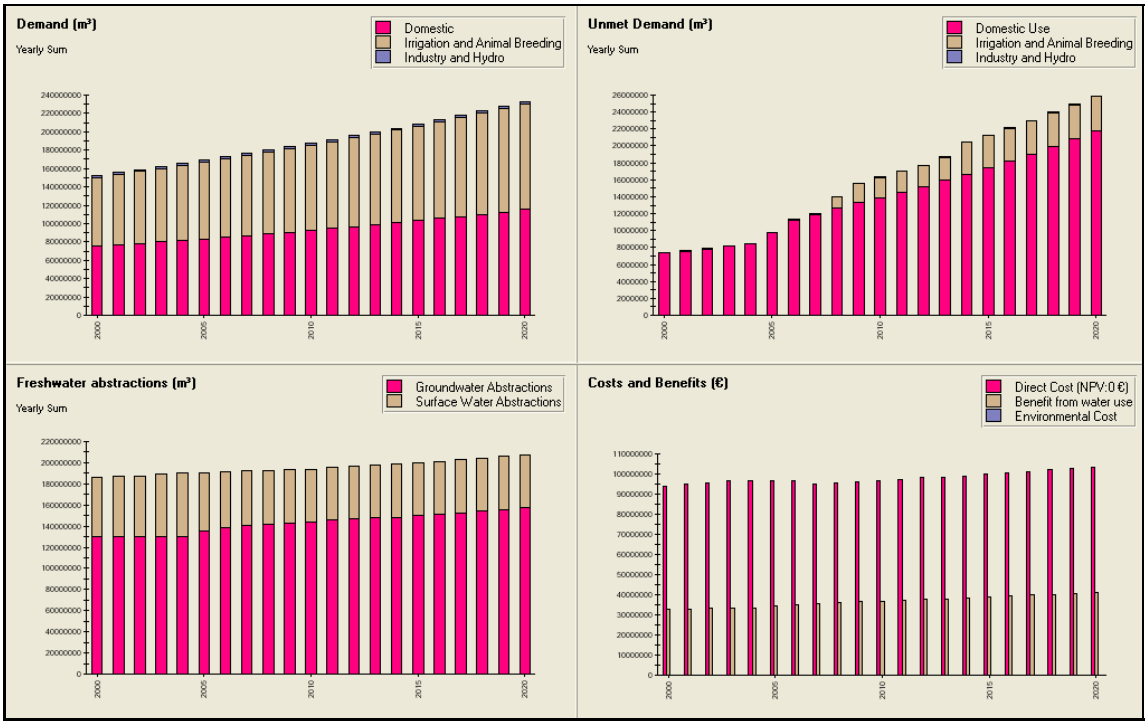


Figure 63 The Overview window of the WSM DSS

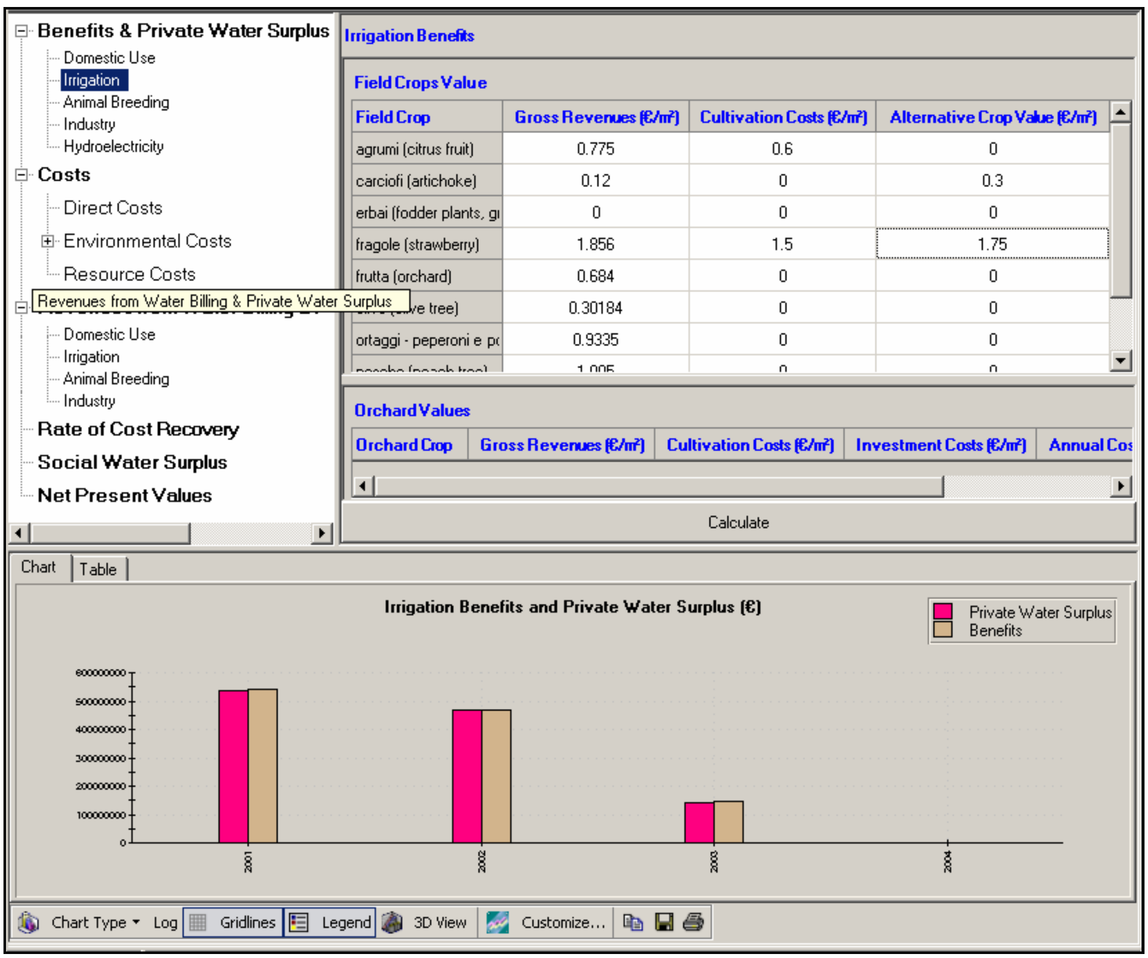


Figure 64 Setting Benefits data for irrigation and viewing results in the Economic Analysis Window

Economic indicators are determined by the DSS together with the water allocation and the calculation of the resulting indicators. However, the economic parameters involved in the estimation of the full water cost can be modified in the **Economic Analysis Window** of interface, and costs, benefits, revenues and cost recovery can be updated as freestanding, without the need of running again the water allocation. The Economic Analysis Window is reachable from the homonymous sub-menu of the generic water management scheme (Navigation Panel). The user is allowed to navigate the different costs in a dedicated panel and to change or enter the specific parameters for the selected cost in the top-right panel. He can for example change the Discount Rate of the direct cost, choose the way the environmental cost is obtained, either relating aquifer abstractions or using the charge model, set the water selling price for each water use in the region, namely domestic, agricultural and industrial, or finally decide to generate a rate of cost recovery by including or not the resource and the environmental costs.

By pressing the *Calculate* button, costs are updated and their annual time series can be investigated either in tabular form or plotted on a graph.

As appendix to the simulation description, a table is presented, which lists all the indicators computed in the DSS, the category they belong to and the types of node or link they are computed for.

Table 9 Indicators Implemented in the WSM DSS

Category	Indicator	Network Element
Exploitation	Total Water Production	Region
	Groundwater exploitation index	Region
	Consumption index	Region
	Non-sustainable production index	Region
Dependencies	Dependence on imported water	Region
	Anthropogenic water produced over total water production	Region
Water Quality	Percentage of Treated urban water	Region
	Share of Primary Treatment	Region
	Share of Secondary Treatment	Region
	Share of Tertiary Treatment	Region
	Concentrations of quality variables	Pipelines, River Links, River Reach Nodes, Canal, GW Recharge/Discharge Link, Return Flow, Importing, Lake, Small Reservoir, Storage Reservoir, Fossil GW
	Concentrations of quality variables in inflows and return flows	Irrigation, Settlement, Exporting (only inflow), Waste Water Treatment Plant, Industry, Tourist, Environmental + Navigation + Recreational (only

Category	Indicator	Network Element
		inflow), Drinking Plant, Hydroelectricity Production (only inflow)
Pressures	Agricultural demand per hectare	Region
	Tourists per inhabitant	Region
	Water abstractions per capita	Region
Deficits	Specific Water use Deficit as a percentage of the specific water use demand	Region
Cost/Revenues	Total Direct Cost	Region, Irrigation, Settlement, Industry, Tourist, Hydroelectricity Production
	Total Benefit from water use	Region, Irrigation, Settlement, Industry, Tourist, Hydroelectricity Production
	Total Income	Region, Irrigation, Settlement, Industry, Tourist, Hydroelectricity Production
	Environmental Costs for abstractions and pollution	Region Irrigation, Settlement, Industry, Tourist
	Revenues	Region
	Overall Rate of Cost Recovery	Region
	Rate of cost recovery without Environmental costs	Irrigation, Settlement, Industry, Tourist
	Rate of cost recovery with Environmental costs	Irrigation, Settlement, Industry, Tourist
	Annualized Capital Costs	Pipelines, River Reach, Waste Water Treatment Plant, Network Reservoir, Canal, Importing, Lake, Small Reservoir, Storage Reservoir, Fossil GW, Renewable GW, Desalination, Drinking Plant
	Total Water Transfer Costs	Pipelines, Canal
	Running Cost	Pipelines, River Reach, Waste Water Treatment Plant, Network Reservoir, Canal, Importing, Lake, Small Reservoir, Storage Reservoir, Fossil GW, Renewable GW, Desalination, Drinking Plant
	Total Supply cost	River Reach, Importing, Lake, Small Reservoir, Storage Reservoir, Fossil GW, Renewable GW
	Total Treatment Costs	Waste Water Treatment Plant,

Category	Indicator	Network Element
		Desalination, Drinking Plant
Irrigation	Cultivated Area	Irrigation
Livestock Number	Livestock Number	Animal Breeding
Industry	Industrial Production	Industry
Water Quantity	Inflow	Pipelines, Network Reservoir, Canal
	Outflow	Pipelines, Canal
	Losses	Pipelines, Canal
	Flow	River Link, GW Recharge/Discharge Link, Return Flow
	Demand	Irrigation, Settlement, Exporting, Animal Breeding, Industry, Tourist, Environmental, Navigation, Recreational, Hydroelectricity Production
	Supply Delivered	Irrigation, Settlement, Exporting, Animal Breeding, Industry, Tourist, Environmental, Navigation, Recreational, Hydroelectricity Production
	Unmet Demand	Irrigation, Settlement, Exporting, Animal Breeding, Industry, Tourist, Environmental, Navigation, Recreational, Hydroelectricity Production
	Losses	Irrigation, Settlement, Animal Breeding, Industry, Tourist
	Return Flow Volume	Irrigation, Settlement, Animal Breeding, Industry, Tourist, Lake, Small Reservoir, Storage Reservoir, Renewable GW
	Abstraction	River Reach, Importing, Small Reservoir, Lake, Storage Reservoir, Fossil GW, Renewable GW
	Total Run-off	River Reach, Lake, Storage Reservoir
	Groundwater recharge	River Reach
	Groundwater discharge	River Reach
	Return flows	River Reach
	Volume of Water Treated	Waste Water Treatment Plant, Drinking Plant
	Available supply	Importing
	Storage	Lake, Small Reservoir, Storage Reservoir, Fossil GW, Renewable GW
	Evaporation Losses	Lake, Small Reservoir, Storage Reservoir
	Seepage Losses	Lake, Small Reservoir,

Category	Indicator	Network Element
		Storage Reservoir
	Natural Recharge	Renewable GW
	Discharge	Renewable GW
	Drinking Water Production	Desalination
Hydroelectricity	Electricity Production	Hydroelectricity Production
Population	Permanent Population	Settlement
	Seasonal Population	Settlement, Tourist
	Total Population	Settlement

Time Series of indicators and WSM Geodatabase

This chapter ends with a description of how the time series of indicators have been modelled within the WSM Geodatabase.

Time series data describe many aspects of a water resource system and are used as an input in the analysis conducted with the WSM Decision Support System, in order to define base demands, available water resources and the initial or reference quality status of water bodies. For example, they can be used to describe the amount of water that is being released from a river system or a series of measurements of BOD concentrations of a river reach.

The two main factors that determine the use of time series are the length of the time series record and the time interval. It is also important to know whether data contain actual recorded values or interpolated values between two recordings or if they represent a result of a calculation procedure, such as those performed within the WSM DSS.

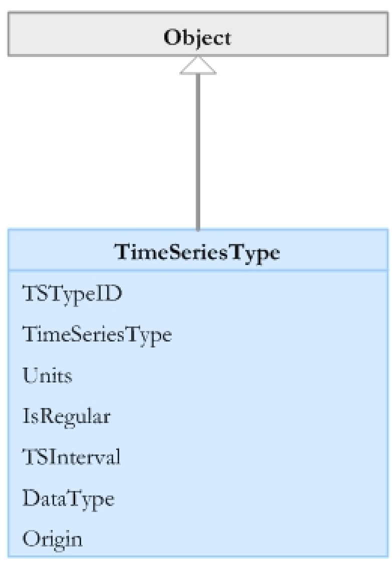


Figure 65 Attributes of the TimeSeriesType object class

The intention of including Time Series Data in the WaterStrategyMan Data Model is not only to build a data model that will satisfy the requirements of the WSM DSS but also to create a database that perhaps will be applicable to many models that operate independently of the GIS and the DSS.

The modelling and conceptualization of Time Series has been adapted from the Arc Hydro Data Model, developed by the University of Texas and ESRI (2002).

Usually, time series data are captured and stored in a variety of formats. Time series data that are directly being stored in the geodatabase can be represented as a standard geodatabase table (inheriting from the Arc Info Object Class) and referred to as a **Time Series Object Class**. In order to accommodate the main characteristics of Time Series, such as interval, type and origin (recorded or generated) a database object describing those elements that characterize the time series types, namely *TimeSeriesType*, is necessary. Raw time series data are stored in the *SimpleTimeSeries* object class and the *QualityTimeSeries* object class.

The time series type object class contains all information that is essential to characterise the time series object. In addition to the basic attributes such as identifier, type of time series (e.g. precipitation, population, etc.), and measurement units (people for population, mg/l for BOD concentrations, cubic meters for runoff etc), there are also some that denote the type of data and their origin. In particular, the *IsRegular* is a logical (True/False) attribute denoting whether all the values of the series have the same time interval (e.g. hour, day etc.), which is specified by the *TSInterval* attribute. *Origin* indicates whether time series data are recorded (measurements) or have been interpolated/generated by a calculation procedure, while the *DataType* attribute describes the aggregation procedure of time series data, e.g. cumulative, instantaneous etc.

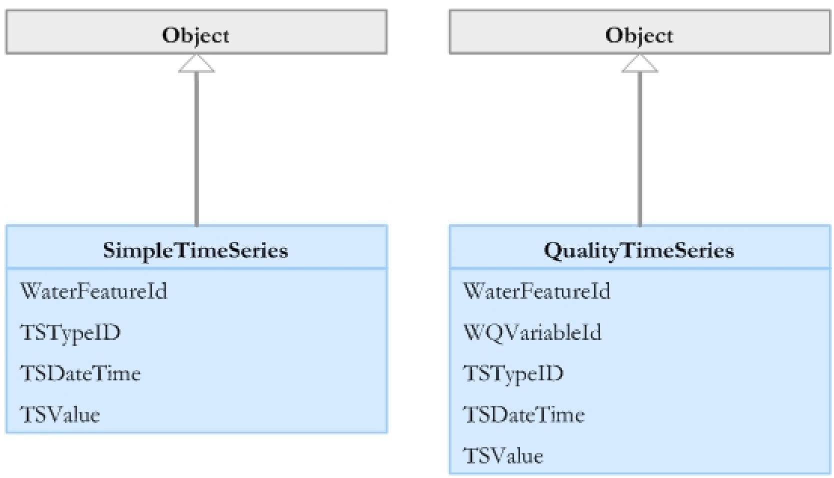


Figure 66 Attributes of the Simple Time Series and Quality Time Series

Within the geodatabase and the DSS, time series source data are treated like any other form of tabular data, with the additional fields of *WaterFeatureId*, *TSTypeID*, *TSDateTime* and *TSValue*. *WaterFeatureId* is an integer identifier, set equal to either *WaterNodeId* or *WaterLinkId* of the feature described by the time series: for example, if the *WaterNodeId* of a Settlement feature is 100 then all the time series classes of Settlement will have a *WaterFeatureID* of 100. *TSTypeID* qualifies the type of data as in the *TimeSeriesType* table described previously. This attribute is very important as it describes the type of data that are stored in the *TSValue* field. The *TSDateTime* attribute is a standard Date field.

As previously mentioned, two time series classes are defined, Simple and Quality Time Series. The *QualityTimeSeries* object class is used to store time series on concentrations and loads for the quality variables modelled within the DSS. The structure of the Quality Time Series Table is similar to that of Simple Time Series with the addition of a relationship relating each record to the relevant quality variable. The complete diagram of the data model for the Time Series component is presented in Figure 67.

The most important aspect of time series is that all data are stored within one single large file, regardless of the feature type and the data stored in it. Thus, any value which in this case is a

TSValue, can be represented by a point in the three dimensional space, which has its corresponding *WaterFeatureID*, *TSDateTime* and *TSTypeID* attributes (Figure 68).

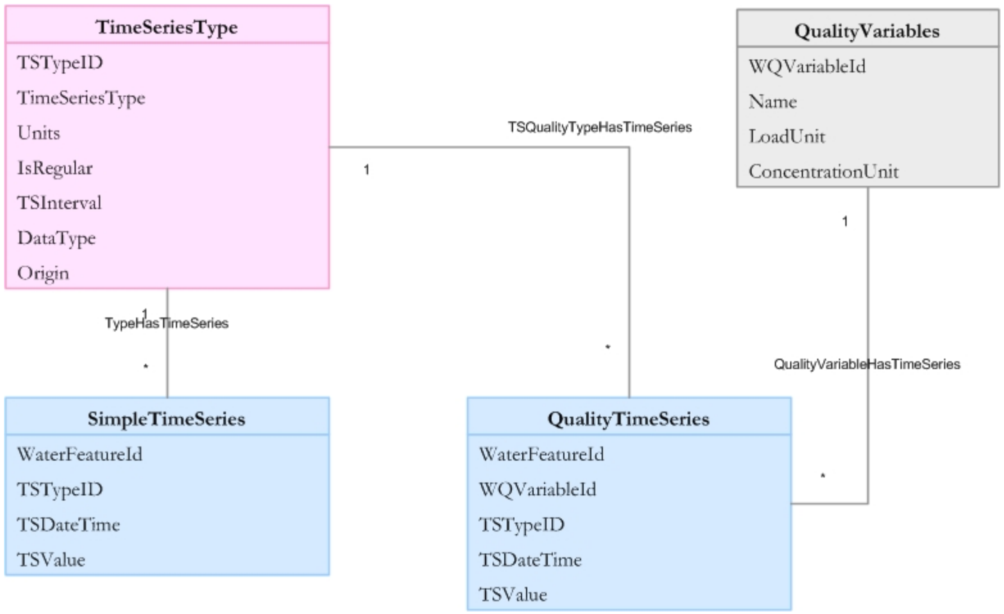


Figure 67 Time Series Object Model

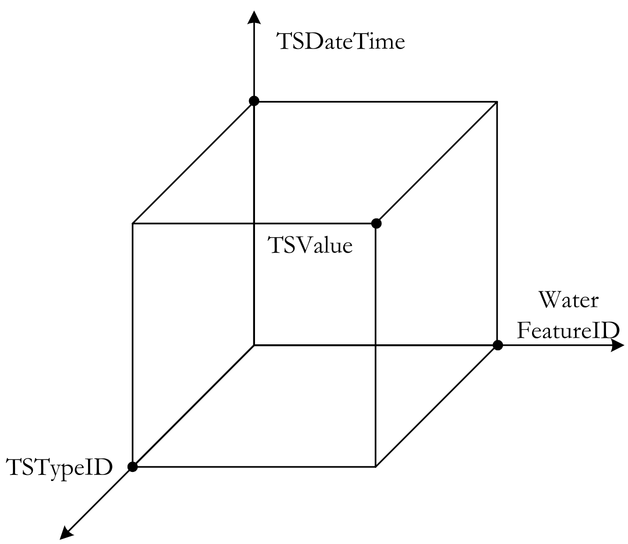


Figure 68 3D structure of time series in the WSM Data Model

The above three-dimensional structure of time series is simple and general, and is formed of a series of vertical and horizontal planes. Therefore, any time series subset (query) that has a single value for *WaterFeatureID* represents a vertical plane, perpendicular to the *WaterFeatureID* axis and it contains several values for *TSType* and *TSDateTime*. A time series subset that has a single value for *TSTypeID* represents another vertical plane that is perpendicular to the *TSType* axis. Similarly, a time series subset that has a single value for *TSDateTime*, represents a horizontal plane that is perpendicular to the *TSDateTime* axis. Therefore, different time series queries can be created from the object class. When two vertical planes intersect, their line of intersection represents a time series query that corresponds to a single *WaterFeatureID* and therefore a feature, and a single *TSTypeID* for several *TSDateTime* values. On the other hand, the intersection of all the three planes represents a single point that has only one value for *WaterFeatureID*, *TSTypeID* and *TSDateTime* respectively.

Chapter 9 Economic Analysis

Methodology Outline

The economic analysis in the WSM DSS consists of a tentative implementation of the principles associated to the estimation of **Full Water Cost** and its components. Article 9.1 of the Directive refers to the recovery of the full cost of water services and clarifies the cost components that should be included in full cost estimation. Those are:

- The **supply cost** (direct or financial cost) that represents the costs of investments, operation and maintenance, labour, administrative costs and other direct costs;
- The **resource cost** that represents the loss of profit because of the restriction of available water resources;
- The **environmental cost** that represents the cost from the damage on the environment and aquatic ecosystems caused by water use and service provision;

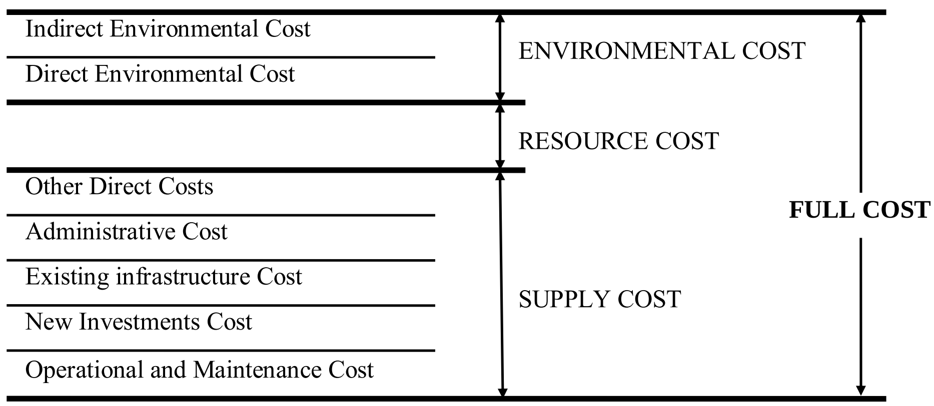


Figure 69 Components of the full cost of water services

Direct Costs

The **supply cost**, or direct cost, comprises of:

- *Operating cost*: all costs needed to maintain the operation of an environmental facility (e.g. material and staff cost).
- *Maintenance cost*: cost for maintaining existing (or new) assets in good functioning order until the end of their useful life.
- *Capital cost*:
    - *New investments*: costs for new investment expenditures and associated costs (e.g. site preparation costs, start-up cost, legal fees)
    - *Depreciation*: the depreciation allowance represents an annualized cost of replacing existing assets in future. The estimation of depreciation requires the definition of the value of existing assets and a depreciation methodology.
    - *Cost of capital*: it is the opportunity cost of capital, i.e. an estimation of return that can be earned by alternative investments. The cost of capital applied to the asset base (new and existing, give the profits that investors are expecting to gain from their investments).
- *Administrative cost*: administrative cost related to water resource management.

- *Other direct cost*: this mainly consists of the costs of productivity losses due to restrictive measures.

The **annual Direct Cost** for the entire water resource system is calculated in the WSM DSS by summating the annual equivalent capital costs, the annual operational and maintenance costs and the annual energy costs related to each infrastructure in the water network, represented both by a node, e.g. a reservoir, and by a link, pipelines or canals. Administrative costs and other components of the direct cost are accounted as *additional costs* and are specified for a water uses such as domestic, irrigation and animal breeding and industrial.

The **annual equivalent capital cost** (AEC), which is a fixed cost, for infrastructure i is calculated for year t as a function of depreciation period, which coincides with the design lifetime, and the discount rate:

$$AEC_{i,t} = \frac{CapitalCost_i \cdot DiscountRate}{1-(1+DiscountRate)^{-DepreciationPeriod_i}} \quad (40)$$

Operation and Maintenance Costs (OMC) and **Energy Consumption Costs** (ECC) are variable costs and are referred to as *Running Costs* in the DSS. The Operation and Maintenance Costs are calculated through the specific cost per unit volume of water distributed, and the total water volume actually entering the infrastructure:

$$OMCost_{i,t} = SpecificOMCost_i \cdot \sum_{Months} WaterInflow_{i,Month} \quad (41)$$

Energy costs are determined through the energy consumption for a part of the infrastructure and the price of energy:

$$ECCost_{i,t} = \sum_{Months} EnergyPrice \cdot EnergyConsumption_{i,Month} \quad (42)$$

The tariff system for energy prices has been introduced in the structure of the regional WSM Geodatabase in order for the DSS to be able to estimate the marginal energy cost for water production. In the WSM DSS the direct cost of whatever node A, taking water from the water source B , is allocated by summating the direct costs and the transfer costs of all the nodes along the water path connecting them. This is based on the principle that each user should pay for the part of the infrastructure that he is using. For example, if a city receives water from a water treatment plant, which is fed by a storage reservoir, which is in turn supplied by a river reach node, then the direct cost of water to the city derives from the direct costs of the four nodes plus the three direct cost of the link carrying water from one another (Figure 70).

In case of uses sharing the same supply sources or a part of the same water path, the direct cost of the infrastructure is distributed according to the supply allocated to each use. The operation is different according to the direct cost component:

- *Annual Equivalent Capital Costs* are distributed according to the yearly share of the inflow of the link over the total outflow from the node.
- *Running Costs (operation and energy)* are distributed according to the monthly share.

Resource Costs

Resource Cost is another component of the full cost of water. Its implementation in the WSM DSS is connected to the *Opportunity Costs* definition from the WATECO Guidance Document. WATECO stands for WATer and ECOnomics. It is an informal working group formed by economists, technical experts and stakeholders from European Union Member States, dedicated to the economic issues of the Water Framework Directive. WATECO prepared a non-legally binding document that aims at guiding experts and stakeholders in the implementation challenge of the Water Framework Directive, with specific focus on its 2004 requirements.

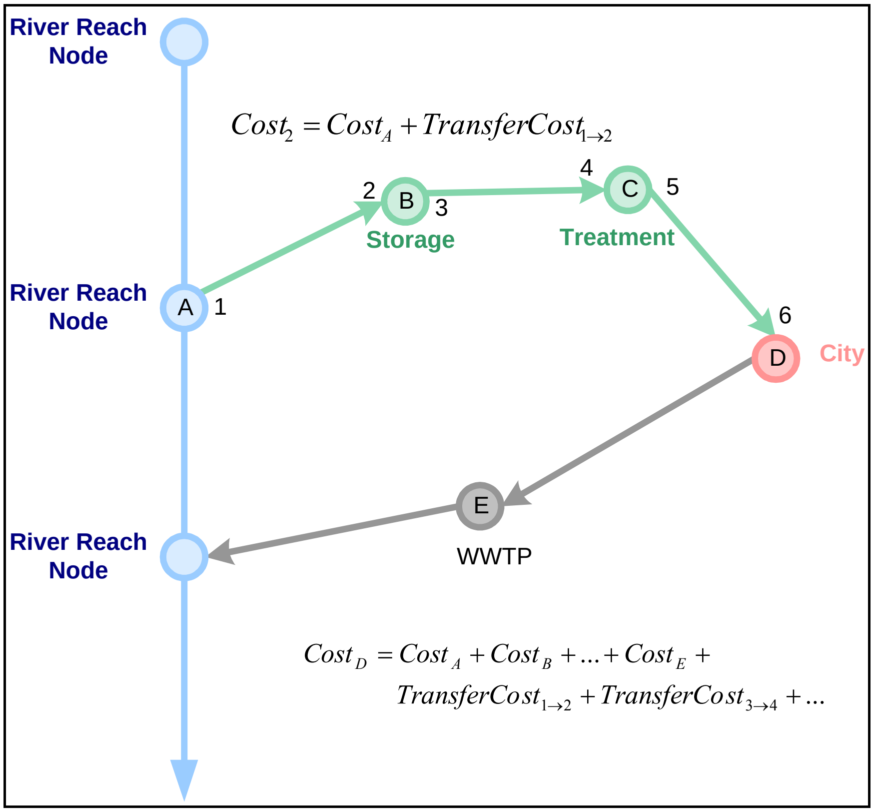


Figure 70 Example of direct cost estimation for a settlement (node 6 - city)

According to the WATECO Guidance Document, "*resource costs represent the costs of opportunities that other uses suffer due to the depletion of a water resource beyond its natural rate of recharge or recovery. These users can be those of today or those of tomorrow, who will also suffer if water resources can be depleted in the future. If markets function well, the opportunity costs of resources are reflected in the financial costs. However, for environmental resources, those costs are often not included in market prices. Opportunity costs, the scarcity value of under-priced environmental resources, like water, should therefore be included in the estimation of the full economic cost*".

Under this context and for meeting the objective of the WSM Economic Analysis, (the estimation of the total cost of each water use and the development of appropriate pricing schemes for its recovery), it is suggested that resource costs are approximated by the scarcity rent.

The **scarcity rent** of water is defined as follows. Rent (per unit) of a scarce water resource is a surplus, the difference between the opportunity cost of water (equal to the market equilibrium price P) and the per unit direct costs (such as abstraction, treatment, environmental and conveyance) of turning that natural resource into relevant products (agricultural crops for farmers and water services for the residence of an urban center). **Opportunity costs** are defined as the benefits forgone when a scarce resource is used for one purpose instead of the next best alternative. It should be emphasised that all costs in the economy are always opportunity costs: energy, capital and labour used to extract and convey water to each use are not available to serve other uses and do not contribute to their welfare.

Opportunity costs, and therefore scarcity rents can be derived only from an economically optimal allocation. However, the allocation algorithm implemented by the tool does not perform economic optimisation. To overcome this obstacle without changing the concept behind the applied methodology, resource costs are estimated as follows.

If we consider having n competing uses (demand nodes that share the same supply source S), the net value (NV) in €/m^3 for each use i will be equal to:

$$NV_i = V_i - ADC_{S \to i} \tag{43}$$

where:

NV_i	=	Net value of water for use i in €/m^3;
V_i	=	Value of water for use i in €/m^3 (estimated according to the type of water use –see section on Benefit estimation);
$ADC_{S \to i}$	=	Average direct cost for transferring one m^3 of water from the supply node S to the use i in €/m^3.

According to the selection of environmental cost components (whether the user has agreed to include the total environmental cost, and respectively groundwater abstraction, surface water abstraction and pollution costs), the formulation is modified. In case that all three components are included, the equation is rewritten as:

$$NV_i = V_i - ADC_{S \to i} - AbsEC_S - PolEC_i \tag{44}$$

where:

$AbsEC_s$	=	The average abstraction environmental cost in €/m^3, estimated according to the type of the resource (surface or groundwater) and the particular model selected;
$PolEC_i$	=	Average pollution cost, in €/m^3 incurred from the use of one additional cubic meter by use i.

The scarcity rent is attributed to the supply source (node) and is estimated by:

$$SRent_S = NV_{max} \tag{45}$$

where:

$SRent_S$	=	Scarcity rent associated with the supply node s (€/m^3);
$NV_{\max}$	=	Maximum net value across the n competing uses;

The total resource cost attributed to a particular use will be equal to:

$$ResourceCost_i = \sum_s ScarcityRent_S * SupplyDelivered_{S \to i} \tag{46}$$

Environmental Costs

The estimation of **environmental costs** (EC) is based on the current practices of French Agences de l'Eau mostly. Two categories of environmental costs can be defined:

- Environmental costs related to **water abstraction and consumptive use**. A distinction is made between renewable groundwater abstractions and surface water abstractions from rivers, reservoirs (small reservoirs, storage reservoirs and lakes).
- Environmental costs related to the **discharge of effluents after treatment** (including return flows from agriculture). In this case environmental benefits from wastewater treatment should be accounted for.

An Environmental Cost can be defined as the cost that a "society" will have to pay in the future (soon or later) because of the impacts on environment caused by economic activities, products or services. Most of time this type of cost is *external*; meaning that the cost is equal to the monetary value attributed to the reduction of an advantage or to a damage undergone by society because of a deterioration of the environmental quality which was not taken into account in a market operation.

According to the neo-classical theory, it is essential to reintegrate (internalise) this monetary value in market operations. There are different justifications for this assumption in the case of the water resources degradation:

- If this cost is underestimated or disregarded, then the future users of the resource will have to pay for the measures needed for the restoration of the resource degraded by currents users;
- The polluter does not pay for the damage he caused;
- If this cost is underestimated or disregarded, the current users are not encouraged in taking care of the water resource.

For these reasons, the European Water Framework Directive underlines the following principle: "*The use of economic instruments by Member States may be appropriate as part of a programme of measures. The principle of recovery of the costs of water services, including environmental and resource costs associated with damage or negative impact on the aquatic environment should be taken into account in accordance with, in particular, the polluter-pays principle*."

Different methods are developed and applied to place monetary values on environmental services. They are outlined in the following table.

Table 10 Available methods to place monetary values on environmental services

Name	Definition
Market methods	These methods use values from prevailing prices for goods and services traded in markets. Values of goods in direct markets are revealed by actual market transactions and reflect changes in environmental quality: for example, lower water quality affects the quality of shellfish negatively and hence its price in the market.
Cost-based valuation methods	This method is based on the assumption that the cost of maintaining an environmental benefit is a reasonable estimation of preventive and/or mitigation measures. This assumption is not necessarily correct. Mitigation may not be possible in all cases, for example, in cases where actual mitigation cost could be an underestimation of true environmental cost. On the opposite, a mitigation measure might not be cost-effective and these costs might lead to an over-estimation of environmental costs. A distinction needs to be made between: The costs of measures already adopted, which are theoretically already included in financial cost category. These costs should be reported as a distinct financial cost category. Counting them as environmental costs would be double counting. The costs of measures that need to be taken to prevent environmental damages up to a certain point, such as the Directives' Objectives. These costs can be a good estimate of what society is willing to forego.
Revealed preference methods	The underlying assumption is that the value of goods in a market reflects a set of environmental costs and benefits and that it is possible to isolate the value of the relevant environmental values. These methods include recreational demand methods, hedonic pricing models and averting behaviour models (see below)
Hedonic Pricing	This method explains variation in price (in the price of goods) using information on "qualitative and quantitative" attributes. They are used in the context of water to value how environmental attributes and changes affect property prices. In addition to structural features of the property, determinant of property prices may include proximity to, for example, a river or lake. The

Name	Definition
	change in property price corresponding to an environmental degradation, for example the pollution of a river or lake is the cost of this degradation.
Averting Behavior	This method derives from observations of how people change defensive behavior – adapt coping mechanisms – in response to changes in environmental quality. Defensive behavior can be defined as measures taken to reduce the risk of suffering environmental damages and actions taken to mitigate the impact of environmental damages. The costs for mitigating the impact may entail expenditure on medical care needed as a consequence of drinking poor quality water. The expenditure produces a value of the risk associated with the environmental damage.
Recreation Demand Models (RDM)	Improvements or deterioration in the water quality may enhance or reduce recreation opportunities (e.g. swimming) in one or more sites in a region. However, markets rarely measure the value of these changes. RDM can be used on the choices of trips or visits to sites for recreational purposes and the level of satisfaction, time and money spent in relation to the activity. By assuming that the consumer spends time and money as if he was purchasing access to the goods, for example a river stretch, patterns of travel to particular sites can be used to analyse how an individual values the site and, for example, the water quality of the river stretch. Reductions in trips to a river due to deterioration of water quality and associated changes in expenditures reveal the cost of this deterioration.
Stated preference methods	These methods are based on measures of willingness to pay through directly eliciting consumer preference on either hypothetical or experimental market. For hypothetical market, data are drawn from surveys presenting a hypothetical scenario to the respondents. The respondents make a hypothetical choice, which is used to derive consumer preferences and value. Methods include contingent valuation and contingent ranking. It is also possible to build experimental market where money changes hand, e. g. using simulated market models. In the questionnaire, it is possible to ask respondents how much they would pay for avoiding an environmental cost or how much they value a given environmental benefit.
Contingent Valuation	Contingent Valuation is based on survey results. A scenario including the good that would be delivered and how it would be paid for (e.g. through an increase of the water bill) is presented to the respondent. Respondents are asked for their willingness to pay (WTP) for the specified good. The mean willingness to pay is calculated to give an estimated value of the good. One of the difficulties with this approach lies in ensuring that respondents adequately understand the environmental change that is being valued.
Use of Value Transfer	It is an alternative option to direct valuation of environmental costs or benefits - more commonly known as benefit transfer in the case of benefits): This method uses information on environmental costs or benefits from existing studies and uses this information for the analysis in the river basin under consideration. As a result, a data set that has been developed for a unique purpose is being used in an application for a different purpose, i.e. it transfers values from a study site to a policy site, i.e. from the site where the study has been conducted to the site where the results are used. Above all, benefit transfer is suitable when technical, financial or time resources are scarce. However, among other problems, it is important to note that since benefits have been estimated in a different context they are unlikely to be as accurate as a primary research. A step-wise approach should be developed in order to ensure that the transfer of values derived in other contexts could minimise the potential for estimation errors.

