

DELIVERABLE 11

INTEGRATED DECISION SUPPORT SYSTEM APPLICABLE TO THE PARADIGMS



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1. Preface

This document presents the concepts, the philosophy and the implementation of the Water Strategy Man Decision Support System. The package has been developed within the *WaterStrategyMan Project* (2002 - 2005), supported by the European Commission under the Fifth Framework Programme, and contributing to the implementation of the Key Action *Sustainable Management and Quality of Water* within the *Energy, Environment and Sustainable Development*. The Project partners who have been actively and directly involved in the DSS formulation, development and finalization are: the National Technical University of Athens, the Ruhr-University and ProGEA S.r.l. None the less, an invaluable support came from all the project partners, either contributing to the methodology definition or applying the software to their own case study: Office International de l'Eau, the Hebrew University of Jerusalem, Water Development Department (Governmental Department – Cyprus), INSULA (International Scientific Council for Island Development), Aeoliki Ltd, Faculdade de Engenharia da Universidade do Porto.

Current work represents the Deliverable 11 of the WaterStrategyMan Project and is structured as follows: first the Water Strategy Man Modeling Approach for the evaluation of water resources strategies is shown, then the DSS methodology is reviewed, and finally the usage of the tool is presented, with particular emphasis on the illustration of the graphical interface, the modules, the functionalities and the way to use them.

2. Introduction

The GIS-based Decision Support System developed for the WaterStrategyMan Project 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 special importance for the WSM DSS, being conceived as comprised by 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 strategies for management through mixes of control measures seeking optimum, efficient and 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.

3. The WSM Modeling Approach and Methodology

The 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 and properly customised databases, aim at:

- Describing the existing situation in a case study area, in terms of hydraulic and environmental characteristics of man-made and natural water systems;
- Assessing the state of the water system under 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, as above, on the basis of assumed or envisaged scenarios of the overall water availability in the region, and of the water demands from the side of the various and different types of users; forecasting the system under the chosen set of water strategies;
- Evaluating the impacts of the actions, by observing and analysing the results of forecasted scenarios, alternatives and policies, through a multi-criteria approach and consideration of local, national or international legal constraints and directives.

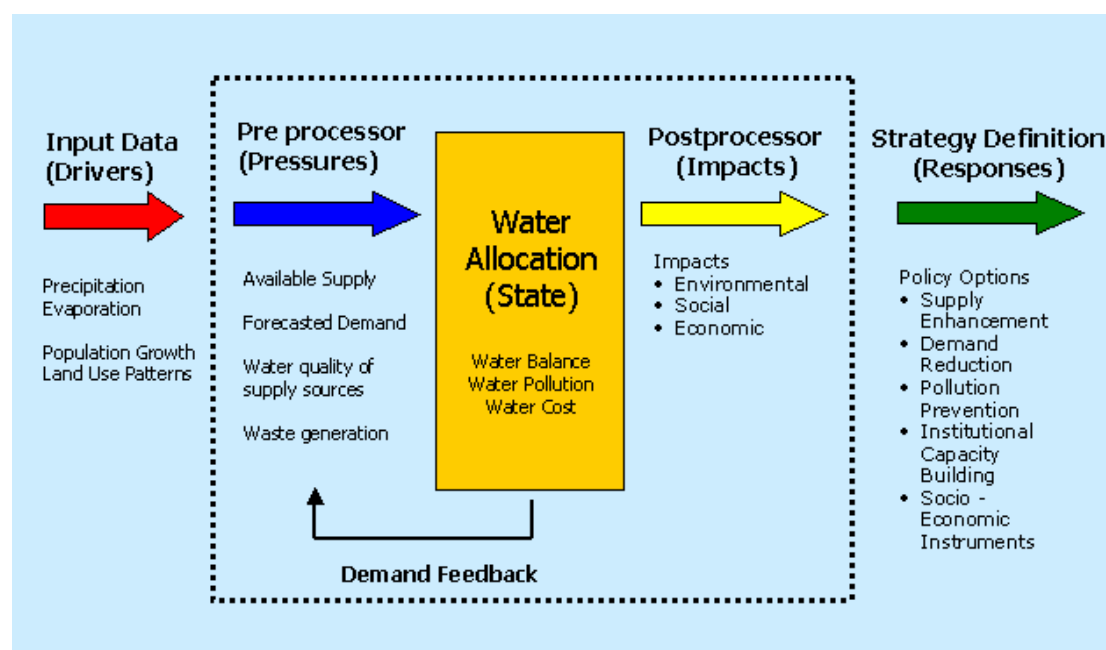


Figure 1. The framework of the Decision Support System

In order to facilitate the regional case study analyses, and pinpoint any water related problems, and a list of possible solutions, the main functions of the DSS have been

framed under the Drivers-Pressures-State-Impacts-Response (DPSIR) structure of indicators as proposed at European level by the European Environmental Agency.

The *Drivers*, defined as natural phenomena and anthropogenic activities that are not easily manipulated, are represented in the WSM DSS by climate changes, demographic growth and 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 in time, is one of the leading factors in determining the domestic water demand. The analysis of Drivers, and the definition of the Pressures they exert on the water resource system, are operated by the Pre-processors of the WSM DSS, namely 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 as well, before simulating the case study. The *State* of the system is described in terms of water allocated over the requested, of how water quality changes at both the water sources, users and treatment plants, and as a cost analysis of water services.

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 users, such as irrigation sites, settlements, animal breeders 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 assessment and presentation of environmental *Impacts* and the state of the system in general, such as high direct costs or insufficient cost recovery or user-conflicts under shortage conditions. From the multi-criteria examination of Impacts, 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.

3.1. Water Availability

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 of surface water, such as artificial or natural lakes and the river network system, and of groundwater, both renewable and fossil.

The availability module, which is part of the DSS pre-processor, reads the topologic water resource network and generates monthly time series of forecast available water for each water source node in the network. These availability scenarios and the demand scenarios generated by the demand module represent the basic information entering the allocation module of the package.

The 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, the *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 define a *Normal Year (Average)* of runoff and recharge (twelve monthly values) respectively, which is obtained from existing recorded data. Given the normal year, the user can create and customize new years, by editing monthly positive or negative rates with respect to the normal one. Then the availability scenario is constructed by customizing 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 through water balance computations on a watershed level. 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 of them. As far as meteorological data are concerned, twelve maps of precipitation, reference evapotranspiration and temperature, containing monthly data for the average year are used as input. The mean values computed at the watershed level are derived from these average year data.

The user can visualise the average water year of precipitation, reference evapotranspiration and temperature from the Graphic Interface and 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:

- 3) repeat the base year as it is for the entire duration of the scenario,
- 4) define a total increment over the entire period, either annual or monthly, thus defining an yearly or monthly trend, or
- 5) 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, in case where temperature scenarios are selected, an intermediate calculation is necessary. Because 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 is currently under development and validation by the WaterStrategyMan Methodology Team, to be next introduced in the water availability module. The idea consists in generating a certain number of forecast 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 by accounting for current moisture state, precipitation occurring, water evaporating, the rapid subsurface flow, water percolating to the aquifers water table and the water volume originating surface runoff, being these latter two 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 on the basis of the average year data maps. Actual evapotranspiration is computed from average year maps of reference ETP, crop factors according to the land use of the region, and the soil moisture state:

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

Where:

E = Actual evapotranspiration

E_{T0} = reference potential evapotranspiration

k_c = crop factor

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

$$\beta = \frac{W}{0.7 \cdot W_{\max}} \quad \text{if} \quad W < 0.7 \cdot W_{\max} \quad (3)$$

$$\beta = 1 \quad \text{if} \quad W \geq 0.7 \cdot W_{\max} \quad (4)$$

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):

$$W_{\max} = L \cdot (\varrho_s - \varrho_r)$$

The surface runoff R is computed as:

$$R = 0 \quad \text{if} \quad W < W_{\max} \quad (5)$$

$$R = W - W_{\max} \quad \text{if} \quad W > W_{\max} \quad (6)$$

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

$$I = \alpha \cdot k_{s,vert}$$

with:

$$\alpha = 0 \quad \text{if} \quad W < W_{\min} \quad (7)$$

$$\alpha = \frac{(W - W_{\min})}{(W_{\max} - W_{\min})} \quad \text{if} \quad W_{\min} < W < W_{\max} \quad (8)$$

$$\alpha = 1 \quad \text{if} \quad W > W_{\max} \quad (9)$$

Finally, the rapid subsurface flow is calculated as:

$$D = k_{s,hor} \cdot SD \cdot 2 \cdot \frac{L}{A} \cdot \alpha^{2.5} \quad (10)$$

with:

$k_{S,HOR}$ = vertical 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)

3.2. Water Demand

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

Within the water demand methodology, a specific formulation for scenario building has been adopted for each one of the different kinds of activity and water use, considered to be part of a generic water resource system. Those are:

- 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.

Besides 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 the water needs within a particular region the tool is applied to, but not necessarily the water of available resources within it are entirely used to meet home requirements only. In many areas of the world the water transfers between neighbouring zones are a usual and sometimes the only way to get water. In order to consider also this practice, a further water demand, namely *Exporting Demand*, has been introduced in the WSM tool, describing the amount of water to be allocated externally the region under study.

In the following paragraphs the approach to each demand type is presented, with more emphasis to 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 Settlement 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, but the presence of people visiting the agglomeration annually is not excluded a priori. To cope with that, growth rates for seasonal population are considered as well. Water demand for domestic use in year y and month m is computed as follows:

$$SettleDemand_{y,m} = (PermPop_{y,m} * ConsRatePerm_y * 30 + SeasonPop_{y,m} * ConsRateSeas_y) * (1 + DistributionLosses_y) \quad (11)$$

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)

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 be specified as well. Consumption rates and loss variables are defined yearly.

Domestic demand estimations are based on the following assumptions:

- Residential and tourist per capita demand are largely different, so they are treated as two separate factors, governed by own 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 is driven by meteorological factors such as reference evapotranspiration and precipitation, as well as by the types of cultivated crops, 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, as follows:

$$IRR_{net_i} = (Kc_i * ET_0 - P) \quad (12)$$

where:

*IRR*_{net} = 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 the 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 type of crop from the reference one. The Kc crop coefficient is different for the four stages of crop development, which usually appear during the growing. Those are:

- 1) the initial stage, running from planting date to approximately 10% ground cover,
- 2) the development stage, from 10% ground cover to effective full cover (where effective full cover for many crops occurs at the initiation of flowering),
- 3) 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
- 4) the late season stage, running from the start of maturity to harvest or full senescence.

The required information about the crops, 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:

$$GrossIRR = \frac{10}{Eff} \sum_{crops} \left[\frac{AreaCrop \cdot IRRnet}{1 - LR} \right] \quad (13)$$

where:

$GrossIRR$ = Gross Irrigation Water requirement (m^3 /month)

$AreaCrop$ = area cultivated with the generic crop (ha)

$IRRnet$ = net irrigation requirement (mm/month)

LR = leaching requirement factor

Eff = global efficiency

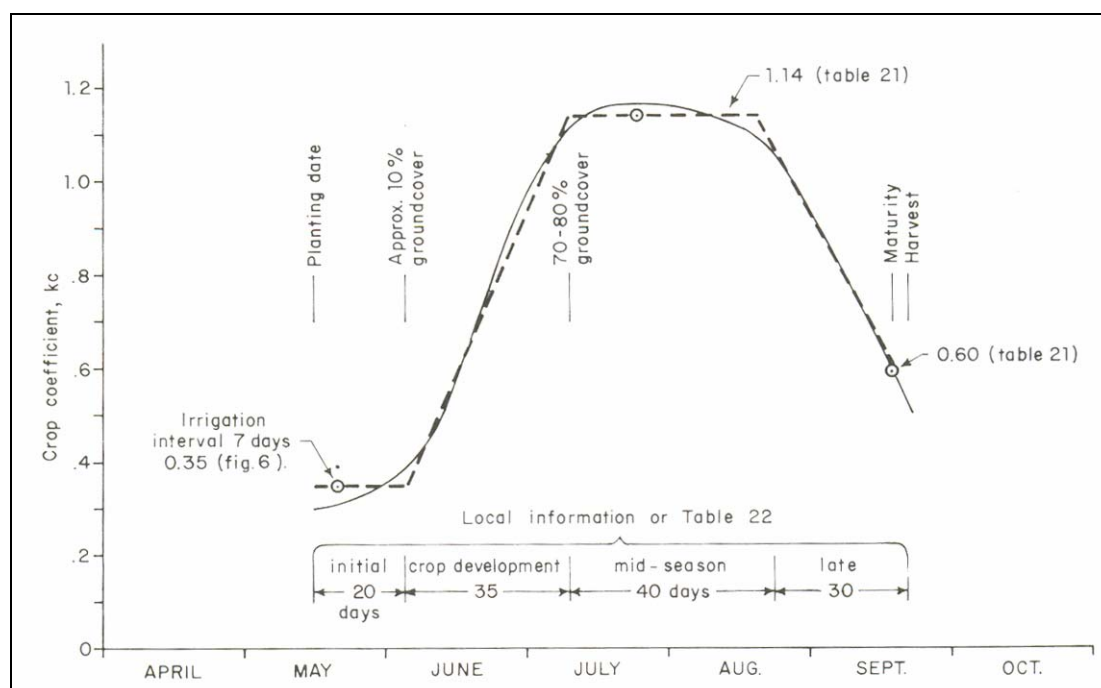


Figure 2 Example of Crop coefficient curve (from FAO, 1977)

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:

- 1) conveyance efficiency, relating the path from the abstraction to the network,
- 2) distribution efficiency, referring to the losses in the distribution network, and
- 3) application efficiency, representing the amount of water that really 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:

For surface irrigation and sprinkler:

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad (14)$$

For drip and high frequency sprinkler:

$$LR = \frac{EC_w}{MaxEC_e} \quad (15)$$

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 climatic 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 about the average amount of water requirement for each kind of cultivated crop 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 items, 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:

$$E = \int_{t=0}^T Q \cdot H \cdot g \cdot e \cdot dt \quad (16)$$

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 kinds of requirements the demand scenarios are assumed to be annually stable over the simulation period and only a monthly distribution should be provided.