The **environmental cost for pollution** is a quantity associated to quality parameters, and depends on their loads, denoted as A, rejected by the different users during a normal day of the month when the maximal discharge occurs (**charge base)**. Charge bases can either be given by monitoring measurements or estimated. Other variables that are defined for each quality parameter and involved in the environmental cost estimation are: the charge rates R in € per unit concentration, and a coefficient $Coef$, that take into account the sensitivity of the aquatic ecosystem. The equation used for each quality variable QW is:

$$EnvCostPollution_{QW} = A_{QW} \cdot Coef_{QW} \cdot R_{QW} \tag{47}$$

while the Total Environmental Cost for pollution incurred by a particular use is given by the summation over all the present quality variables.

The environmental cost for a quality variable should represent an estimate of the costs of measures that need to be taken to prevent environmental damages up to a certain point, such as the Directives' Objectives (*Cost-based* valuation approach). This should be equal to the total of investment, maintenance and operation costs of treatment for each quality parameter, both for wastewater treatment and water production.

The general methodology applied by the French Agences de l'Eau, and implemented in the WSM DSS, for estimating the environmental benefit produced from a wastewater treatment plant starts from the same equation as for pollution charges, and applies a new term, the Bonus Annual coefficient. This value is usually defined for each quality variable as the pollution abatement coefficient, estimated according to an overall appreciation of the effectiveness of the wastewater process. The equation expressing the **environmental benefit (EB) by waste water treatment** is:

$$EB = \sum_{QW}\left(A_{QW} \cdot Coef_{QW} \cdot R_{QW} \cdot BonusAnnualCoef_{QW} \right) \tag{48}$$

where A_{QW} and $Coef_{QW}$ are the corresponding charge base and the sensitivity coefficient for the quality parameter QW.

The **environmental cost for water abstraction and consumption** applied in the WSM System is estimated through the following equation:

$$\begin{gathered} EnvCost_{Abs,Cons} = \left[Abs \cdot Abs_{CB} \cdot (AreaCoef + ImpactCoef) \right] + \\ \left[Cons \cdot Cons_{CB} \cdot (AreaCoef + ImpactCoef) \right] \end{gathered} \tag{49}$$

The involved terms are: Abs and $Cons$ as the abstraction and consumption during the reference period, Abs_{CB} and $Cons_{CB}$ as the corresponding charge base, and a set of coefficients. Area coefficients vary according to type of the water resource, either surface or groundwater, and to the localisation of the abstraction, that is if the abstraction affects a resource that is overexploited or not in that area.

An impact coefficient may be applied when the two following conditions occur at the same time:

- *Abstraction* > *Y* m^3 during the reference period in no over exploited area
- The ratio between the average monthly flow at the abstraction point and the natural flow in the driest month within a five-years frequency at the abstraction point is greater than *X* m^3, where *Y* and *X* must be chosen according to local conditions.

The reference periods are user-defined and depend on the type of the resource; normally for surface water it runs from 1st of May to the 30th of November and for groundwater from the 1st of April to the 31st of October. In principle, they should be chosen according to the local meteorological and hydrological conditions.

In addition to the methodologies applied the French Agences de l'Eau, environmental costs are also formulated in the WSM DSS based on sustainable groundwater production and the satisfaction of minimum surface flow requirements. The related concepts are presented hereunder.

The model relating environmental cost for groundwater abstractions defines the non-sustainable water production and multiplies it by the cost per unit volume:

$$NonSusGWProd = \sum_{Month=1}^{12} Abstraction \text{ - } NonSusGWIndex \cdot \sum_{Month=1}^{12} Recharge_{Month} \tag{50}$$

where:

NonSusGWProd	=	Non-Sustainable groundwater production;
Abstraction	=	Total abstraction from the renewable groundwater node;
NonSusGWIndex	=	Non-Sustainable groundwater production index;
Recharge	=	Total recharge (infiltration) to the node.

Total environmental cost is estimated as:

$$TEC_{GW} = Cost_{Non\text{-}SusGWProd} \cdot \sum_{RGW} NonSusGWProduction_{RGW} \tag{51}$$

The Non-sustainable groundwater index cannot be defined for fossil groundwater where no recharge exists. In case that fossil groundwater is included, all abstractions are considered as non-sustainable and the equation above is modified as follows:

$$TEC_{GW} = Cost_{Non\text{-}SusGWProd} \cdot \left[\sum_{RGW} NonSusGWProduction_{RGW} + \sum_{FGW} Abstraction_{FGW} \right] \tag{52}$$

As far as surface water abstractions are concerned, the estimation of environmental costs is performed in a similar way to groundwater, where non-sustainable production is replaced by uncovered minimum flow requirements here symbolizing the environmental deficit:

$$TEC_{SW} = Cost_{EnvDeficit} \cdot \sum_{Month=1}^{12} EnvDeficit_{Month} \tag{53}$$

Cost Recovery and Water Surplus

The equations that are presented next express the economic parameters involved in the calculation of the **cost recovery** for water, which is defined as the ratio of total revenues from water billing over the total cost of water production (including environmental and resource costs):

$$RCR = \frac{TotalRevenues}{TotalCost} \cdot 100\% \tag{54}$$

Within the calculation of the total costs, the cost of water supply for each water source is computed first and then that is summed over the sources to get the total cost.

In order to present the relevant formulation, a simple network of water sources and users is supposed to exist, the one supplying water to the others. The notation used is:

i	=	water source;
j	=	water use;
C_{ij}	=	average cost of allocating water from source i to user j;
Q_{ij}	=	amount of water from source i allocated to user j.

The marginal value of water for each user V_j is assumed identical to the average value and it is defined by the DSS user or estimated according to the specific water user. For instance, it can be approximated by the marginal cost of the most expensive source under use, in the case of urban use, or it can depend on crops market price, average annual yield, annual water supplied and the alternative value of land.

The **cost of water supply** from source i to all the users j derives from the unit cost for allocating the resource multiplied by the amount of it that is actually allocated:

$$TDC_i = \sum_j C_{i,j} \cdot Q_{i,j} \tag{55}$$

The Total Direct Cost of water production and supply is the summation on sources of the specific cost of water supply:

$$TDC = \sum_i TDC_i \qquad (56)$$

The **total billing revenues** are computed with a similar formulation, where the price P_{ij} is the price of water from source *i* allocated to used *j*:

$$TR = \sum_i \sum_j P_{i,j} \cdot Q_{i,j} \qquad (57)$$

As it can be noted that, in case the price of water from source *i* allocated to user *j* is equal to the average costs of allocating water from source *i* to user *j*, the total revenues from water billing are equal to the total cost of water production and supply. As a consequence, all direct costs are recovered.

Other economic parameters implemented are the Total Water Value, Private Water Surplus and Social Water Surplus.

The **Water Value** TV associated with water consumption accrue to the j^{th} user is given by marginal value of water for each user multiplied by the amount of water allocated:

$$TV_j = \sum_i V_i \cdot Q_{i,j} \qquad (58)$$

Based on the Water value, the **Private Water Surplus**, which signifies the Net Benefit from Water Use, accrue to each water user is:

$$PWS = \sum_j PWS_j = \sum_j \left(TV_j - \sum_{\mathrm{i}} P_{i,j} \cdot Q_{i,j} \right) \qquad (59)$$

On the other side, the total **Social Water Surplus** (SWS) in the hypothetic network considered can be approximated by the difference between the total value and the total cost:

$$SWS = TV - TDC = \sum_j TV_j - \sum_i TDC_i \qquad (60)$$

Going back to the assumptions on prices, if prices coincide with the average costs for allocating water from resources to users, the rate of cost recovery that incorporates only direct costs is equal to 1 and the private water surplus equals the social water surplus. If prices are subsidised (in this case prices will be lower than costs), then the total income to water suppliers is less than the total cost for water supply. In this case, the rate of cost recovery is less than 1 and the private surplus exceeds the social surplus by the level of subsidy.

Implementation in the WSM DSS

As already presented in Chapter 8, the economic analysis is performed within the simulation of the water network, according to (a) the economic data entered in the Data Editor by the DSS user and (b) the economic simulation settings that are selected by default. However, the user is enabled to run the economic analysis separately after the simulation. The economic parameters involved in the calculations of direct, resource and environmental costs, the type of sub-model and the preferences can be changed from the **Economic Analysis Window** that is reachable from the Navigation Panel of the main interface. The available information is divided into *Benefits & Private Water Surplus*, *Costs*, *Revenues from Water Billing*, *Rate of Cost Recovery*, *Social Water Surplus* and *Net Present Values* of cost components. These categories are listed in the tree view of the window and the selection of a sub-menu invokes the loading of the relevant information in the panel on the right. Data appearing in the panels strictly reflect the economic variables and sub-models presented in the methodology part of this chapter. The only exception is for the direct cost, because the required data is specified in the *Cost* Tabs of the Data Editor, for every single part of the infrastructure (dams, desalination, drinking water treatment, desalination, wastewater treatment, renewable groundwater, supply links etc.).These data are:

- *Construction Cost* and *Depreciation Period* for the estimation of annualized capital costs;
- *Specific Operation and Maintenance Costs* in terms of €/m^3 produced or treated;
- *Energy Consumption* in kWh/m^3 produced or treated for the estimation of variable costs, and

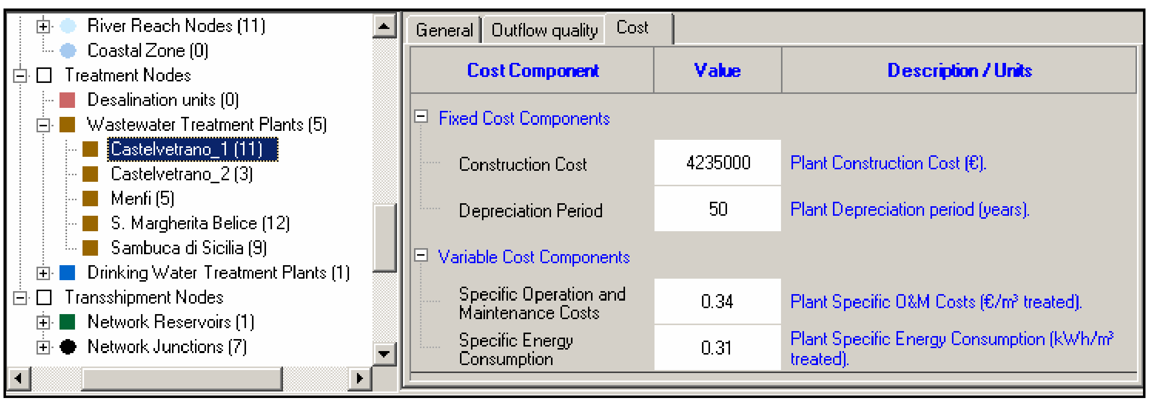


Figure 71 The Data Editor Panel showing the direct cost components for a Wastewater Treatment Plant

The information for direct costs that is considered in the Economic Analysis Window is the additional cost specified for water users in order to incorporate administrative and other direct costs related to the operation of the water service. This additional cost can also include an indicative cost for operation and maintenance, in case specific costs for water nodes are not available.

The interface panel for the environmental costs is here presented as an example, to illustrate how the DSS user can apply the economic methodology to water network simulations. With respect to groundwater water production, the method for cost calculation can be selected between the simple mode, where the user directly defines a cost per unit of water volume, and the charge model applied by the French Agences de l'Eau. This latter requires some general information as well as specific coefficients for the modelled aquifers. These settings can be configured in three window tabs, namely *General*, *Impact Coefficients* and *Area Coefficients*. In the General tab the user selects the reference period for the resource vulnerability and the abstraction and consumption charges. The impact coefficients tab relates the factor characterising the impact of abstractions on the water table in both vulnerable and non-vulnerable areas, and the selections of its application criteria according to thresholds of abstracted volumes. The Area coefficients tab lists all the renewable groundwater nodes in the case study area and the value expressing the vulnerability of the resource is to be entered for each.

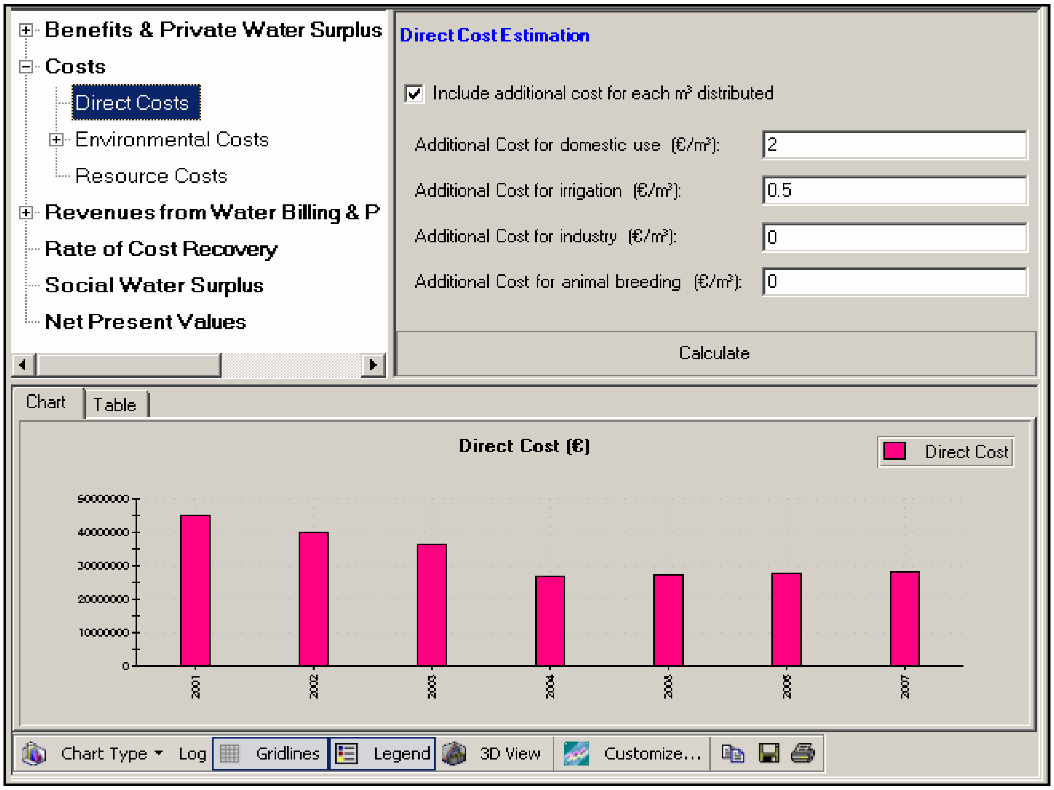


Figure 72 Additional Direct Cost Panel

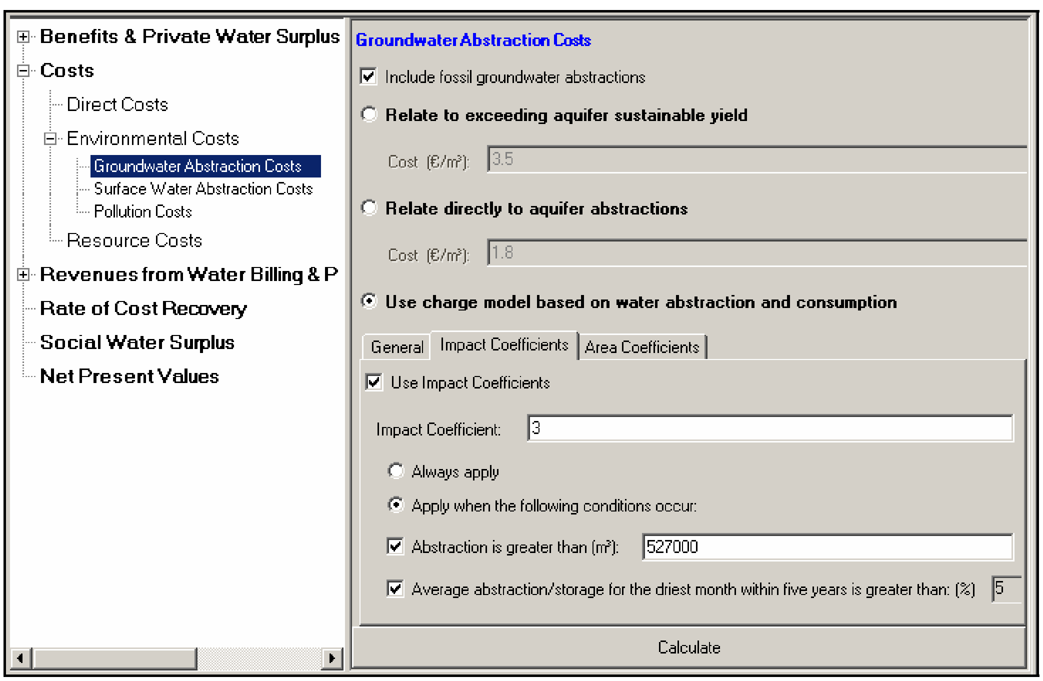


Figure 73 Selection of Environmental Cost sub-model for groundwater abstractions

Chapter 10 Evaluation of Water Management Schemes

Methodology Outline

The aim of the *Evaluation Module* of the WSM DSS is to facilitate the **comparison** of at least two alternative Water Management Schemes (WMS), which incorporate different scenarios and/or strategic options. The procedure provides the user with a classification, where the high-ranked water management schemes are supposed to be better than low-ranked ones.

The score of the schemes is defined as the value of a **Relative Sustainability Index**, which is derived from specific statistic criteria that are calculated for each scheme and based on a predefined list of indicators. This approach for measuring sustainability has been adapted from "*Sustainability Criteria for Water Resource Systems*" (Task Committee on Sustainability Criteria, 1998).

More specifically, the procedure to get the final score of one WMS is the following:

- The desired indicators, on which the evaluation will be based, must be selected (activated). Weights and least and maximum acceptable values must be assigned to each of them according to the specific goals of the case study and the decision maker;
- Three statistical criteria are calculated for each indicator, over their time series in the simulation horizon: *Reliability*, *Resilience* and *Relative Vulnerability*; those are connected with the concept of *Range of Satisfactory Performance Value* whose extent is fixed by the least and maximum acceptable values;
- Statistical criteria are normalised where necessary and then aggregated in the sustainability index;
- Sustainability indices for the respective indicators are weighted to get the *Relative Sustainability Index*, at both the indicator category level and the entire management scheme level.

In order to generate a valid score of sustainability, the user should pick up and activate those indicators that strictly pertain the water system simulated and the scheme he wants to evaluate. The available indicators for evaluation are grouped under the three categories of *Environment and Resources*, *Efficiency* and *Economics*. The first one includes: Minimum flow requirement coverage, Desalination and Reuse Supply Share, Dependence on Imported Water, Groundwater Exploitation Index and Non Sustainable Groundwater Production Index. The Efficiency group is characterised by the rate of demand coverage for each kind of water use in the region, from domestic to hydroelectrical. The economic indicators are: Total Benefit from Water Use, Total Environmental Cost and Rate of Cost Recovery.

The statistical criteria express the behaviour of the monthly or yearly time series of each indicator with respect to the predefined range of satisfactory values the indicator can assume.

The lower and upper limits of the satisfactory field of values are not fixed, although suggested usual ones are proposed. The first represents the lower, minimum satisfactory value the indicator is expected to assume, whereas the latter is the upper, the maximum. For example, in the case of Domestic coverage, satisfactory values can range from 0.8 to 1, meaning that the user (or decision maker) is satisfied if at least 80% of the domestic demand is met.

Statistical criteria aim at indicating if the simulation results, obtained under particular scenarios and strategies, can be considered reasonable, acceptable and adequate to the goals set out by the decision maker. A tentative example of their estimation is presented below.

Let's consider a selected indicator C, whose time series of values are denoted as C_t. (Figure 74).

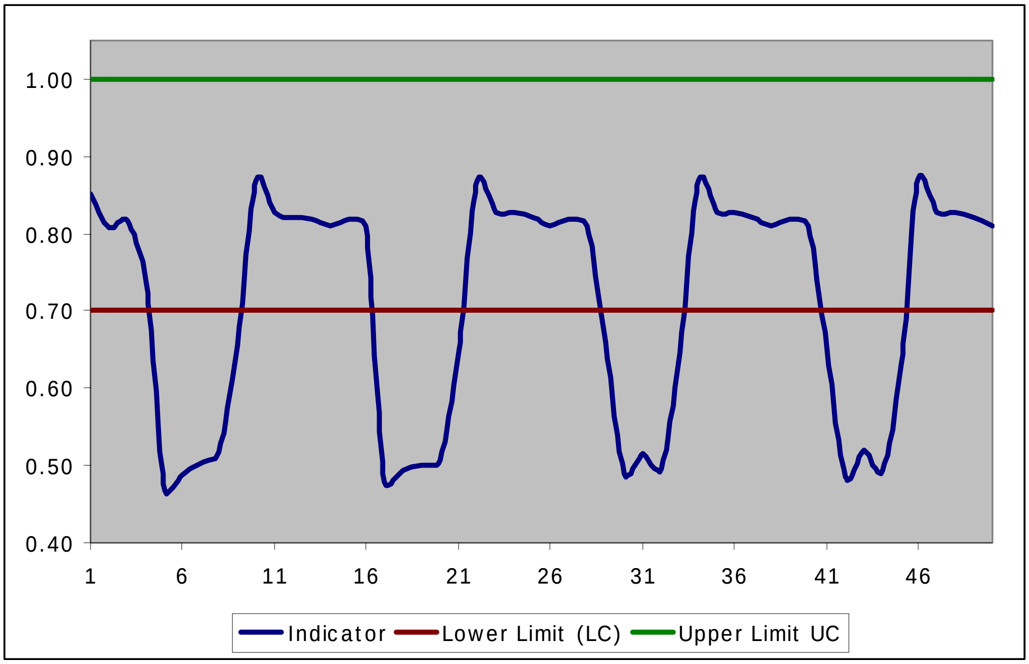


Figure 74 Domestic coverage time series and range of satisfactory values

Reliability is defined as the probability that any particular C_t value will be within the range of values considered satisfactory:

$$Reliability\ of\ C = \frac{Number\ of\ satisfactory\ C_t\ values}{Total\ number\ of\ simulated\ periods} \tag{61}$$

Resilience is a criterion describing the speed of recovery from an unsatisfactory condition. It is the probability that a satisfactory value C_{t+1} will follow an unsatisfactory C_t value:

$$Resilience\ of\ C = \frac{Number\ of\ times\ a\ satisfactory\ C_{t+1}\ value\ follows\ an\ unsatisfactory\ C_t\ value}{Total\ number\ of\ unsatisfactory\ values} \tag{62}$$

The **Vulnerability** statistical index measures the extent and the duration of failures (unsatisfactory values) in a time series. The extent of a failure is the deviation when the indicator value exceeds the upper limit, C_t-*Upper Limit*, or that falls short the lower limit, *Lower Limit*-C_t. It can be based on the extent of failure of individual unsatisfactory values or the cumulative extent of failure of a continuous series of unsatisfactory values. In the latter case, each individual extent of failure is added together for the duration of each continuous failure sequence.

Within the evaluation module of the DSS, vulnerability is expressed for each indicator by three indices, namely a **Conditional Expected Extent** or simply **Extent**, the **Maximum Extent** and the **Expected Duration**. They are defined as follows (Eq. (63) - (65)):

$$Conditional\ Expected\ Extent - Vulnerability\ of\ C = \frac{\sum individual\ extents\ of\ C_t\ failures}{Total\ number\ of\ individual\ extents\ of\ C_t\ failures} \tag{63}$$

$$Maximum\ Extent - Vulnerability\ of\ C = Max\left[0, LowerLimitC_t - C_t, C_t - UpperLimit\right] \tag{64}$$

$$Expected\ Duration - Vulnerability\ of\ C = \frac{Total\ Number\ of\ failures}{Number\ of\ continuous\ failures} \quad (65)$$

As it can be seen from the formulation of these criteria, all vulnerability criteria are not positive indices as opposed to reliability and resilience (in the sense that higher values have a negative meaning) and their values do not range from 0 to 1. Therefore, each vulnerability criterion (extent, max extent and duration) is converted by the DSS to be comparable with the other two. First, the largest vulnerability value for each indicator C is defined amongst all Water Management Schemes that are compared and each vulnerability measure for each Water Management Scheme is divided by this maximum value. This procedure defines the **Relative Vulnerability** for each indicator:

$$Relative Vulnerability\ of\ C = \frac{Vulnerability\ of\ C}{Max Vulnerability\ among\ all\ WMS} \quad (66)$$

Then the **Sustainability Index** for each indicator is computed, where each relative vulnerability measure is subtracted from 1 so that higher values are to be preferred:

$$\begin{aligned} & Sustainability_C = \\ & [Reliability_C]*[Resilience_C]*[1 - Relative\ Vulnerability\ Duration_C]* \\ & *[1 - Relative\ Max\ Extent_C]*[1 - Relative\ Extent_C] \end{aligned} \quad (67)$$

The *Sustainability* index ranges from 0, for its lowest and worst possible value, to 1 at its highest and best possible value.

To obtain a combined weighted relative sustainability index that considers all indicators, the relative weights W_C entered by the DSS user are used. Since all weights for the activated indicators should sum to 1, a normalization of weights is performed before presenting the aggregated sustainability indices in the WSM Evaluation Scorecards.

Finally the relative sustainability of each alternative Water Management Scheme being compared is:

$$Relative\ Sustainability_C = \sum_C W_C * Sustainability_C \quad (68)$$

Since each sustainability index ranges from 0 to 1 and relative weights W_c after the normalization sum to 1, the relative sustainability index computed for each water management scheme will also range from 0 to 1. The Water Management Scheme having the highest value can be considered to be the most sustainable with respect to the indicators selected, the indicator values that are considered satisfactory and the relative weights.

Implementation in the WSM DSS

The Graphical User Interface of the Evaluation Module (EM), as described in the methodology section, can be opened by the *Evaluation* menu of the Navigation Panel. Necessary condition to run the module is that more than two water management schemes have been simulated, so that their results are ready to be compared and involved in the statistical analysis.

The window of the EM interface comprises of four panels. From the two of the upper part which should be accessed first, the user can choose the schemes to be evaluated and for which period of time, defined by a first and last evaluation year. He can also select and activate the indicators whose time series will be subjected to the evaluation. Indicators are classified in three categories *Environment and Resources*, *Efficiency* and *Economics.* The variables belong to the regional set that is shown in the Simulation Detailed Results View.

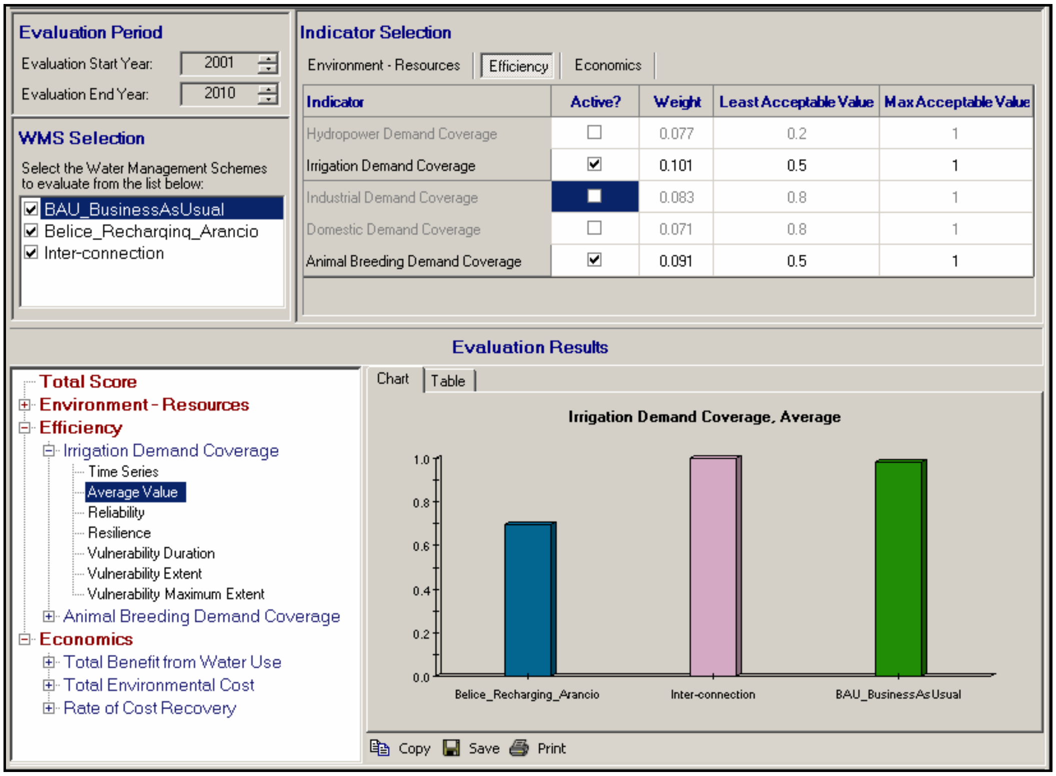


Figure 75 The Evaluation Module's window

The **Indicator Selection** panel is structured in three tables, each one related to a category. From there, indicators are activated with a tick in the *Active?* column and the weight to be used in the calculation of the *Relative sustainability index* at the category or WMS level can be edited. Least and Max acceptable values can be modified according to the preferences of the Decision Maker or the existing suggested values can be confirmed.

The two panels at the bottom of the window show the evaluation results. The DSS user can navigate through the activated indicators in the left panel and for each select one of the statistical measures, whose value is then plotted in the chart panel on the right. The statistical indices available are the following (see methodology part for a definition): Reliability, Resilience and the three figures of Relative Vulnerability, namely Duration, Extent and Maximum Extent. Moreover, the user can view the time series and average value of the single activated indicator over the selected evaluation period.

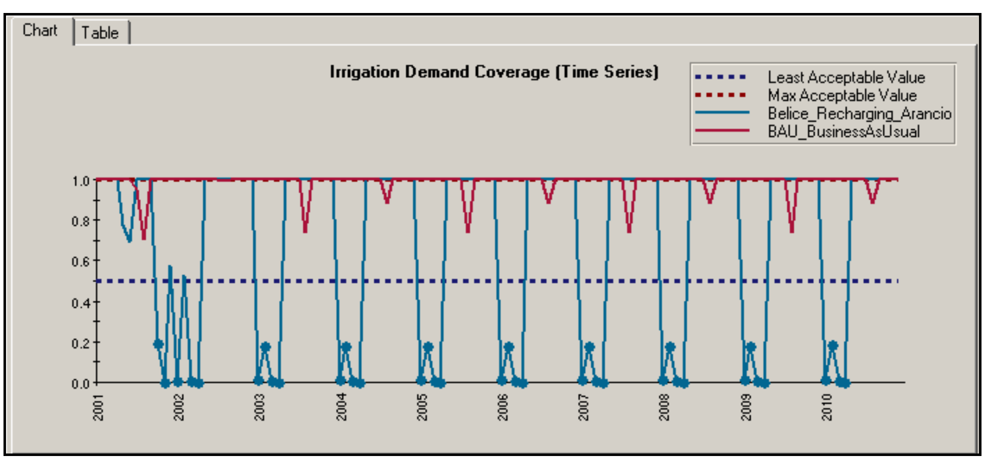


Figure 76 Comparing time series of irrigation demand coverage

The **Evaluation Table** displays the statistical information for all the indicators and categories and thus finally shows the aggregated Total Score for every single management scheme. The schemes are in the table columns so that their score for each index can easily be compared. Both chart and score table can be copied, saved as images and printed by using the corresponding buttons in the toolbar below them.

Chart | Table

Indicator / Criterion	BAU_BusinessAsUsual	Inter-connection	Belice_Recharging_Arancio
⊞ Environment - Resources	0	0	0
⊟ Efficiency	0.07097369	0.07097369	0
⊟ Irrigation Demand Coverage	0.7027027	0.7027027	0
Average	0.98407456	1	0.69482722
Reliability	1	1	0.69166667
Resilience	1	1	0.2972973
⊟ 1-Relative Vulnerability			
Extent	1	1	0
Max Extent	1	1	0
Duration	0.7027027	0.7027027	0
⊞ Animal Breeding Demand Coverage	0	0	0
⊞ Economics	0	0	0.03175521
Total Score	0.07097369	0.07097369	0.03175521

Figure 77 The Evaluation Table of the WSM DSS

Part II

Existing Tools for Water Management

Chapter 11 Introduction to the Review of Tools and Models for Water Resources Modelling

The following Chapters aim at providing an overview of Decision Support Systems for water management. A part of this work was undertaken in the Analysis Phase of the WaterStrategyMan Project (EVK1-CT-2001-00098). The review aimed at analysing the characteristics of available tools as well as at evaluating their applicability to the WSM Paradigms of Water Deficient Regions in Southern Europe. The criteria used for determining the applicability of reviewed tools were identified within the definition of the appropriate methodologiesfor a comprehensive, integrated and sustainable water resource management, adapted to the Southern European regional context. The first criterion was the functionality of a Windows-based Graphical User Interface, connected with a Geographical Information System(GIS), which would have to allow for: (a) the graphical schematisation of water resource systems, and (b) the active user-interaction in their construction and/or modification. The second criterion was the integration of a framework of indicators able to cover a wide range of aspects, such as water quantity and water quality, climatic driving forces, demographic pressures, sustainable exploitation, full water cost components and environmental demand. The third criterion concerned the capability to create and manage scenarios of driving forces such as rainfall and population growth, and the possibility to simulate multiple alternative cases and compare them through appropriate multi-criteria approaches, taking into account economic, social and environmental indicators. Last but not least, a vital criterion for the assessment was the ability to perform comprehensive economic analyses, in light of the requirements imposed by the Water Framework Directive. The satisfaction of those requirements is shortly discussed at the end of each tool review.

The software packages reviewed are Decision Support Systems and Tools that can support decision makers in addressing water resources issues within a framework of analysis, planning and management that integrates multiple aspects, such as environmental, socio-economic, administrative and sustainable development goals. The majority of the software packages presented have been developed for and are currently applied to specific river basin case studies, but the features and approaches they use and the models they embed are general and can fit specific user-defined regions and zones.

Tools and Models for Water Resources

The tools reviewed were 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 National 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 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 EU funded 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.

Chapter 12 Mike Basin

In terms of actual Decision Support Systems, one may consider MIKE BASIN to be a first example of a 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 allows for maintaining the full functionality of the ESRI software and applying its standard facilities to water resource modelling.

Main Interface and Basin Schematisation

The user is introduced to the main window of the MIKE BASIN (MB) interface by a dialog box where he chooses the simulation options. By default Mike Basin aims at studying water allocation within a basin; however a water quality option and a module for simulating groundwater can also be selected.

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 effort, some networks can be simplified according to modelling objectives and data availability. For example, 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, while civil and industrial supply can be aggregated into one entity. However, MB leaves either the alternative to draw a simplified *schematic* scheme, or to analyse the basin in full detail.

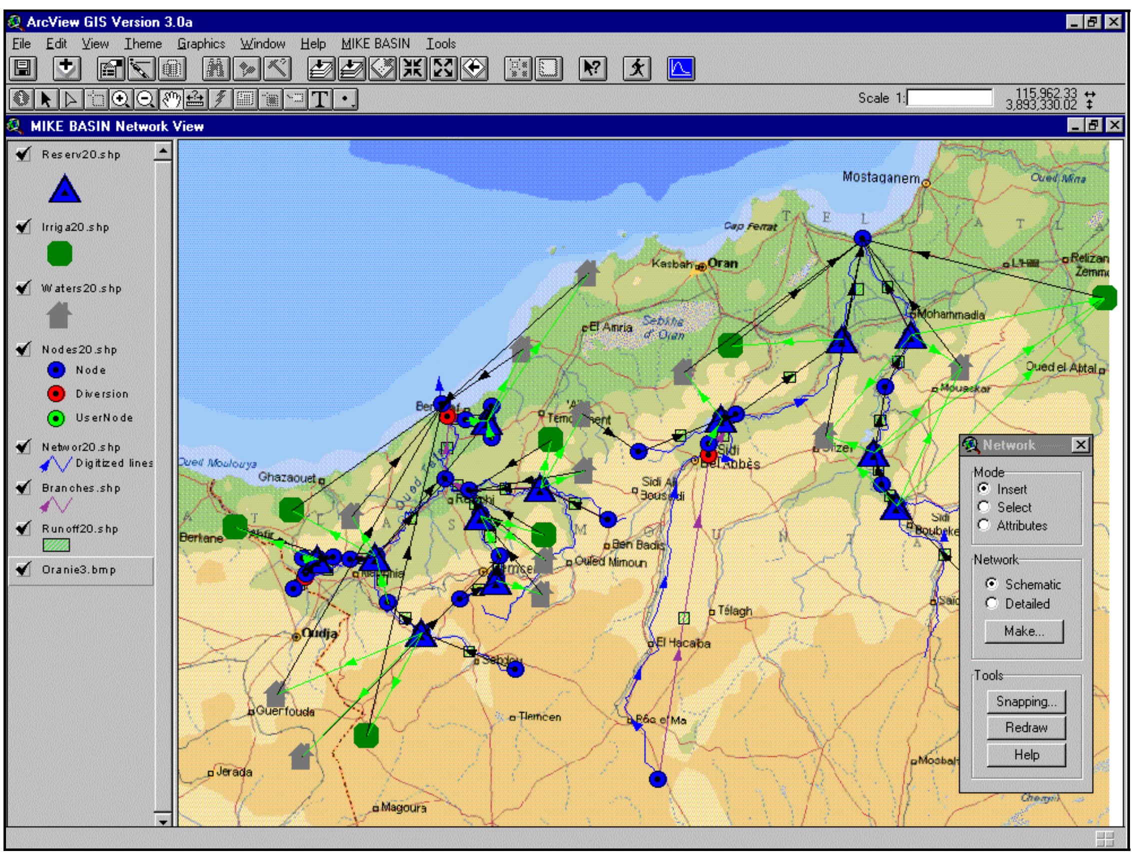


Figure 78 An example of Basin Schematisation in the Network View of MB

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 the nodes should be placed in the following order: River nodes, Reservoirs, Hydropower nodes and Water Demand nodes. River nodes are placed on the river polyline and are of *Simple* or *Catchment* type. *Simple* river nodes define confluences, diversions, upstream end of tributaries and the outlet of the river system, while *Catchment* river nodes represent the outlets of upstream catchment areas. These areas are depicted hatched in green colour in the specific *Runoff* layer. A *Simple* or *Catchment* node can assume the further role 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 in the end and represent irrigation sites and water supply systems conveying water to cities or industries.