3.3. Water Allocation

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. The water network elements are represented by a schematic network of nodes and links, where the former symbolise physical entities such as settlements, lakes and treatment plants and the latter stand for man-made or natural water conduits such as pipelines, canals and river reaches. The framework of the network is constructed by connecting the nodes with links according to their physical locations in the water resource system.

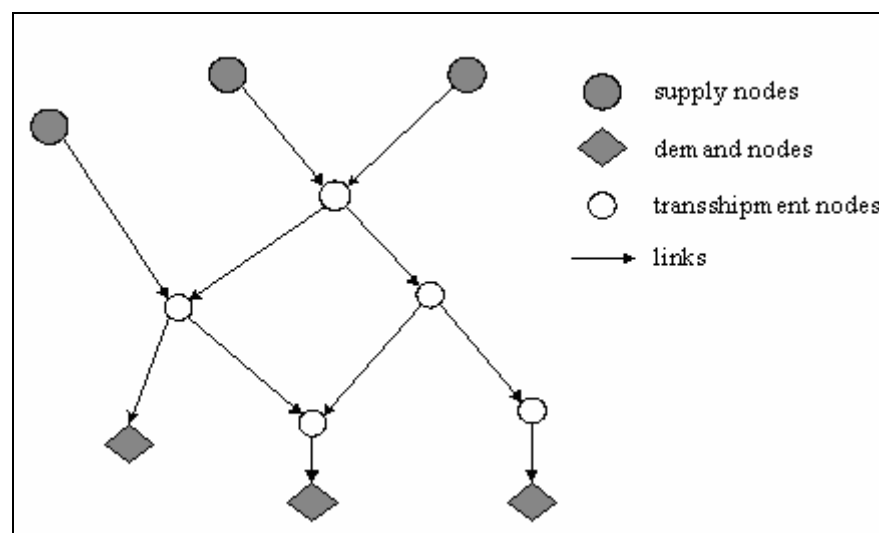


Figure 3 Network representation of a water resource system

The network nodes are classified into three categories:

- 1) Supply Nodes,
- 2) Demand Nodes, and
- 3) Transshipment 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. In the following paragraphs the main types of nodes that have so far been considered and modelled within the DSS are presented.

Supply Nodes conceptually provide water to demanding users through the outgoing links, thus having a water source function, but some of them have also ingoing links, so functioning as water accumulators or final receptor body. Those are:

- *Renewable Groundwater* - this node represents 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* – this node represents 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* – a river and his 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)* – this node represents three kinds of reservoirs: a man-made storage reservoir fed either by a natural water course 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* - it represents the amount of water coming from a neighbouring area. As a supply node it has the role of water source.
- *Fossil Groundwater* – this node represents 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 zero recharge.

Demand nodes are:

- *Settlement* – it describes the civil urban population and infrastructures of a defined area, i.e. a city, a town or a village.
- *Tourist site* – this node represents a tourist community originating a seasonal water demand.
- *Irrigation Site* – this demand node represents the activity of cultivating land either for the survival of land-owners or for commercial purposes.
- *Industrial Site* – this node describes a productive reality producing or supplying goods, services etc. An Industrial Site can be public or private. It is also characterised by its field of application: Petrochemical, Electronics, Aerospace, Food and Beverage, Pulp and Paper, Textile etc
- *Animal Breeding* - it is a demand node describing the activity of animal breeding.
- *Exporting* – it represents the amount of water to be exported to a neighbouring area.
- *Hydro-electricity production* – this node 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* – they represent non-consumptive demand nodes that are created to address the minimum water requirements of rivers or the water needs for recreational purposes and navigation in rivers.

Three types of Treatment Plants are considered in the DSS:

- *Drinking Water Treatment Plant* - this node represents a plant treating water in order to make it safe and acceptable for human use.
- *Wastewater Treatment Plant* – this node represents a plant treating water in order to remove or at least abate pollutants' concentration before water is re-used or discharged into a body of surface water.
- *Desalination* – this node represents a plant removing dissolved salts from seawater, brackish waters of inland seas or highly mineralized groundwater.

One Transshipment Node has been formalised:

- *Network Reservoir* – It represents a physical reservoir of very small capacity, around 2000 m³, 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.

The links of the conceptual water network have two generic characteristic variables: a) the link capacity, which represents the maximum monthly flows allowed, and b) the monthly flow rate, that is the decision variables of the problem. The types of link that have been conceptualised in the WSM are:

- *Canal* - this is supply link carrying water through a open-air artificial waterway. It can connect rivers to agricultural sites;
- *Pipeline* - this type of supply link represents long pressure pipes conveying water from reservoirs or rivers to demand nodes or treatment plants;
- *River Link* - it connects river reach nodes. River links are drawn automatically when new river reach nodes are placed on the river map in the Map Editor Window;
- *Groundwater Link* - it carries recharges to aquifers from rivers or discharges from aquifers to rivers, lakes or the sea;
- *Return Flow Link* – it carries water outgoing the consumptive demand nodes.

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). By default, a priority of 1 is assigned to each link. 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.

$$\text{minimize } \sum_{\text{all demand nodes } i} \left(d_i - \sum_{\text{all incoming links } j} f_j \right) \quad (17)$$

Supply constraints associated with all supply nodes:

$$\sum_{\text{all outgoing links } j} f_j - \sum_{\text{all incoming links } j} f_j \leq s_i \quad (18)$$

Demand constraints associated with all demand nodes:

$$\sum_{\text{all incoming links } j} f_j - \sum_{\text{all outgoing links } j} f_j \leq d_i \quad (19)$$

Flow conservation constraints associated with all transshipment nodes:

$$\sum_{\text{all outgoing links } j} f_j - \sum_{\text{all incoming links } j} f_j = 0 \quad (20)$$

Capacity constraints associated with all links:

$$0 \leq f_j \leq c_j \quad (21)$$

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 non-negative link flows, satisfying the conditions that no link's flow is greater than the link's capacity (Eq. 21) and that the total flow into each internal node is equal to the total flow out of that node (Eq. 20). 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, also known as the Augmenting-Path Maxflow algorithm.

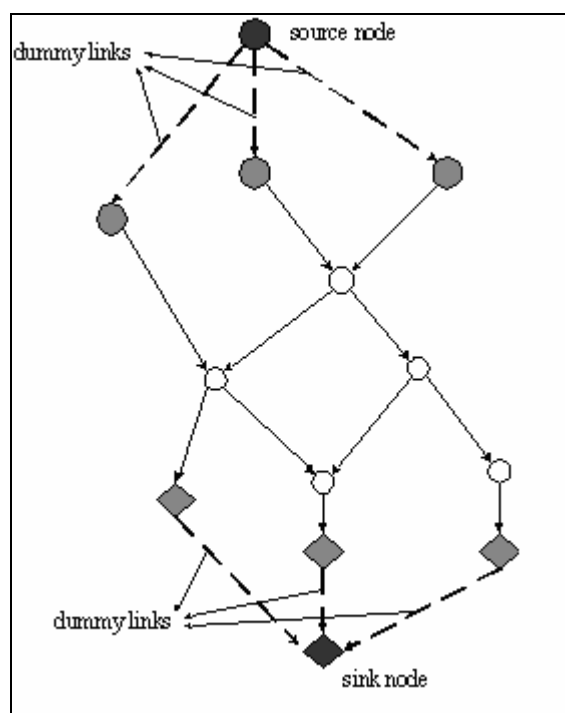


Figure 4 Network transformations

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.

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.

A 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.

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:

$$V_t = V_{t-1} + U_t + RF + R - REL - E - S - RuleREL \quad (22)$$

where:

$$SPIL = V_t - StorageCapacity \quad \text{if} \quad V_t > StorageCapacity$$

$$V_t = StorageCapacity$$

and

$$D = RuleREL + SPIL$$

with:

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.

The river 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:

$$D = U + R + GWF + SR - Abs - GWT \quad (23)$$

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_{RUP}) 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 balance.

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

$$V_t = V_{t-1} + INF + IRR + GWT + AGWT - P - B \quad (24)$$

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:

$$BS = w * (INF + IRR + GWT) \quad (25)$$

with :

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

At this point, as a sort of appendix to the water allocation chapter, two simplified examples of water allocation are presented.

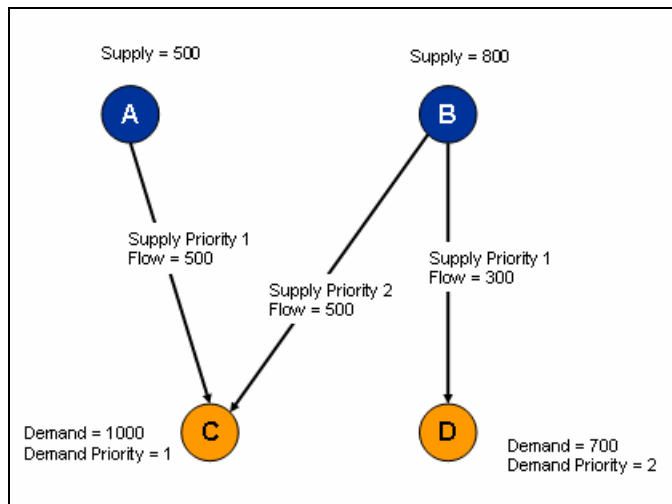


Figure 5 Example 1 of water allocation

In the first example 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 asking for 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: because C has the higher priority, its demand is satisfied first and, according to the supply priorities on the links, the water from the A node is allocated first with respect to the water supplied by 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.

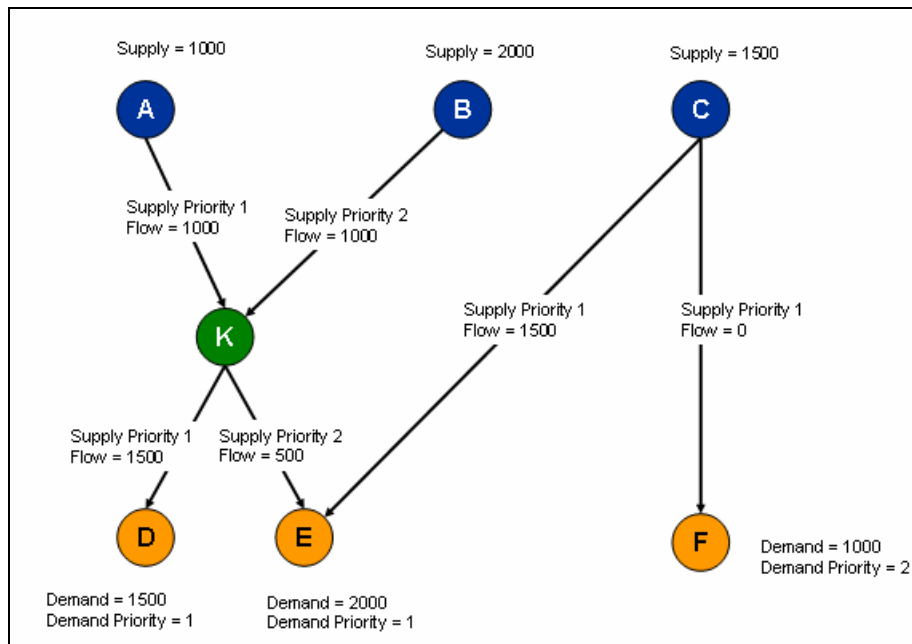


Figure 6. Example 2 of water allocation

In this second example of water allocation, 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, or another water source node 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 his side, node D asks node K for his entire demand 1500. Supply nodes A and B have enough water resource to satisfy the requirement of 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 as a consequence the resource at A has to be allocated first.

3.4. 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, climatic 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 is that water flowing in the water links (computed at each time step by the Water Allocation Model) has the same concentration as the water sources (supply nodes) it comes from, and it does not change during the transfer towards the demand sites (if of course the path does not intersect any treatment plants). 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 of:

- 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.

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 of them, 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:

$$\frac{di}{dt} = -A \cdot i + B \quad (26)$$

with an analytical solution of the type:

$$i = i_0 \cdot e^{-At} + \frac{B}{A} \cdot (1 - e^{-At}) \quad (27)$$

The specific equations for each quality variable are presented below.

Volume V of the water body:

$$\frac{dV}{dt} = I - O \quad (28)$$

where:

I = water flow entering the water body

O = water flow exiting the water body

Salinity S :

$$\frac{d(S \cdot V)}{dt} = Load(S)_{in} - O \cdot S \quad (29)$$

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.

$$Chla = \alpha_0 * A \quad (30)$$

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

$$\frac{d(A \cdot V)}{dt} = Load(A)_{in} - O \cdot A + V \cdot [(\mu - \rho - \sigma_1) \cdot A] \quad (31)$$

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 :

$$\frac{d(N_1 \cdot V)}{dt} = Load(N_1)_{in} - O \cdot N_1 + V \cdot [-\beta_1 N_1 - F_1 \alpha_1 \mu A] \quad (32)$$

with

$$F_1 = \frac{P_N N_1}{P_N N_1 + (1 - P_N) \cdot N_3} \quad (33)$$

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:

$$\frac{d(N_3 \cdot V)}{dt} = Load(N_3)_{in} - O \cdot N_3 + V \cdot [\beta_1 N_1 - (1 - F_1) \alpha_1 \mu A] \quad (34)$$

with

$$F_1 = \frac{P_N \cdot N_1}{P_N \cdot N_1 + (1 - P_N) \cdot N_3} \quad (35)$$

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:

$$\frac{d(E \cdot V)}{dt} = Load(E)_{in} - O \cdot E + V \cdot [-k_5 \cdot E] \quad (36)$$

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):

$$\frac{d(BOD \cdot V)}{dt} = Load(BOD)_{in} - O \cdot BOD + V \cdot [-(k_1 + k_3) \cdot BOD] \quad (37)$$

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 = deoxygenation rate coefficient

k_3 = rate of BOD loss due to settling

Dissolved Oxygen (DO):

$$\frac{d(DO \cdot V)}{dt} = Load(DO)_{in} - O \cdot DO + V \cdot [k_2(DO^* - DO) + (\alpha_3\mu - \alpha_4\rho) \cdot A - k_1 \cdot BOD - \alpha_5\beta_1 \cdot N_1] \quad (38)$$

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 = deoxygenation rate coefficient

k_2 = reoxygenation 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 1. 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
Deoxygenation 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
Recreation 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
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	$\mu\text{g-Chla/mg-A}$
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 to be 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 generic 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 so as to consider the different monitored conditions over one-year period. The equation used is the following:

$$X_{t+1} = X^o_{t+1} \cdot (Load(X)_t / Load(X)^o_t) \quad (39)$$

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 the quality variables.

Water quality at supply nodes changes at each time step due to incoming loads carried by return flows from demand nodes and treatment plants. The loads at the exit of each waste water treatment plant are computed based on removal rates the DSS user has to assign to each quality variable before running the simulation. 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 user-defined as well: a rate per unit of activity level is specified for each quality variable (Table 2).

Table 2. 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

3.5. Economic Analysis

The economic analysis in the WSM DSS consists of a tentative implementation of the principles associated to the estimation of the *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 the water uses and services.

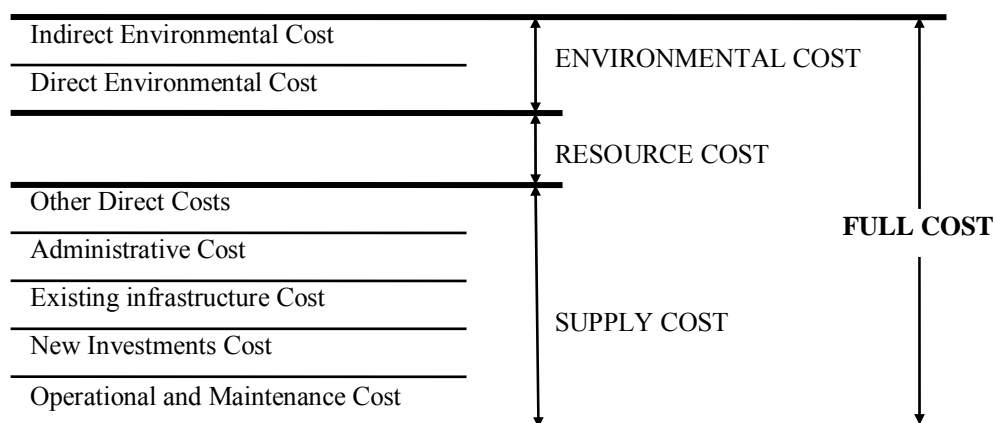


Figure 7. Components of the full cost of water services

For describing the formulation for the estimation of Resource Costs in the WSM DSS, 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 to be 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 following equations express the economic parameters involved in the calculation of the cost recovery for water, which is defined as the percentage ratio of the total revenues from water billing over the total cost of water production (including environmental and

resource costs). As far as the latter, the cost of water supply for each water source is computed first and then that is summated over the sources to get the total cost.

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:

$$TDC_i = \sum_j C_{ij} \cdot Q_{ij} \quad (40)$$

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

$$TDC = \sum_i TDC_i \quad (41)$$

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 user j :

$$TR = \sum_i \sum_j P_{i,j} \cdot Q_{i,j} \quad (42)$$

Note that, in case the price of water from source i allocated to user j is to equal 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:

$$TV_j = \sum_i V_i \cdot Q_{i,j} \quad (43)$$

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

$$PWS = \sum_j PWS_j = \sum_j \left(TV_j - \sum_i P_{ij} \cdot Q_{ij} \right) \quad (44)$$

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:

$$SWS = TV - TC = \sum_j TV_j - \sum_i TC_i \quad (45)$$

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 which incorporates only direct costs is equal to 1 and the private water surplus equals the social water surplus. If prices are subsidized, prices are lower than costs and 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.

The estimation of environmental costs (EC) is based on the current practices of French Agences de l'Eau. 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 disposal of effluents after treatment (including return flows from irrigation). 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:

- a) 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 current users;
- b) the polluter doesn't pay for the damage he caused;
- c) 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 Table 3.

Table 3. 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

Name	Definition
	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	<p>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:</p> <p>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.</p> <p>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.</p>
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 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

Name	Definition
	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 be given either by monitoring measurements or estimated. Other variables defined for each quality parameter are involved in the environmental cost estimation: the charge rates R in euros per unit concentration, and a coefficient $Coef$, that take into account the sensibility of the aquatic ecosystem. The equation used for each quality variable QW is:

$$EnvCostPollution_{QW} = A_{QW} \cdot Coef_{QW} \cdot R_{QW} \quad (46)$$

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

The environmental cost for a quality variable represents 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), that is should equal the total of investment, maintenance and operation costs of treatment for each quality parameter, both waste water 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, namely the Bonus Annual coefficient. This value is defined for each quality variable as its pollution abatement coefficient, estimated according to an overall appreciation of the wastewater process operation effectiveness. The equation expressing the environmental benefit (EB) by waste water treatment for all the QW quality variables is:

$$EB = \sum_{QW} (A_{QW} \times Coef_{QW} \times R_{QW} \times BonusAnnualCoef_{QW}) \quad (47)$$

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

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

$$EnvCost_{Abs,Cons} = [Abs \cdot Abs_{CB} \cdot (AreaCoef + ImpactCoef)] + [Cons \cdot Cons_{CB} \cdot (AreaCoef + ImpactCoef)] \quad (48)$$

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. The Area coefficients vary according to type of the water resource, either surface or groundwater, and to the intake localisation, 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:

- a) $Abstraction > Y \text{ m}^3$ during the reference period in no over exploited area
- b) 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 $X \text{ m}^3$, 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.

The supply cost, or Direct cost is another component of the full cost of water. It comprises of:

- a) Operating cost: all costs needed to maintain the operation of an environmental facility (e. g. material and staff cost).
- b) Maintenance cost: cost for maintaining existing (or new) assets in good functioning order until the end of their useful life.
- c) 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).
- d) Administrative cost: administrative cost related to water resource management.
- e) Other direct cost: this mainly consists of the costs of productivity losses due to restrictive measures.

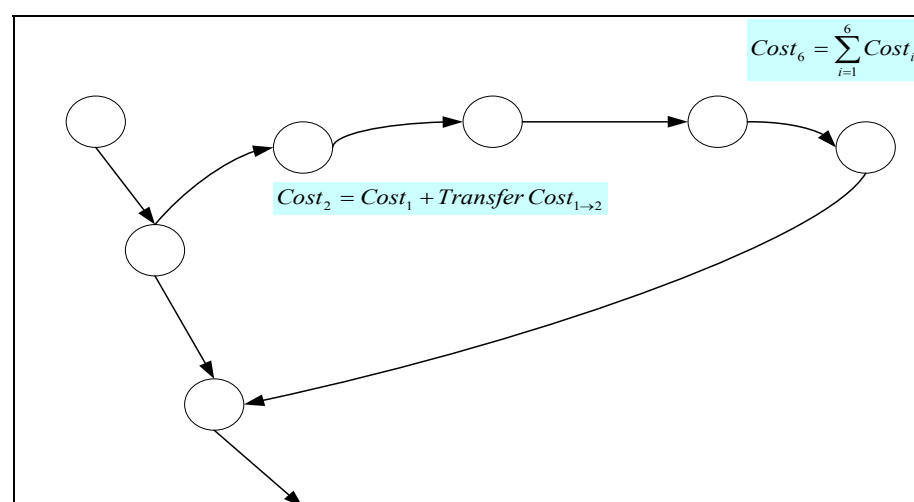


Figure 8. Example of direct cost estimation for a settlement (node 6 - city)

In the WSM DSS the direct cost of whatever node A, taking water from the water source B, both belonging to the regional water resource network, is computed by summing the direct costs and the transfer costs of all the nodes along the water path connecting them. 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.

The direct cost of each node is based on the present value of the different parts of the infrastructure. Present values can be estimated by using one of the following methods:

- a) Historical value (used as methods of valuation of capital asset): It is the value of assets at the price they were originally purchased. Because of inflation, this value bears no relation with what it would actually cost today to replace those assets – therefore, it is not the best measure for estimating economic costs.
- b) Current value (used as methods of valuation of capital asset): It is the historical value multiplied by an inflation index. Calculating this value raises a number of issues:
 - Estimating the inflation index may be open to interpretation [should the general inflation or the construction (or consumer) price index be used];
 - This method does not take into account technical progress: a water treatment plant that costs a given amount 10 years ago might cost half today thanks to technical progress.
 - However, this method is relatively easy to apply and is more appropriate than the historical value method.
- c) Replacement value method (used as method of valuation of capital asset). This method estimates the present value of an asset from the current cost of replacing it for an identical service level. The advantage of this method is that it allows taking into account technical progress. However, it might be difficult, costly and time-consuming to apply to all the capital stock.

For the evaluation of the Direct Cost (DC) per m³ for the entire time horizon, all fixed and variable costs should be estimated in present value (PV) terms:

$$DC = \frac{PV_{Fixed\ cost} + PV_{Variable\ cost}}{PV_q} \quad (49)$$

where *Fixed cost* refers to capital-investment costs while *variable costs* are the Operation, Maintenance and Energy Costs, Running Costs in the DSS, which depend on the monthly flows in network links computed by the allocation module of the DSS. For the estimation of energy cost, a 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 cost of water production. The present value of quantities allocated to demand nodes, for the entire simulation time horizon T , is computed through the annual real interest rate r relevant for the investor, the price P per unit of supplied water charged by the water company, and the annual quantity of supplied water Q :

$$PV = \sum_{t=0}^T \frac{P \cdot Q_t}{(1+r)^t} \quad (50)$$

3.6. Evaluation¹

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 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 statistical criteria that are calculated for each scheme and based on a predefined list of indicators. More specifically, the procedure to get the final score of one WMS is the following:

- a) The desired indicators, on which the evaluation will be based, must be selected (activated). Weights and least and maximum acceptable values must be assigned for each of them according to the specific goals of the case study and the decision maker;
- b) 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;
- c) Statistical criteria are normalised where necessary and then aggregated in the sustainability index;
- d) 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 and sensible score of sustainability, the user should pick up and activate those indicators that strictly pertain the water system simulated and the strategy 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.

¹ The methodology for the Evaluation module has been adapted from “Sustainability Criteria for Water Resource Systems” (Task Committee on Sustainability Criteria, Water Resources Planning and Management Division), American Society of Civil Engineers – ASCE.

The lower and upper limits of the satisfactory field of values are not fixed, although suggested usual ones are proposed; they can be assigned by the user of the DSS properly: they are the least and maximum acceptable values mentioned in point a) above. The first represents the lower, minimum satisfactory value the monthly 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, and also how good or bad they are.

Let's consider a selected indicator C , whose time series of values is denoted as C_t (Figure 9).

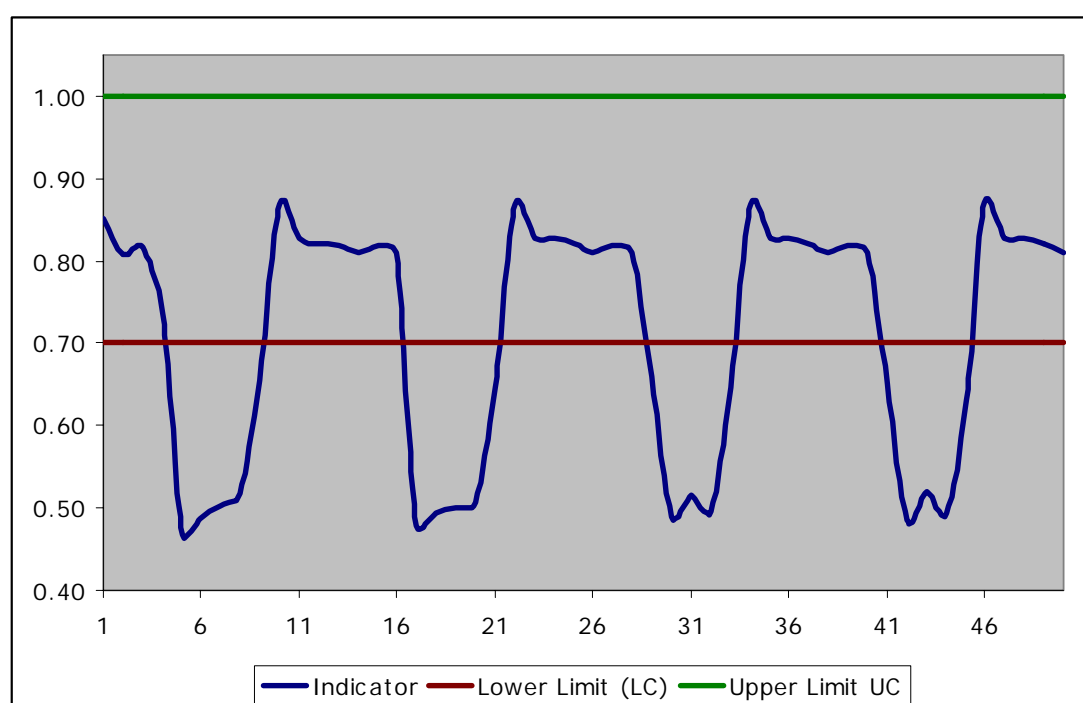


Figure 9. Domestic coverage time series and range of satisfactory values

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

$$\text{Reliability of } C = \frac{\text{Number of satisfactory } C_t \text{ values}}{\text{Total number of simulated periods}} \quad (51)$$

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:

$$\text{Resilience of } C = \frac{\text{Number of times a satisfactory } C_{t+1} \text{ value follows an unsatisfactory } C_t \text{ value}}{\text{Total number of unsatisfactory values}} \quad (52)$$

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 criterion by three indices, namely a Conditional Expected Extent or simply extent, the Maximum Extent and the Expected Duration. They are defined as follows (Eq. 53-55):

$$\text{Conditional Expected Extent – Vulnerability of } C = \frac{\sum \text{individual extents of } C_t \text{ failures}}{\text{Total number of individual extents of } C_t \text{ failures}} \quad (53)$$

$$\text{Maximum Extent – Vulnerability of } C = \text{Max}[0, \text{LowerLimit}C_t - C_t, C_t - \text{UpperLimit}] \quad (54)$$

$$\text{Expected Duration – Vulnerability of } C = \frac{\text{Total Number of failures}}{\text{Number of continuous failures}} \quad (55)$$

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. As a consequence, 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 criterion 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. That defines the *Relative Vulnerability* of each the criterion:

$$\text{Relative Vulnerability of } C = \frac{\text{Vulnerability of } C}{\text{Max Vulnerability among all WMS}} \quad (56)$$

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:

$$\text{Sustainability}_C = [\text{Reliability}_C] * [\text{Resilience}_C] * [1 - \text{Relative Vulnerability Duration}_C] * [1 - \text{Relative Max Extent}_C] * [1 - \text{Relative Extent}_C] \quad (57)$$

The Sustainability_C 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:

$$Relative\ Sustainability_C = \sum_C W_C * Sustainability_C \quad (58)$$

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 the most sustainable with respect to the indicators selected, the values of each criterion that are considered satisfactory and the relative weights.