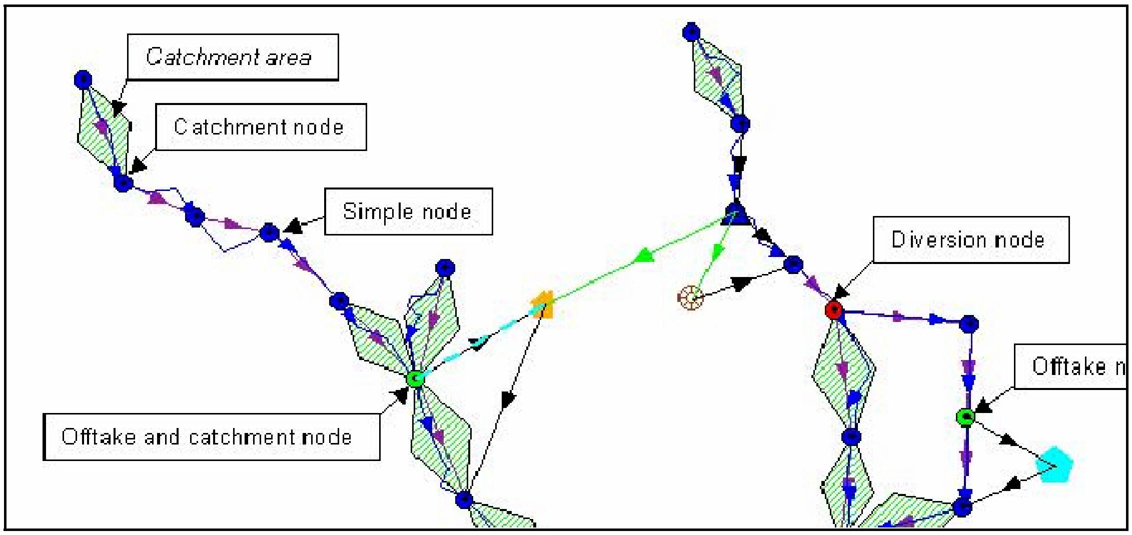


Figure 79 Definition of Catchment areas and Offtake nodes

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

Time Series may have been previously prepared in text files. In this case it is possible to import them directly from the dialog boxes. Otherwise, time series can be edited through the **Time Series Edit** tool (TSEdit). The interface of the tool 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 Demand Node in the relevant boxes, he browses and specifies the files with the water demand and the return flow data for the node. Additionally, he has to define the water sources supplying water to the node and the *sink nodes* receiving his *return flows*. The nodes connected to the demand node are defined on the network map by dragging a little square around each selected water source (river or reservoir nodes), and each sink node that is usually of a River node type. Then the Identifier number of the selected source or sink node appears automatically in the property box of the demand node. The same operation is performed when editing the properties of offtake nodes, which are River nodes with the additional role of water source. The user specifies the demand nodes served by the offtake node; however these connections should be consistent with the ones previously defined in the demand node boxes. In fact, 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 use is specified for a source node, the same node must be specified for that use.

The **Check Topology** tool can sweep the network connections and validate the basin schematisation before running the simulation.

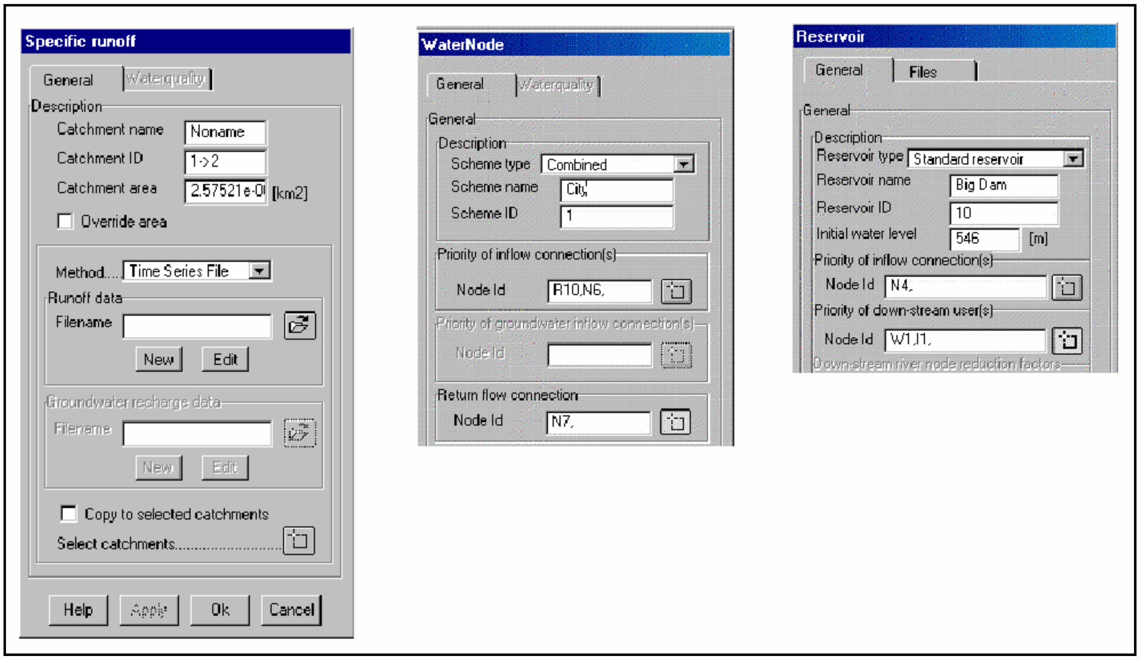


Figure 80 Dialog boxes for data editing concerning Catchments nodes, Water Supply System nodes and Reservoir nodes

Priorities for water allocation

If the user of MB connects an offtake node with multiple water demanding users, the order he follows in their selection is important: it represents the sequence in which connected use nodes will be supplied and their water demands met. Each demand node will receive the minimum between its entire water demand and the water available at the offtake node after upstream demands have been met. 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 represents the sequence in which abstractions are requested from the connected supply sources. The first node in the list will supply the entire demand (if enough water is available) before the second node is considered. This second node will supply the rest (if any after the abstraction from the first node), and so on for all the subsequent supply nodes. This is the **Local Priority** principle and it is at the basis of the allocation algorithm of MB. It is named *local* because once there is an offtake with multiple nodes connected to it, the closest nodes are assigned a higher priority than those placed at longer distance. The priority approach is useful under 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 uses supplied have the same priority and receive water proportionally to their water demands.

MB has another principle for managing water allocation, the *Global Priority Rules*. This option can be selected along with the overall simulation options in the first window of the MB 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 allocation of water is governed by rules only, thus implying some restrictions to the basin schematisation:

- ❖ Diversion nodes are not allowed and they must be replaced by a virtual use, which is provided with an abstraction rule with the same abstraction volume;

- Return flow from water uses must be directed to a node on the river immediately downstream to the abstraction node.

Global Priority Rules concern abstractions, minimum flows, reservoir storage and reservoir target levels. Table 11 presents the types of rules, their purpose, nodes and data affected.

Table 11 Global Priority Rules of Mike Basins

Type	**Purpose**	**Specification Required**
Abstraction	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 abstraction	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

Global Priority Rules are edited in specific dialog boxes and summarised in the **MB Rules Window,** where information about involved nodes and time series is also reported. Here the rules can be selected and edited again. When a rule is selected, the affected nodes are highlighted on the map.

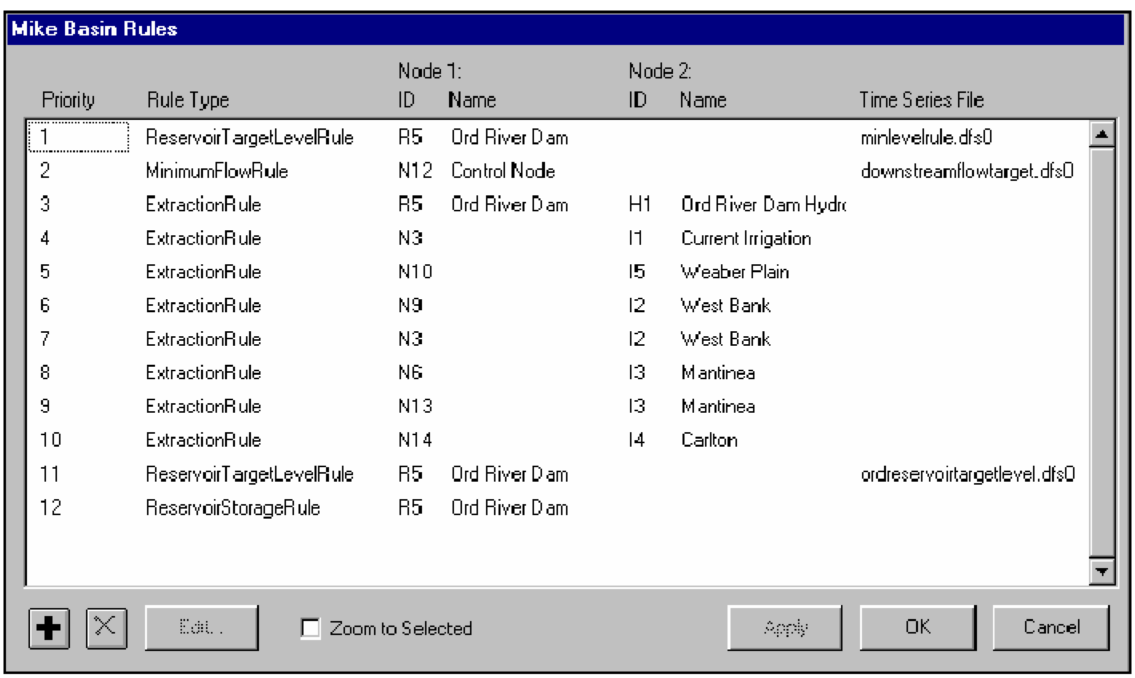


Figure 81 The MB Rules Window, summarising Global Priority Rules

Simulation and models

Once the river basin schematisation has been completed, required data have been entered and rules have been defined, some parameters characterising the simulation must be specified. The user is prompted to enter the start and end dates for the simulation period in the simulation window, and to choose between a monthly or a daily time step. Some options related to the result presentation can be selected as well: some result views can open automatically when simulation is terminated or output can be visualised for only a specific subset of nodes.

Water Quantity

As previously said, 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 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 information in the **Rainfall-Runoff Modelling** dialog box that can be accessed from each 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 in particular it calculates surface-overland flows, interflows and baseflows as a function of soil moisture content, surface storage, accumulation, and melting of snow. It is of lumped type, and therefore 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 measurements.

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 for 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 type 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 is provided as daily mean values.

NAM comprises the following modules:

- Basic modelling module,
- Extended Groundwater module,
- Snow module, and
- 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.

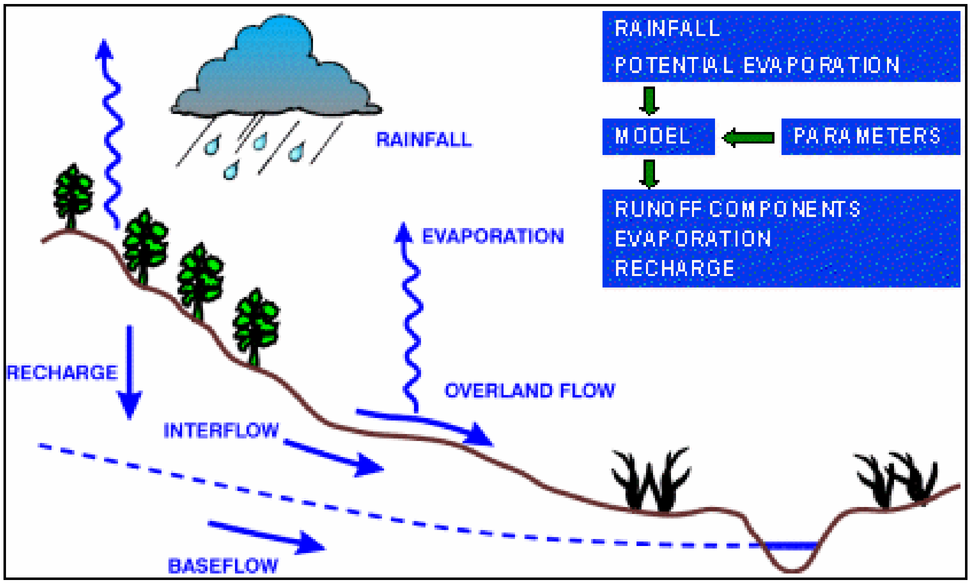


Figure 82 The schematisation of natural phenomena in the NAM model

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, which usually has a slow responding component of the base flow, and an upper storage providing a faster response. Both are modelled as a 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 is referred to the snowmelt component of runoff that is mostly significant in mountainous areas, where precipitation is retained in terms of accumulating snow during cold periods and appears as snowmelt in warmer ones. The module is of distributed type. It divides the catchment area in many *altitude zones* and studies separately the contribution of each one to the total. This reflects the fact that in mountainous areas snow cover, precipitation, evapotranspiration, temperature and radiation vary remarkably within a catchment; therefore the use of separate data and coefficients improves 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 can be accounted in order to consider seasonal variations of incoming short wave radiation and 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. Those affect the runoff distribution in terms of local water abstractions (from aquifers and rivers), and increased local infiltration and groundwater recharge. Increased evapotranspiration, as well as possible external water transfers for irrigation may significantly influence 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 are also used to consider the proper evapotranspiration and stage of growth.

The **Unit Hydrograph Module** (UHM) is a hydrological model of the Mike 11 package which simulates the runoff from a single storm event using unit hydrograph methodology. The total rainfall subtracting the amount that infiltrates in the root zone gives the volume of precipitation that generates the land-flows. Infiltration can be calculated through (a) a hortonian approach, (b) a loss rate proportional to the rainfall intensity (Rational Method), or (c) determined by the Soil Conservation Service curve number method.

The third model of Mike 11 included in the Rainfall-runoff module of MIKE BASIN is SMAP. It is a hydrological model simulating the runoff of a catchment area by accounting for moisture storage in the root zone and in aquifers. These two types of storage are schematised as linear reservoirs, as in the NAM model. The model works on a monthly basis and updates the storage of both reservoirs at each time step according to 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. Since it uses monthly data, SMAP can be used instead of NAM when daily data are not available.

Water Quality

The **Water Quality module** of MIKE BASIN simulates transport and degradation of significant substances affecting water quality in reservoirs and rivers. The substances modelled are: Total Organic Matter expressed as Biological Oxygen Demand, Ammonia, Nitrates, Dissolved Oxygen, Chemical Oxygen Demand, Total Phosphorus and E. Coli bacteria. The user can add more substances for case-specific analysis.

Solute transport is modelled as purely advective and dispersion is not considered. This assumption is reasonable in rivers without much turbulence and under the assumption that degradation time is less than residence time.

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

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 generating water recharge.

MIKE BASIN supports the definition of pollutant loads both at point and at non-point sources. Point sources are associated with water supplies which discharge a total pollutant load into the rivers that is proportional to the return flows outgoing them. As water supplies are usually connected to waste water treatment plants whose effluents finally end up in rivers, MB allows describing 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 most used ones. This information can be accessed from the property box of water supply nodes.

Non-point sources are associated with 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. This tool calculates 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 load inputs when runoff changes or to adjust them for calibration purposes.

Groundwater

The **Groundwater module** of MIKE BASIN can be activated in the first window together with the other simulation modules and the choice of a local or global rule approach. This module consists of a simple physical model of an aquifer that is conceptualised as a linear reservoir that exchanges water with water users and surface water bodies. Water balance is analysed according to pumping, recharge, seepage from rivers and discharge to rivers. The first three are assigned by the user as time series. This type of information is defined in the property box of the respective network elements (catchment areas and river branches) since groundwater is conceptually linked to them. In more detail, the user specifies: 1) seepage loss fraction, to be multiplied by the simulated flow in the stream branch in order to obtain the water volume lost to the aquifer 2) groundwater recharge from the catchment area encompassing the stream 3) pumping demand rates, which Mike Basin will try to cover on the basis of actual groundwater availability. Groundwater discharge represents the water flows from the shallow and deep outlet levels (Figure 83) feeding rivers and it is proportional to the water level of the aquifer and also to its storage. Being a hydraulic response, discharge is not assigned by the user but computed by the groundwater module.

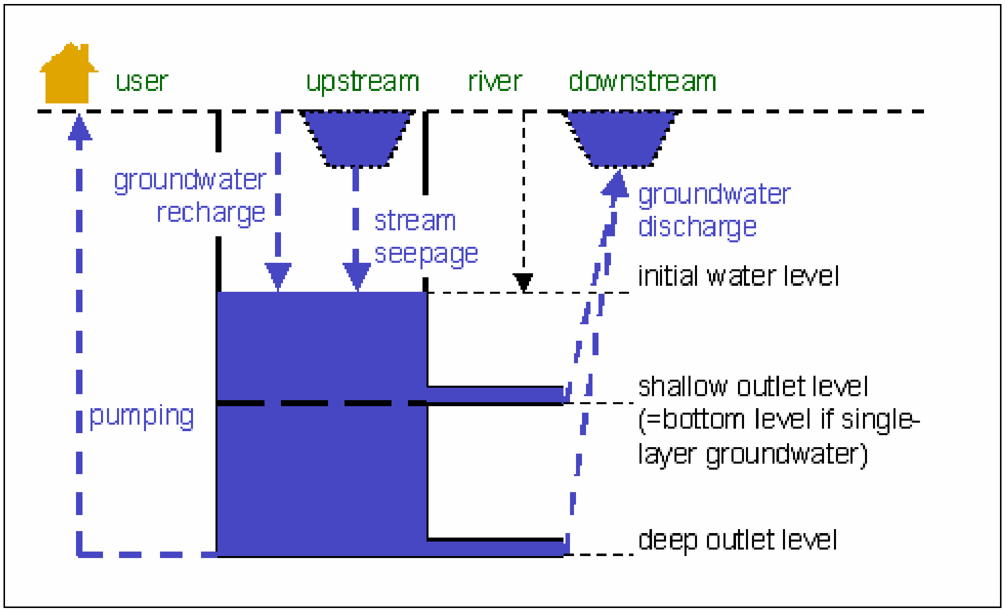


Figure 83 Aquifer schematisation and exchanged flows

Viewing Results

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

- **Time series** and related **graphs**,
- **Summary HTML tables**, and
- **Animated Features** 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. With respect to time series, a window of the TSEdit opens for the specified node, showing its characteristic two panels. In the right panel, output is organised in tabular form with the time dates simulated in rows and the different output items in columns. In the left panel 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.

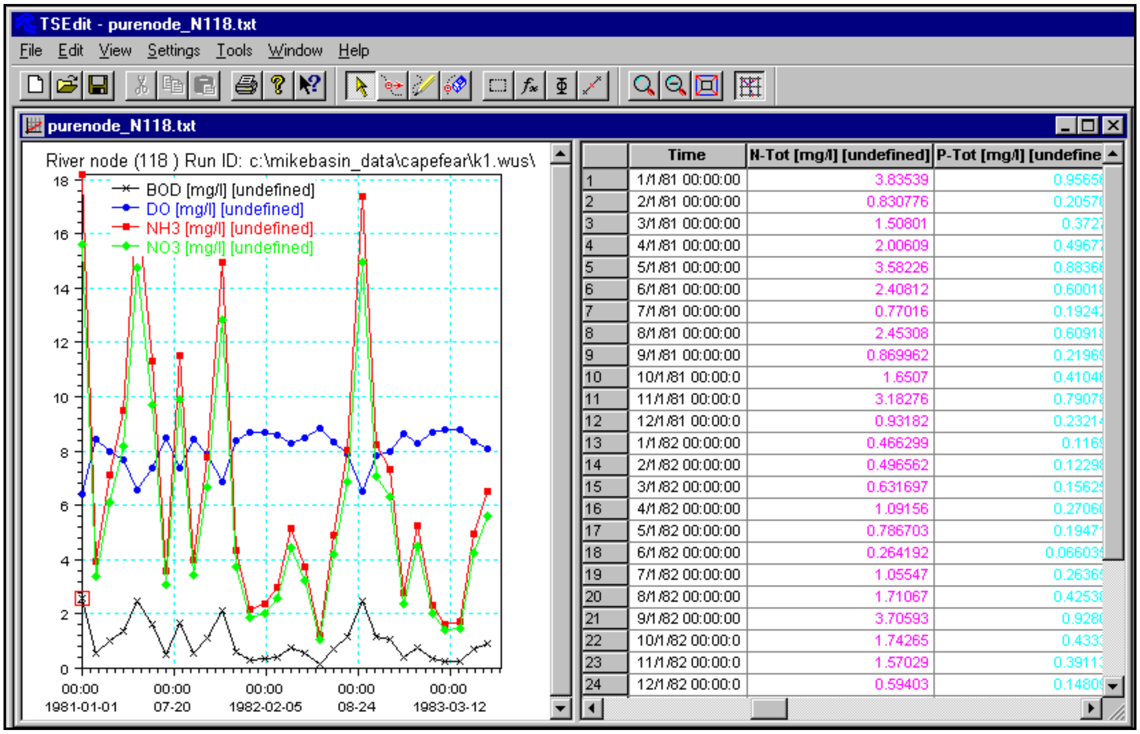


Figure 84 The TSEdit tool displaying results

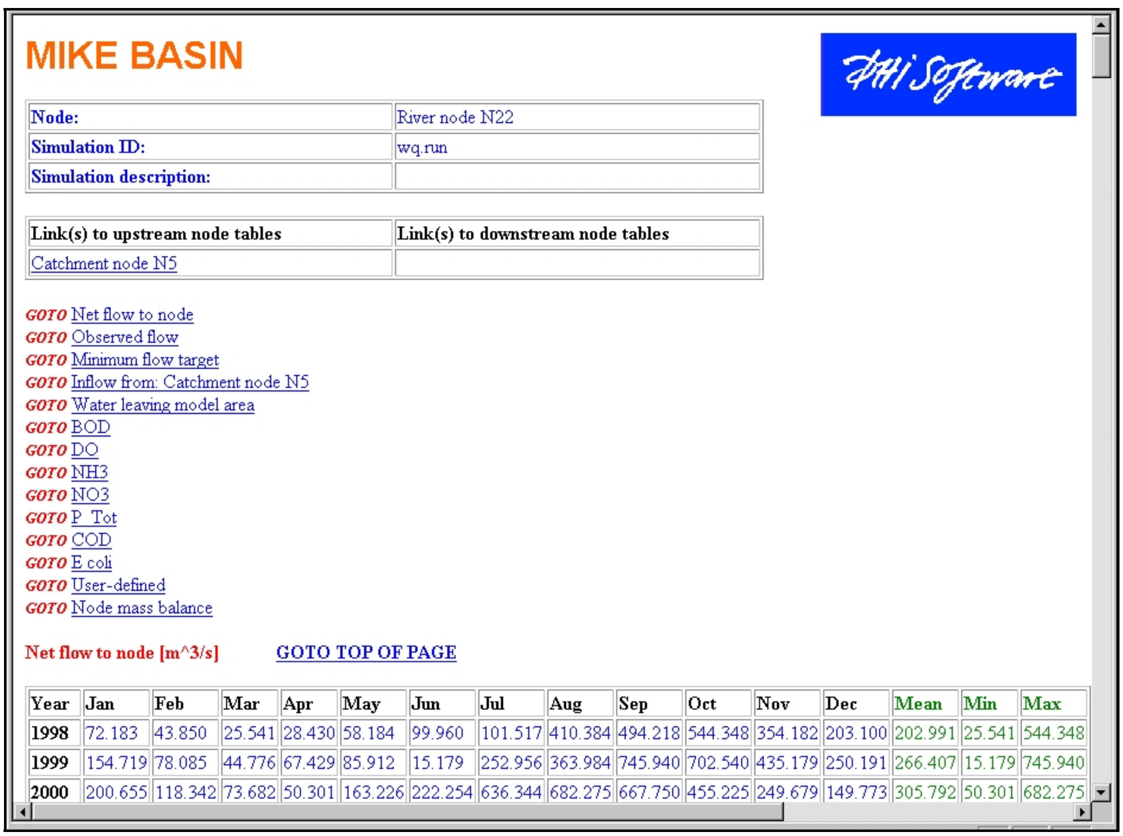


Figure 85 An HTML table for a river node

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. Links to HTML files associated with the neighbouring nodes, actually the upstream and downstream ones, are also provided. The HTML file also contains descriptive statistics of results, such as minimum, maximum and mean values for each data series.

As a third option, the MB User can visualise 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 output type can assume and the associated colours and sizes. A dedicated bar displays the time steps and the time position within the simulation horizon.

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

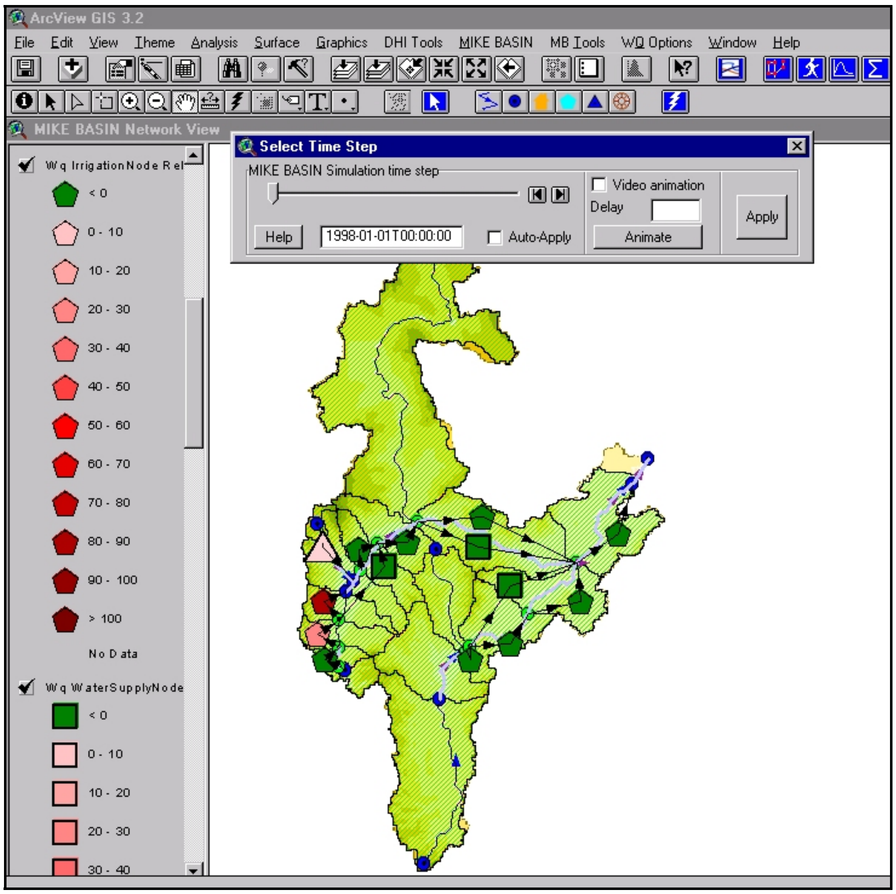


Figure 86 The Animated View displaying simulation results

Summary of Pros and Cons

According to the developer, MIKE BASIN should facilitate sustainable management of surface and groundwater resources, and water quality. Unfortunately the system concentrates on the physical and optimisation aspects of water resources, without taking into account socio-economic 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) adopted by the European Environment Agency (EEA), which links policy objectives to information and analysis in the context of management implementation.

Chapter 13 Basins

Another DSS example for Water Resources Modelling 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 the third version, dated June 2001. It has been originally conceived to meet the needs of local, regional and state Environmental and Pollution Control Agencies in performing ecological and water quality studies at the watershed scale.

Objectives

The main objectives of Basins are to:

- **Facilitate** the examination of environmental information;
- **Support** the analysis of environmental systems;
- **Provide** an integrated and modelling framework for examining point and non-point source management alternatives;

Although the software package is mainly used for analysing the maximum daily pollutant loads from point and non-point sources, it has also been applied to other problems: wet weather combined with 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 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 pollutant loads and their transport, and
- a scenario generator tool.

The use of ArcView makes the architecture of BASINS open and flexible, so that each agency or a user can develop and customise their own utilities to better address specific needs and different applications. 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. In this way users can load as BASINS components only the extensions that apply to their water basin project. On the other hand, this also helps the developers to maintain and upgrade the package as they can 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 GIS environments, provides built-in additional procedures for data query, spatial analysis, and map generation. These custom BASINS procedures allow the 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. 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,
- networks of the major highways,
- populated and urbanised areas, and
- administrative boundaries.

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

In more detail, Environmental Background Data consist of:

- delineation of the Eco-regions defined by the U.S. EPA and of the study areas,
- soil information,
- results of the wastewater control,
- stream networks,
- drainage networks,
- Digital Elevation Model,
- land Use and land Cover, and
- 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,
- meteorological station sites,
- location of public water supplies, their intakes, and sources of surface water supply, and

- ❖ location and extent of shellfish areas.

The fourth type of data stored in the databases of BASINS is the **Point Source/Loading Data** that includes information on locations and type of facilities generating and discharging pollutant loads, such as:

- ❖ industrial facilities discharge sites,
- ❖ toxic release inventory Sites and pollutant release data,
- ❖ location of transfer, storage, and disposal facilities for solid and hazardous waste, and
- ❖ 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 regional assessment of in-stream water quality conditions, the identification of point source discharges on a watershed scale and the analysis and review of summary data for a specific site.

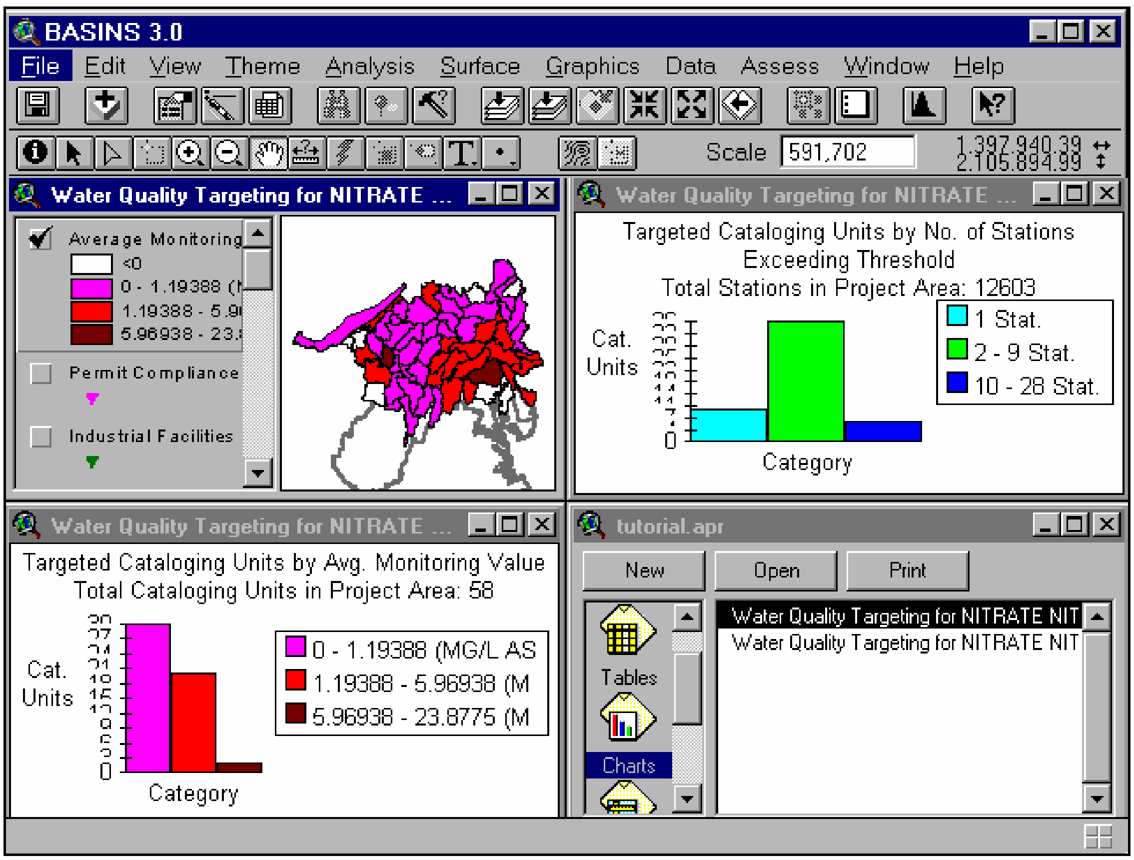


Figure 87 The Target tool of BASINS

Target works at the macro-level of regions and areas with many watersheds. It investigates the monitored data concerning concentrations of pollutant and parameters or the permitted discharges and it ranks the various watersheds, according to 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 showing the distribution of watersheds with respect to the number of stations exceeding the selected threshold value;

❖ A bar chart that summarising the distribution of watersheds with respect to the average monitoring values.

Assess works on an individual watershed or a group of watersheds, which may have been identified as areas of interest in a previous **Target** analysis performed on a regional scale. Similarly to **Target**, **Assess** examines the monitored data on the basis of specified time periods and threshold parameters, however in this case the tool evaluates each monitoring station separately and provides a comparative view of water quality conditions at each station. The results of **Assess** 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, and evaluation of monitoring programs.

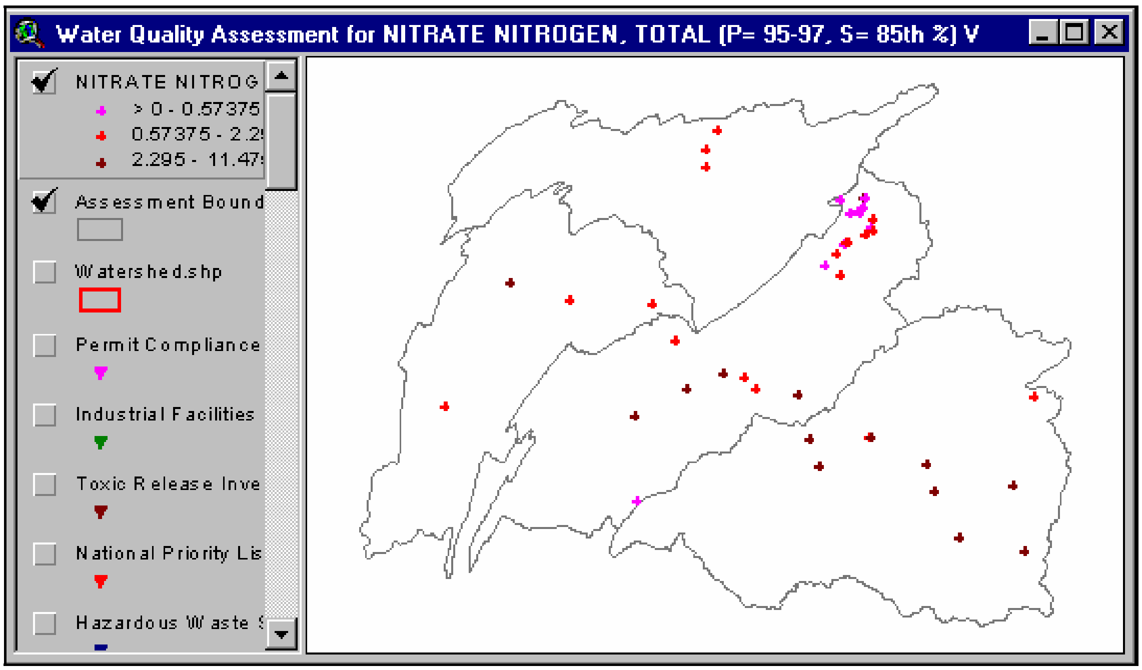


Figure 88 The Assess tool of BASINS

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 location of facilities that have received permits for discharging wastewater 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.

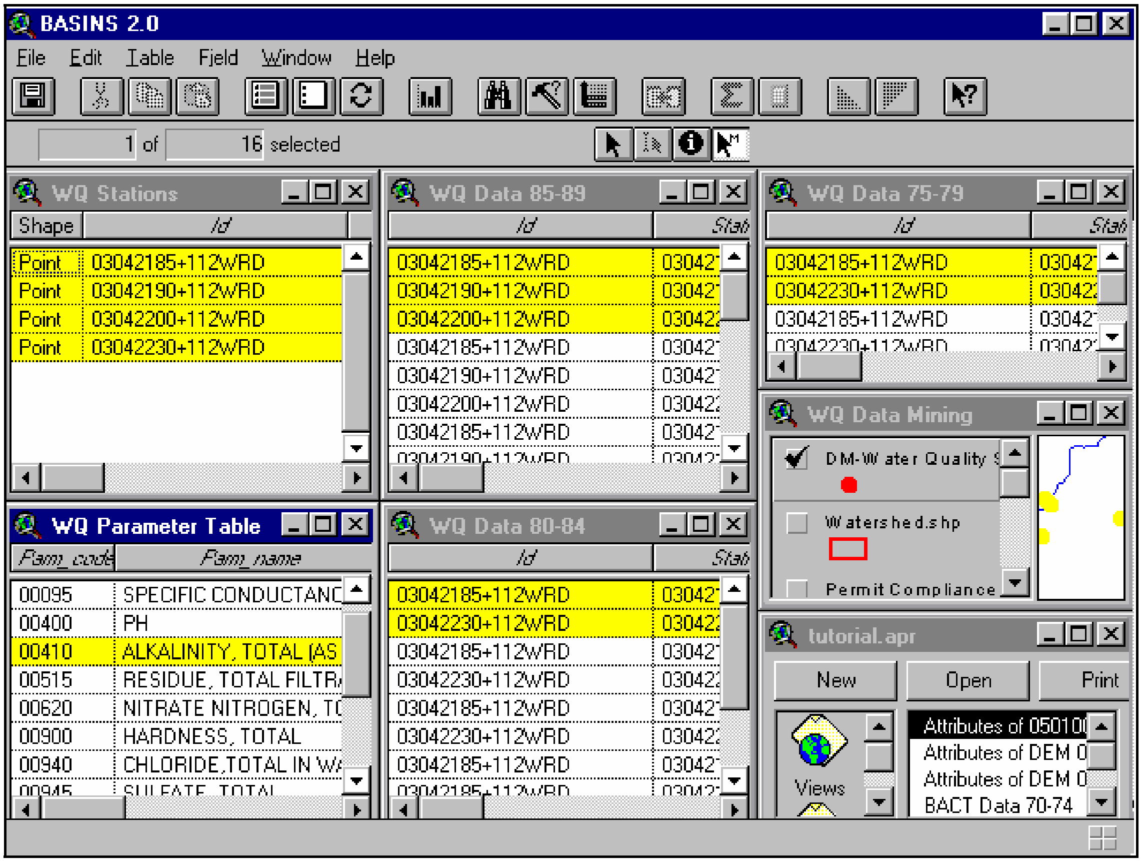


Figure 89 The Data Mining of BASINS

Watershed Delineation tool

The Watershed Delineation Tool permits the division of a watershed into one or more sub-watersheds. 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 HSPF or SWAT models and the Watershed Characterisation Report tools integrated in BASINS.

Watershed Characterisation Reports

BASINS can assist the user to in creating customised maps and tables to summarise the overall conditions 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 quickly identify point sources, evaluate their proximity to major streams and assess 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.

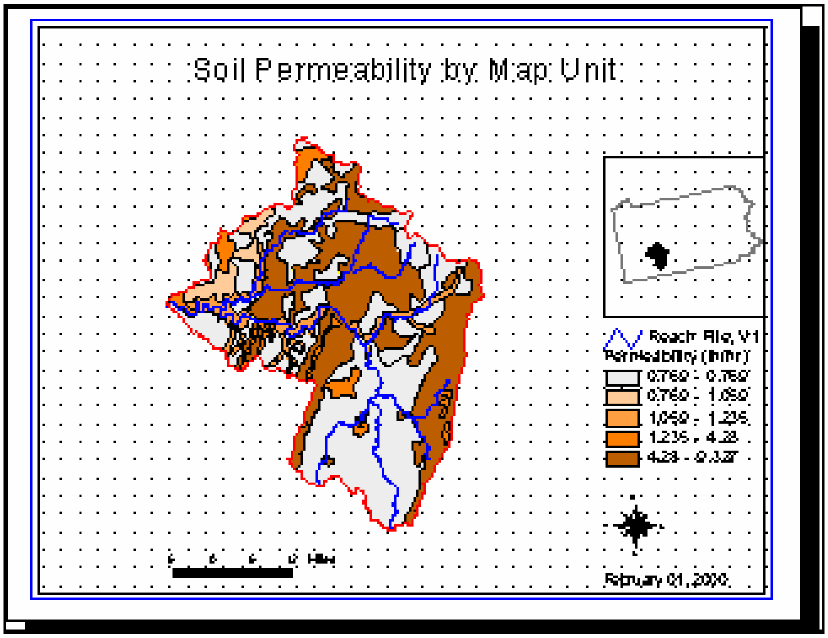


Figure 90 An example of Soil Characteristics Report

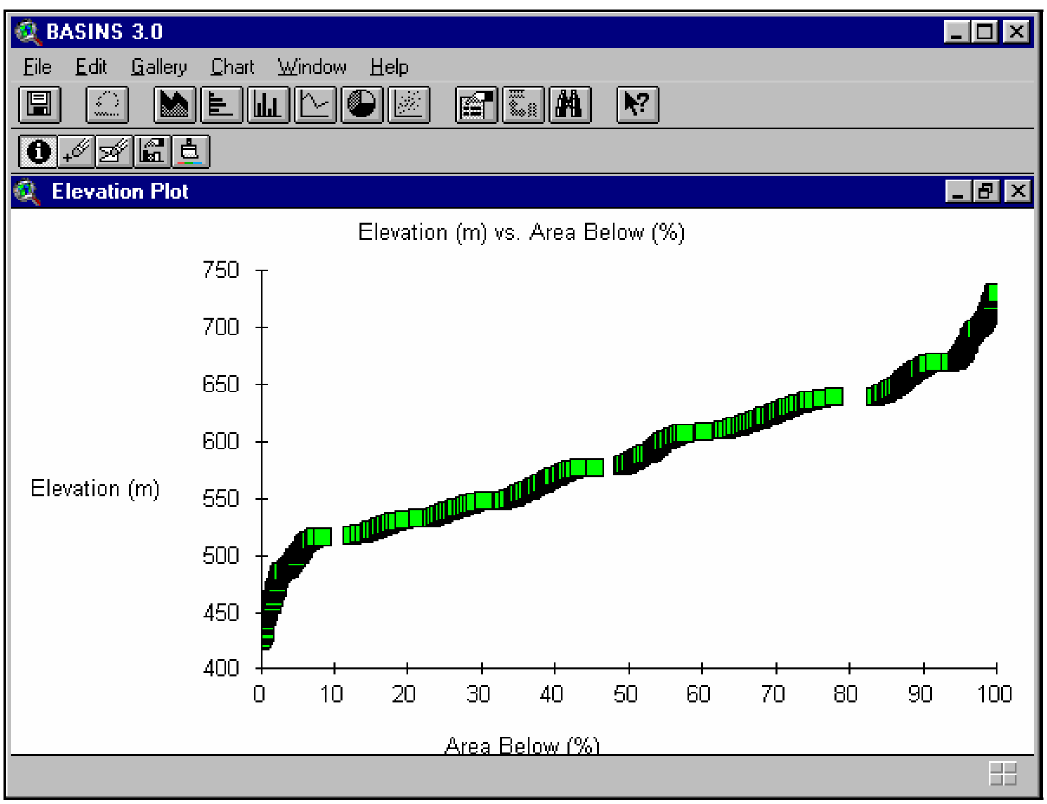


Figure 91 The Hypsometric Curve of the Watershed Topographic Report

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 soil themes to determine the area and the distribution of hydrologic response units of each land-soil category considered in the simulation. 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, in order to evaluate alternative water quality impacts based on changes of 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**. This is used to display large amounts of spatially distributed information in appropriate detail by modifying default colours and the range of values.

Models used in BASINS

The models included 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). A short description of each model is given in the paragraphs that follow.

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

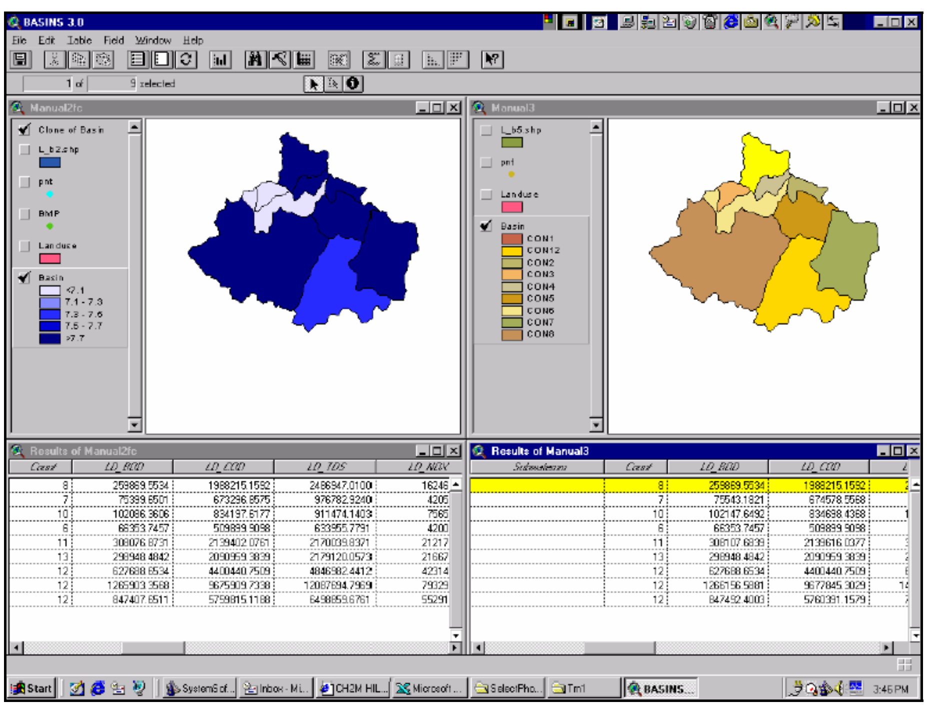


Figure 92 A comparison of two calculations with the View Sessions

Results can be displayed on maps, together with the corresponding tables of values, and in two different spatial scales: the user can visualise the pollutant loads aggregated by watershed, expressed in lb/year, or per unit of watershed area, expressed in lb/acre-year. Additionally, a *View Sessions* option allows to view simultaneously up to three different outputs, resulting from three different calculation sessions, in order to compare different 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 on a daily time step. It is particularly suitable for predicting the 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 for a long time horizon (up to a hundred years). As SWAT describes physical processes associated with water, it requires specific information on meteorological parameters, soil properties, topography, vegetation, and land management practices occurring in the watershed. Moreover, Swat includes five databases concerning specific pollutant loads generated from agricultural practices and municipalities:

- ❖ Land cover-plant growth, containing information about ideal conditions and impact of some stresses on plant growth;
- ❖ Tillage information, useful to simulate the redistribution of nutrients and pesticide that occur in a tillage operation;
- ❖ Pesticides;
- ❖ Fertilisers and related content of nutrients; and
- ❖ 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***;* 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 specific 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 evapo-transpiration, 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 stretches 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. Data required by the model concern hydrologic flows, water quality parameters and meteorological information. The latter includes monitored values of air temperature, atmospheric pressure, wind velocity, net solar radiation and cloud cover, all of which are 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 an extension 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 changes in input data and display of output reports in graphical and tabular form. On the other hand, the definition of input data describes a Scenario that can be evaluated through the simulation results and compared against others. Therefore, GenScn is said to be a Scenario Generator. Moreover, this tool can also be used for visualising observed time series data, for making comparisons with modelled data and for performing statistic analyses.

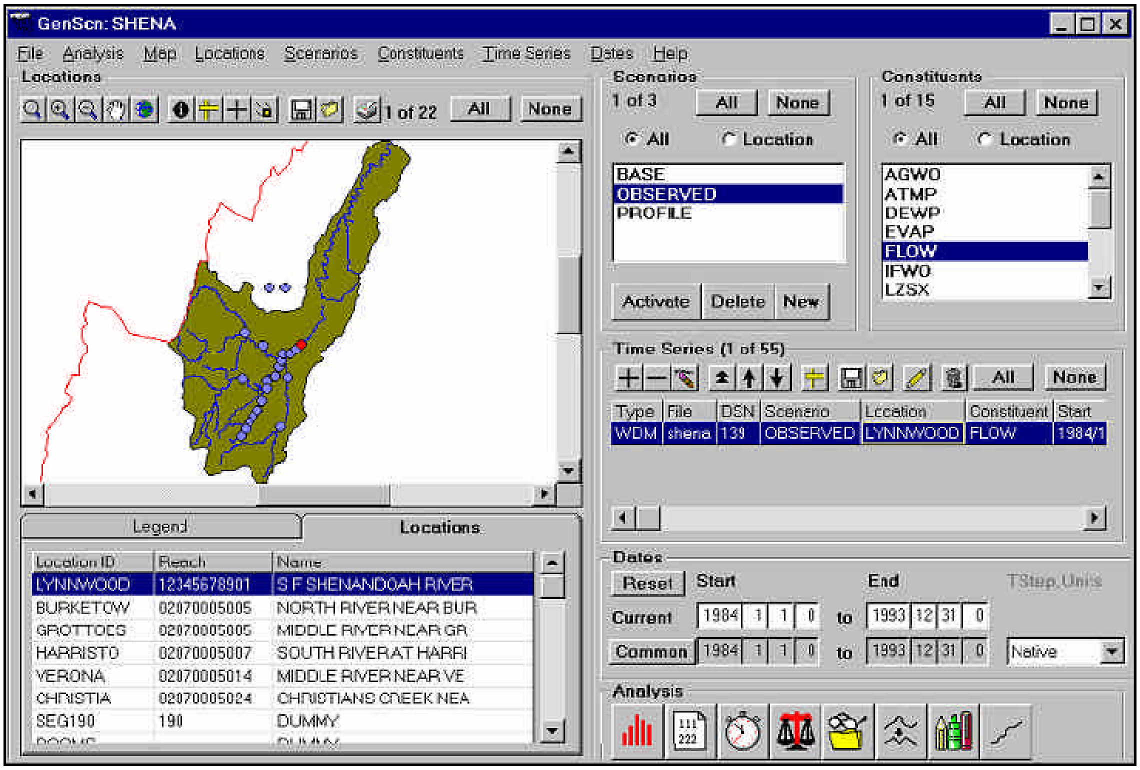


Figure 93 The main form of GenScen Graphical User Interface

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 map of the basin, displaying boundaries and locations to be analysed 2) a toolbar containing map handling commands 3) a table with a legend and summary of information found on the map. A location can be selected both by clicking the corresponding point on the map and by selecting its entry in the table. In both cases entry and point are highlighted;
- ❖ A **scenarios frame,** containing a list of simulated or monitored scenarios available in the project. A preferred scenario for the chosen location can be selected by clicking on it;
- ❖ A **list of items**, named *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**, containing information about available ranges for the currently selected time series and the default time step.
- ❖ The **analysis frame,** containing a toolbar that links to the tools of GenScn for generating and editing various types of plots, tables and statistical text reports useful to compare various data series.

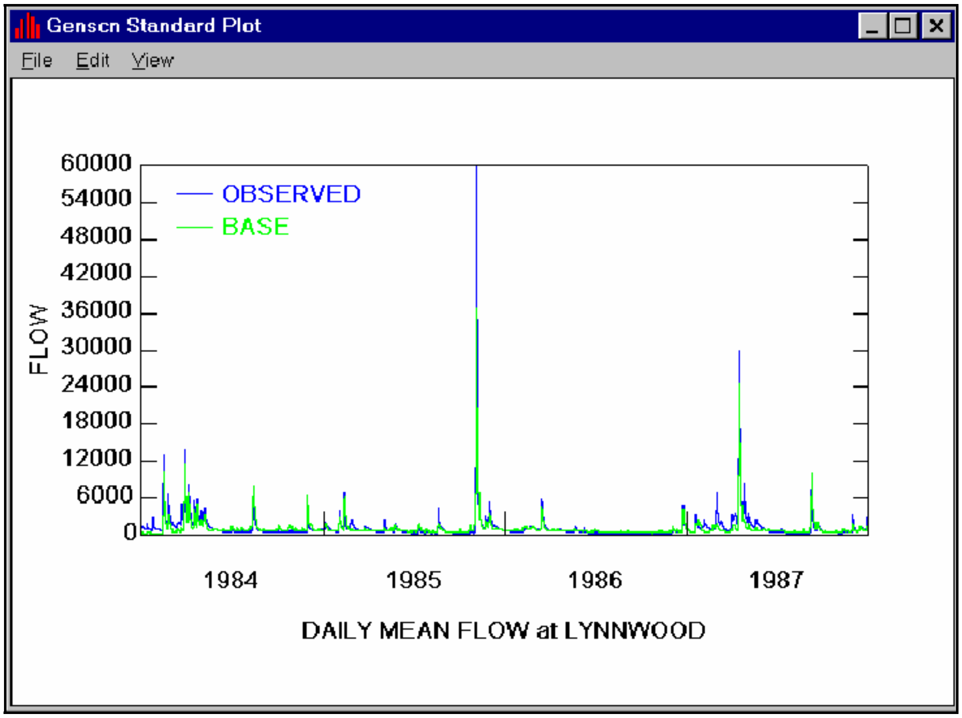


Figure 94 Comparison of time series of flow item in the selected Lynnwood location

Summary of Pros and Cons

BASINS is more environmentally oriented than MIKE BASIN; nonetheless, the physical aspects prevail over a comprehensive analysis and assessment of sustainability that can link policy options to information and analysis in an integrated water management context.

The *GenScn* program allows the management of different scenarios; however the definition of a scenario is quite different from the one required for analysing water stress conditions. In BASINS the word "*scenario*" refers to a set of data series that are model inputs and to the relevant outputs. A scenario is in more general terms 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 interpretation, a scenario should be formed by choosing from predefined climatic or economic scenarios, which consist the exogenous background in the simulation of water quantity and quality and indicator computation. The variables assuming the data values of time series that define a scenario are used by models but are not updated at each time step.

Chapter 14 DSS for Water Resources Planning Based on Environmental Balance

This chapter presents a *Decision Support System for Water Resources Planning based on Environmental Balance*, output of a project recently funded by the Italian Cooperation with Egypt. The project aimed at developing a methodological approach to sustainable water resource planning (Figure 95). The project started at the beginning of 1998 with a one-year inception phase, while the implementation phase ended in August 2001.

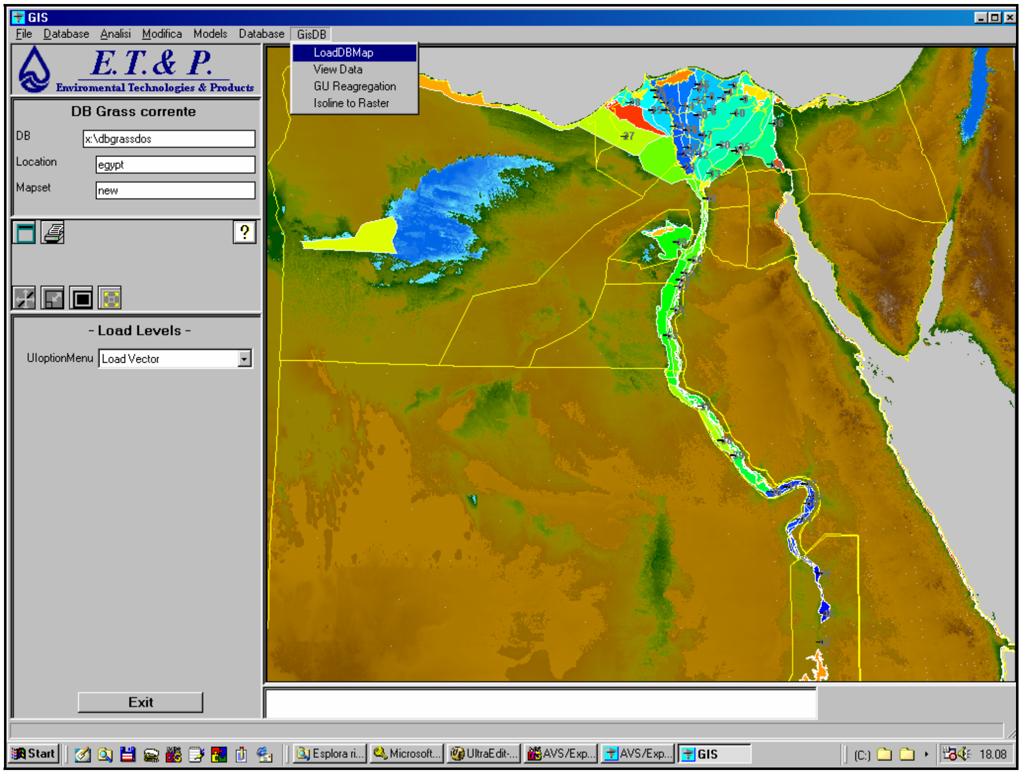


Figure 95 The integration of GIS (GRASS), DB and models under the same DSS structure allows for the automatic preparation of inputs to models and the thematic map viewing of results.

Objectives

The objectives of the project were the development of:

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

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

The project is developed starting from 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, etc.);
- 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 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 (Figure 96). The models are activated by the user through the GUI, which interacts with the Logical Co-ordination and Scheduling Unit (LCSU). Using a set of pre-processors (filters), the LCU is able to prepare 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 permits to use external data and external models results.

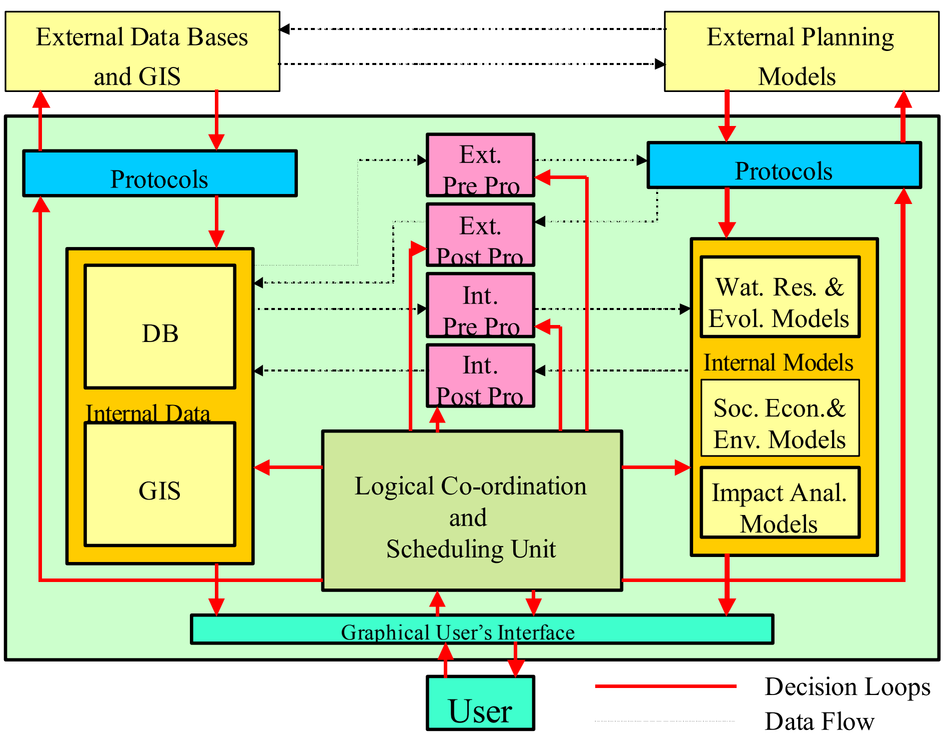


Figure 96 A schematic representation of the system structure

Indicators and Models

The purpose 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 and 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 12) run the different hypotheses over a defined time span (10-20-30 years) using all the available data (Table 13) 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 12 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 13 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			

Summary of Pros and Cons

The Graphical user interface of the DSS outcome of the Italian Cooperation with Egypt has been developed with the AVS/Express software that is also used to manage access and data exchange between the GIS layers, the Database and the models. AVS/Express has also supported the attractive presentation of analysis results in terms of 2D tables and plots. However, it should be noted that its major capabilities, that concern the 3D visualisation of data, have not been exploited within the development phase of the DSS, since this was a step beyond the primary objectives of the project. AVS was chosen from the beginning of the project not only because of the 2D and 3D viewing enhancements and the management of time series data, but also because of the possibility to integrate external software written in different programming languages such as C, C++ and Fortran, and the compatibility with other available types of commercial Database Management Systems. Some less positive aspects of AVS/Express concern the use of its own programming language and the fact that the construction of graphical user interfaces seems to be much more complex and time consuming with respect to Visual Basic. While ESRI ArcView could be programmed only using the Avenue language, AVS/Express has been a valid alternative for DSS buildings. However, the recent release of ESRI ArcGis 8.x has allowed developers to program the ArcView Software in Visual Basic and C++, which permits to link and embed external routines, customise toolbars, and add user-defined extensions that can address specific cases and modelling issues. Furthermore, ArcView is worldwide used and most data is available in the well-accepted and disseminated shape file format.

Chapter 15 A Spatial DSS for the Evaluation of Water Demand and Supply Management Schemes[2]

The following paragraphs present a prototype Spatial Decision Support System for the evaluation of water demand and supply **management schemes**, developed by the National Technical University of Athens . 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. Within the present review, the tool is demonstrated through its application to 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 Figure 97. 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.

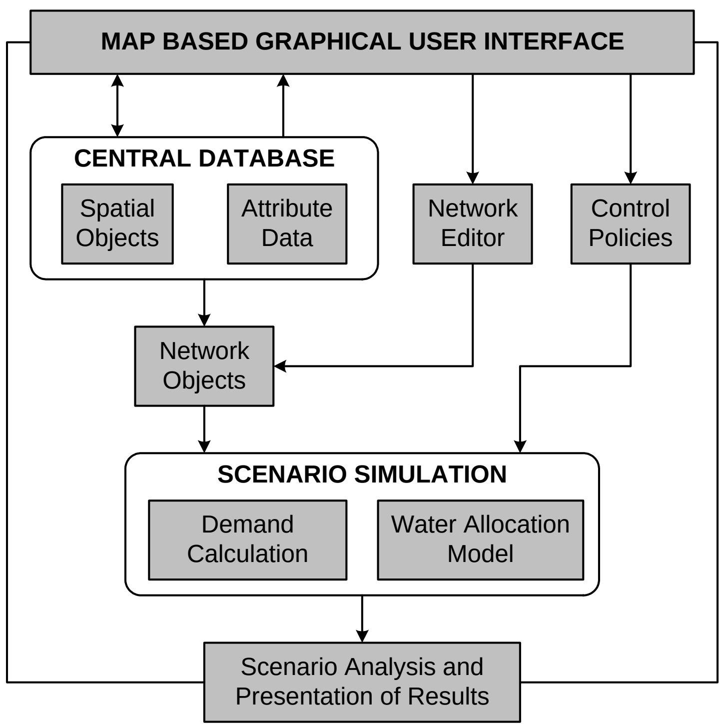


Figure 97 Architecture of the Spatial Decision Support System

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,

[2] Adapted from: E. Manoli, G. Arampatzis, E, Pissias, D. Xenos and D. Assimacopoulos. Water demand and supply analysis using a spatial decision support system. Global NEST: The International Journal, Vol. 3 (3), 2001, pp. 199-209.

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, and can then be planned, simulated and evaluated. Results can support decision-makers in undertaking rational actions with respect to specific objectives.

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 Figure 98. 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 (cartographic 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.

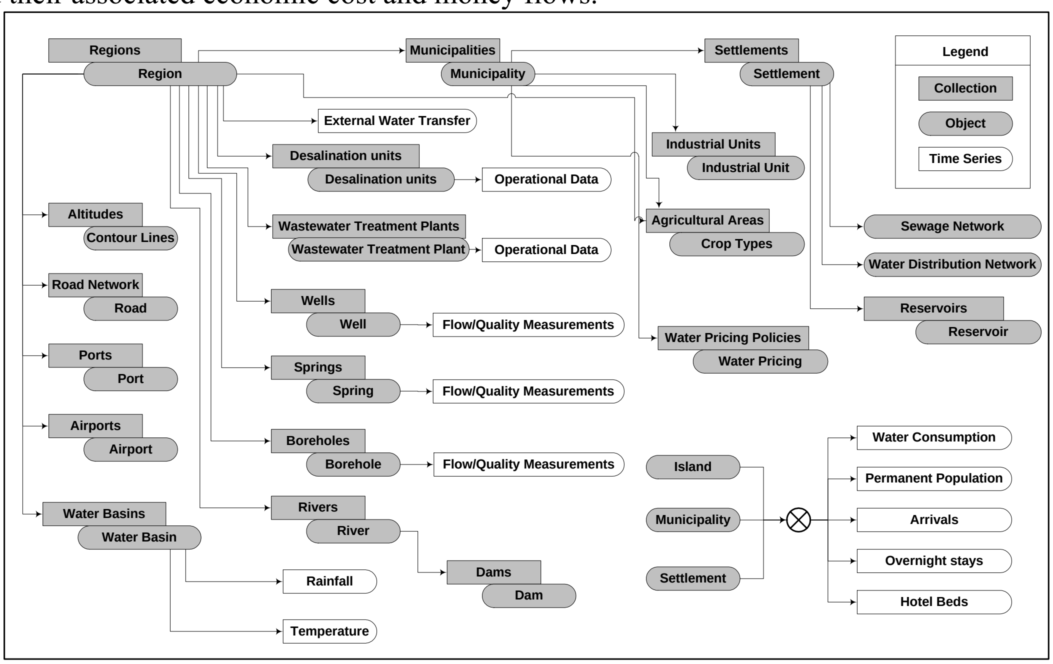


Figure 98 Central database object model and attribute data

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

In this Spatial Decision Support System, water allocation is achieved through a simulation model. A network representation of the hydrological basin is derived from the database (Figure 99). **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 manufactured 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.

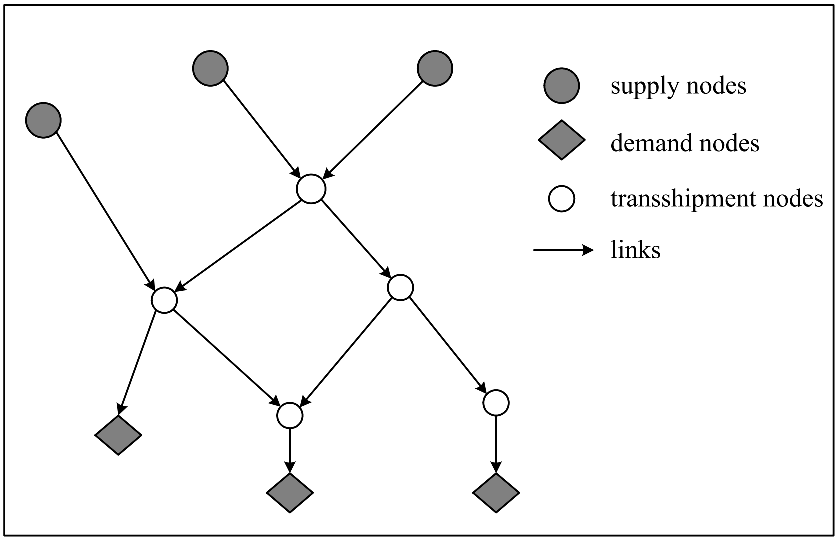


Figure 99 Network representation of a water resource system

Each node *i* can be classified into one of the following three categories:

- **Supply** node, which is characterized by a positive monthly supply rate s_i;
- **Demand** node, which is characterized by a monthly demand rate d_i, and
- **Transhipment** node.

Two characteristic variables are introduced for each link *j*: the **link capacity** c_j that represents the maximum monthly flows allowed (unbounded links can be defined by assigning a sufficiently large capacity), and 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 **minimises the water shortage** on all demand nodes:

$$\text{minimize} \quad \sum_{all\ demand\ nodes\ i} \left(d_i - \sum_{all\ incoming\ links\ j} f_j \right) \tag{69}$$

subject to the following constraints:

- **Supply constraints** associated with all supply nodes:

$$\sum_{\text{all outcoming links } j} f_j - \sum_{\text{all incoming links } j} f_j \le s_i \tag{70}$$

- **Demand constraints** associated with all demand nodes:

$$\sum_{\text{all incoming links } j} f_j - \sum_{\text{all outcoming links } j} f_j \le d_i \tag{71}$$

- **Flow conservation constraints** associated with all transhipment nodes:

$$\sum_{\text{all outcoming links } j} f_j - \sum_{\text{all incoming links } j} f_j = 0 \tag{72}$$

- **Capacity constraints** associated with all links:

$$0 \le f_j \le c_j \tag{73}$$

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 positive link flows f_j, satisfying the conditions that no link's flow is greater than the link's capacity c_j, Eq. (73), and that the total flow into each internal node is equal to the total flow out of that node, Eq. (32). 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. (69) - (73)) is reduced to an equivalent maxflow problem using the following transformations:

- 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 (Dolam and Aldous, 1993; Sedgewick, 2002).

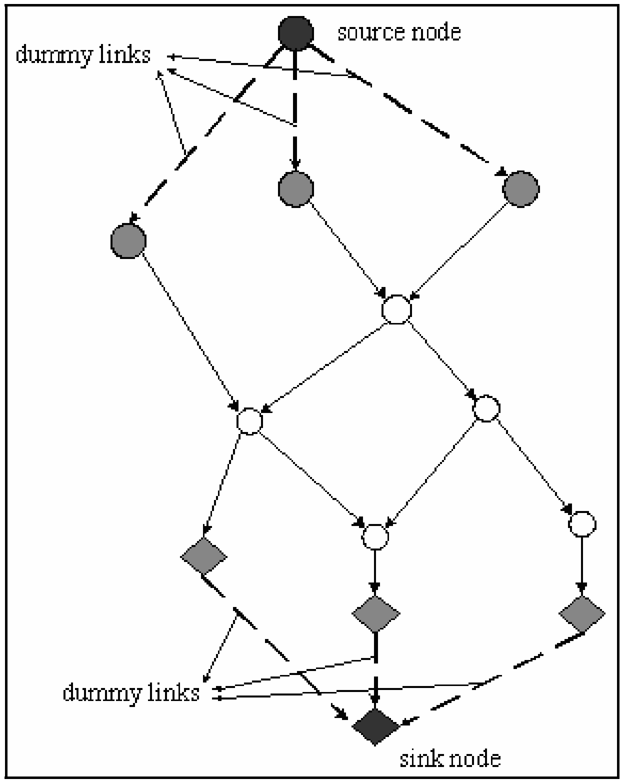


Figure 100 Network transformations

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 (Figure 101) 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 km^2. 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 20,220 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.

Urban water consumption for the entire island in the year 2000 was about 900,000 m^3 of which 25% was allocated for tourism activities. Irrigation withdrawals for the same period were estimated at 1,200,000 m^3. Natural water resources are limited with scarcity problems being more acute during the arid summer period. With low rainfall (approximately 400 mm/year) 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.

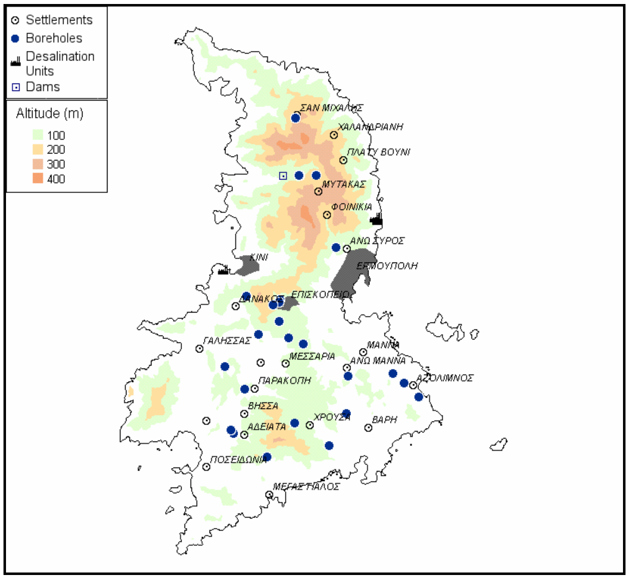


Figure 101 Syros island water resources

Water demand analysis and supply requirements estimation

The disaggregation of water use sectors derived from the database is presented in Figure 102. 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 14. Estimation of irrigation water needs was based on data from the 2000 agricultural census and consumption rates for the most important crops.

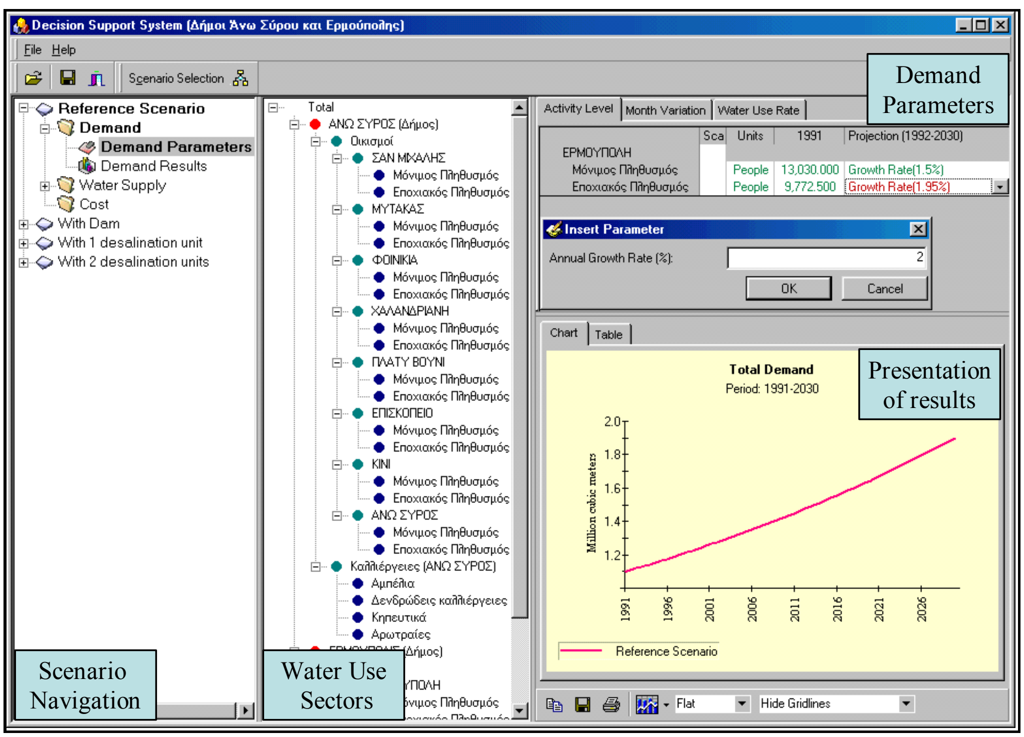


Figure 102 Demand parameters and estimation modules

Table 14 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 103 presents the annual water demand for A. Syros and Ermoupolis agglomerations while Figure 104 depicts the monthly variation of water demand for irrigation and domestic use as it is estimated for permanent and seasonal population needs, in 2030.