4. Using the Decision Support System

This chapter describes the use of the DSS in terms of graphical user interface, main functionalities and the implementation of the methodology as presented in chapter 3. The sections of the chapter have been structured according to a specific sequence of steps as to guide the reader throughout the building of a case study and its analysis through scenarios and strategies. First the main panels and menus of the interface are presented, then the construction of water availability and demand scenarios is addressed. Finally, strategy definition and case study evaluation are explained.

4.1. DSS Opening, Menus and Operating Interface

When running the Decision Support System for the first time, after the Splash Screen (Fig. 10), a small window appears, showing the flags of the case study countries of the WaterStrategyMan Project. The user is prompted to choose the flag/country where the region he wants to study is, and add this region, as a new one. In order to load a region, he has to browse for the regional Geodatabase, containing all information needed by the DSS to run properly, and for a folder containing a set of maps in raster and shapefile format, including the Digital Elevation Model (DEM), climatic and soil data.

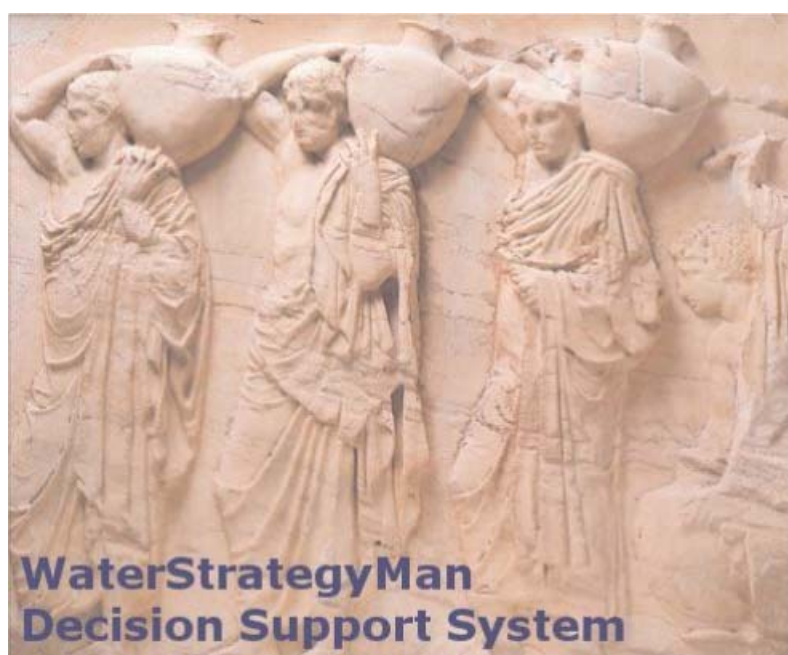


Figure 10. The Splash Screen Image of the DSS

Then the main graphical user interface opens, with the **Navigation Panel** on the left. This panel is always loaded, whatever functionality or sub-module is running, and presents the Base Case and the list of Water Management Schemes. The Base Case represents the regional case study as it is when loaded to create the region. So, its geodatabase contains all the most recently measured data that characterize 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 the available information and the

conceptual network of nodes and links which schematize the water system of sources, demand uses and treatment plants. The data entry or network modifications can be done in the relevant windows accessed by the *Edit Base Case Data* menu of the Base Case, in the Navigation panel.

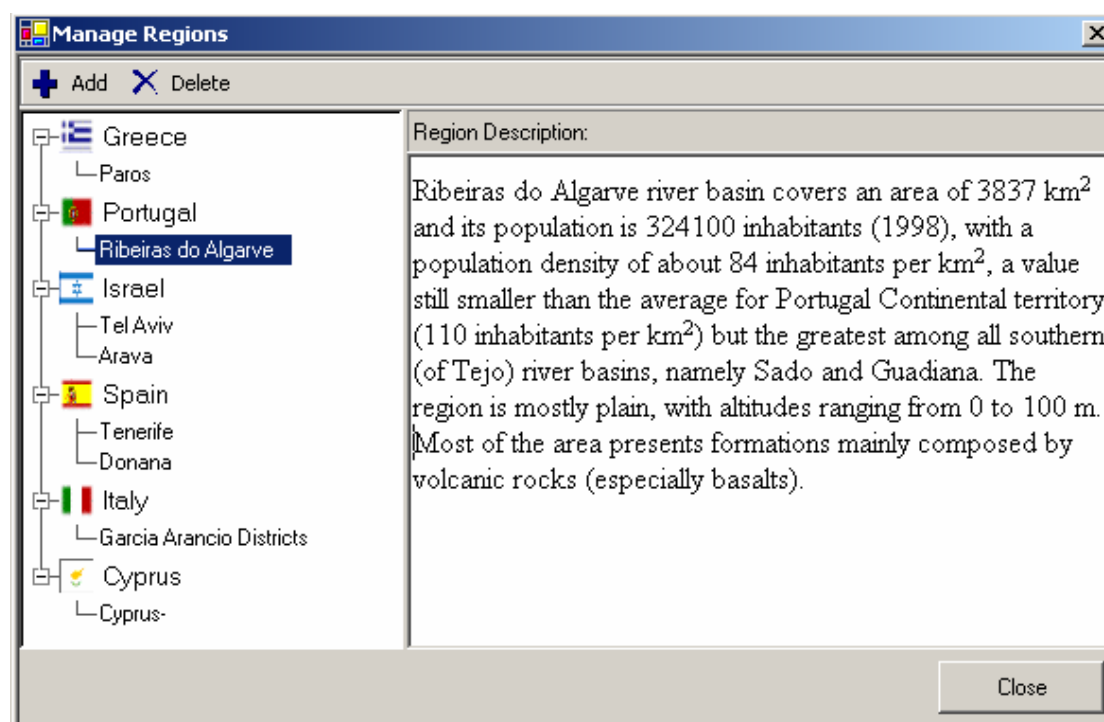


Figure 11. The Window for managing the case study regions loaded on the DSS

The Water Management (WMS) Schemes are based on the Base Case, in the sense they are created as copies of it, and are the actual object of the DSS analysis. For each scheme, the water allocation from sources to demand sites will be simulated under user-generated scenarios of water availability and/or demand, and strategic options selected and applied to particular time periods. Each WMS works with the data of the base case at the beginning (when created), but both data and the water network can be modified, thus customizing the scheme according to the type of analysis and objectives of the Decision Maker.

The two main menus of the graphical interface are *Main* and *Basic Data*. The latter is described in the data editor paragraph. The *Main* menu is responsible for opening the *Manage Regions* window to add or remove case study regions, choose which country and related region to work with, and create, rename or delete new or existing water management schemes. As already said, the WMSs the user generates appear listed in the Navigation panel, just under the Base Case. The selection of one of them provokes the opening of its connected geodatabase and the loading of all the network maps and information needed to run the simulation. Then a tree view expands under the scheme name, presenting the menus that will support the user throughout modelling and evaluation. Three are the categories of commands: *Create Scenario*, divided into *Availability* and *Demand* sub-menus, *Create WMS*, including the *Modify Map*, *Modify Data* and *Apply*

Strategy, and *Simulation*, with the *Overview*, *Cost Analysis* and *Detailed Results*. Each menu and the related DSS module are presented in the pertinent sections of this document. Here just the Modify menu is considered, as it loads another important and useful interface panel, the **Object Manager**.

The **Object Manager** is also a tree view form, opening next to the Navigation Panel. It presents the nodes and the links of the water network, classified by type, firstly according to their water function 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 by click on the plus sign or collapsed, by clicking on the minus sign, according to the desired level of detail. Each type of node is marked with its own coloured symbol, such as circles, squares or rhombi. This symbol characterizes each node on the regional map that displays the water network and the physical features. Each network node/link has a user-defined name, and its unique identifier (ID) that appears next to the name in brackets. The Object Manager is used to navigate through the network in order to get node or link-specific data or information when used in combination with the Data and Map Editors of the WSM DSS.

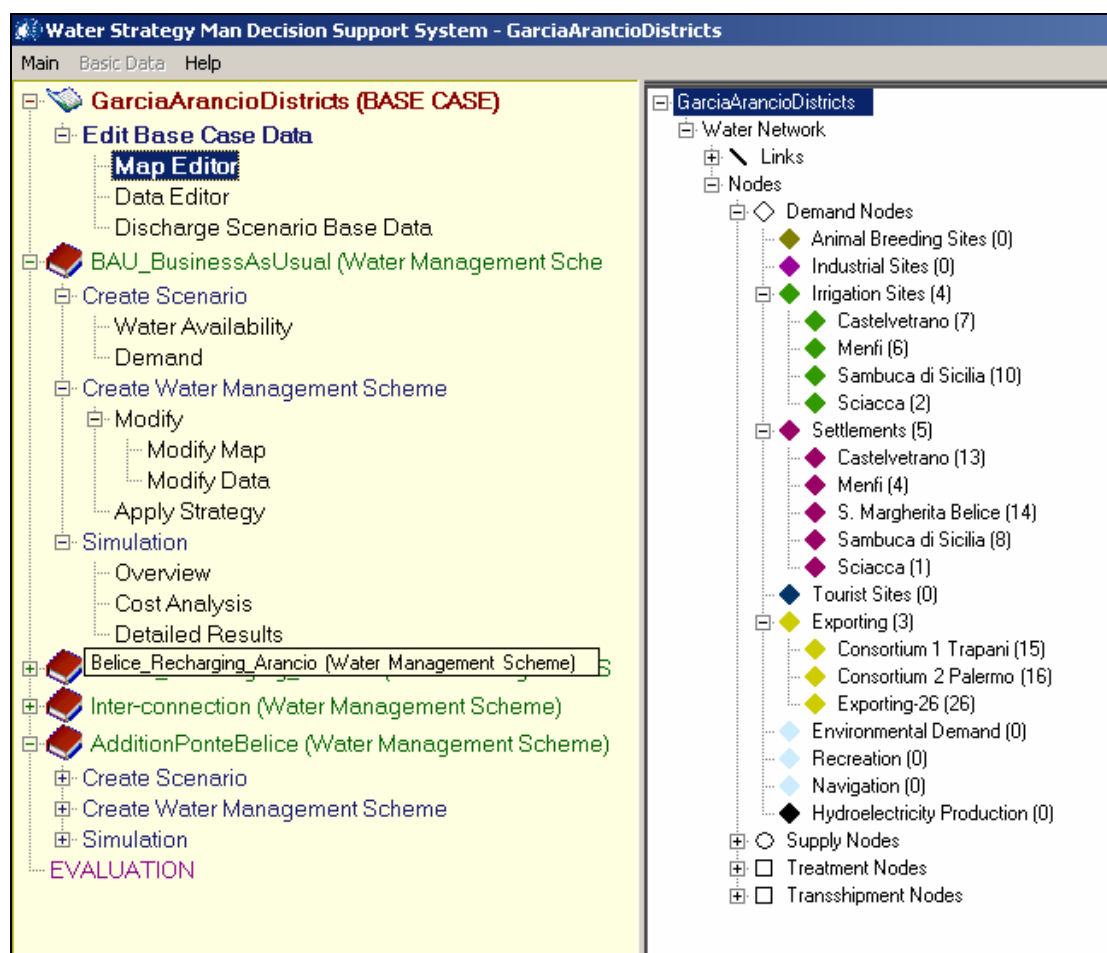


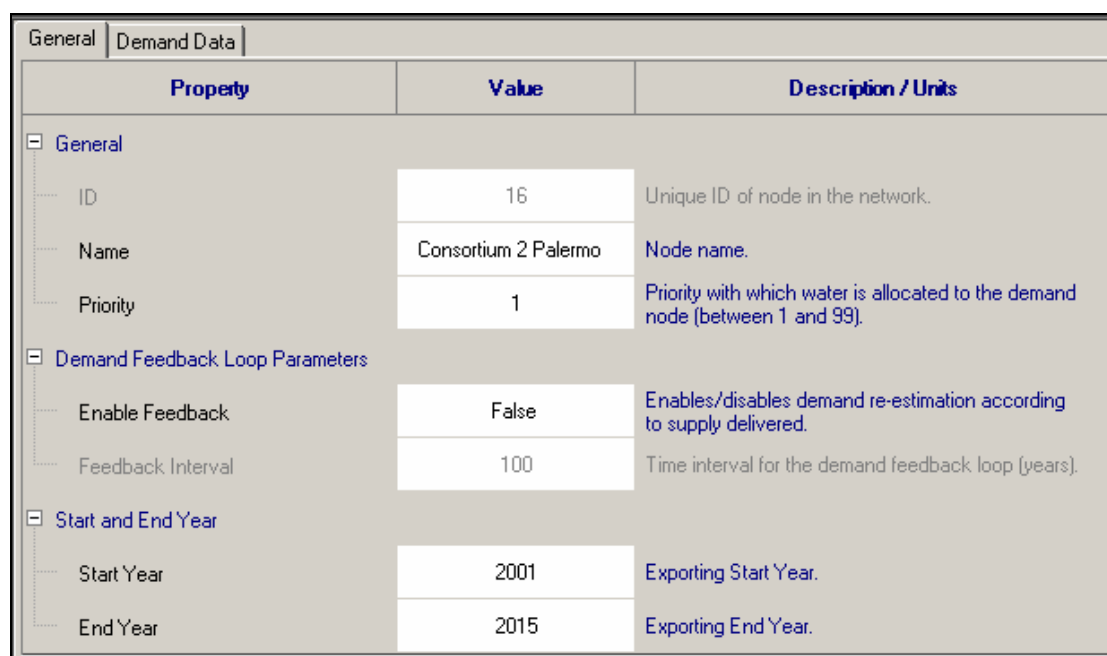
Figure 12. The Navigation Panel (left) and the Object Manager Panel (right) of the DSS

4.2. Data Editor & Map Editor

The Data Editor (DE) of the WSM DSS gives access to the data featuring the region under analysis. 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 change the data or simply to enter the information and numbers 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 as to whether he is going to edit the Base Case or a Water Management Scheme. The DE comprises of a series of tabs, grouped together in a dedicated resizable panel in the top-right of the GUI.



Property	Value	Description / Units
General		
ID	16	Unique ID of node in the network.
Name	Consortium 2 Palermo	Node name.
Priority	1	Priority with which water is allocated to the demand node (between 1 and 99).
Demand Feedback Loop Parameters		
Enable Feedback	False	Enables/disables demand re-estimation according to supply delivered.
Feedback Interval	100	Time interval for the demand feedback loop (years).
Start and End Year		
Start Year	2001	Exporting Start Year.
End Year	2015	Exporting End Year.

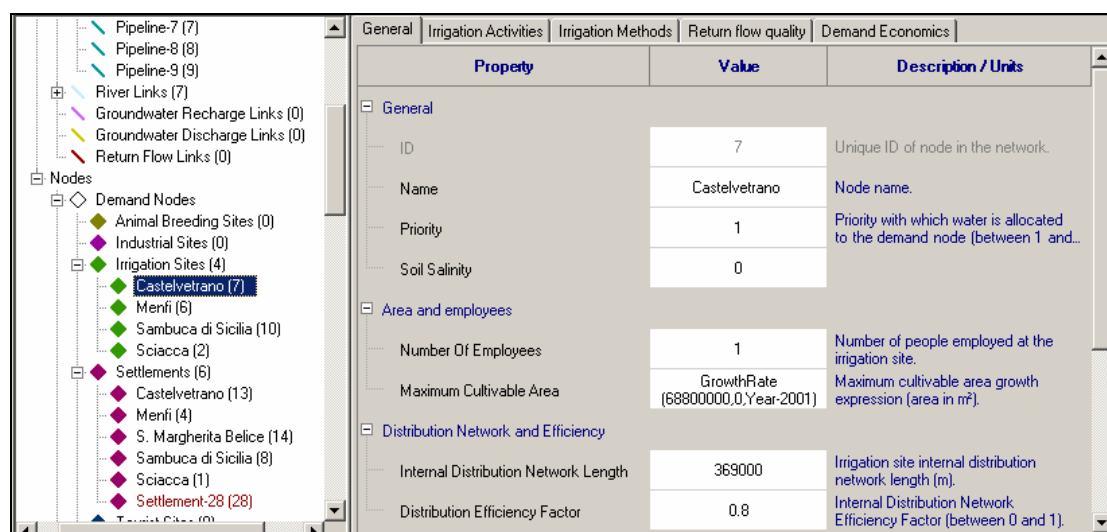
Figure 13. The General tab of the Data Editor for exporting nodes

Each tab consists of a list of information addressing specific aspects of the regional element accessed. For instance the first tab, *General*, contains the basic information, such as identifier, name and allocation priority, which are defined by the network element data refers to. This general information is displayed on three different columns: the first presents the type and name of information, the second one its value that can be edited and the third one provides a short explanation of the attribute. The classification of information in other tabs is presented in more detail throughout the document. They mainly concern irrigation activities and methods, permanent and seasonal population, water distribution losses and costs, water resources quality etc.

As already said in the Navigation Panel description, the Data Editor presents the data characterising the elements of the water resource network in the region under study. Those network elements represent available water resources, such as groundwater, river

reaches and reservoirs, water uses, among which settlements, irrigation sites and animal breeders, of treatment and transshipment plants and structures, and the connections such as canals and pipelines, linking them all conceptually and physically. All the water network elements are schematically represented in the DSS in terms of coloured spots and links placed on the region map.

In order to enter the DE of whatever 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 the data associated with the network features. For example, through the Object Manager, the user can navigate through all the list of items and left-click on the one he wants to see the data for. The items' name 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. If the panel is already active, and displays data related to a previously selected item, the tabs with the data of the new item are simply loaded. 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 read its name on the map, look for its type in the navigation panel and search it by name of identifier. 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 position of the target elements and he's panning the map. 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, all the pipelines for example, because they are all placed in the list one below the other, and not scattered on the map.



Property	Value	Description / Units
General		
ID	7	Unique ID of node in the network.
Name	Castelvetrano	Node name.
Priority	1	Priority with which water is allocated to the demand node (between 1 and...
Soil Salinity	0	
Area and employees		
Number Of Employees	1	Number of people employed at the irrigation site.
Maximum Cultivable Area	GrowthRate (68800000,0;Year-2001)	Maximum cultivable area growth expression (area in m²).
Distribution Network and Efficiency		
Internal Distribution Network Length	369000	Irrigation site internal distribution network length (m).
Distribution Efficiency Factor	0.8	Internal Distribution Network Efficiency Factor (between 0 and 1).

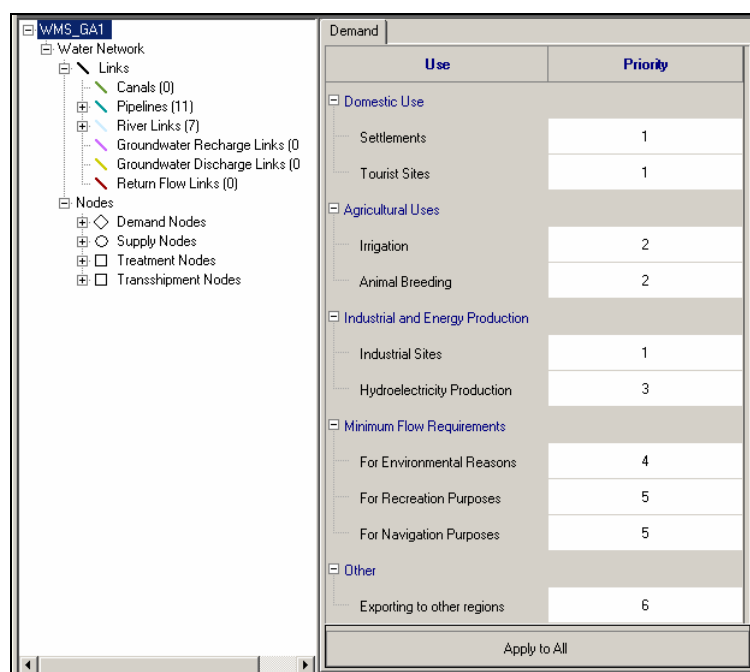
Figure 14. Opening the DE editor for irrigation site Castelvetrano (on the right) from the Object Manager Panel (on the left)

The two options to proceed are interrelated. The water network element that is selected by the user from the navigation panel is also automatically selected on the region map in

red colour. 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 a WM Scheme, the panel opens with a preloaded table, showing the priorities associated by default to the various categories of demand nodes. These 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.

The default priorities are associated with categories of nodes according to the demand type: the maximum, one, is for domestic use, thus for settlements and tourist site nodes, a value of two is attached to agricultural and animal breeding use, a value of three to industries and hydroelectricity production and finally values of four and five to the minimum flow requirements in river reaches, either for geomorphology or aquatic life protection and preservation, or for recreation and navigation purposes. A default priority of six is given to export nodes, which account for water transfers towards water demand realities in neighbouring regions.



Use	Priority
Domestic Use	
Settlements	1
Tourist Sites	1
Agricultural Uses	
Irrigation	2
Animal Breeding	2
Industrial and Energy Production	
Industrial Sites	1
Hydroelectricity Production	3
Minimum Flow Requirements	
For Environmental Reasons	4
For Recreation Purposes	5
For Navigation Purposes	5
Other	
Exporting to other regions	6

Figure 15. The Default Priority Window of the data editor

It is possible to change the default priority value of one or more single demand nodes of the network through the *General* data editor tab of the node. The *priority* property of the node is set to the desired level by double-clicking the current value and editing the new number. 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 provokes the

opening of a small *Properties window* at the bottom of the Object Manager panel. Here the user can find the name of the node, its' identifier, geographic coordinates and priority. All information, except the ID (which is generally locked for editing), can also be edited. Every property modification can be verified on the map, through the values appearing between square brackets next to the name of the node.

In case that many demand nodes have been given new priorities and the user would like to go back to the original default priority assignments, he can restore the default priority values for each node category through 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*.

As far as the Map Editor is concerned, some of its functionalities have already been presented. The Map Editor (ME) is launched for a WMS from the Manager Panel, *Modify Map* menu. The Map window includes a GIS control where the map of the region is loaded, 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 DSS user to select a type of node/link within the category and to position it on the map with a click of the mouse 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. When editing network links, they 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.

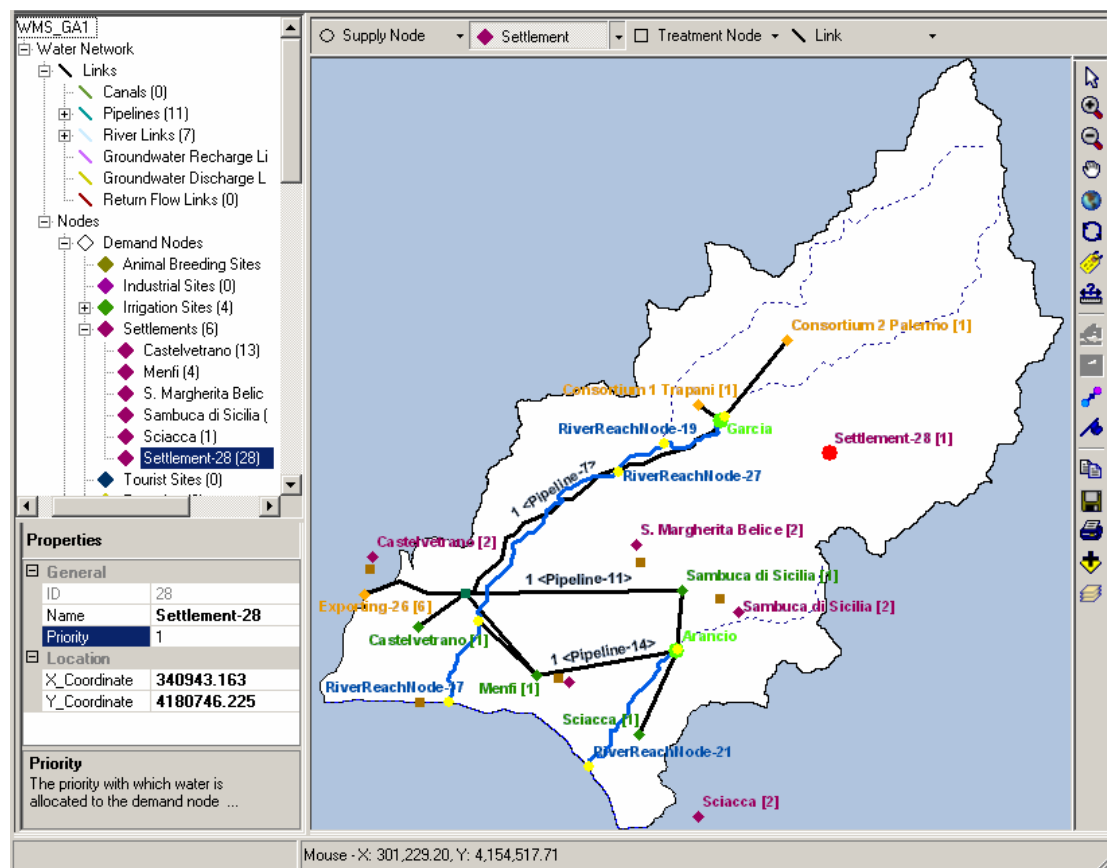


Figure 16. Creating a new settlement (28) with the Map Editor

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 go from common ones, such as the Zooming, Panning and Labelling to more advanced ones, such as the Flip Tool and the Move Point Tool. Hereunder, the functionalities of the toolbar are shortly presented.



Select: select a network element on the map and load the its property 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, at 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: customizes 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): this command reverses the direction of a polyline so that the last vertex of the sketch becomes the first, if such an operation is permitted by the connectivity rules of the network;



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



Clear Unconnected Network Junctions: deletes all unconnected network junctions¹;



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.

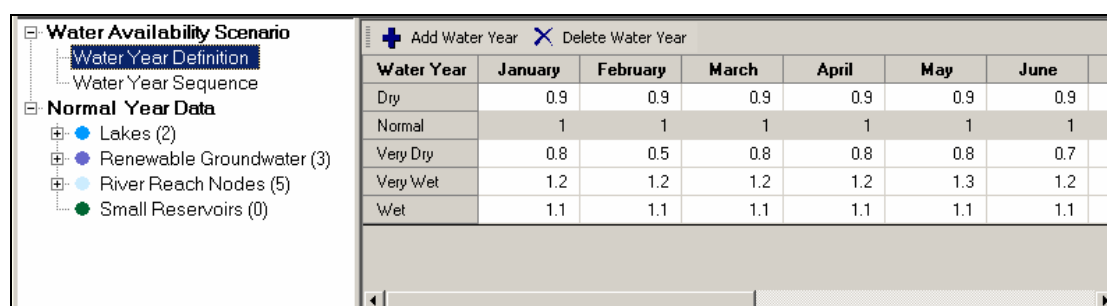
¹ Network junctions are created by default when links are splitted. They have no modelling functionality but are used to maintain the network connectivity and mass balances. Existence of unconnected junctions may slow down the computational speed during the simulation.

4.3. Availability Scenarios

This chapter presents the graphical user interface of the availability module of the WSM DSS. As explained in Chapter 3, the 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 real observations at existing monitoring stations or through the estimation of a water balance based upon monthly meteorological data and the soil characteristic 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.



The screenshot shows a software interface for defining water years. On the left is a tree view under 'Water Availability Scenario' with sub-items: 'Water Year Definition' (selected), 'Water Year Sequence', and 'Normal Year Data'. Under 'Normal Year Data', there are four categories: 'Lakes (2)', 'Renewable Groundwater (3)', 'River Reach Nodes (5)', and 'Small Reservoirs (0)'. The main area displays a table with columns for months (January to June) and rows for different water year types. Above the table are buttons for '+ Add Water Year' and 'X Delete Water Year'.