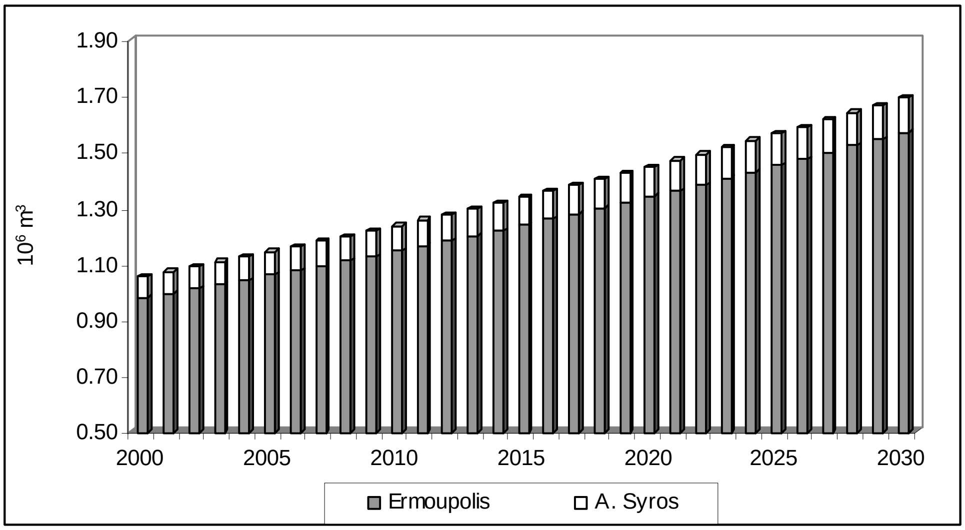


Figure 103 Annual water demand for A. Syros and Ermoupolis

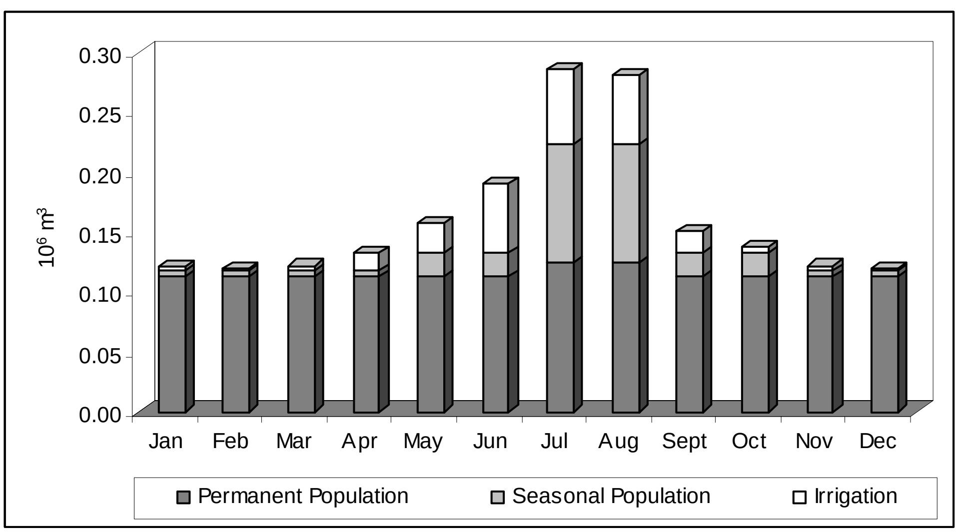


Figure 104 The monthly demand in 2030

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 (Figure 105). 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.

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 15.

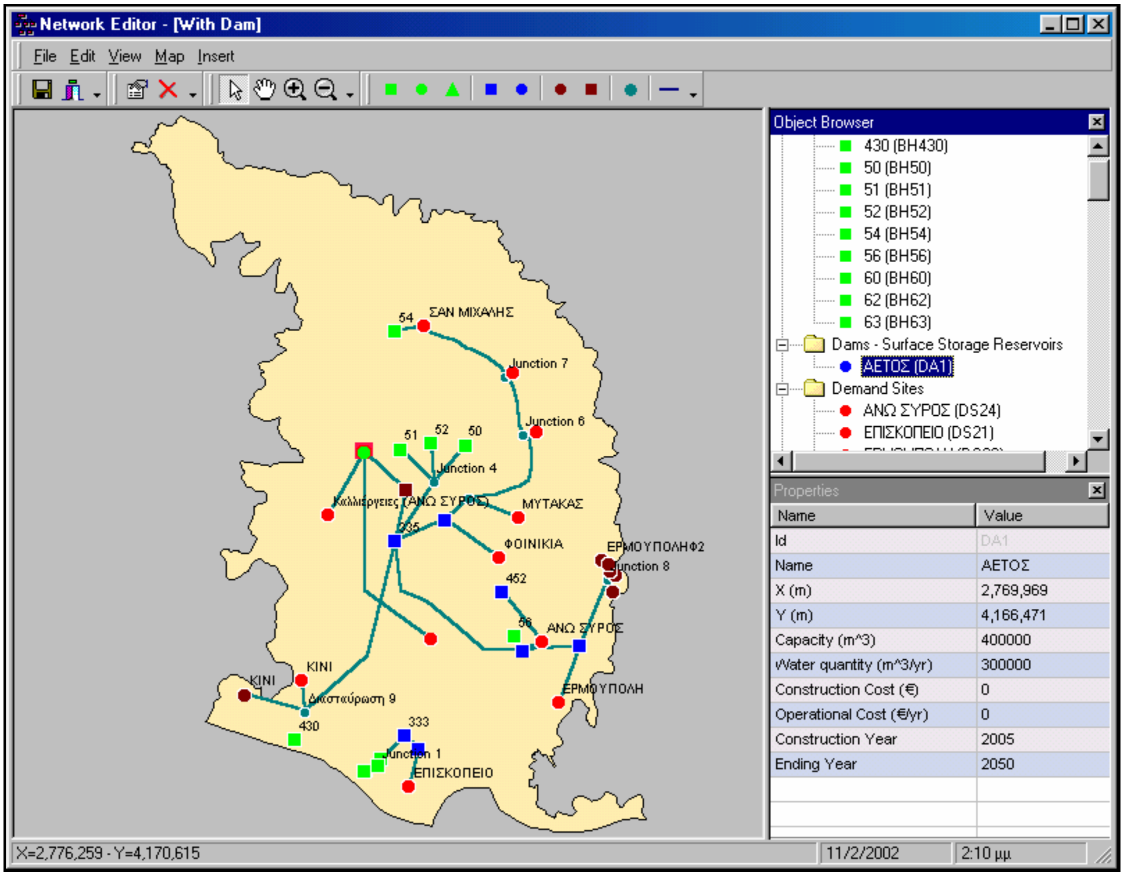


Figure 105 Network modifying module

Table 15 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 m^3 and a maximum annual withdrawal of 300,000 m^3, it should primarily meet the domestic demand of A. Syros and Ermoupolis and secondarily irrigation demand. The proposed infrastructure is presented in Figure 105 and Figure 106.

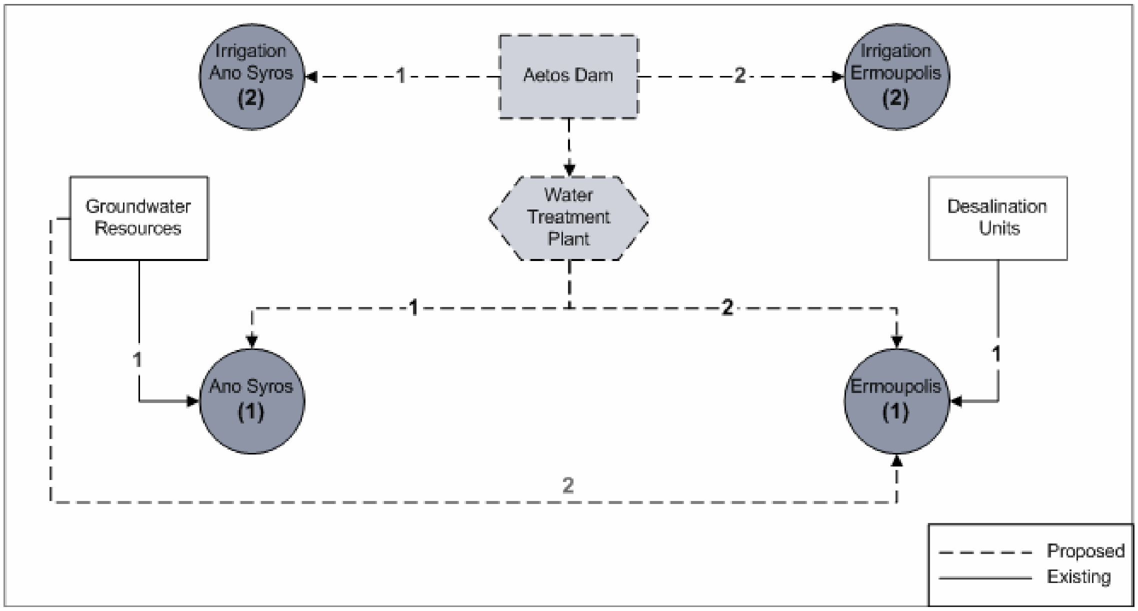


Figure 106 Demand site priorities and network configuration for Aetos dam construction

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 m^3 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 (Figure 107).

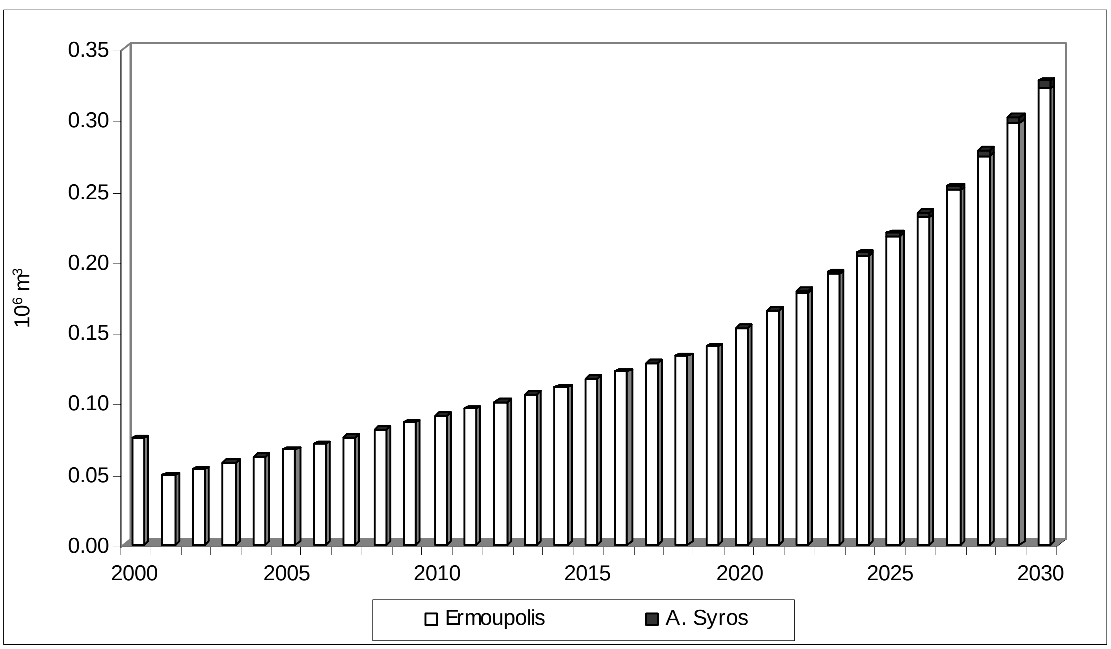


Figure 107 Evaluation of existing infrastructure for Ermoupolis and A. Syros

The water shortage for the scenario with the Aetos dam construction is presented in Figure 108. 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 withdrawed 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 Figure 108, 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 m^3/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 m^3/d in order to meet water needs up to the year 2030.

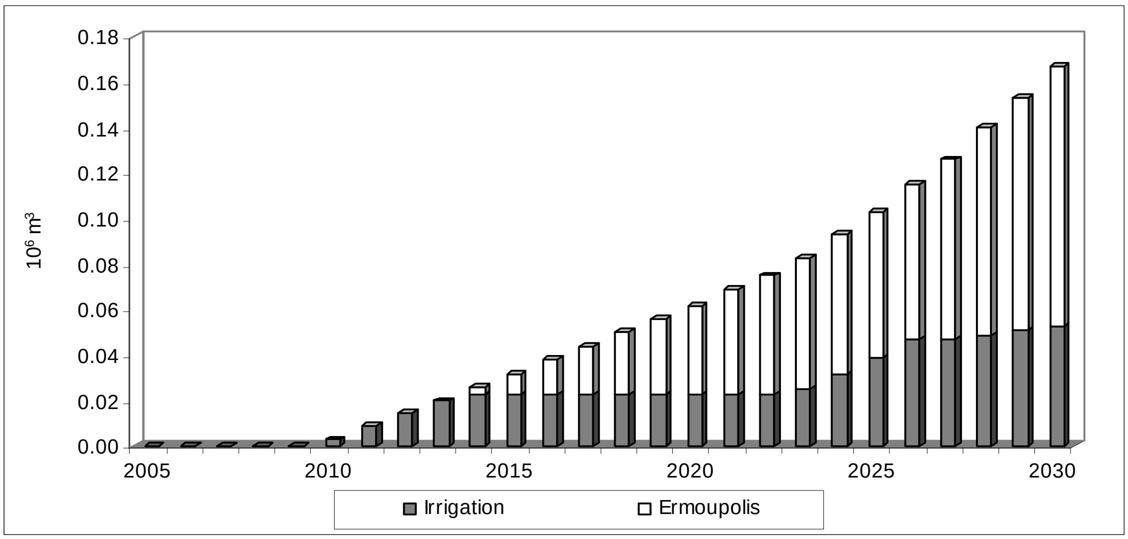


Figure 108 Water shortage in domestic and irrigation sectors after dam construction

Summary of Pros and Cons

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 and demand nodes. This, along with the use of demand priorities and supply preferences, emphases an approach that can be useful in analysing and solving possible water conflicts among different uses; it can also pinpoint water shortages which may occur in the water resource system. Each particular water resource situation corresponds to a certain scenario and each alternative scenario may be the expression of different planning and management decisions.

Chapter 16 Integrated Quantity and Quality Model – (IQQM)

The Integrated Quality and Quantity Model (IQQM) is a hydrologic modelling tool aiming at simulating river systems and at supporting 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, and
- data retrieval and utilities.

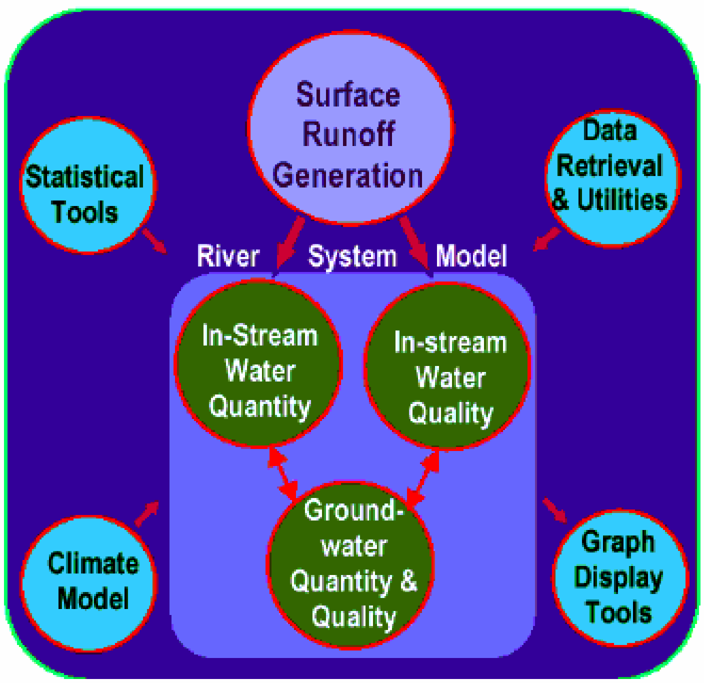


Figure 109 Main IQQM Components

Graphical Interface and Models

The graphical user interface starts with the **Function Menu Window** (FMW) that gives access to the main IQQM 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 network diagram drawing, a GIS map of the basin can be imported into the user interface from an external GIS application. Moreover, types of nodes and links can be chosen from a dedicated palette. Nodes considered can, for example, stand for reservoirs, irrigated areas, municipalities, wetlands, and industries.

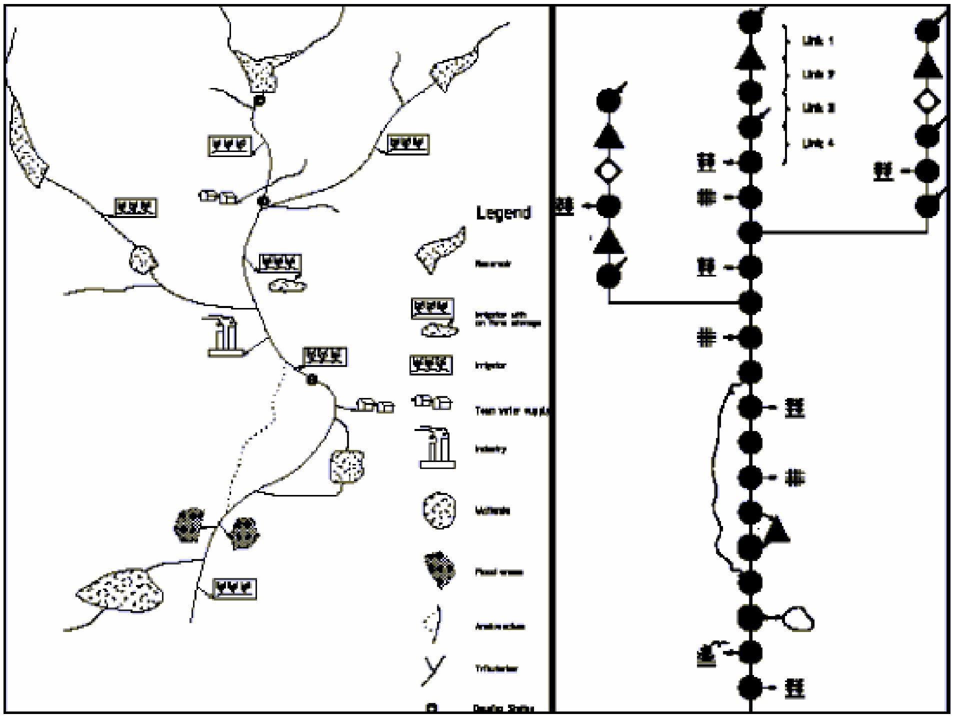


Figure 110 Representation of a typical river system in IQQM

The **River System Model** consists of the two sub-modules *In-stream Water Quantity* and *In-stream Water Quality*. The first concerns flow routing, reservoir operations, assessment of water resource availability, 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 storage operation. The *In-stream Water Quantity – Reservoir Module* is used 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 can simulate 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 used to consider all the processes driving the agricultural needs, such as precipitation, evapotranspiration, water harvesting and re-use, infiltration and planting decisions and to calculate the relevant water demands. Features modelled by the irrigation module include:

- soil moisture accounting,
- different crop types,
- simulation of 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,
- simulation of water ordering and usage, taking into account on-farm storages where those occur; distribution losses, local runoff,
- detailed modelling of on-farm storage operation, and
- 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 adapted to use standard IQQM file input and output formats. The calibration of parameters has also been improved. The following figure presents a schematisation of the physical phenomena studied by the models.

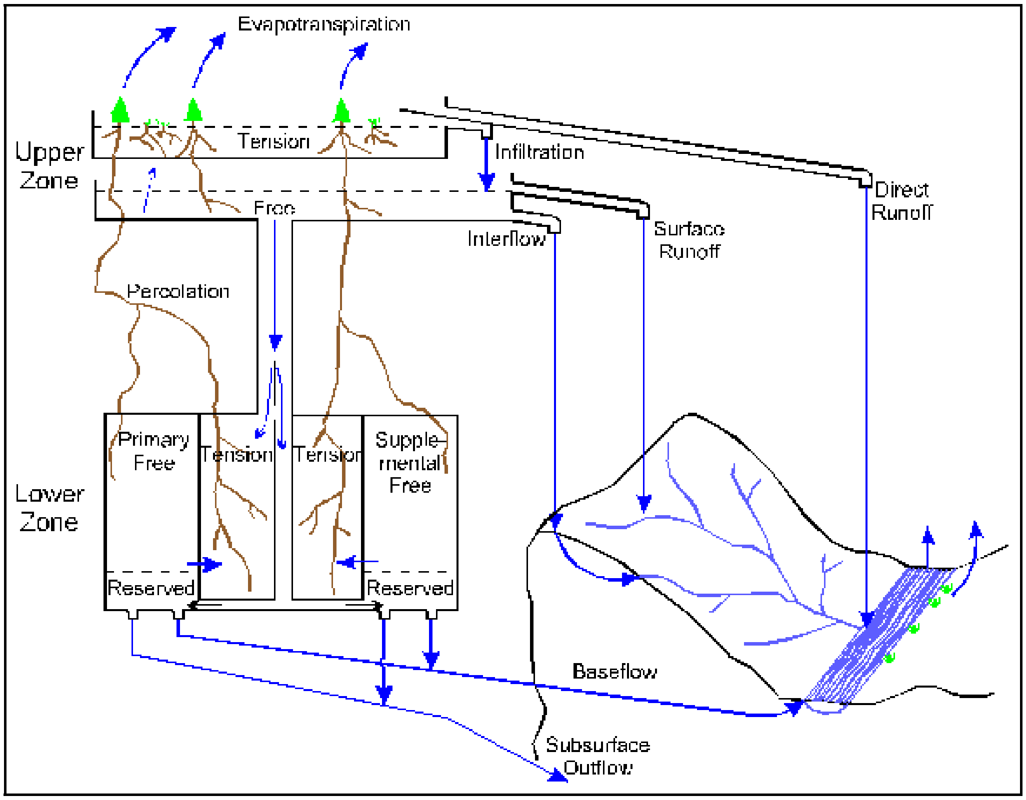


Figure 111 Schematisation of the physical phenomena studied within the Sacramento Model

The **Gate Operation model** simulates extreme flood behaviour in gated storages with the aim of minimising flood discharges downstream the dam without endangering it. The model also 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 in different types of graphs (e.g. continuous line graphs, histograms, cumulative and frequency curves). A specific toolbar supports the building of graphical displays and customisation of graphs. 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.

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

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

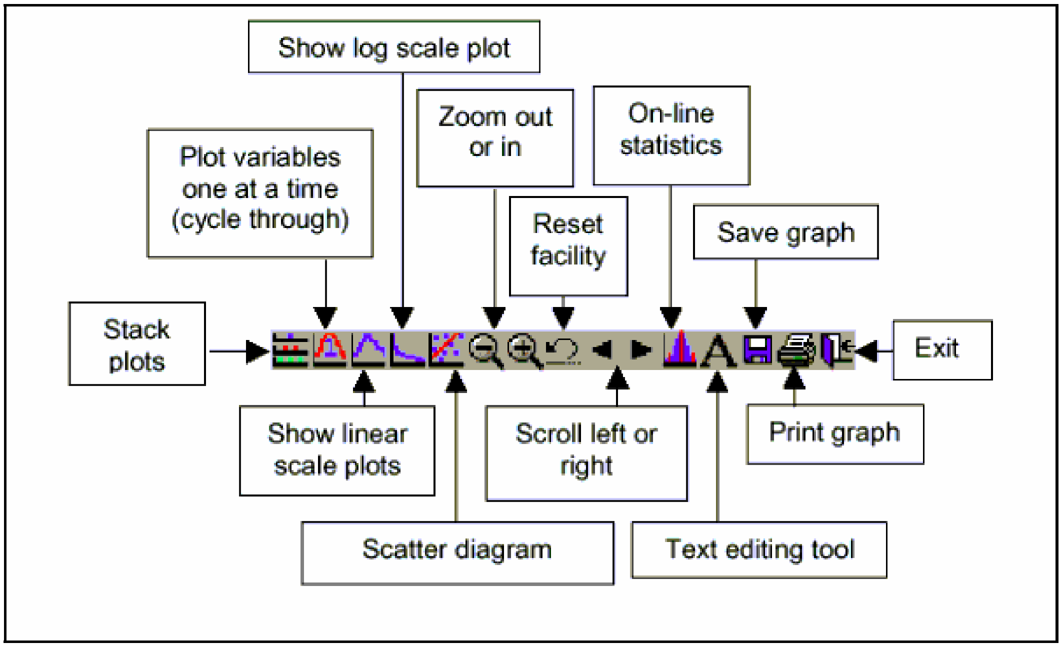


Figure 112 Graphical display toolbar for all plot types

Summary of Pros and Cons

IQQM allows the representation of the river system in node and link objects; however those are not geographically referenced. 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, and therefore lacks the related useful capabilities of data management and geo-referenced display. It also does not incorporate scenario management or conceptual scenario definition.

Chapter 17 Ensis

ENSIS stands for “ENvironmental Surveillance and Information System”. It is a tool for the environmental monitoring and protection, and consists of two main Decision Support Systems, **WaterQuis** and **AirQuis**. WaterQuis is concerned with water resources quality and has been developed by NIVA, the Norwegian Institute for Water Research, while AirQuis is concerned with air quality and pollution levels and has been developed by NILU, the Norwegian Institute for Air Research. Both Norwegian Institutes have been supported by Norgit, an agency developing information systems for governmental organisations, research institutes and private (sector) clients. Particular emphasis is given here to WaterQuis DSS; however it should be noted that both systems are included in the ENSIS package, use the same basic features; moreover, 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 that are all integrated in the system. The GIS is programmed with MapObjects from ESRI, which makes it compatible with ArcView and ArcINFO.

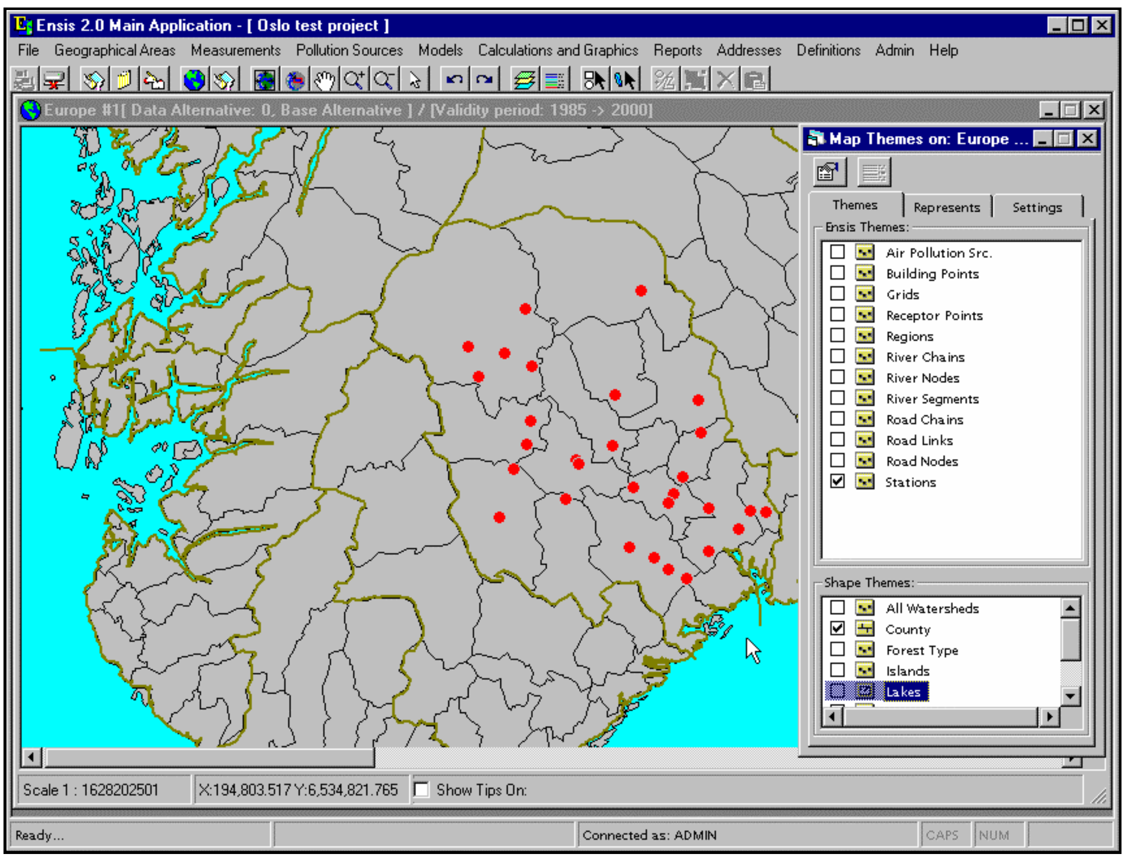


Figure 113 Ensis GIS

The GIS layers permit 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 refer to (e.g. lakes, watersheds, counties). Moreover, the data associated to each displayed element can be searched and accessed directly via the GIS interface. As an alternative, users can access the integrated Oracle Database and retrieve information by simply choosing the more suitable alphanumerical criteria among those concerning geographical location, time period of measurements, type of industry etc. The majority of data is organised in **time series**: those could be water quality measurements at determined river stations, each of them described by more detailed information such as instrument on the station, sampling method, time step, and analysis method. All those data can be entered or just viewed in relevant dialog boxes and menus.

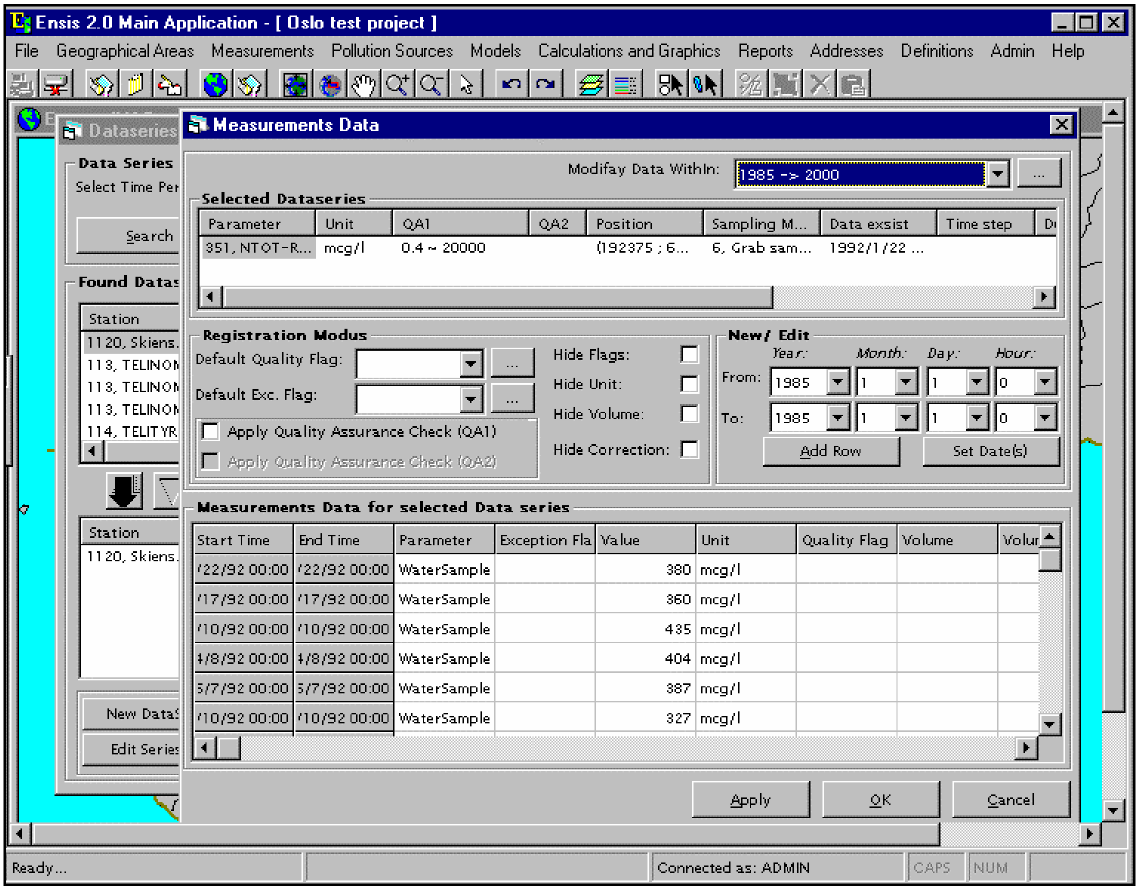


Figure 114 Viewing the measurement values

Time-series can be plotted by the **ENSIS Internal Graphics Utility**. Interesting and helpful capabilities are the ability to simultaneously display different plotted series, in order to facilitate comparison, and to export data series to Windows software like Excel. The latter operation can be performed by one dedicated ENSIS routine or by a “copy & paste” operation from the ENSIS time series graph to Excel Worksheets.

The ENSIS system has a **report generator** that is helpful in presenting analysis and results in an easy and clear manner and in disseminating them on the Internet. The standard report of ENSIS shows the water quality distribution in the studied area 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 the report the aspect of a water quality classification.

The ENSIS system can encapsulate programs for environmental modelling and can 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 integrates **atmospheric dispersion models**, covering air pollution on all scales in the urban environment.

Further, WaterQuis-specific features are: the definition and recording 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.

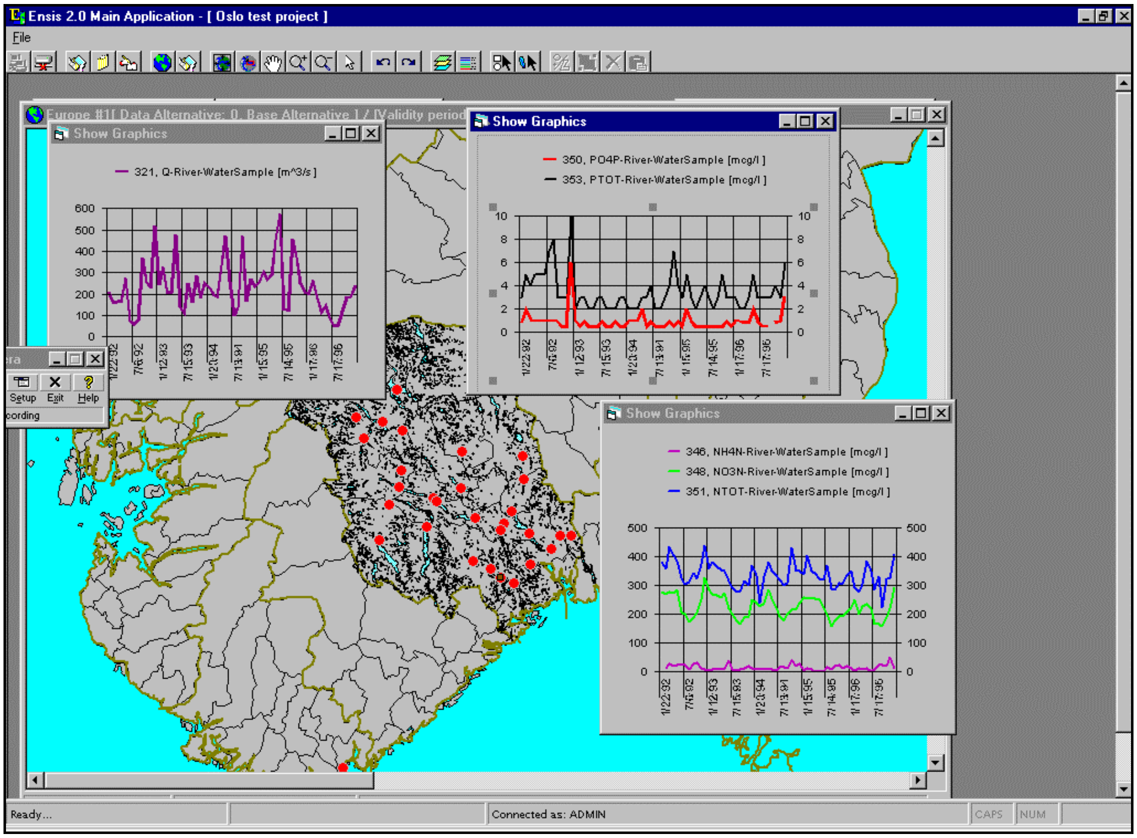


Figure 115 Comparison of time-series

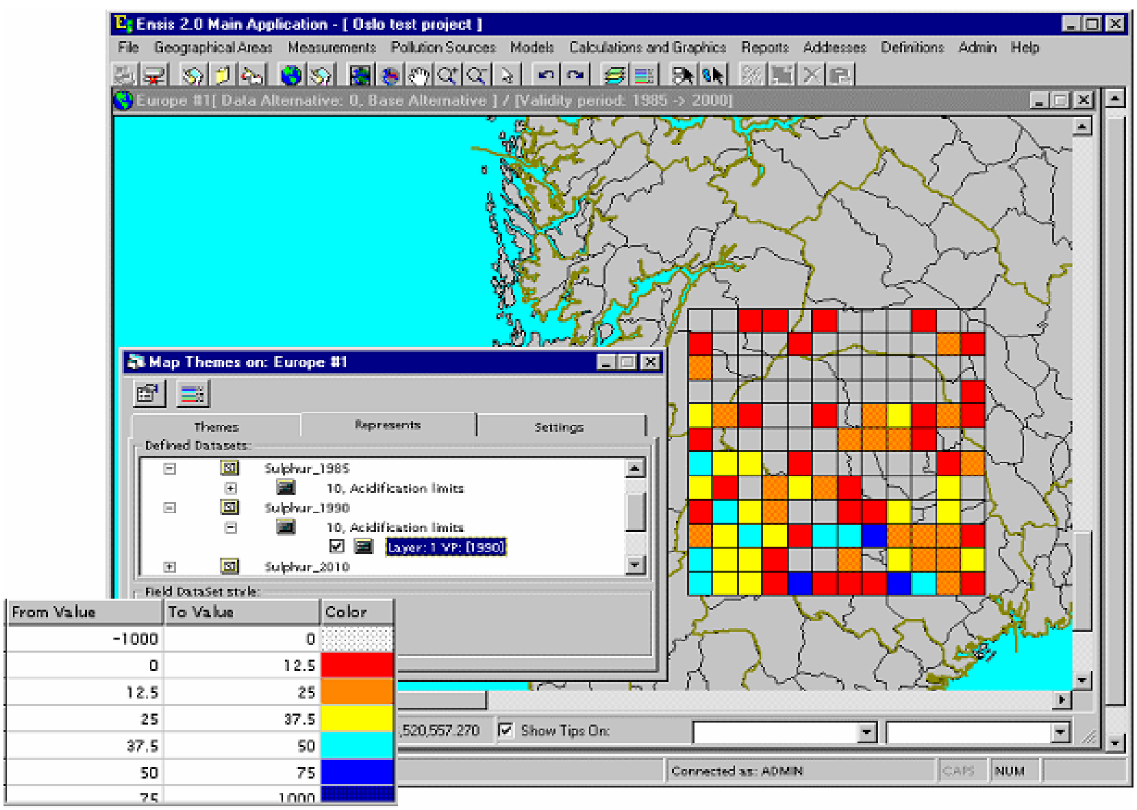


Figure 116 Acidification limits displayed on GIS layers

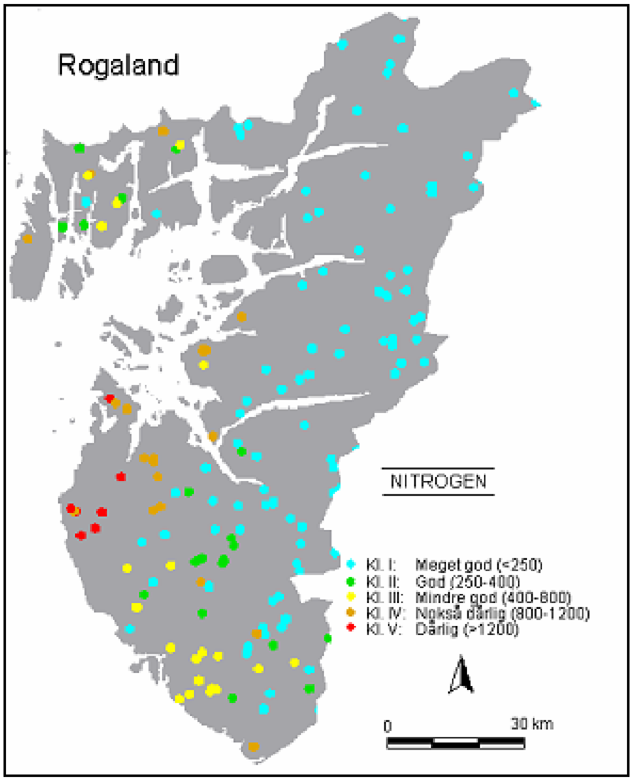


Figure 117 Classification of water quality in Rogaland

Summary of Pros and Cons

As derived 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. Although ENSIS embeds water quality models for calculation of pollution loads and proper routines showing their output, the package does not provide capabilities for the management and comparison of alternative simulation scenarios.