Water Year	January	February	March	April	May	June
Dry	0.9	0.9	0.9	0.9	0.9	0.9
Normal	1	1	1	1	1	1
Very Dry	0.8	0.5	0.8	0.8	0.8	0.7
Very Wet	1.2	1.2	1.2	1.2	1.3	1.2
Wet	1.1	1.1	1.1	1.1	1.1	1.1

Figure 17. 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 characterize the first month of the normal year.

Water Availability Scenario Water Year Definition Water Year Sequence Normal Year Data Lakes (2) Renewable Groundwater (3) River Reach Nodes (5) Small Reservoirs (0)	Year	Water Year Type
	1998	Normal
	1999	Dry
	2000	Dry
	2001	Dry
	2002	Normal
	2003	Wet
	2004	Normal
2005	Very Dry	

Figure 18. 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 instance 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.

Water Availability Scenario Water Year Definition Water Year Sequence Normal Year Data Lakes (2) Lake-431 (431) Lake-433 (433) Renewable Groundwater (3) Almadena - Odeaxere (192) Ferragudo - Albufeira (157) Mexilhoeira Grande - Portimao (284) River Reach Nodes (5) Downstream of Arade (412) Downstream of Bravura (409) Upstream of Arade (415) Upstream of Bravura (410) Upstream of Funcho (413) Small Reservoirs (0)	Copy Paste Save Import	
	Month	RunOff at the River Reach (m³/month)
	January	11866400
	February	9683400
	March	9969000
	April	4751100
	May	305300
	June	0
	July	0
	August	0
	September	0
	October	4095500
	November	11686900
December	10722000	

Figure 19. 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. On the opposite, 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 approach based on climatic and soil data, 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.

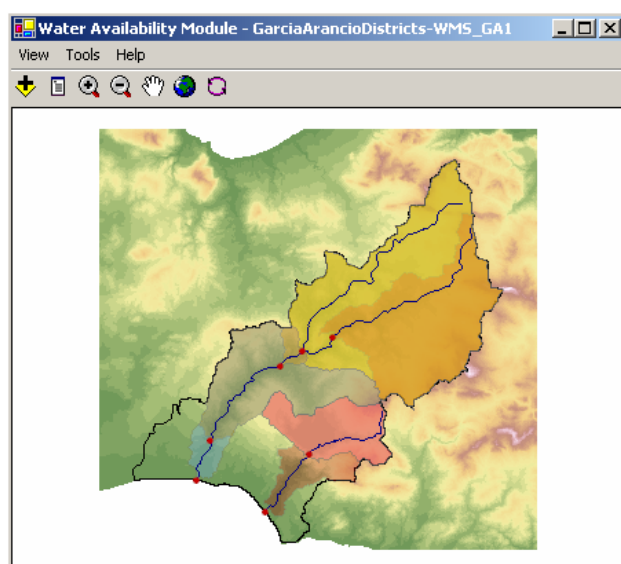


Figure 20. The sub-basins generated by the pro-processor of the availability module using climatic data

The module has a pre-processor, running in the interface 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 based on the information of the Digital Elevation Model. Then it makes also statistics on the input climatic raster maps and aggregates these data to the watershed level. The opening view of the module shows the generated river basins over the DEM (Figure 20).

The data maps involved in the statistics are: twelve monthly maps of rainfall, temperature and reference evapotranspiration (ET_0), 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.

Based on the average years of climatic data, aggregated at watershed level, the user is prompted to build the weather scenarios. First of all, he can use the 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 he does for the discharge scenarios. This operation is carried out in the Base Year Window. Then a dedicated wizard, formed by a few windows, allows him to build the sequence of years one by one, or to assign a yearly or monthly trend to the customized starting Base Year, or to repeat it as it is for the entire duration of the scenario. The windows of the wizard that are responsible for that are the *Custom Sequence* and the *Trend Definition* (Figures 21 and 22)

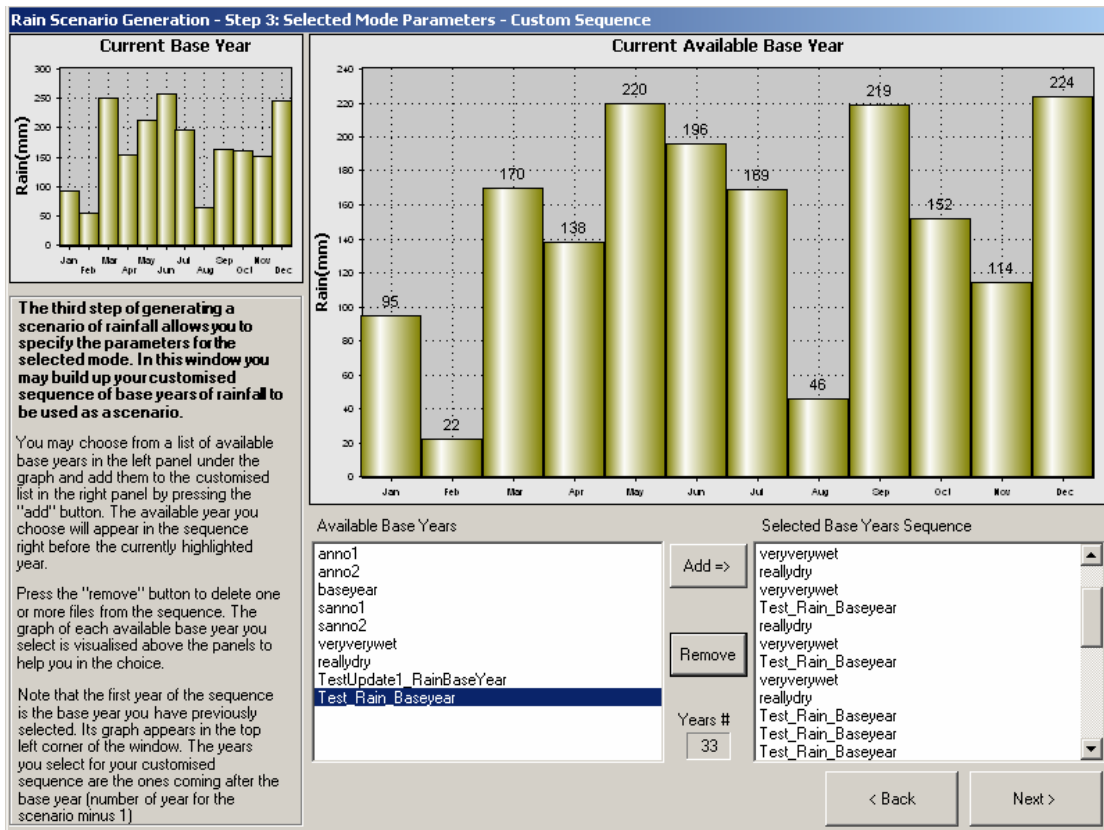


Figure 21. Displaying available base years to be selected and added to the scenario sequence

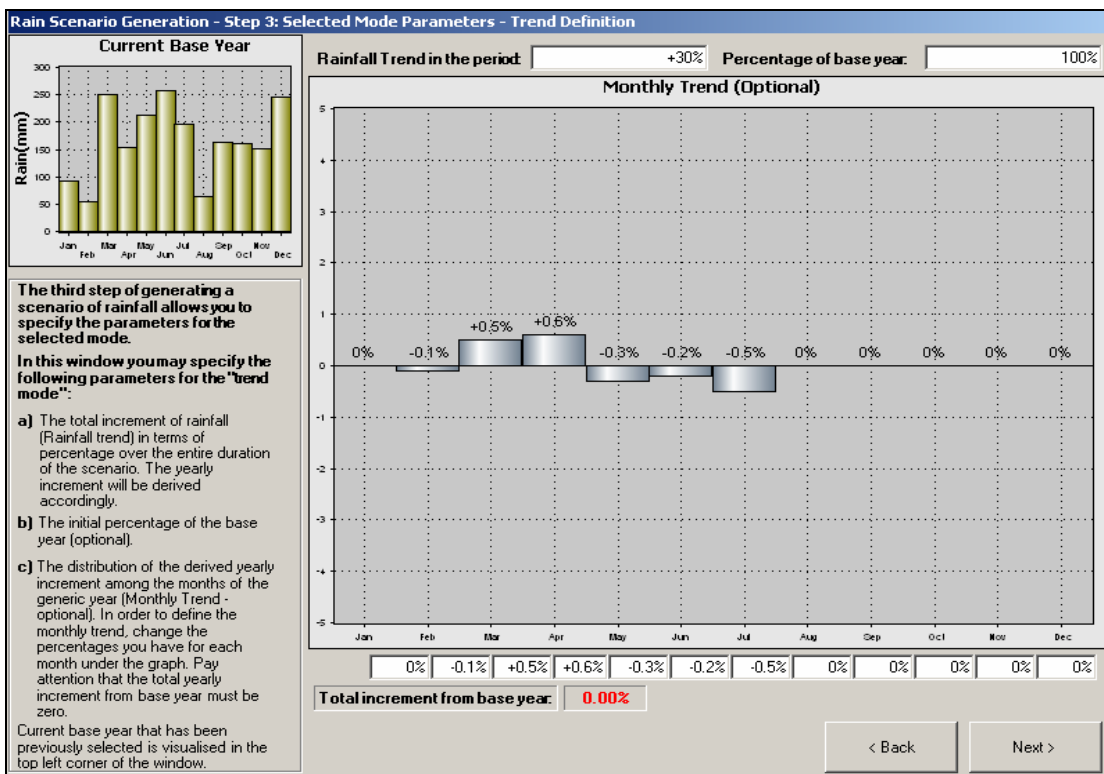


Figure 22. The Trend Definition window of the wizard for rain scenario generation

After the rainfall and ET_0 scenarios have been generated, they are read by the water balance routine and time series of discharge are computed for each cross section in the river water body. Time series of natural recharge for the aquifers are produced as well.

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

- 1) a drop-down menu where the type of network element can be chosen, either a lake, a river reach or an aquifer;
- 2) a list of available elements of the type selected by the user;
- 3) the 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.

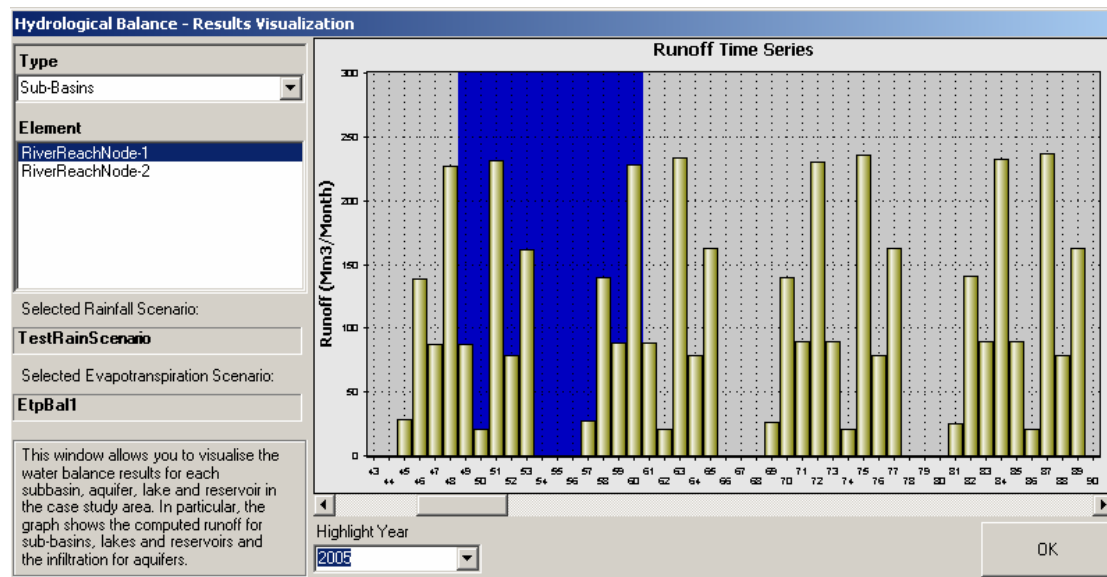


Figure 23. Displaying Results for river reaches

4.4. Demand Scenarios

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 done in two ways:

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

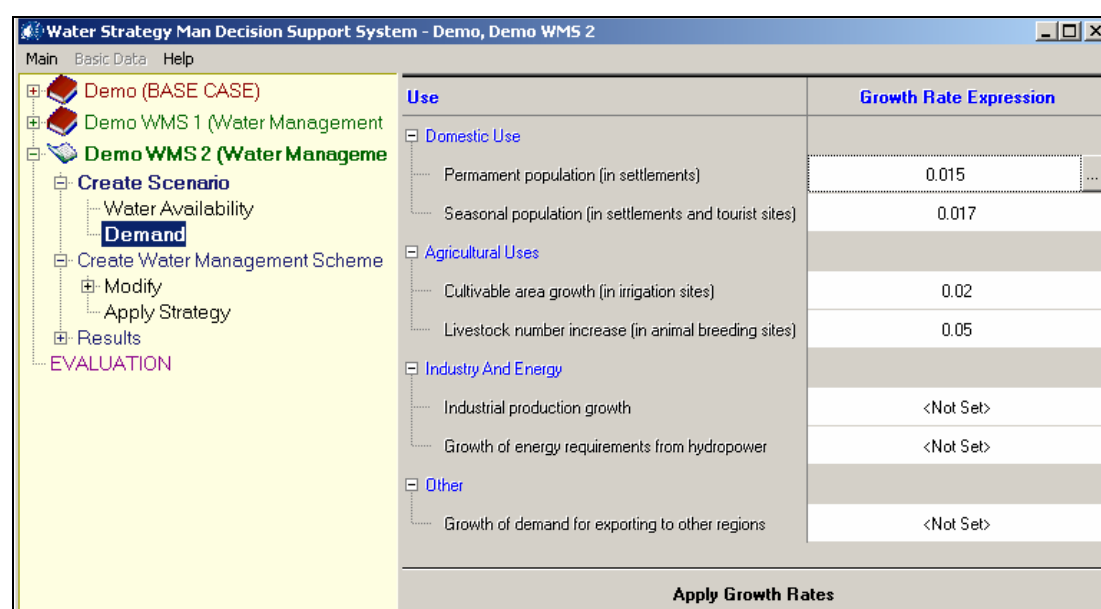
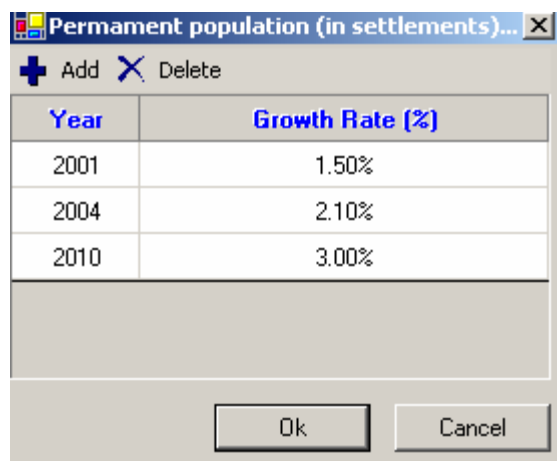


Figure 24. Definition of growth rates from the Create Scenario\Demand Panel (on the right)

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. 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 end user may have previously entered, even if it has been assigned to a particular node.



Year	Growth Rate (%)
2001	1.50%
2004	2.10%
2010	3.00%

Figure 25. Growth rate form with time-variant rates.

Having confirmed the application of the desired values, it is possible to see graphically what is 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 visualized data.

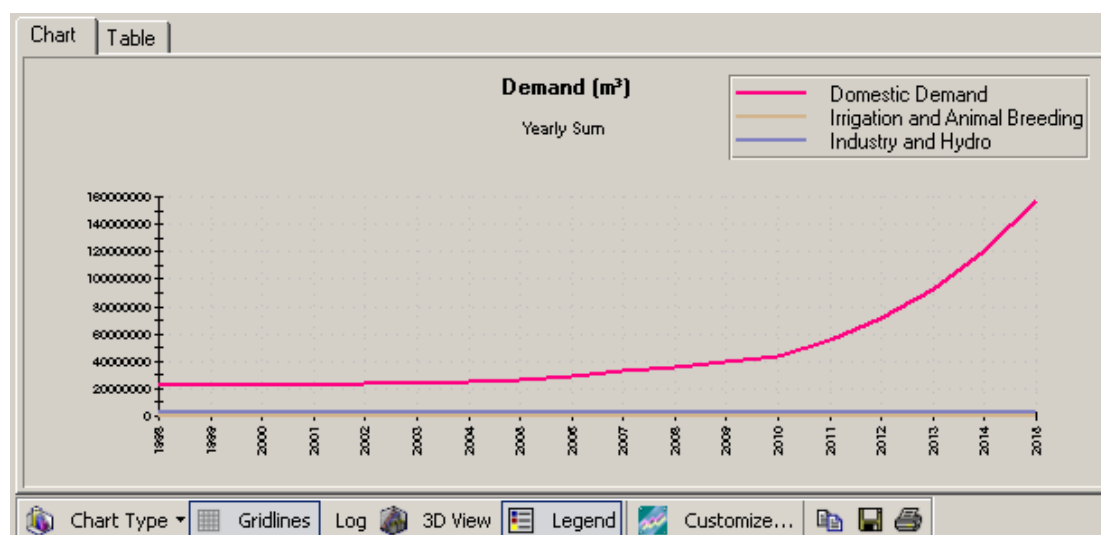


Figure 26. The chart below the Demand Panel displays the Demand Scenarios for each water sectors. Here the effect of three different growth rates for years 2001, 2004 and 2010 is visible.

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 4 shows for node type, the variables to be assigned a growth factor (or another type of customized expression) and their location in the Data Editor table of attributes.

Table 4. 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
Hydroelectricity	Energy Requirements	Demand Data
	Month Variation (optional)	Demand Data

The *Month Variation* variable, identified in Table 4 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.

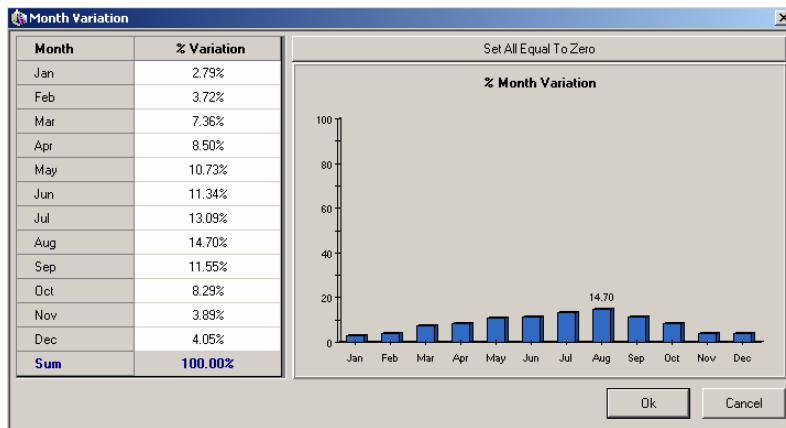


Figure 27. The Month Variation Window

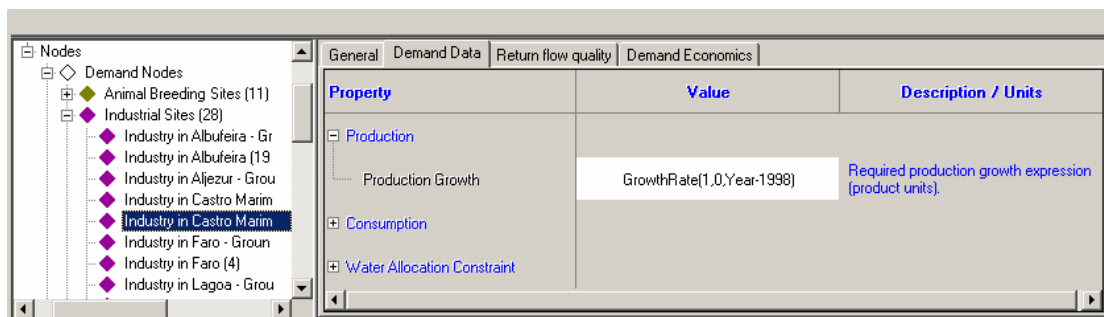


Figure 28. Editing growth rate for a single Industrial Site

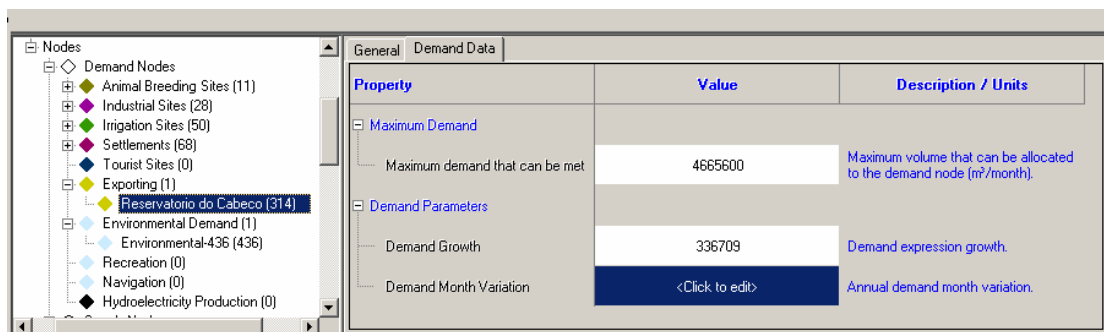


Figure 29. Editing growth rate for a single Export node

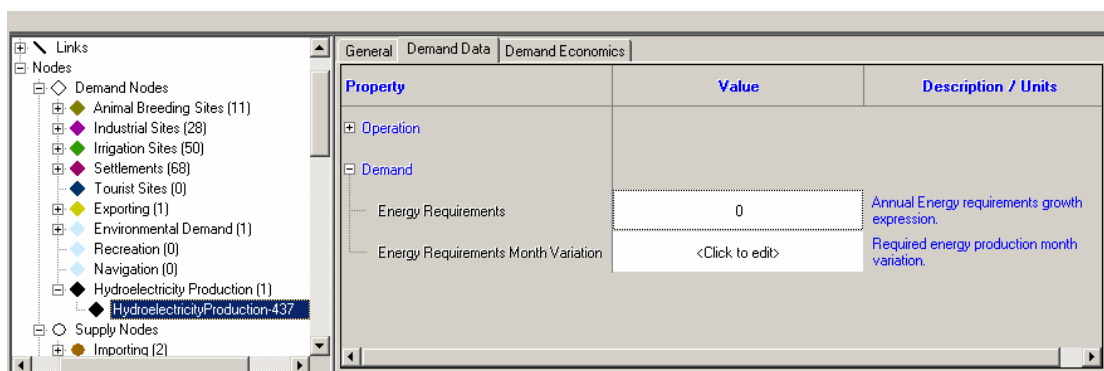


Figure 30. Editing growth rate for a single Hydroelectric Plant

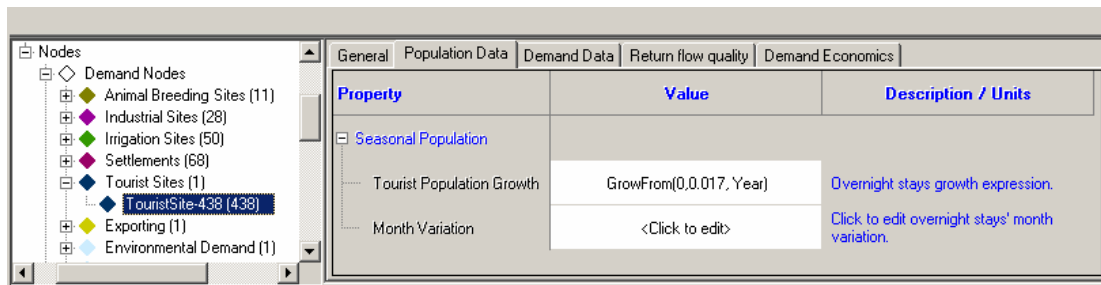


Figure 31. Editing growth rate for a single Tourist Site

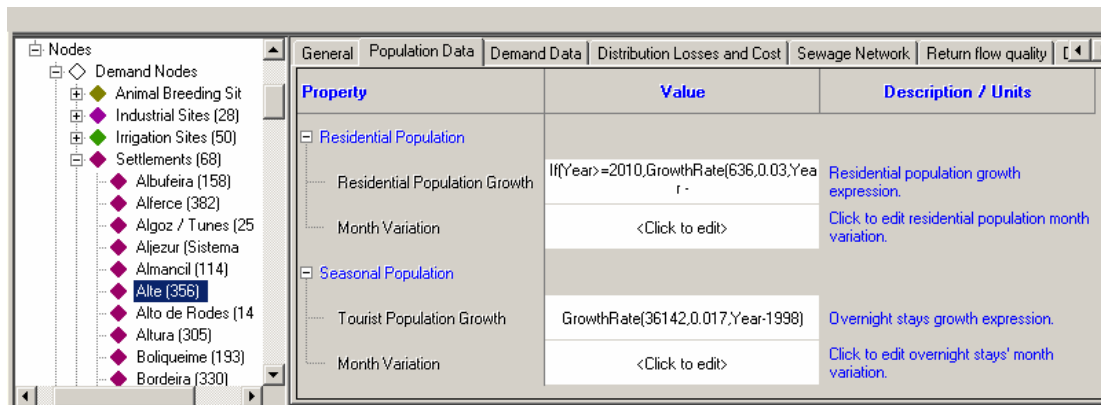


Figure 32. Editing growth rate for a single Settlement

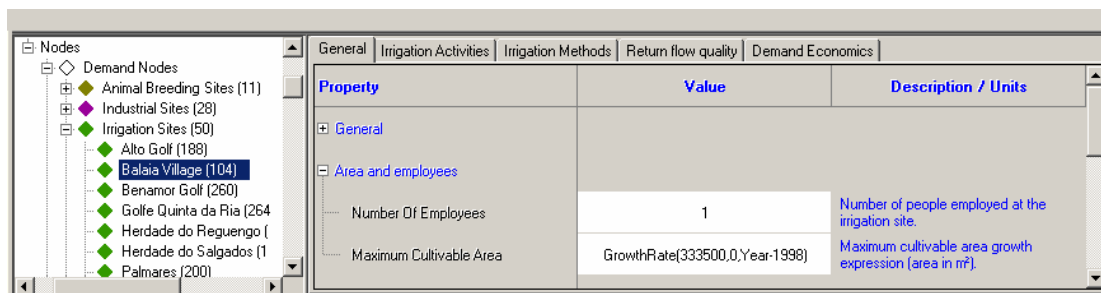


Figure 33. Editing growth rate for a single Irrigation Site

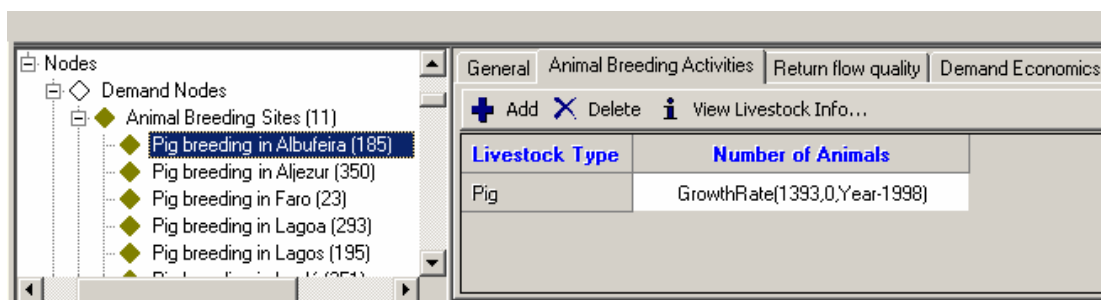


Figure 34. Editing growth rate for a single Animal Breeding Site

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.