Moreover, water allocation in the area under surveillance is not considered, and water availability and demand evaluation are not included. Those aspects are considered of fundamental importance in identifying possible deficit conditions and building appropriate strategies to face them.

Chapter 18 Realm

The REsource ALlocation Model is a package for the **simulation of water supply systems**, developed in 1997 by the Victoria University of Technology and the 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 simpl,e as well as large and complex water supply systems, both under drought and normal conditions with high stream flows. It can be used to study different water resource options, as for example new operating rules or physical system modifications and graphically compare them.

The water allocation is performed by a fast network linear programming algorithm that runs at each simulation time step. This algorithm **optimises** water allocation on the basis of the carrier costs: if a demand node is connected to the supply node through multiple different carriers, the one with the lowest cost is used 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 needed to meet the demand, always following the order mentioned above.

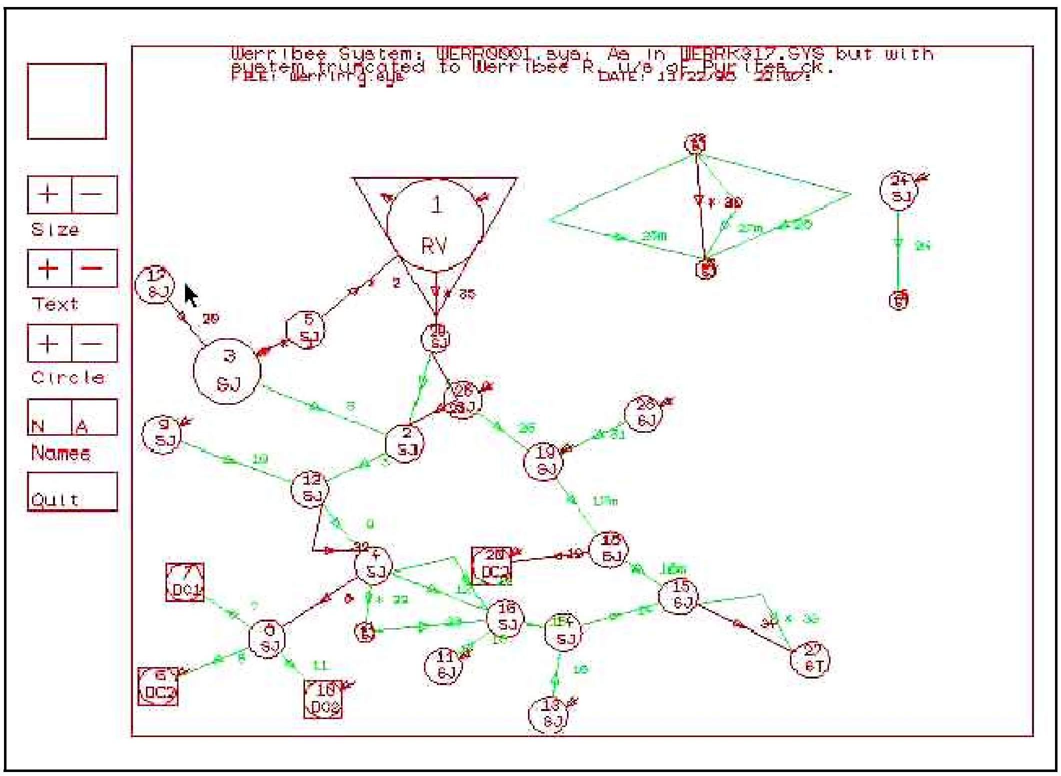


Figure 118 REALM Screen Plot [3]

REALM comprises a program manager, a graphical editor, a group of routines for listing, plotting and text editing, and the simulation core. It uses 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. These data can be organised on a monthly, weekly or daily basis. Stream flows also include meteorological variables, such as temperature and rainfall. Water demand consists of time series data specific

3 The original background colour of some of the REALM screenshots here presented is black.

to determined demand zones in the area under study 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 mentioned as "*carriers*") and their operating rules.

The system network can be drawn just by choosing specific types of node or carrier from a palette of buttons at the left and at the bottom of the System Network Screen and positioning those to its centre with a simple "drag & drop" operation. The eight node types considered are: Reservoir, Demand, Irrigation demand, Diversion, Pipe junction, Stream junction, Groundwater, Stream terminator. Later the entire network can be properly viewed and zoomed with the **Network Plotting utility**.

The user can introduce the carriers connecting the demand nodes to suppliers with the same drag & drop procedure. Carriers can be RIV type, representing river sections, and PIP type, representing pipes, aqueducts and general carriers that are not river sections. The user can access and introduce each carrier's characteristics though the "pipe-river editing" window. Attributes include: cost or penalty, used in the 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. Carrier capacity can be expressed as a function of many system variables and edited by the user from a dedicated menu.

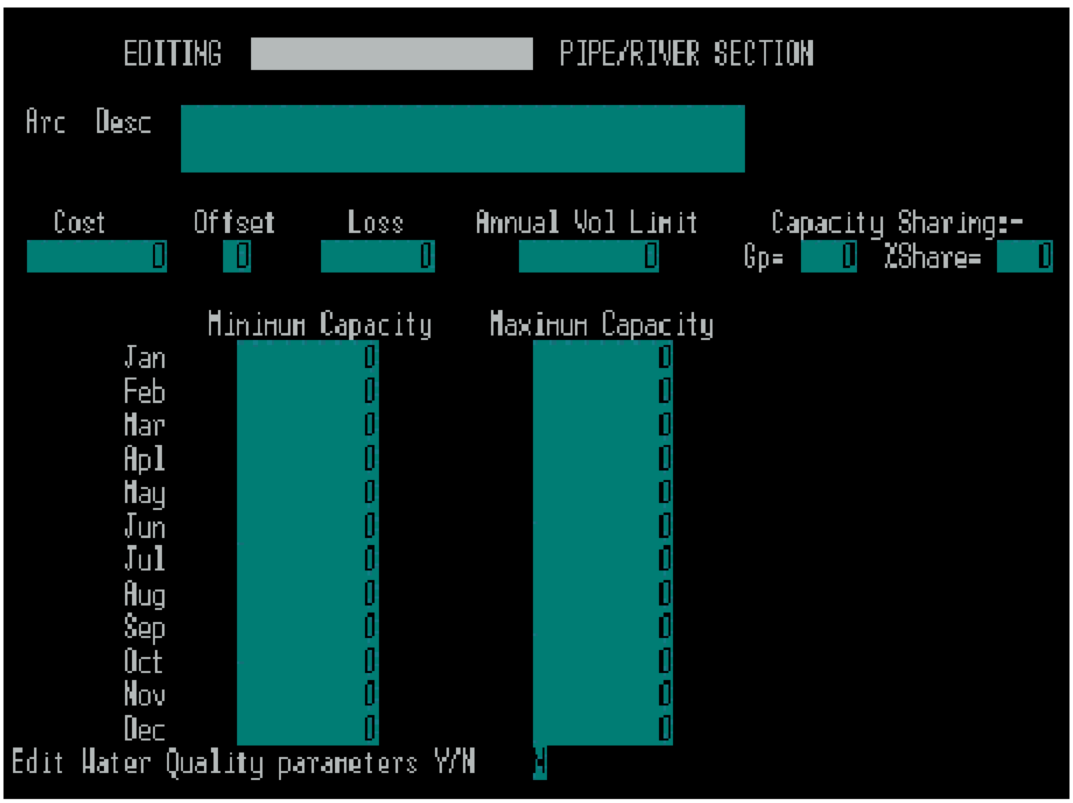


Figure 119 Editing Capacity Type 1 Pipe/River Section Menu

REALM manages the periods of low storage and stream flow through the *demand restriction curves*; those determine the manner with which each demand is restricted and the degree of severity of this restriction. The package considers two types of demand restrictions, namely urban restrictions, applied 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 carriers of the system network from a list and highlight them in red. This can be very helpful in finding specific nodes and carriers in large networks.

Before running the water allocation simulation, the user has to define the "*simulation scenario*". In REALM the scenario refers to the set of run-time parameters such as simulation period, inputs of stream flows and demand, initial reservoir volumes, initial irrigation deliveries, water quality initialisation data and output options. The definition of parameters is conducted through the relevant dialog windows of the REALM setup program.

Figure 120 Restriction Parameters for Irrigation Demand Group Menu

REALM can generate several outputs, which are grouped into different categories (Table 16)

Table 16 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 that can be used to perform basic processing of input-output data such as **graphical plotting**, **data ranking** from highest to lowest value, **statistics computation** (total, mean, minimum and maximum value, standard deviation etc).

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

Summary of Pros and Cons

REALM has a network editor that allows the user to schematise the system of water users; however, the elements of the network are not geo-referenced, since the tool does not integrate GIS software and GIS maps cannot be imported, even to be used as a network background.

The economic aspect of water resources is reduced to the simple estimation of costs for conveying water through the carriers. As mentioned, these costs are actually the parameter that defines the priority of water uses in the water allocation algorithm.

As the main task of REALM is water allocation, impact analysis and multi-criteria evaluation are not available. Moreover, scenarios are simply defined as a set of simulation parameters and initial conditions to be used within the allocation process, and are not conceptualised as exogenous variables affecting Driving Forces.

Chapter 19 Mulino

The acronym MULINO stands for "*MULti-sectoral, INtegrated 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 started in January 2001 and has a duration of three years. This review concerns the first of the three planned intermediate versions of the tool. 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.

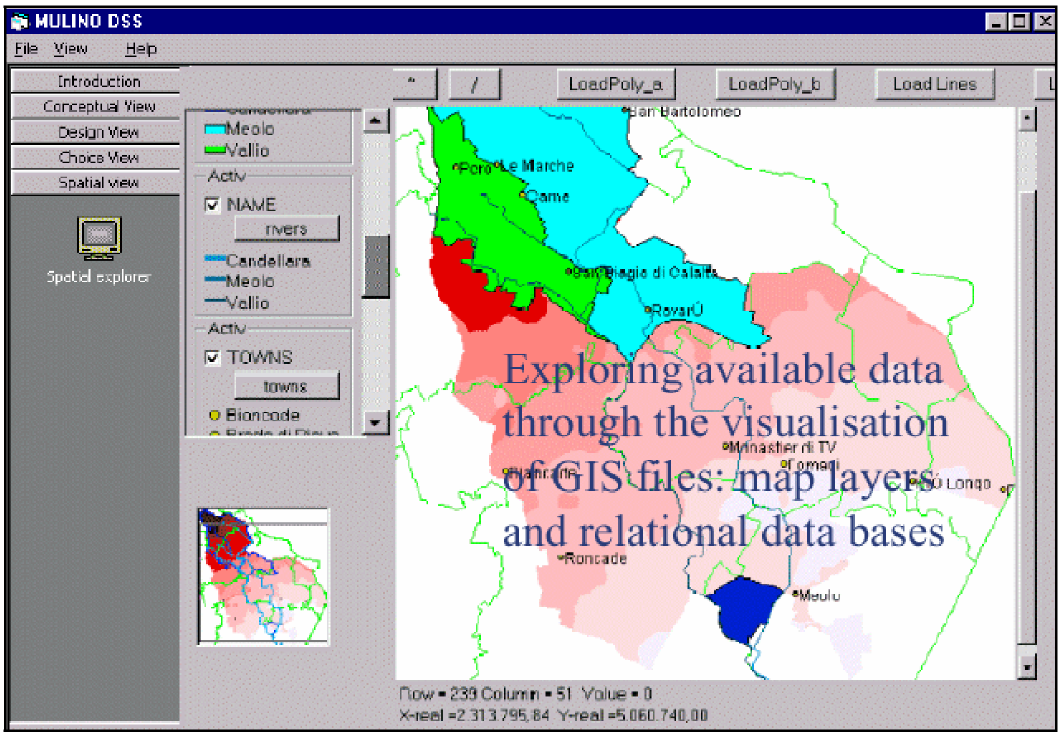


Figure 121 The Spatial View of MULINO DSS

MULINO DSSintegrates social, economic and environmental modelling techniques with GIS capabilities, a geo-referenced database and a multi-criteria approach for evaluating simulation results. Moreover, the core structure of the tool is based on the **Driving Forces-Pressure-State-Impact-Response Framework** adopted by the European Environment Agency.

The system has been conceived as an operational tool aiming at supporting and guiding the Decision Makers in each step of the overall decision making process, from problem conceptualisation to the choice of the best policy to solve it. A proposed series of "*decision steps*" has been encapsulated in the Mulino DSS and defined at the user interface level by the three Conceptual, Design, Choice Views:

- ❖ In the **Conceptual View**, the Decision Maker (DM) is directly involved, and 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 technicians is prevalent since they have to implement the problem formulated by the DM and find practical solutions that will constitute the set of possible options to be investigated.

- In the **Choice View**, DM and technicians assign weights to the options so as to select the preferred one.

In addition, the user can access the **Spatial View** and explore geo-referenced data on the GIS layers that describe the river catchment.

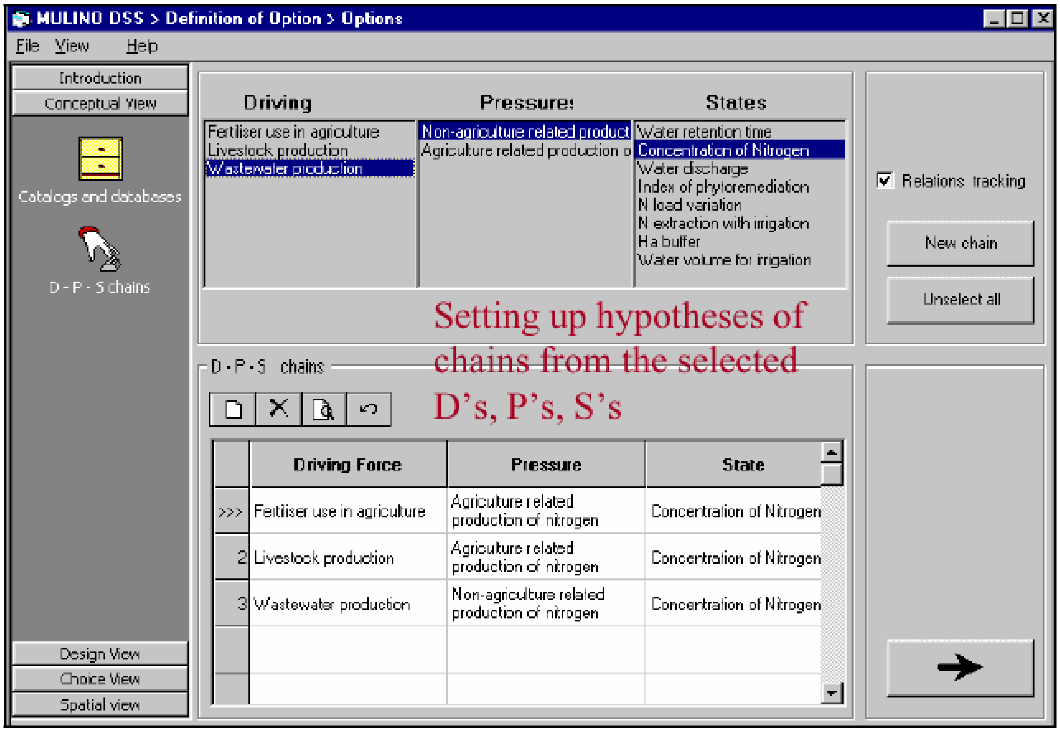


Figure 122 The Conceptual View and the D-P-S Chains

The entire decision process is based on D-P-S-I-R indicators and the cause-effect relationship existing among them: the Decision Maker describes the problem in terms of a set of Driving Forces that lead to specific Pressures exerted on the basin, so determining its State, 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 a list of Driving Forces-Pressure-State indicators is already available from the database. Then they choose those which are relevant to the particular water resource problem and 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 have been defined: 1) use of fertilisers in agriculture and livestock production (Driving Forces), leading to production of nitrogen (Pressure), which increases the nitrogen concentration in the water basin (State), 2) wastewater production, (Driving Forces) that leads to production of nitrogen (Pressure), which in turn increases nitrogen concentrations in the water basin (State).

The Design view consists of two parts. The first allows for the creation and definition of the alternative 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 extracts 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 following:

- 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 manipulates 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 *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.

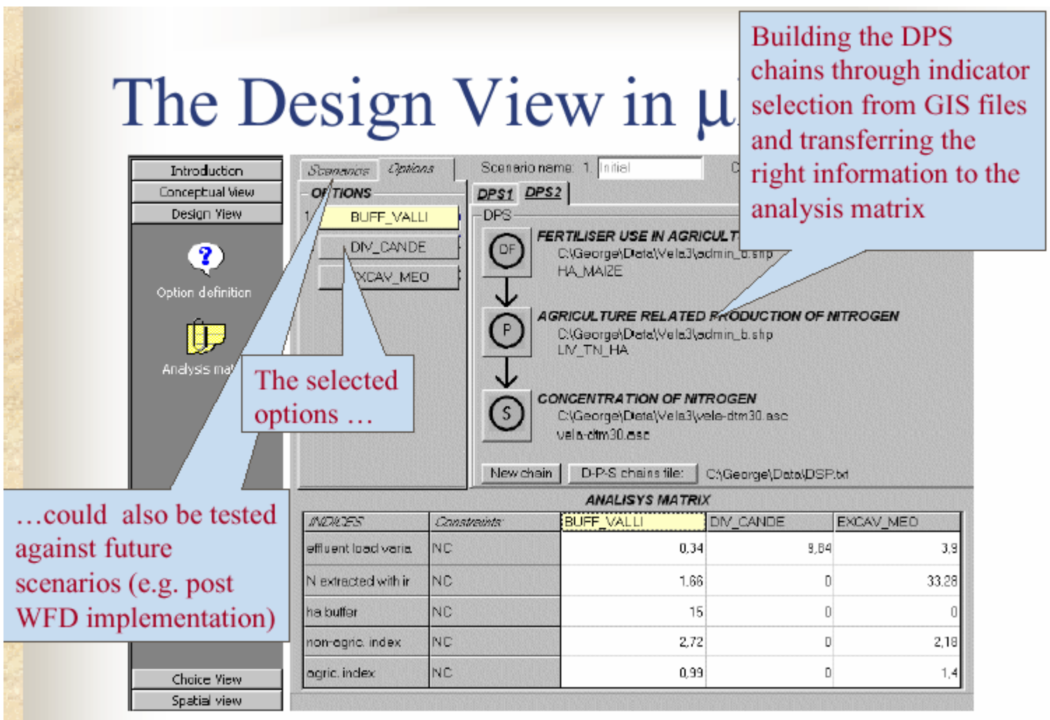


Figure 123 The Design View and the Analysis Matrix

The decision process described above can 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 works on top of external models; however the full integration of simple hydrological models has been planned for the next two releases.

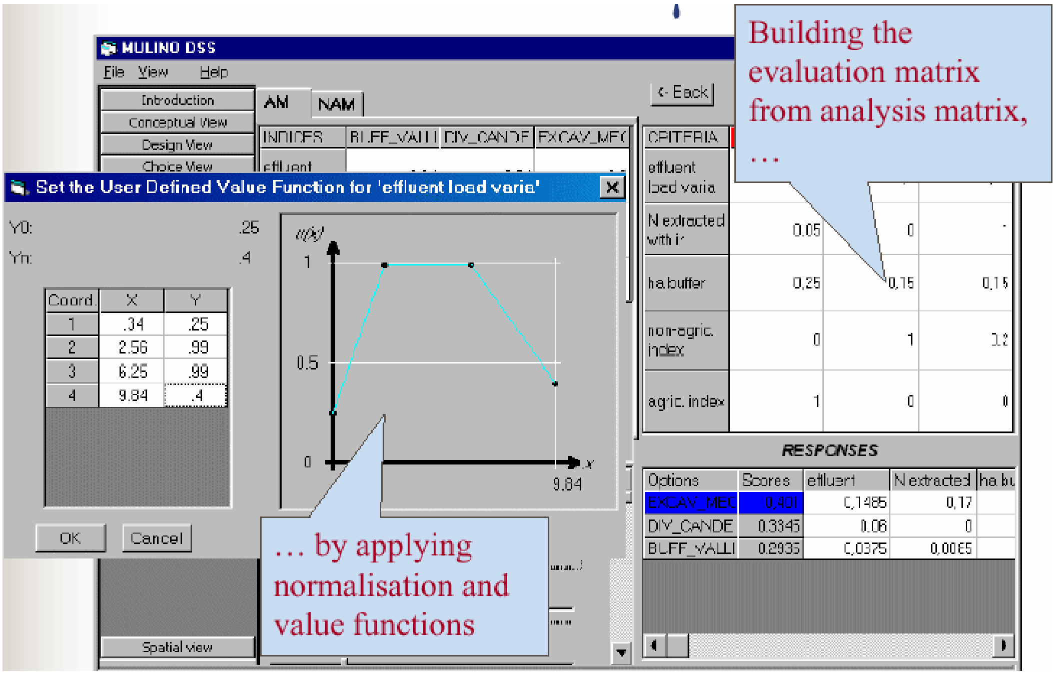


Figure 124 The Choice View and the Value Functions

Summary of Pros and Cons

The first version of MULINO DSS suggests an interesting approach to problem definition and evaluation that 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. A network editor and simple hydrological models are going to be integrated in the DSS in the next versions.

Chapter 20 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 uses** and to perform a simulation of the **water allocation** along a certain time horizon. It can be helpful in identifying possible water use conflicts among different types of uses, such as farmers or industries, in studying the sustainable development of the river basin itself and in planning the adequate measures to solve conflicts or generally improve the water resource status. Moreover, the water balance and the flow composition are the basis for further water quality analysis to be performed by external models or by the Delft DeltaQ water quality model.

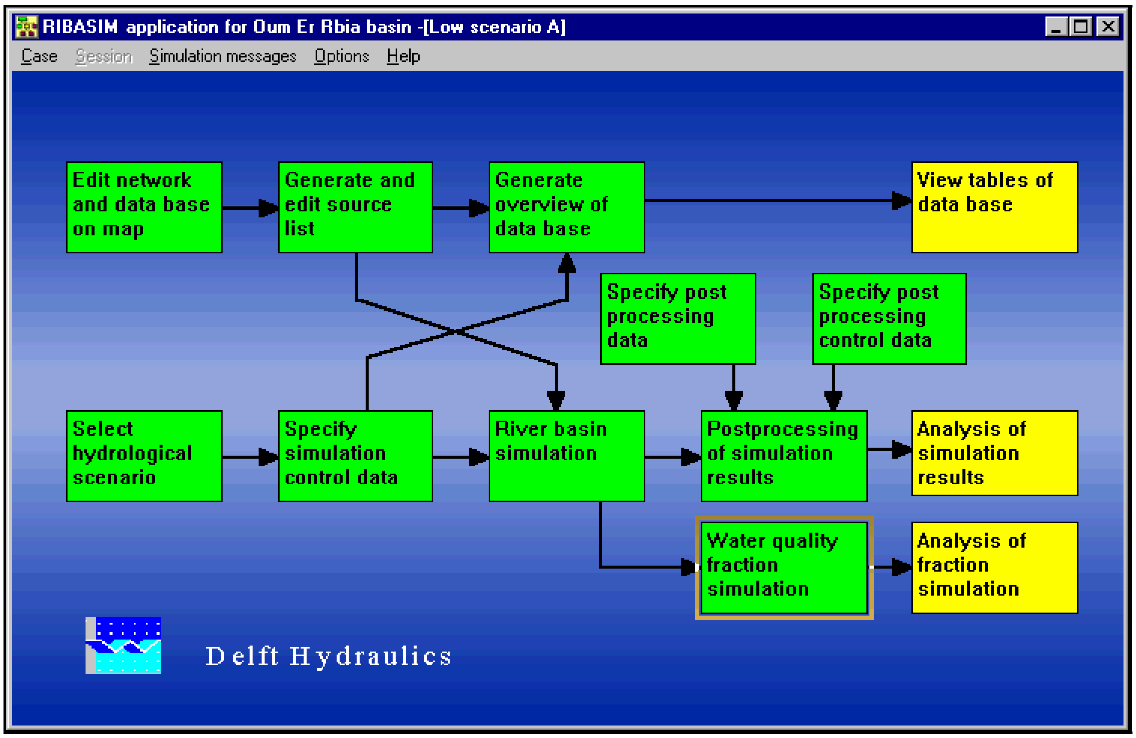


Figure 125 The main view of theRIBASIM interface with the application steps.

RIBASIM is a Windows-based software with a graphical user interface, a database, a simulation program and a tool for the analysis of results. The main view of the User Interface shows a flow chart aiming to guide the user in the application of models to the river basin under analysis: 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) the preparation of input such as hydrological time series, operational rules for reservoirs, hydrobiological and crop requirements etc., 4) the simulation, 5) the post-processing of results and 6) their analysis.

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**. Netter has a window where all node types are listed. Users can choose the types they want and place them on the geographical layer of the basin. The same stands for branches. The geographic layer can be imported from ArcView or MapInfo. Node attributes can be entered in specific forms and tables, just by clicking on the desired element of the layer. A number of consistency tests may assist the user in filling congruent data.

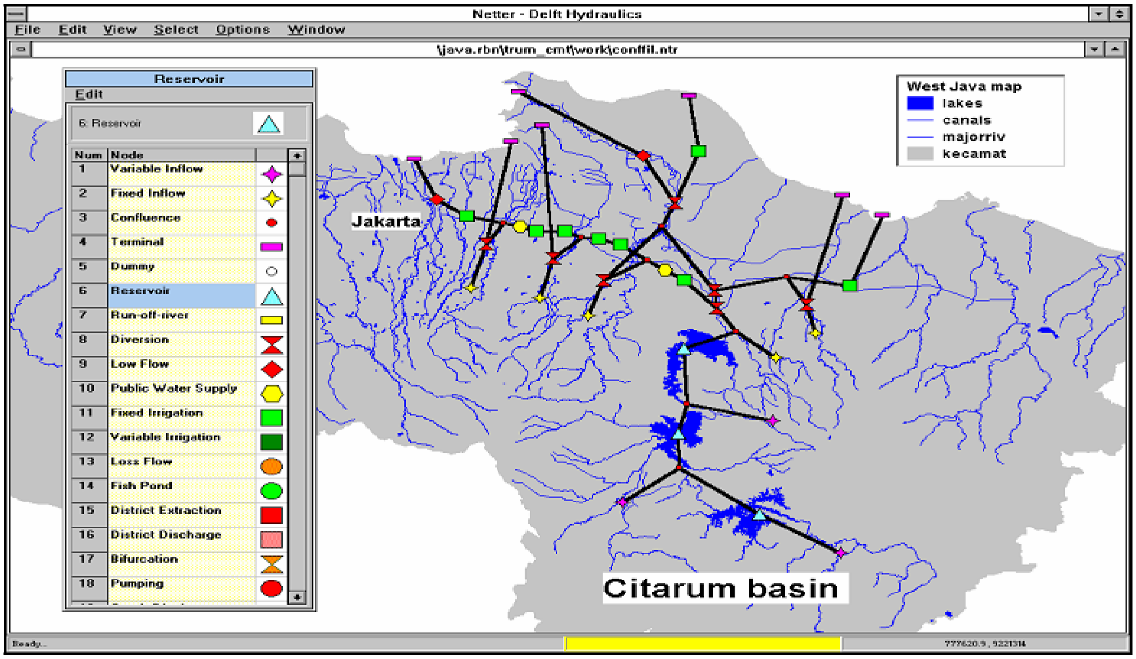


Figure 126 The Netter and the network building

As far as the simulation is concerned, it is usually run over time series of many years to include dry and wet periods. 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 must be noted 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 used for 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* that estimate a more detailed demand for irrigation, industries and municipalities. Table 17 lists the models used in Ribasim.

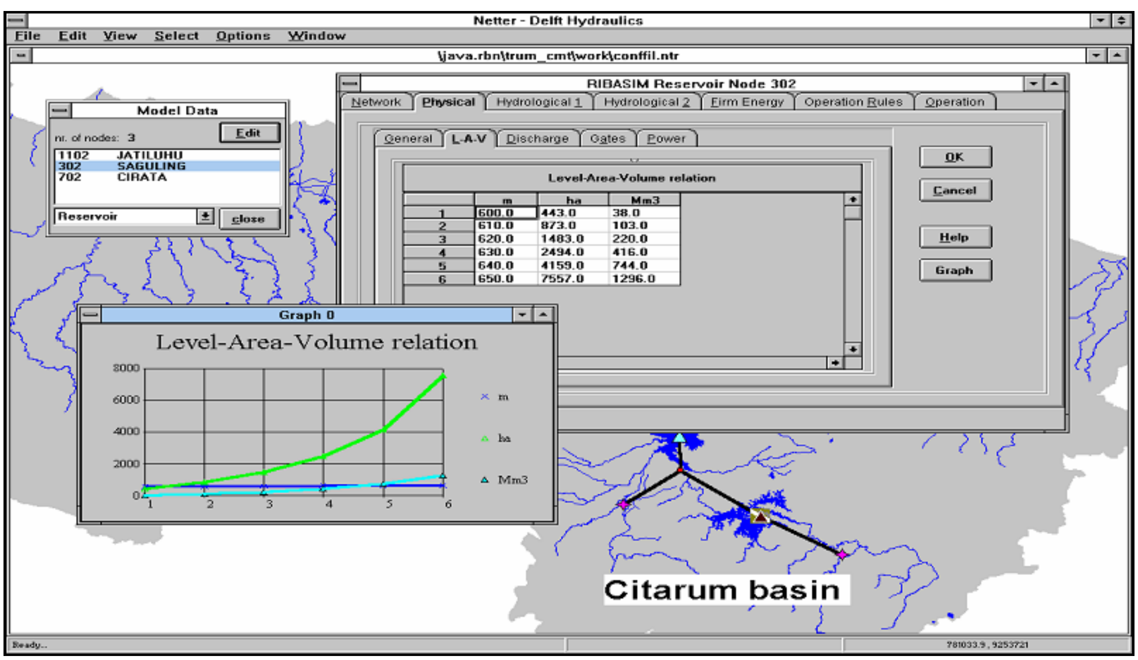


Figure 127 Data entry and related graphs

Table 17 Models embedded in the Ribasim Tool (Description 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 allocation 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 water allocation 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 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, 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 also into account the output from the *Demes* and *Agwat* models and the runoff from the non-irrigated part of the water district, which 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) **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.

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, are the applied cropping pattern, water allocation, shortages per user, the actual surface or groundwater reservoir storage, the overall water balance of the basin and the energy production. Default tables summarise the 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 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.

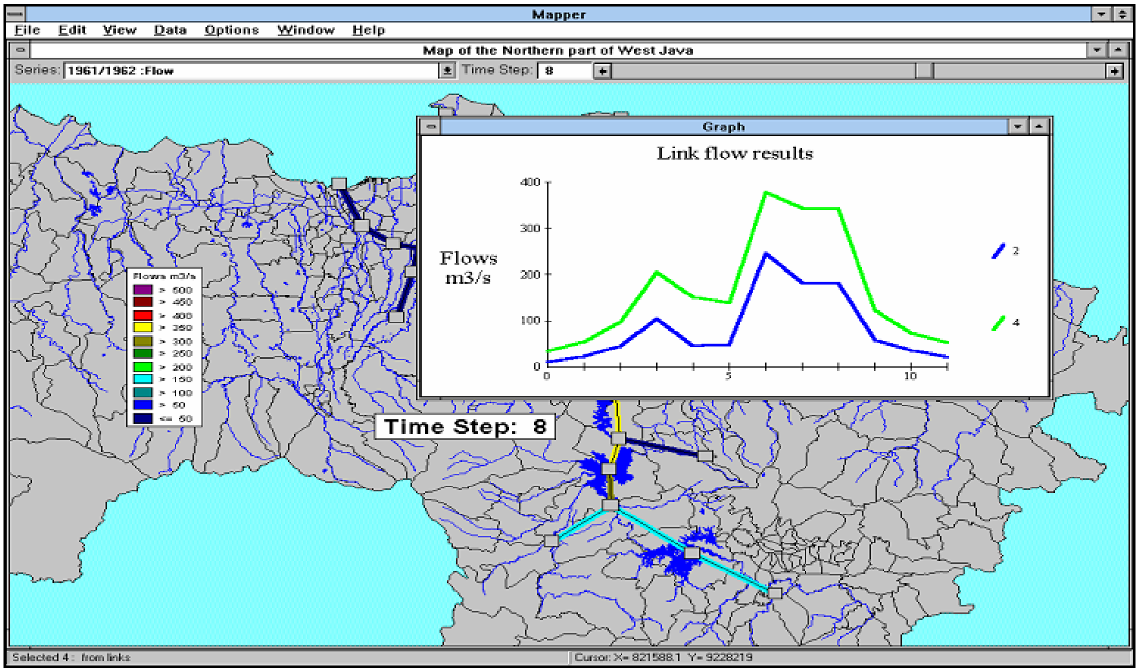


Figure 128 The plotted results

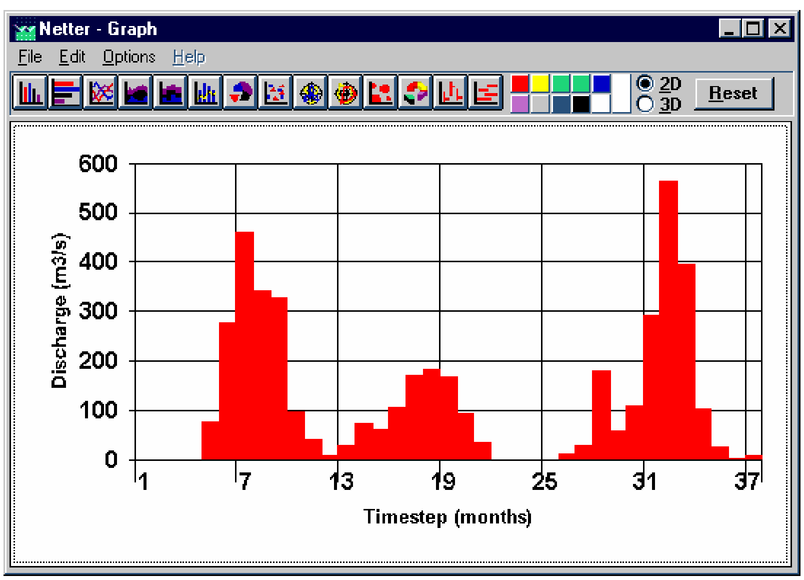


Figure 129 A specific output can be plotted over the simulation period

Summary of Pros and Cons

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, as well as strategies or groups of strategies (*cases*). However, there is not a real multi criteria evaluation procedure based on a comprehensive set of indicators.

Chapter 21 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, USA.

It aims at assisting 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 latest release of the software. It is windows-based and has been developed in the Delphi programming environment 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.

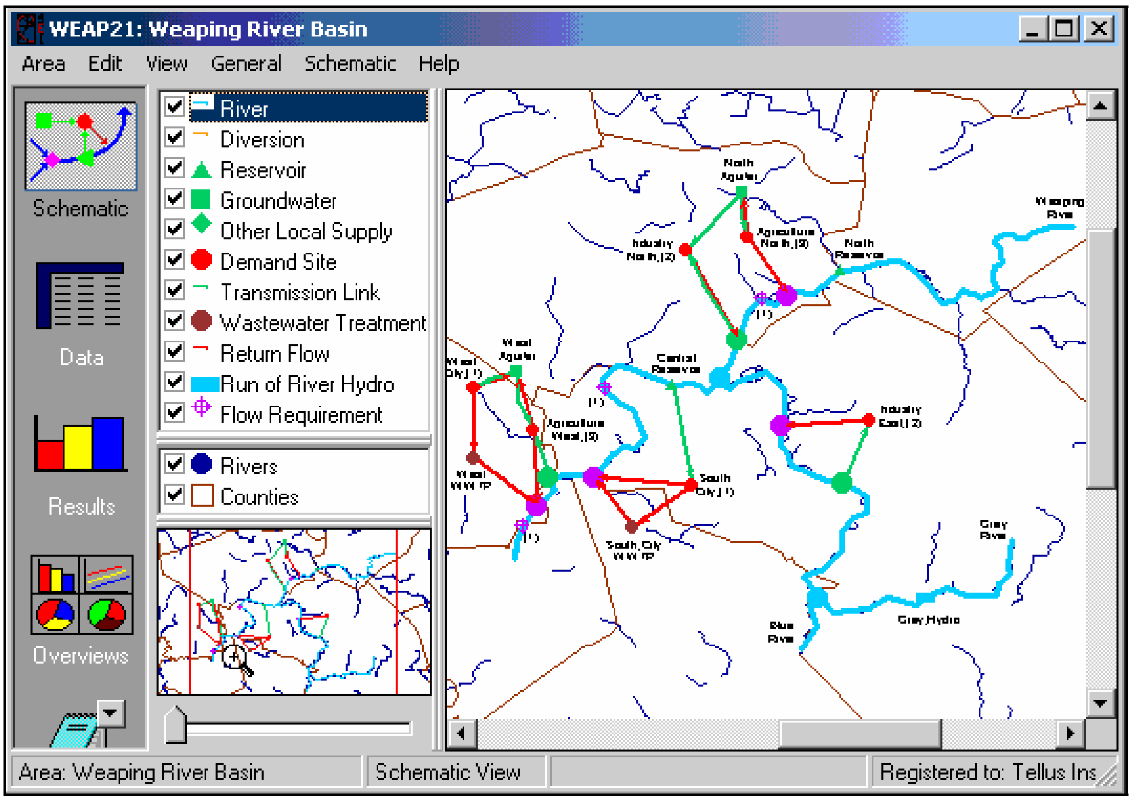


Figure 130 The Schematic view of Weap

In the **Schematic View** the user finds a GIS layer of the area of interest and can build the network of nodes and links representing the water resource system of the area. WEAP is usually applied to river watersheds but the area can 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 list window at the upper-left, to the specific position on the map in the centre of the interface. After dropping the node type on the map, a pop-up window requests some minimum general information about the new node, such as the name and whether the node will be included in the simulation of the default scenario. Additional required data depend on the specific element type and will be described later on. Network elements can 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 carry water from the water resource nodes to the demand sites nodes, while the latter exit the demand sites towards treatment plants or river locations. A small window, under the node types list, 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 network elements and maps are loaded by ticking the list elements with the mouse left button. The GIS map can be navigated by moving the little hand cursor over it, and a specific part of the map can be selected and zoomed.

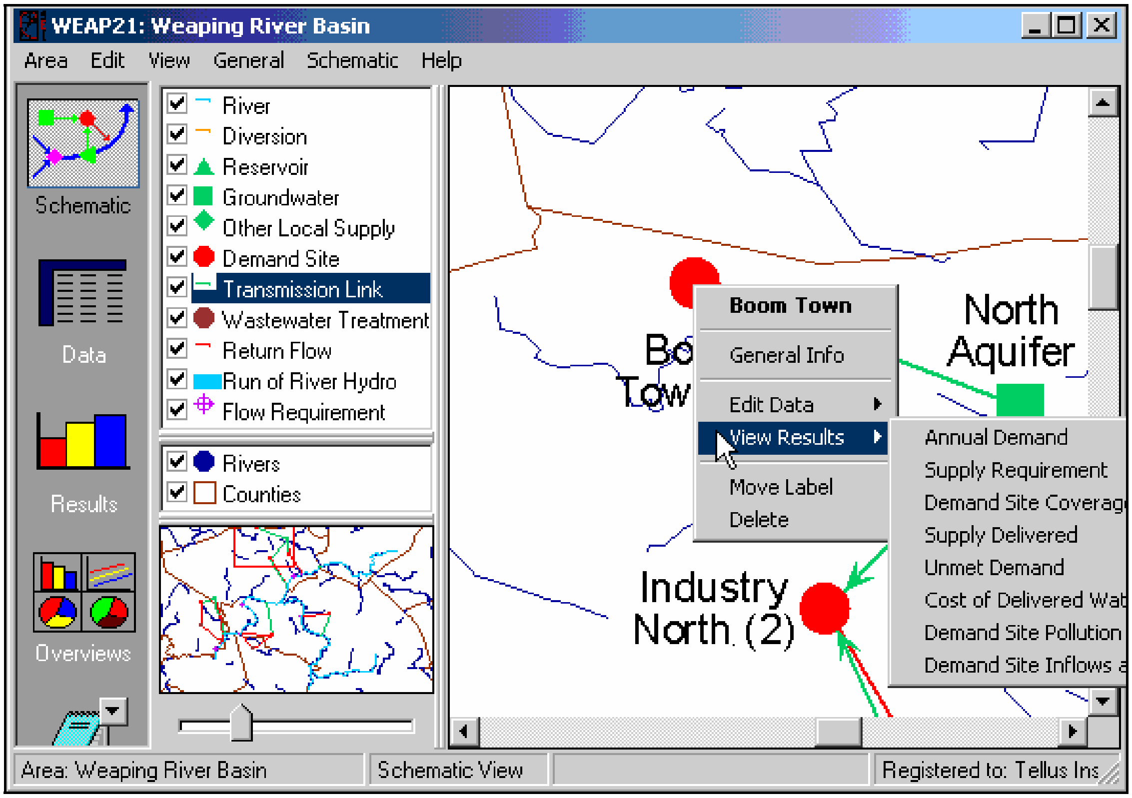


Figure 131 The user can access data and results by clicking the network elements in the Schematic view

The **Data View** is used to organise, edit and model data associated with 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, where data can be accessed. In order to display information for a specific node in the data entry, the node itself must be selected by clicking in the inset schematic. The inset schematic is a small map of the area that can be navigated and zoomed, whereas the tree is a hierarchical outline similar to the folder structure of Windows Explorer that is used to organise the data under predefined 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. In more detail, 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, where the simple specification of parameters allows for defining the variable behaviour. Examples are the *Growth* and the *Interp* functions that calculate a value in any given year using a growth rate from the base year value or a linear interpolation of a time series of year/value pairs respectively. Variable trends can also be built through dedicated wizards for monthly and yearly time-series construction. Once data have been filled-in, the user can convert and display them in different measurement units and scales. The list of units depends on the category of network elements data refer to. Data Entry Tables also concern the management of scenarios, which in WEAP are 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. This year is the starting point for all the simulated and alternative scenarios which are formulated from that year on. As previously mentioned, the behaviour of variables is built through mathematical expressions that can either be constant or generate time series of values. These expressions can be exported from one scenario to another; in this way it is possible to minimise the amount of data entries and to facilitate the scenario editing and management.

The Data View Tree is organised into six major categories, 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. Examples of such variables are the Gross Domestic Product (GDP) and water price. **Demand sites** include cities, industries and agricultural area demanding for water. They are described in terms of annual water use, monthly share of annual demand among all the sites of the same category, loss and re-use rates within a demand site and the costs and savings due to the application demand management options. The **Supply and Resource** category groups all water sources and network links. These latter are featured by the maximum flow volume, loss rate and cost per unit of water delivered while each source type has its own specific variables. The **Hydrology** category refers to future time series of inflows to supply resources, specified via mathematical expressions or entered on a monthly basis. The **Environment** category concerns pollutant generation, concentrations, decay rates and removal within the treatment plants.

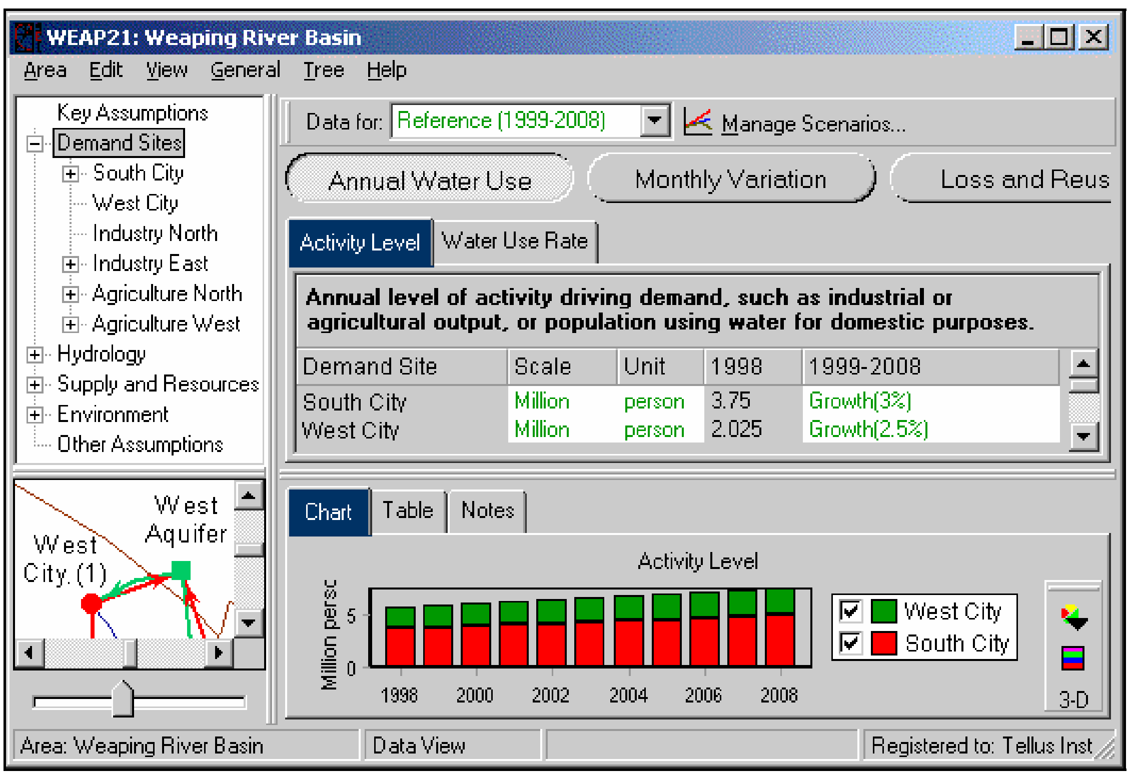


Figure 132 The Data View of Weap

When the WEAP user selects the **Result View** from the *View Bar*, the system starts the allocation of water to the demand sites and pollution calculations. The water resource system is schematised in WEAP as supply nodes giving water to 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 under water shortage conditions, because they assign the demand sites with the highest priority 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 type 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 "*General Information*".

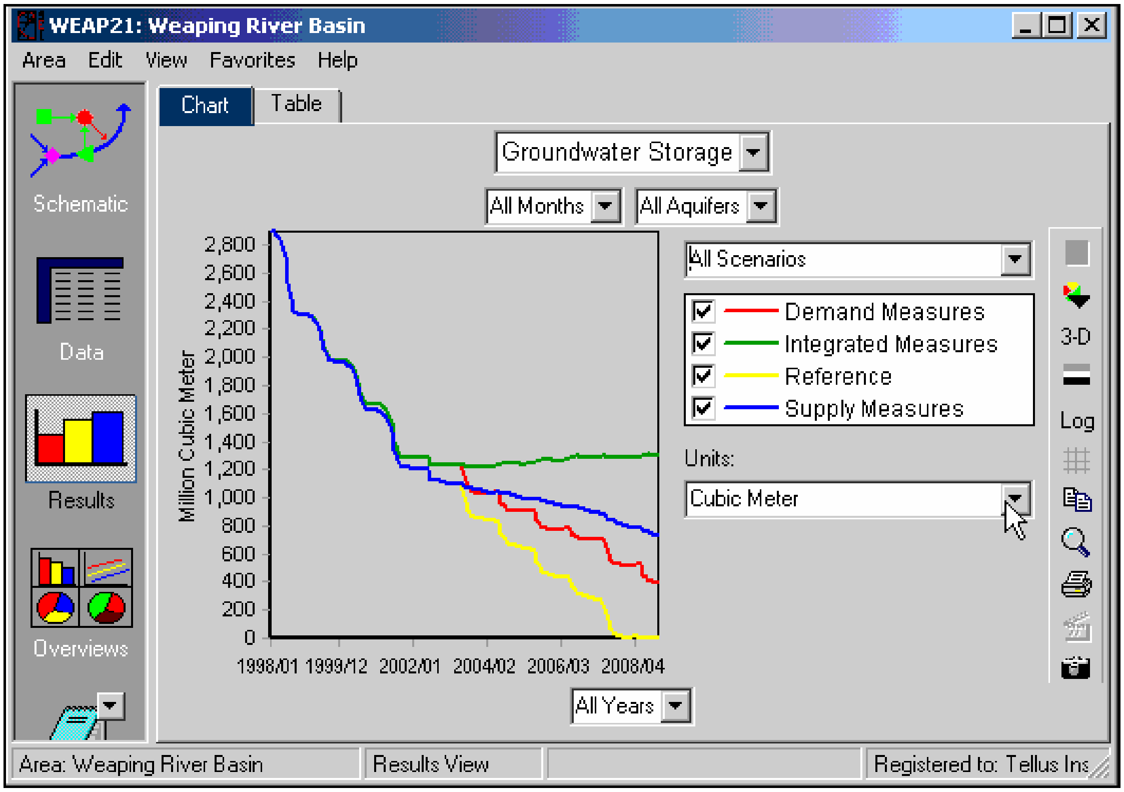


Figure 133 The Result View of Weap

After the simulation is performed, 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, choose the variables to plot, choose a specific month or display the entire time-series, and plot information associated with just one network node or with all the nodes of the same type (e.g. groundwater storage for all aquifers). Moreover, the user can choose and change the graph type, select a scenario, and change the display units. Data tables can be exported to Excel by clicking on the dedicated button; while graphs can be copied and printed. Graphs previously saved as favourites can be viewed simultaneously in the *Overview*, in order to compare 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. Each single graph of one overview can be further modified and saved again.

A fifth tool that appears in the View Bar "Notes" is a word processor for writing documentation on the network elements, trends built or expression used

WEAP has been applied in water assessments in the United States, Mexico, China, Central Asia, Africa, Egypt, Israel and India. The main objectives of those applications were:

❖ The identification and evaluation of 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.

- The representation of alternative water development and allocation scenarios.
- The assessment of water supply augmentation through an inter-basin transfer within firm yield analysis.
- The resolution of water use conflicts in river basins.
- The development of supply and demand balances and alternative strategies to study the water costs in watersheds.

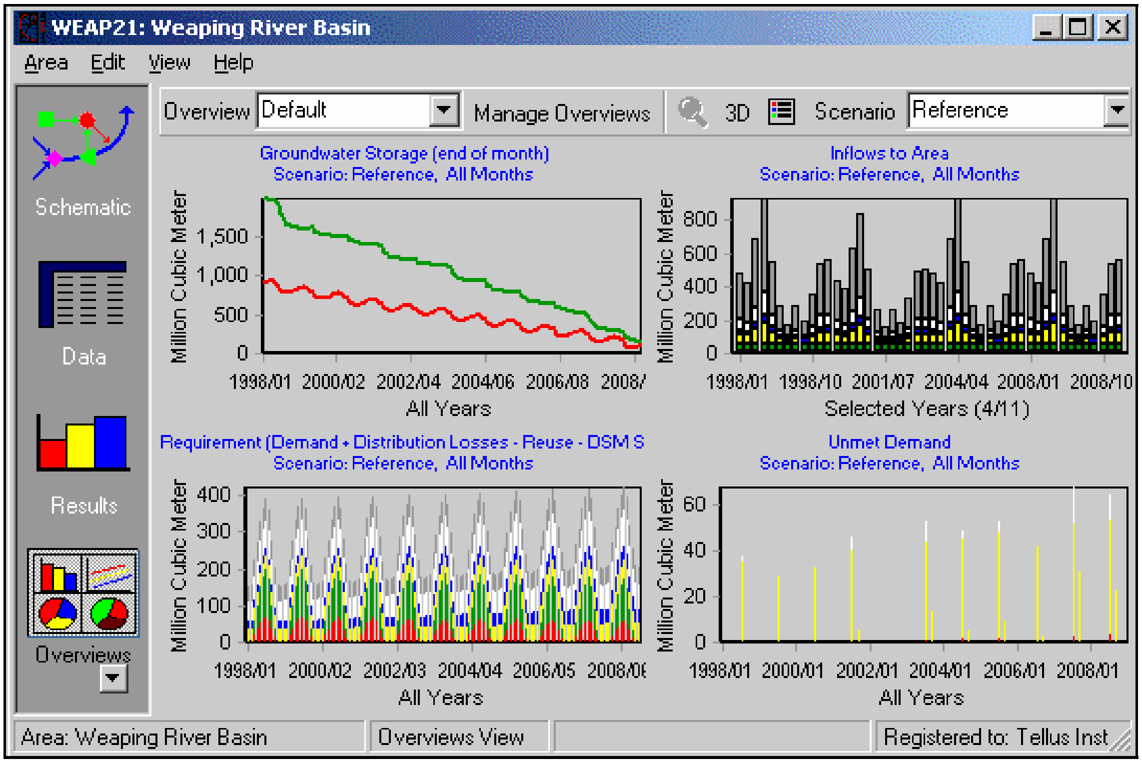


Figure 134 The Overview of Weap

Summary of Pros and Cons

WEAP could certainly represent a good starting point for the development of a comprehensive decision support system. Unfortunately, it does not integrate a GIS software and a formalised data base.This is certainly a limitation.

In addition no feedback in terms of water demand can be accounted for , which limits its real interest for the analysis of interventions such as for instance demand management.

Chapter 22 Waterware

WATERWARE is a DSS for integrated river basin planning and management, main objective of the European research program Eureka-EU487. Within this 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 in 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.

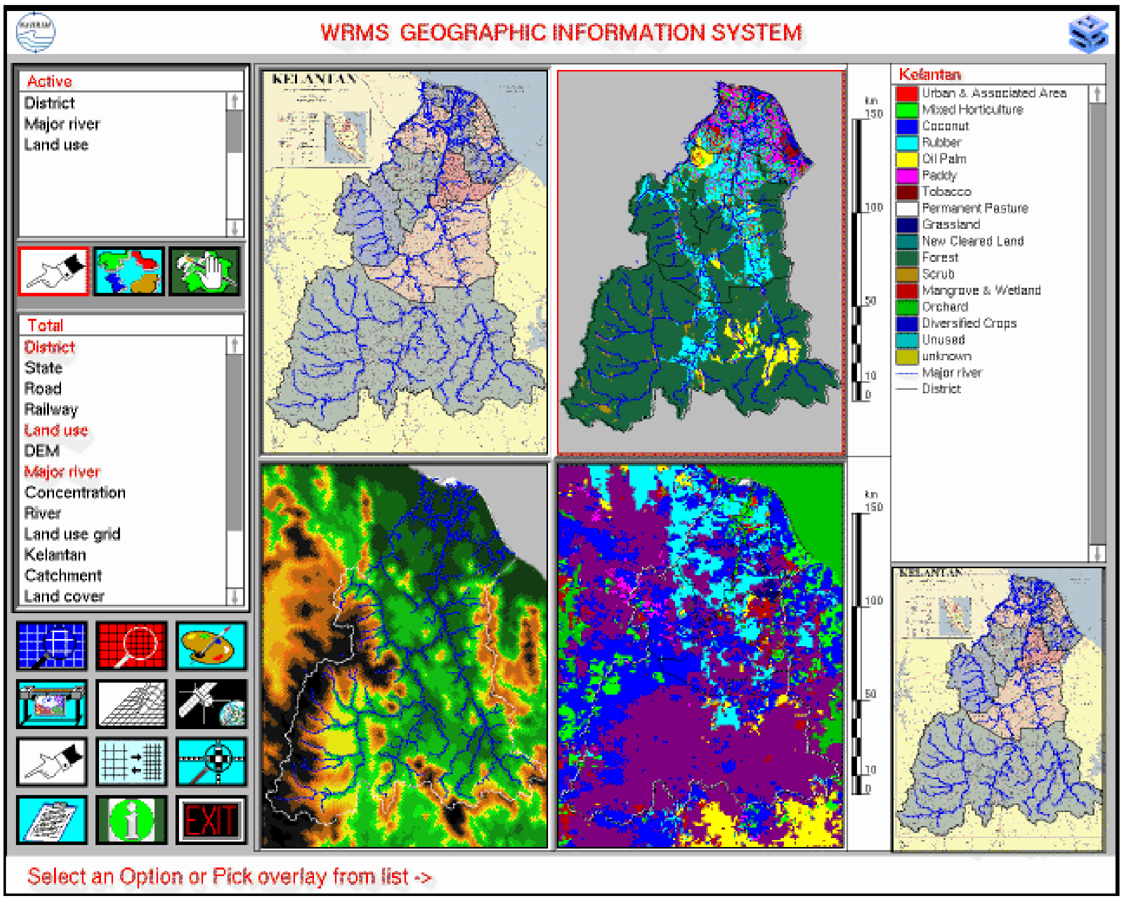


Figure 135 GIS layers drainage network, land use, soil, and DEM

Among the Water resource issues considered by Waterware are:

- the **definition** of the exploitation limits of available water resources and the planning and development of new ones in time and space;
- the **evaluation** and assessment the sustainability of water supply development as far as the impacts on the environment is concerned;
- the **formulation of** strategies to track down pollution in rivers and aquifers and to control the effectiveness of environmental legislation.

WATERWARE is coded in C/C++ but it is capable of integrating 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 the database, the models, and 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:
  - o mono-dimensional stochastic river water-quality model
  - o bi-dimensional finite-difference model of groundwater flow and contaminant transport
  - o UN Food and Agriculture Organisation's CROPWAT model to estimate the crops water requirements
  - o rainfall/runoff model
  - o water resources planning model
- ❖ utilities for time series analysis and reporting, and
- ❖ a rule-based expert system for Environmental Impact Assessment.

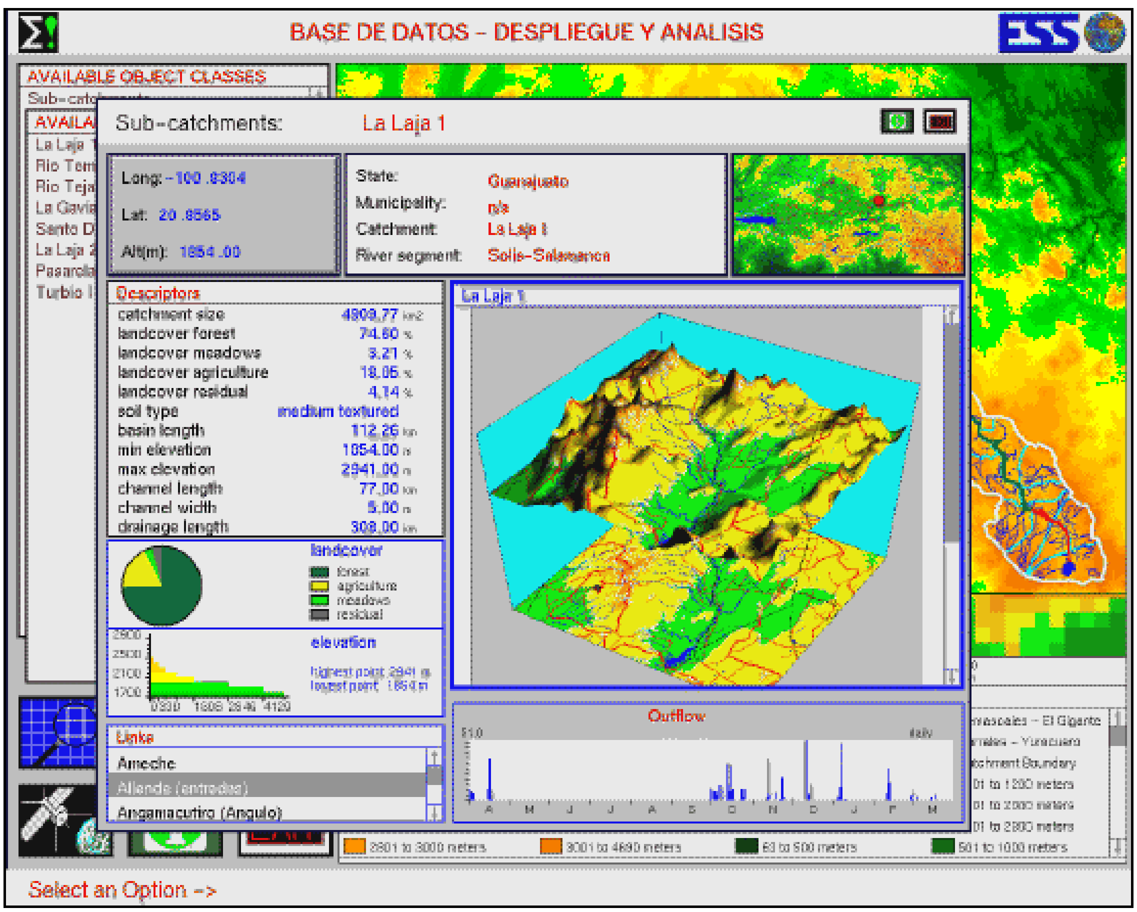


Figure 136 The window for a sub-catchment object

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 model.

The river basin is schematised according to a set of **RiverBasinObjects** that are: meteorological 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. Properties, describe the status of the element while functions drive their behaviour in time.

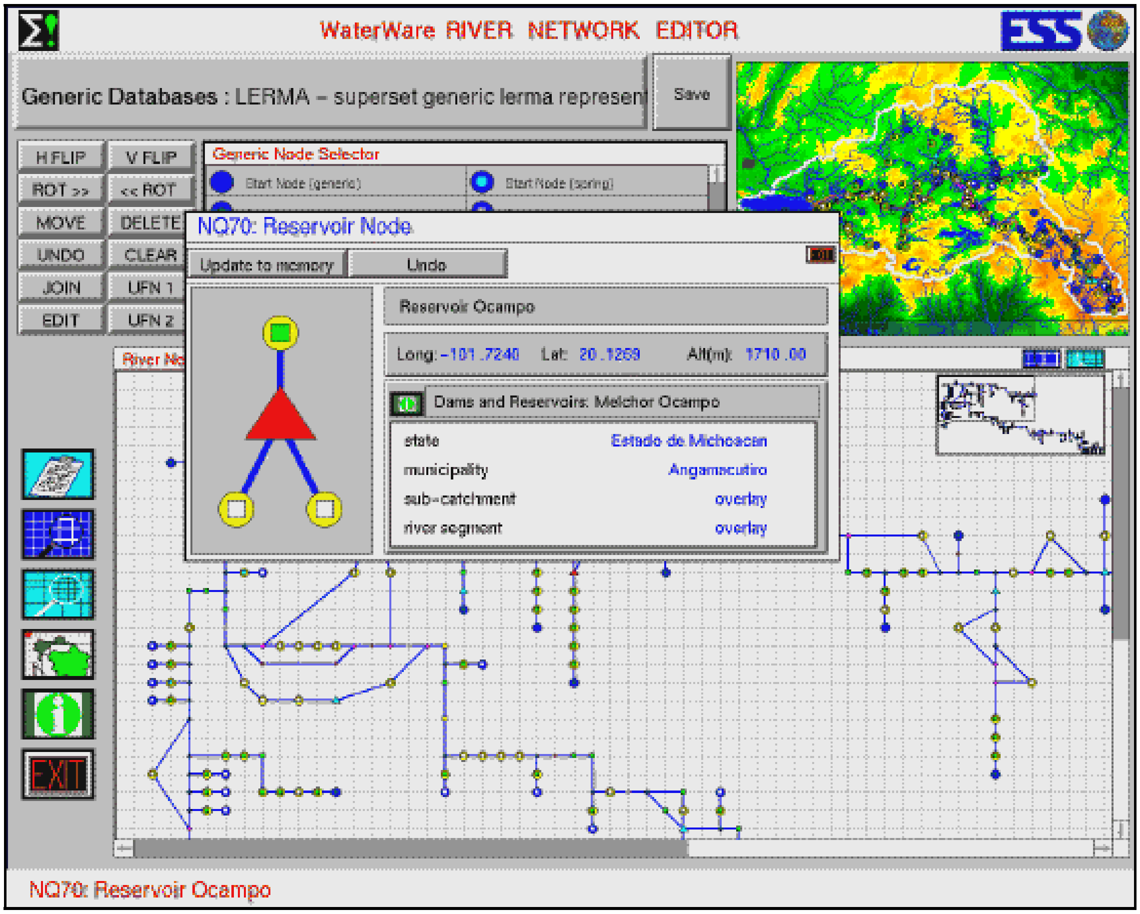


Figure 137 The Interactive River network editor of Waterware

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 Object Model.

The models embedded in WATERWARE simulate the behaviour of the basin objects, providing their input from the geo-referenced database and displaying their output on 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 computes 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 through a dedicated windows and menus. Examples are presented in the figures that follow.

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

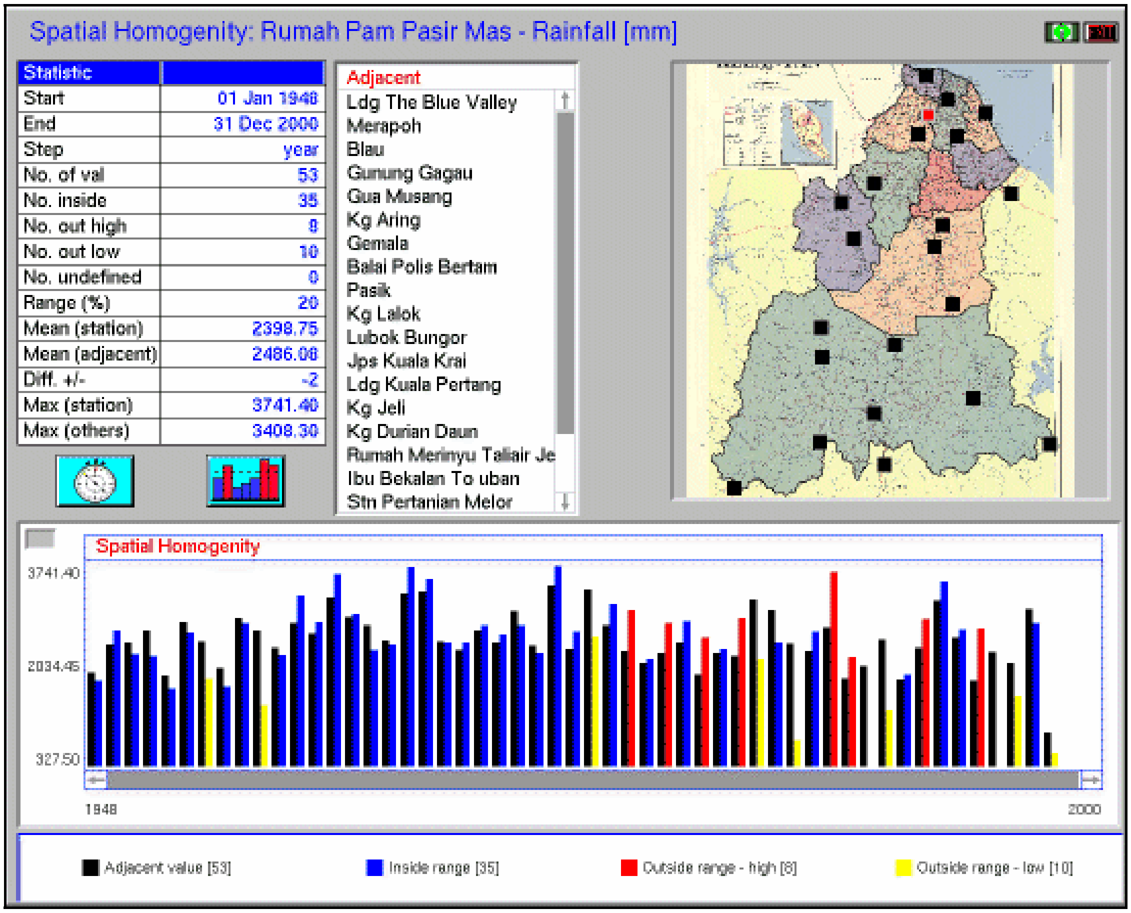


Figure 138 Examples of time series analysis: selection of stations and spatial homogeneity

Data analysis utilities go beyond the basic functionality of displaying time series data, scrolling, zooming, data aggregation and unit converting. Data associated with individual gauging stations can be accessed through selection 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, data can be tested in terms of spatial homogeneity and seasonality of specific values and the cumulative distributions of time-series of different neighbouring stations can be compared.

Summary of Pros and Cons

WATERWARE is certainly a comprehensive DSS: it has been developed using an open architecture that integrates 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. Models used within WATERWARE are all conceptually linked together in a sort of data processing chain: during the simulation they are launched according to a predefined sequence, and the output of a model represents the input of the next ones. This is not an unusual way to perform the simulation. However, it surely can represent an obstacle if new modules are added or the existing ones are modified, at least for the need of adapting input and output to common standard file formats.

WATERWARE does not operate with economic, hydrologic or meteorological 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 an information system rather than of a system that can support decision making under an integrated and multi-objective analysis.

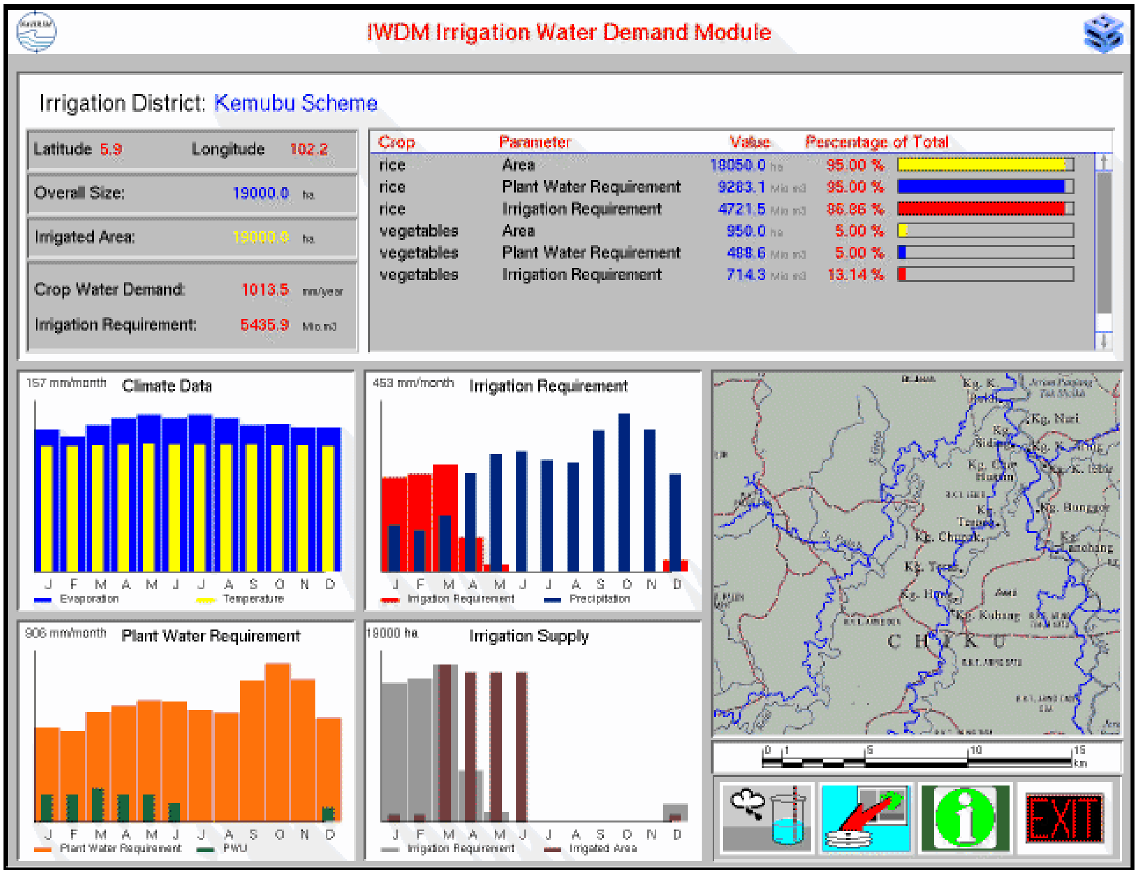


Figure 139 The Irrigation Water Demand Model window

Chapter 23 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 reporting 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 periods and have not been integrated in one package; this makes AQUATOOL highly flexible to work with, to upgrade and further develop.

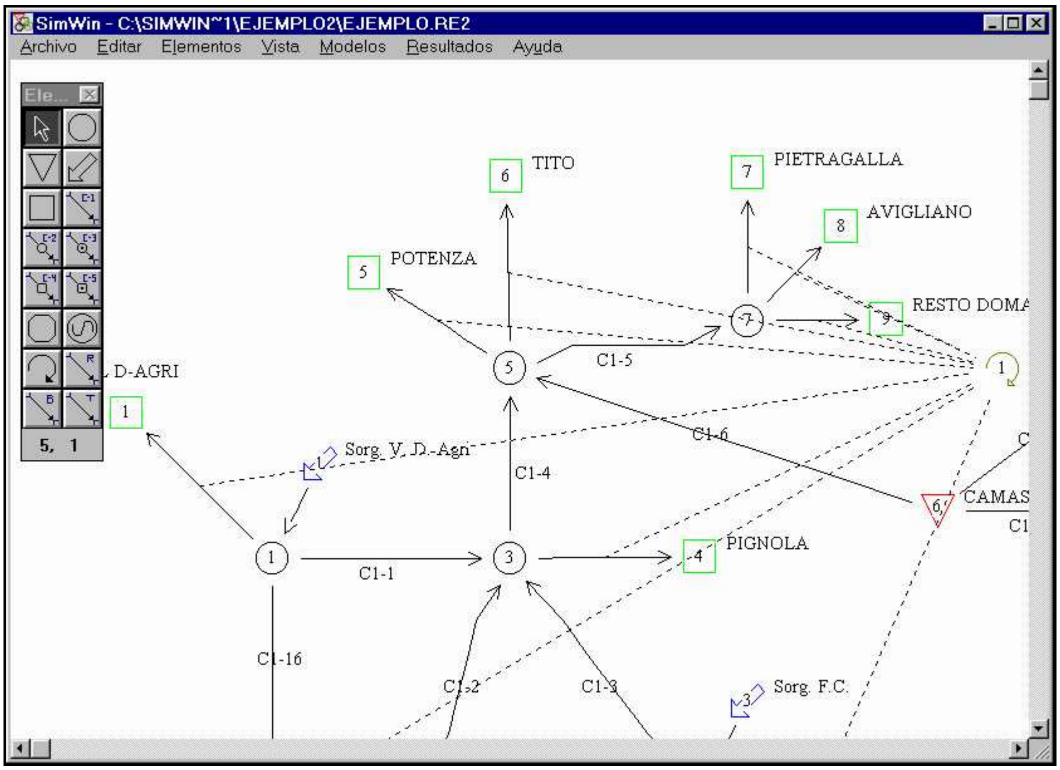


Figure 140 Building the river basin schematisation

The user accesses the modules from a graphical interface, which also supports 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: nodes with storage capacity like lakes and reservoirs, diversions and junctions, natural channels, aquifers, evaporation and infiltration losses and water uses 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 those should be placed. An interesting feature of the tool helps the user to find the location of a determined object in case of large water systems: there is a list of all the geo-referenced nodes and links placed on the map layer, and they 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 elements of the basin 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, can be opened by double-clicking the elements themselves on the map. Operating policies are defined by the following variables: target, minimum and maximum volumes of reservoirs, inter-reservoir relationships and priorities of use, minimum flow in rivers, flow requirements for hydroelectric plants, targeted water demand for each agricultural, industrial and domestic areas and their demand priorities that are used in the water allocation.

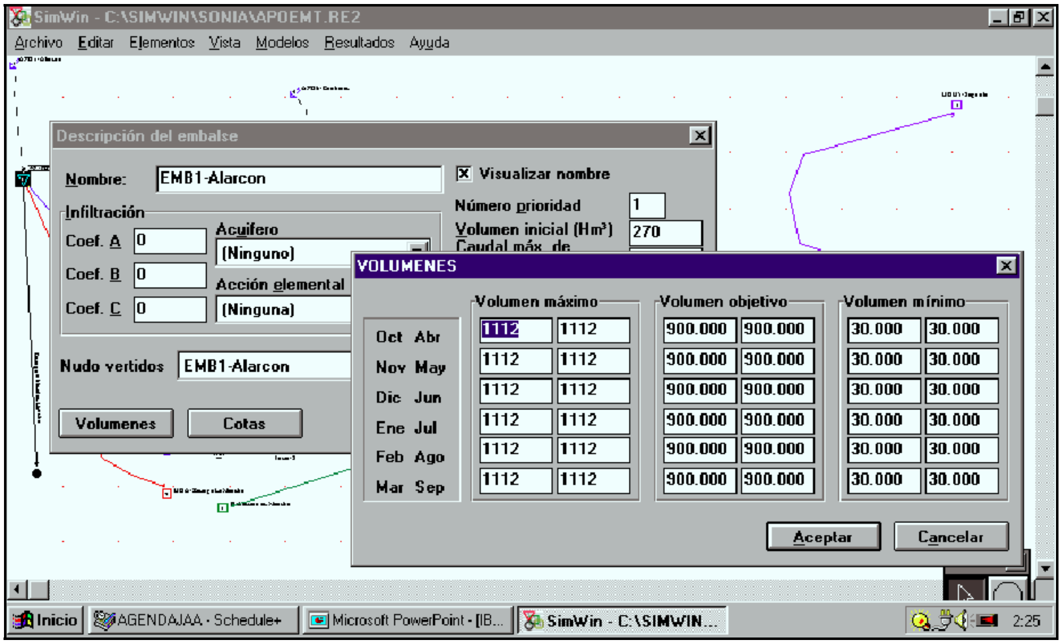


Figure 141 Accessing the geo-referenced database from the basin scheme

The **SIMGES** Fortran-coded mathematical model performs the simulation of the operational management of the system on a monthly basis. It is responsible for the water allocation to water uses and considers the conjunctive use of surface water and groundwater. This issue is of particular importance, since in most Spanish basins aquifer exploitation helps considerably in facing water scarcity and competition between conflicting uses. For that reason, the model takes into account 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 which 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 instead of another can depend on the amount of data available from hydrological and geological studies and the desired level of detail for a realistic representation of the aquifer.

OPTIGES is the optimisation module of AQUATOOL. The algorithm works with a subset of the basin elements, and in particular nodes with and without storage capacity, channels, hydrological inflows, water demands and return flows. OPTIGES is based on mass conservation within the network of nodes and links: it uses an iterative function that minimises the weighted sum of the water demand deficits and minimum flows, taking for account reservoir evaporation and return flows. Weights reflect the use priorities assigned by the Decision Maker to the different uses in the basin. OPTIGES results can be plotted, in order to support the analysis and comparison 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 achieved.

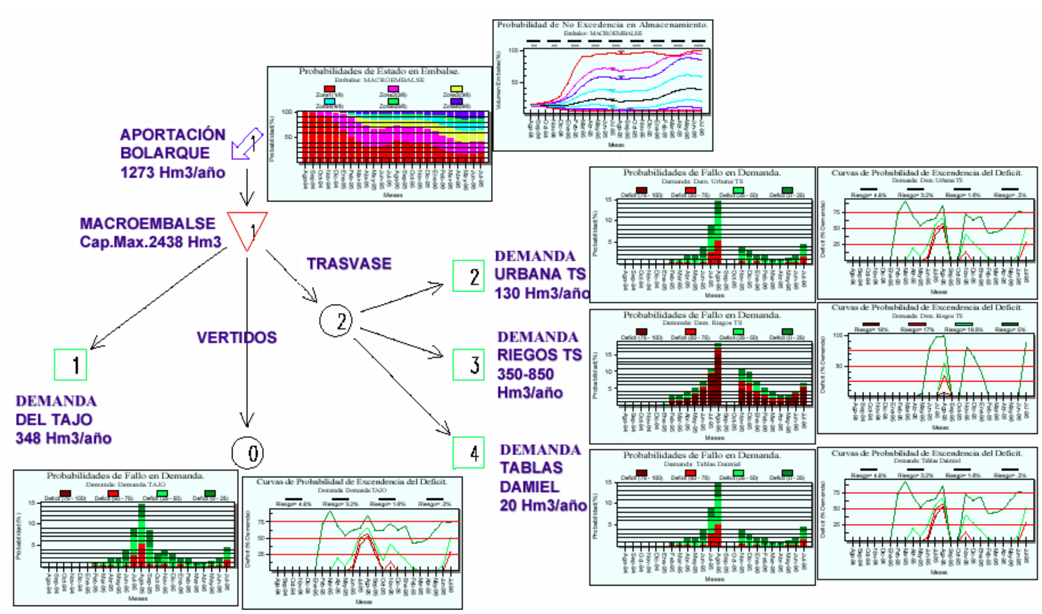


Figure 142 Risk assessment analysis for a sub-watershed of the Tagus Basin

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

The **Graphical Analysis Module** of AQUATOOL provides graphs, tables and report files, helpful for investigating the values of decision variables that result from simulations and optimisations, and for displaying hydrologic time series and parameters. Results are saved in the geo-referenced database and their corresponding plots and tables can easily be accessed and retrieved for each element of the basin schematisation by pointing at 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 running project at the department of Hydraulic and

Environment Engineering of the Technical University of Valencia: currently economic and ecological modules are under development.

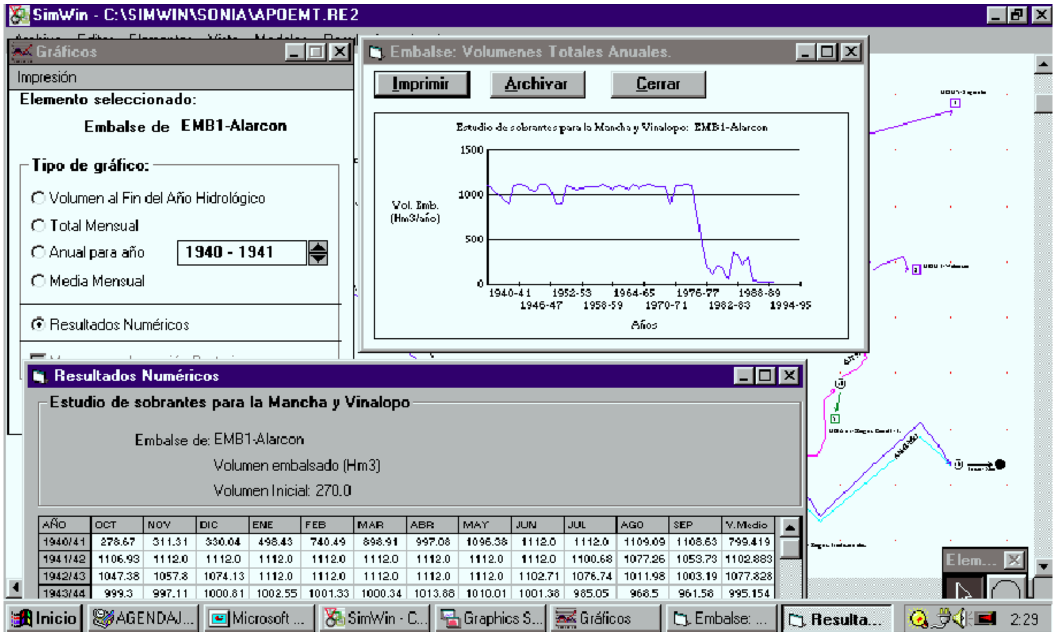


Figure 143 Example of tabular and graphical display of results for a specific reservoir of the system

Summary of Pros and Cons

AQUATOOL is basically an optimisation frame for water resources allocation. AQUATOOL is not linked to GIS software and, moreover, the current version does not have an approach that integrates economic and ecological aspects, whilemanagement options, such as construction of new supply nodes, arenot considered.

Chapter 24 Iras

IRAS is the acronym for *Interactive River-Aquifer Simulation* program. It is a tool for **simulating surface and groundwater resources,** their reciprocal interactions and flow exchanges over space and time. IRAS was first released in 1994 and 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, the user can:

- draw and define the features of the WR system components as a network of nodes and links
- edit data and operating rules 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

The Iras Network

The IRAS network elements can model 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 nodes but are conceived in IRAS as items featuring river links. Hydropower can be placed 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 if water goes respectively one direction only or both.

Uni-directional links are:

- ❖ Natural streams or river reaches, connecting two surface-water nodes. River reaches are stretches of river that may be connected to hydroelectric power plants 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 drawn by the user in a blank Iras window. A digitised geographic map of the area can be loaded as a black and white image in order to facilitate a consistent placement of nodes.

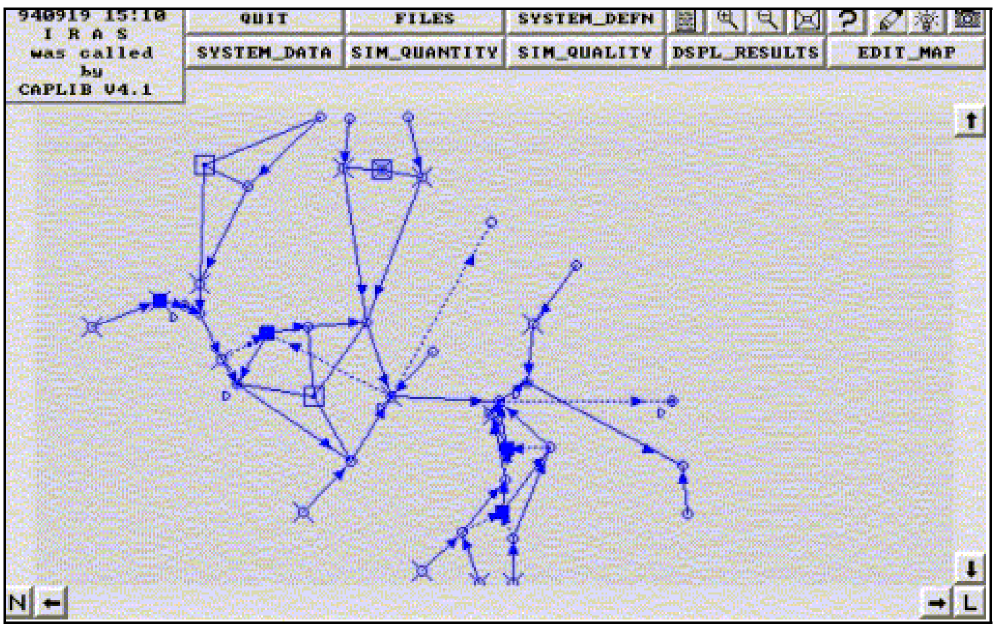


Figure 144 An example of schematic representation without background mapping: the Raritan River-Aquifer system in New Jersey

Data Enter and requirements

The type of nodes and links determines the data required for simulating their behaviour. 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. Data requirements for some type of nodes and links are listed below:

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**, accounting for spatial interpolation or extrapolation. On the other hand, Gauge-Flow Multipliers can also be defined for all node types, here for 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 definitively. According to that, seepage volumes from surface water bodies or adjacent aquifers entering other aquifers are not defined as losses and their transfer should be represented through a proper link connecting these two related 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 as a demand.
- Water sources identifiers and factors. Each demand node can have a set of assigned possible sources of water, either a reservoir or a 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, and
- 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 measurements 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 losses 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 as 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*. 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.

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, and files with monitored natural flows and their relevant concentrations.

The IRAS program simulates water resource systems over multiple within-year time periods that can be months, weeks, days, or time periods of different duration. The *within-year time periods* can be up to 60 and could cover an entire year, even if this is not necessary; 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 considered 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.

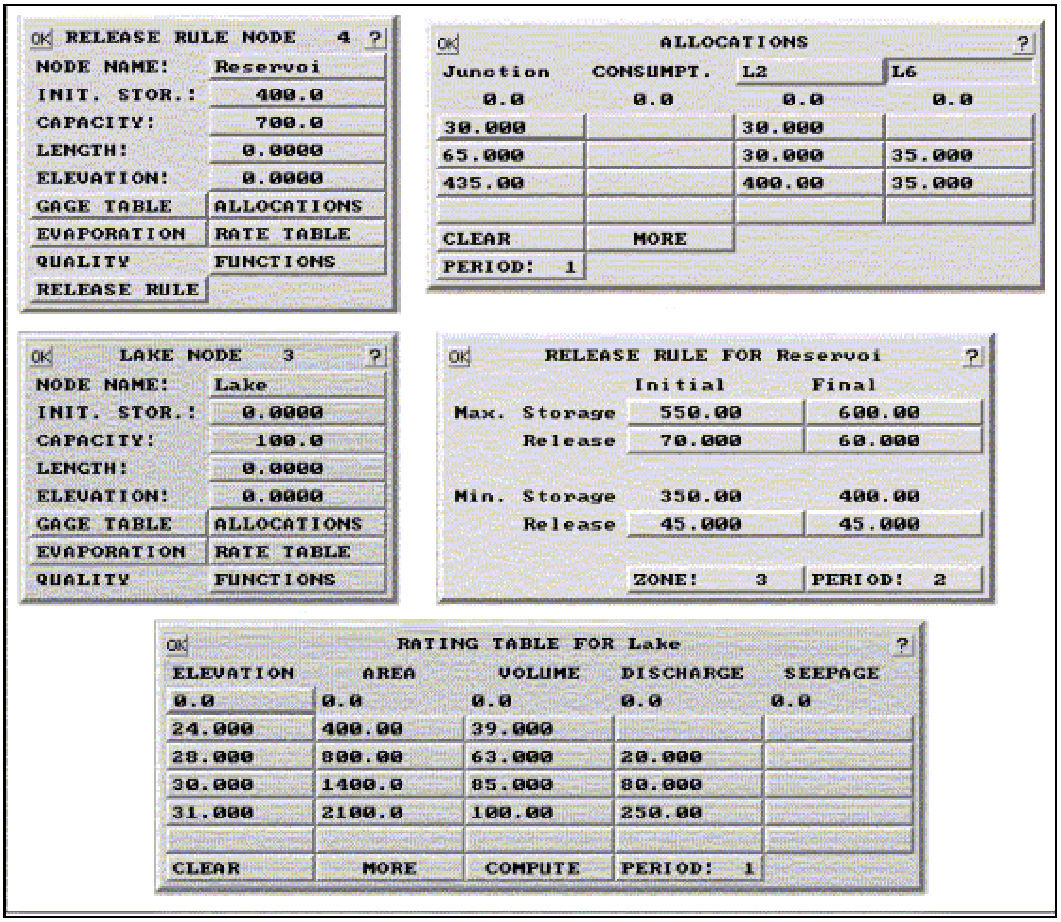


Figure 145 Dialog boxes with entered data for selected nodes and links. They are accessed by right clicking on the relevant network node or link.

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:

4) **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, from daily evaporation rates and from daily seepage loss functions, entered by the user. Reservoir release targets, which are not necessarily the actual reservoir releases, are also computed according to current reservoir storage volumes and capacity, downstream demand target deficits and a specified minimum required release. The discharge from each natural lake node is calculated as the storage volume less evaporation and seepage losses plus inflows;

5) **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;

6) **Bi-directional link flows** between aquifers and/or wetlands. These flows are functions of current storage volumes, groundwater physics, 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;

7) **Groundwater and wetland inflows**, outflows and storage volume. Water exchange with neighbouring rivers is also taken into account. 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 multiplied by the area through which the flow travels divided by the length of the flow path;

8) **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 concentration 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 of 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 ranges 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 respectively: satisfactory, marginal, or unsatisfactory. Plots having the three coloured areas in the background may be created so as to analyse graphically the behaviour of a variable. 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 relatively quick way to identify the locations and periods, when the system may be stressed. Furthermore, defining thresholds also permits the computation of system performance statistics and probability distributions of both red and yellow zone deviation extents and durations.

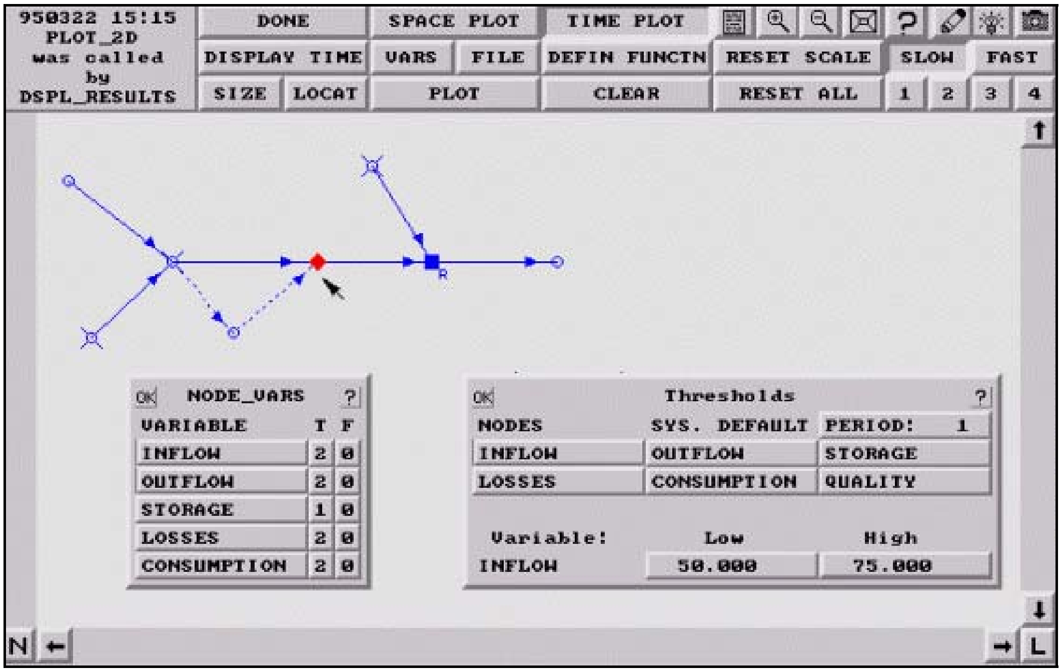


Figure 146 Assigning thresholds values to variables permits to check visually their behaviour over the simulation time steps: nodes in the network scheme change colour according to the range of values assumed by the variables. This type of visualisation may be performed for each simulation variable.

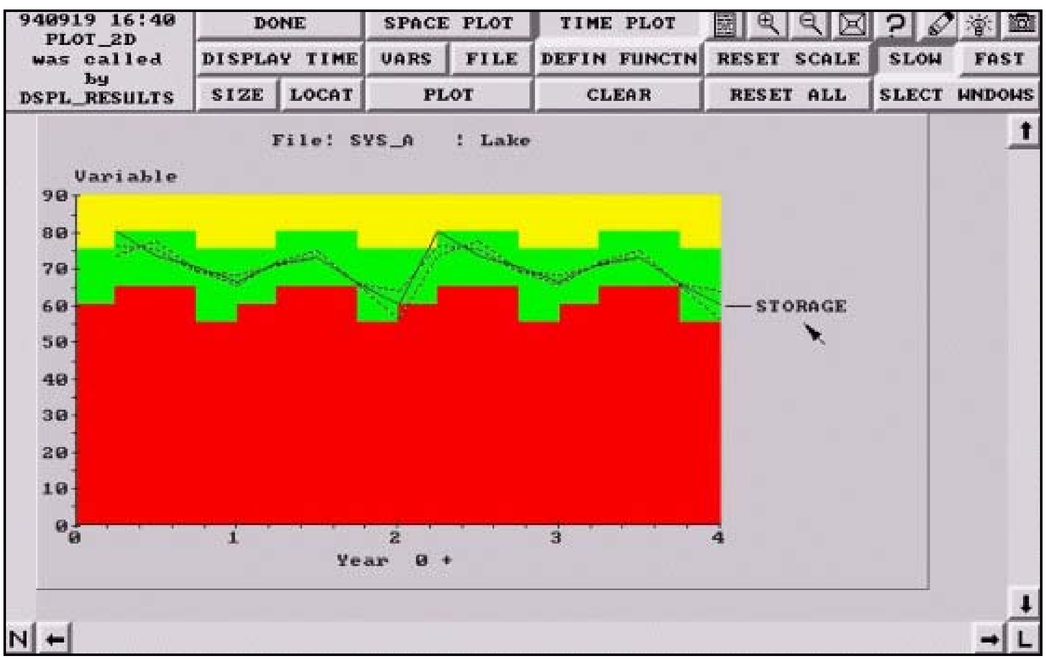


Figure 147 Coloured display of a lake storage over years

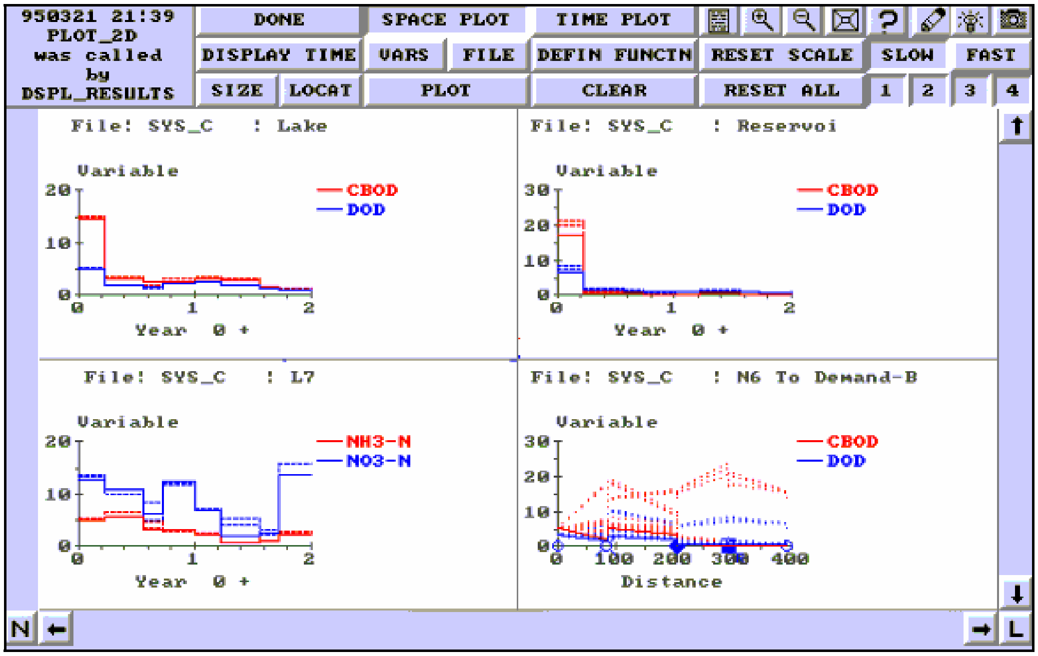


Figure 148 Displays water quality output data

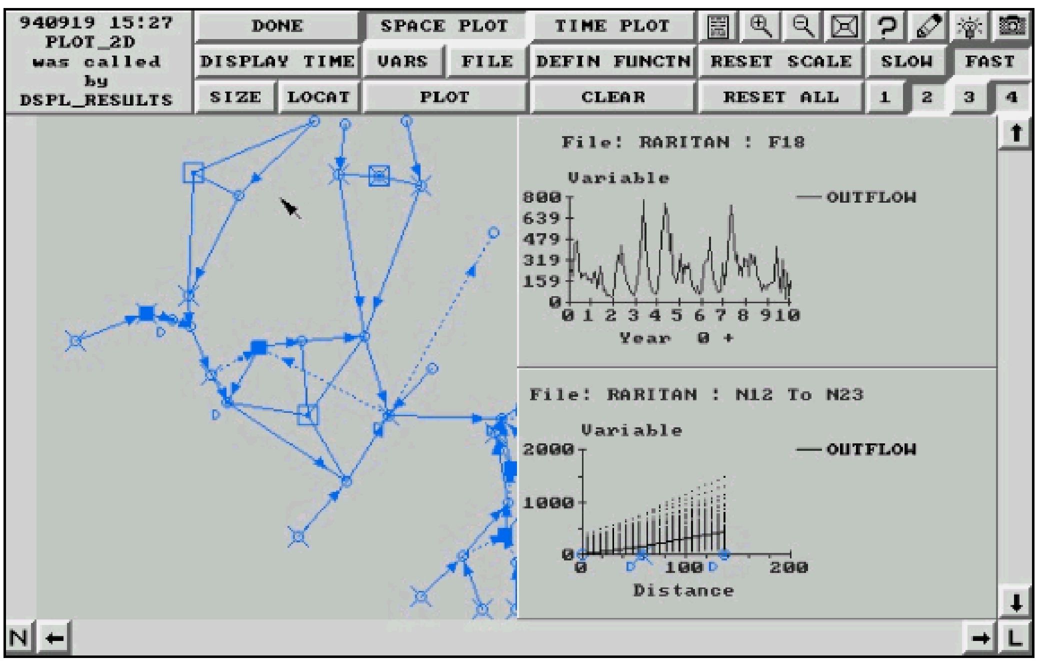


Figure 149 Displaying outflows from a node

Summary of Pros and Cons

IRAS does not use geo-referenced data and GIS software. It seems that economic analysis and relevant indicators are not taken into account. Moreover, the software package does not include a definition of scenarios and related management options and strategies. Also, the high number of different link types connecting the nodes may lead to confusion.

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Appendices

Basic WSM Glossary of Technical Terms

This appendix presents the definitions of some general and technical terms relevant to the Water Strategy Man Project, being used either within the Decision Support System or in the produced documentation of the Project outcomes.

General

ARIDITY – a permanent natural condition of lacking moisture especially relating to insufficient rainfall to support trees or woody plants;

ARIDITY INDEX – the aridity index AI of an area can be calculated by the Penman-Monteith calculation- AI=Precipitation/Potential Evapotranspiration. The values it can assume define the following classes: a) Hyperarid (AI<0.05), b) Arid (0.05<AI<0.2), c) Semi-arid (0.2<AI<0.5), and d) Dry subhumid (0.5<AI<0.65);

DROUGHT – indicates a temporary and prolonged status of dry weather caused by a continuous absence of rainfall;

WATER SHORTAGE – refers to water deficient conditions as a man-made and temporary phenomenon;

DESERTIFICATION – indicates a process of alteration of the ecological regime often associated with aridity and/or drought but principally brought about by man-made activities which change the surrounding ecosystem to a significant degree;

ACTION – the basic element of a policy option, defined at spatial and temporal scale;

CASE STUDY – The application of a Paradigm on a selected Region;

SCENARIOS – Developments that cannot be directly influenced by the Decision Maker such as Weather, Market Prices;

STRATEGY – the set of actions / sequence of responses to existing and emerging conditions, that is suited / available aiming at the fulfilment of a selected goal (in the case of the project the goal is that of Integrated Water Resources Management);

INTEGRATED WATER RESOURCES MANAGEMENT (IWRM) – a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems;

MULTI CRITERIA DECISION MAKING TECHNIQUES (MCDM) – Framework of techniques to address decisions characterised by a large set of alternatives and multiple, conflicting and incommensurate evaluation criteria;

PARADIGM – For the purposes of the WSM project, the word Paradigm describes a school of thought on prioritising during the selection of Policy Options, for the Management of Water Resources. The Dominant Paradigm is the current school of thought for each region; the shifting paradigm is an alternative prioritising of policy options, and respective actions, aiming at achieving Integrated Water Resources Management, which is slowly becoming a necessity due to the increasing challenges of managing the water resources, particularly in water deficient regions, in a sustainable way;

POLICY OPTION – an integrated water management issue to be addressed to support sustainable development. The following types of Policy Options have been defined in the

Syros workshop: Supply Enhancement, Demand Management, Development, Economic Principles, Environmental, Institutional and Social;

GUIDELINES – a set of (relatively generalised) instructions that analyse a strategy into actions required set within a time framework;

PROTOCOL OF IMPLEMENTATION – a set of step-by-step analytical instructions that need to be taken in order to affect a specific task in the framework of a strategy;

Indicators

INDICATOR [4]– a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon or an environment or an area, with a significance extending beyond that directly associated with a parameter value.

1st LEVEL INDICATORS – the basic data (model output) is the model output at node level (time series). Example: Time series of pollutants, deficits, etc. at a given node;

2nd LEVEL INDICATORS – time series of indicators at a spatially aggregated level (regional scale). However, some indicators cannot be aggregated in space and can only be evaluated on node level;

3rd LEVEL INDICATORS – they are preferably represented by a single number for a given strategy that is aggregated in both time and space of 2nd level indicators. Since the aggregation strongly depends on the DM's expectations, some guidance by socio-economists is needed;

RELIABILITY – it is the probability that a criterion value will be within the predefined range of satisfactory values, being defined as the ratio between the number of values in a satisfactory range and the total number of simulated values;

RESILIENCE – the number of times a satisfactory value follows an unsatisfactory value related to the total number of values. It indicates the speed of recovery of an unsatisfactory condition;

VULNERABILITY – it measures the extent or duration of failure. It is the amount of time the performance indicator exceeds the upper and lower limits of the satisfactory range, i.e. it falls outside the range;

RESOURCES TO POPULATION INDEX (RP) – it can be calculated as the estimation of total water resources in an area over the population (m3/person per year). Within the Water Strategy Man project, for RP< 200 (m3/person per year) critical conditions are developed and for RP< 100 (m3/person per year) severe water shortage problems exist;

CONSUMPTION INDEX (CI) – the percentage of water consumed in the area over the total water resources. Usually, high values of CI indicate possible water shortage problems and in particular values of CI > 100 % indicate exploitation of non-conventional water sources;

EXPLOITATION INDEX (EI) – the water distributed over the stabilized water resources. Values of EI > 1 indicate bad management of water resources in an area while values of EI < 1 indicate good management;

DPSIR[5]

DRIVERS – they reflect pressures exerted by natural phenomena and anthropogenic activities;

[4] OECD, Organisation for Economic Co-operation and Development
[5] Jay J. Walmsley, Framework for Measuring Sustainable Development in Catchment Systems

PRESSURES – They are exerted on the water resources as a result of the driving forces (e.g., increased pollution from domestic waste due to increased population and poor sanitation; increased consumption due to increasing economic activity);

STATE VARIABLES – they assess the current status of the water resource, in terms of quantity and quality for each habitat-ecosystem type;

RESPONSE – it relates to the social response via policies, laws, programmes and research etc;

IMPACT – assessment of the effect that a pressure has on the state of the water resource or on water-user groups;

Decision Support System

NODE – it is both a network element and an object representing a physical reality or item of a water resource system. In the latter case, the node is featured by specific properties and methods;

METHODS – equations attached to the nodes describing the evolution of each node status and behaviour over time;

PROPERTIES – attributes attached to the nodes defining their status and behaviour within the water resource system;

SURFACE IRRIGATION METHOD [6]– the application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders);

SPRINKLER IRRIGATION METHOD – Sprinkler irrigation is similar to natural rainfall. Water is pumped through a pipe system and then sprayed onto the crops through rotating sprinkler heads;

DRIP IRRIGATION METHOD – With drip irrigation, water is conveyed under pressure through a pipe system to the fields, where it drips slowly onto the soil through emitters or drippers, which are located close to the plants;

RIVER BASIN DISTRICT [7]– It means the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwater and coastal waters, which is identified as the main unit for management of river basins;

RIVER BASIN – the area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta;

RIVER SUB-BASIN – River Sub-basin means the area of land from which all surface run-off flows through a series of streams, rivers and, possibly, lakes to a particular point of a water course (normally a lake or a river confluence);

PROTECTED AREAS – they include many different areas such as:

a) Areas designated for the abstraction of water intended for human consumption;

b) Areas designated for the protection of economically significant aquatic species;

c) Bodies of water designated as recreational waters, including areas designated as bathing waters under Directive 76/160/EEC;

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[6] Definitions of irrigation methods are from FAO, Irrigation Water Management: Irrigation Methods - Training manual no. 5

[7] Definitions of river basins, protected areas, coastal waters and transitional waters are from WORKING GROUP GIS, Guidance Document on Implementing the GIS Elements of the WFD, 4th December 2002

d) Nutrient-sensitive areas, including areas designated as vulnerable zones under Directive 91/676/EEC (Nitrates Directive);

e) Areas designated as sensitive under Directive 91/271/EEC (Urban Waste Water Treatment Directive);

f) Areas designated for the protection of habitats or species where the maintenance or improvement of the status of water is an important factor in their protection, including relevant Natura 2000 sites designated under Directive 92/43/EEC (habitats) and Directive79/409/EEC (Birds);

COASTAL WATERS – it means surface water on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters;

TRANSITIONAL WATERS – they are bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows;

FAOSOIL [8]– it is the Soil Unit within the FAO soil map of the world;

FAO PHASES – phases are subdivisions of soil units based on characteristics which are significant to the use or the management of land but which are not diagnostic for the separation of soil units themselves. The phases are: stony, lithic, petric, petrocalcic, petrogypsic, petroferric, phreatic, fragipan, duripan, saline, sodic and cerrado;

CROP GROWTH STAGES (1) – INITIAL STAGE [9]– The crop initial stage runs from planting date to approximately 10% ground cover;

CROP GROWTH STAGES (2) – DEVELOPMENT STAGE – The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering;

CROP GROWTH STAGES (3) – MID-SEASON STAGE – The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit;

CROP GROWTH STAGES (4) – LATE SEASON STAGE – The late season stage runs from the start of maturity to harvest or full senescence;

Economics[10]

SUPPLY (OR FINANCIAL OR DIRECT) COST – represents the costs of investments, operation and maintenance, labour, administrative costs and other direct economic costs;

RESOURCE COST – represents the loss of profit because of the restriction of available water resources;

ENVIRONMENTAL COST – represents the cost from the damage on the environment and aquatic ecosystems caused by the water uses and services;

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[8] Definitions of faosoil and fao phases are from FAO, documentation about The Digital Soil Map Of The World

[9] FAO, Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56

[10] The Hebrew University of Jerusalem, Department of Agricultural Economics and Management, AND Office International de l' Eau, Service National d' Information sur l' Eau, France

RATE OF COST RECOVERY FOR WATER SERVICE – it is defined as the percentage ratio of the total income to water suppliers over the total cost of water production;

MARGINAL VALUE OF WATER – Rational water users would buy an additional unit of water as long as its price does not exceed the benefit they can derive from it. Thus, the marginal value of water to a user is the maximum utility (for urban consumers) or benefits (for producers) generated by the last water unit in use;

OPPORTUNITY COST FOR WATER – it represents the benefits forgone when a scarce water resource is used for one purpose instead of the next best alternative;

SCARCITY RENT OF WATER – rent per unit of a scarce water resource; it represents a surplus, the difference between the opportunity cost of water (equal to the market equilibrium price P) and the per unit (marginal) direct costs (such as extraction, treatment, environmental and conveyance) of turning that natural resource into relevant products (agricultural crops for farmers and water services for the residence of the urban centre);