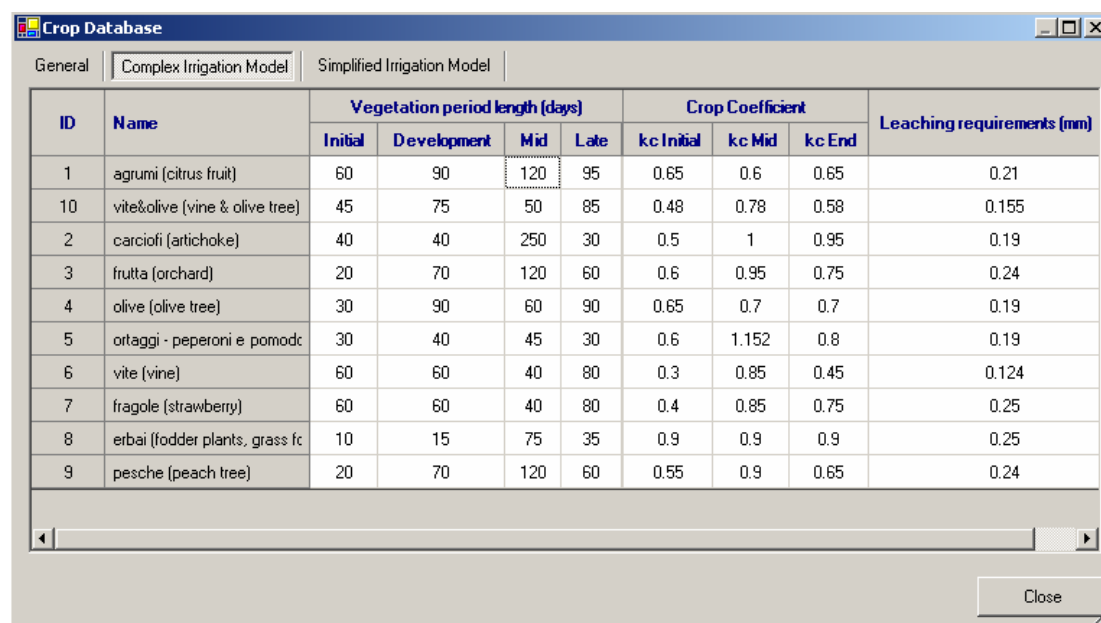
In particular, the Crop Database Form presents crop data classified in three sections: the *General*, the *Complex Irrigation Model* and the *Simplified Irrigation Model*. In the General section two tables show a number of economic and crop type data for field and orchard crops respectively. Among the economic information for field crops there are Crop Market 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 also 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 WSM Approach chapter of this document: vegetation periods, crop factors and leaching, for the complex model, and monthly water requirements for the simplified.

The screenshot shows the 'Crop Database' application window with three tabs: 'General', 'Complex Irrigation Model', and 'Simplified Irrigation Model'. The 'General' tab is active, displaying two tables. Above the tables are buttons for '+ Add', 'X Delete', and 'Move'. The 'Field Crops' table has columns for ID, Name, Crop Market Value (£/m²), Crop Cultivation Costs (£/m²), and Maximum Crop Height (m). The 'Orchard Crops' table has columns for ID, Name, Crop Market Value (£/m²), Crop Investment Cost (£/m²), Lifetime (years), and Annual Growing Costs (£/m²). A 'Close' button is located at the bottom right of the window.

ID	Name	Crop Market Value (£/m ²)	Crop Cultivation Costs (£/m ²)	Maximum Crop Height (m)
10	vite&olive (vine & olive tree)	2.58	0	2.75
2	carciofi (artichoke)	0.12	0	0.7
4	olive (olive tree)	0.30184	0	3.5
5	ortaggi - peperoni e pomodori (pepper & ton)	0.9335	0	0.6
6	vite (vine)	4.862	0	2
7	fragole (strawberry)	1.856	0	0.2
8	erbai (fodder plants, grass for hay)	0	0	0.1

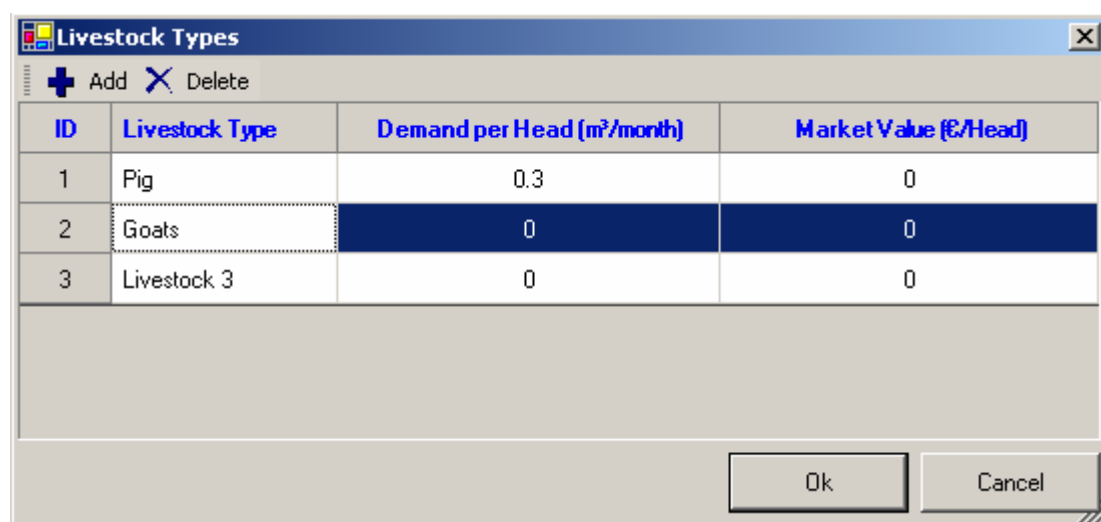
ID	Name	Crop Market Value (£/m ²)	Crop Investment Cost (£/m ²)	Lifetime (years)	Annual Growing Costs (£/m ²)
3	frutta (orchard)	0.684	0	1	0
9	pesche (peach tree)	1.005	0	1	0
1	agrumi (citrus fruit)	0.775	0	1	0

Figure 35. The General Section of the Crop Database



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 36. The Complex Irrigation Model Section of the Crop Database



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

Figure 37. 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.

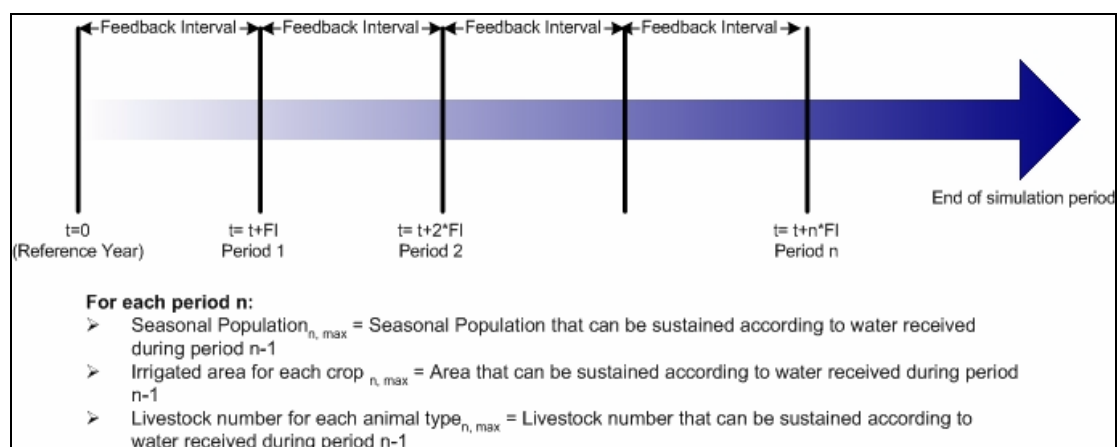


Figure 38. Feedback loop runs every feedback interval in the simulation period

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 market 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 its' 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.

4.5. Strategic Options

This chapter describes the strategic options currently available within the decision support system. They are grouped under four categories:

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

Table 5. Summary Table of Policy Options and related Actions

Policy Options	Actions
A. Supply Enhancement	A1. Unconventional/untapped resources A2. Surface Waters and precipitation (direct abstraction, dams, reservoirs) A3. Groundwater (drillings, wells) A4. Desalination A5. Importing A6. Water Reuse
B. Demand Management	B1. Quotas, Regulated supply B2. Irrigation method improvements (drip irrigation, enclosures) B3. Conservation measures in the home (water saving plumbing systems) B4. Recycling in industry and domestic use B5. Improved infrastructure to reduce losses (networks, storage facilities) B6. Raw material substitution and process changes in industry
C. Social-Developmental Policy	C1. Change in agricultural practices (low irrigation crops, genetic improvement) C2. Change of regional development policy (tourism/agriculture limitation)
D. Institutional Policies	D1. Institutional Capacity Building (Education and awareness campaigns, Use of standards, Public participation, Stakeholder involvement, Conflict resolution, Contingency planning) D2. Economic Policies (Water pricing, Cost recovery, Incentives) D3. 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 minimizing water shortage and for distributing costs equitably among domestic, tourist, agricultural and industrial users. Environmental protection is connected to regulation enforcement and impacts mitigation whereas economic efficiency is founded on cost recovery of direct, opportunity and environmental figures, also on a local level.

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, but the real objective of the DSS Strategy Module is to assist in building a combination of management measures in a timeframe into a strategy.

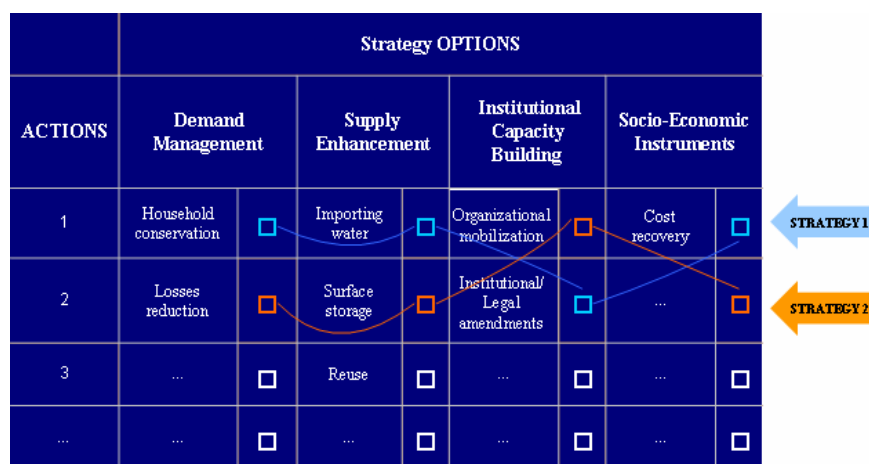


Figure 39. Combining options into strategies

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:

- a tree view, listing the pending or the already applied actions;
- a form containing descriptive detailed information for each action, that is used for its definition, and
- 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 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 which also allows for the successive implementation of actions and their organization in both space and time.

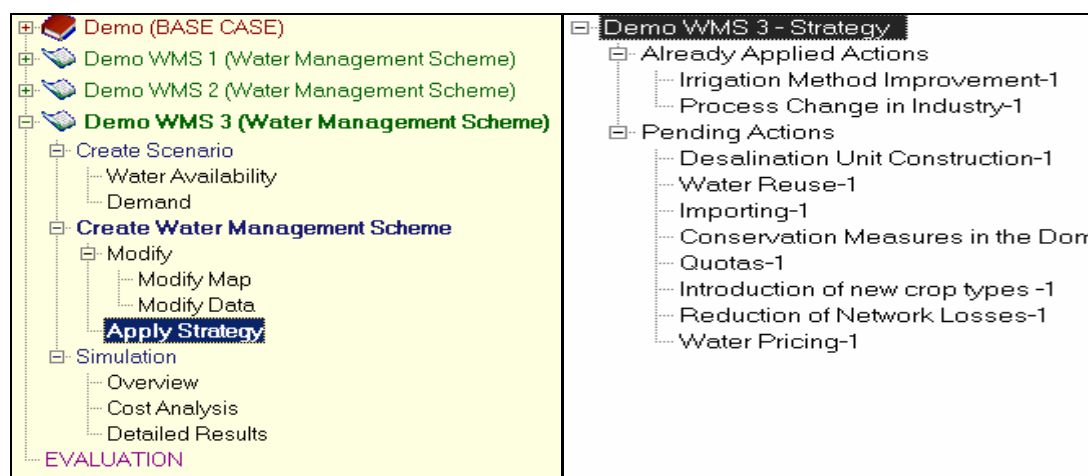


Figure 40. Running the Strategy Options Panel from the Navigation Panel (left), and the tree view of pending and applied actions (right)

The supply enhancement options currently implemented in the DSS are:

- 1) Desalination Unit construction,
- 2) Water Reuse and
- 3) 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. The form also presents Unit and Process type of the desalination plant, cost figures relating 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 and a supply priority of the link can be assigned as well. 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.

Desalination Unit Construction-2

Design

Unit Type: Construction Cost (€):

Process Type: Lifetime:

Capacity (m³/d): O and M Costs (€/m³):

Construction year: Energy Consumption (kWh/m³):

Link and Location Properties

Minimum Distance from source (m):

Maximum Distance from demand nodes (m):

Settlement / Tourist site	Is Connected	Supply Priority
Albufeira (158)	<input type="checkbox"/>	
Alferce (382)	<input checked="" type="checkbox"/>	1
Algoz / Tunes (251)	<input type="checkbox"/>	
Aljezur (Sistema Norte) (393)	<input type="checkbox"/>	
Almancil (114)	<input checked="" type="checkbox"/>	1
Alte (356)	<input type="checkbox"/>	
Alto de Rodas (14)	<input type="checkbox"/>	
Altura (305)	<input type="checkbox"/>	
Boliqueime (193)	<input type="checkbox"/>	
Bordeira (330)	<input type="checkbox"/>	

Apply Action

Figure 41. 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 implementation of 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 that symbolizes the importing of water from outside the regional 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).

Water Reuse-1

Details:

Wastewater Treatment Plant: Carrapateira

Implementation Year: 1998

Effluent Price (£/m³): 1.5

Treatment Process Info:

Unit Type: Primary

Quality Variable **Removal Rate (%)**

Coliform Bacteria	0
Inhibiting Matter	1
Biochemical oxygen demand	0

Connections:

Lower priorities for all incoming links with the same (or lower) supply priority

Irrigation Site	Connect?	Priority	Indicative Distance (m)
Alto Golf (188)	<input checked="" type="checkbox"/>	1	29,815
Balaia Village (104)	<input checked="" type="checkbox"/>	1	60,056
Benamor Golf (260)	<input type="checkbox"/>		
Golfe Quinta da Ria (264)	<input type="checkbox"/>		

Apply Action




Figure 42. Supply Enhancement – Water Reuse Policy Form

The demand management options currently implemented in the DSS are:

- 1) Conservation measures in domestic sector;
- 2) Limitation to water use in terms of quotas;
- 3) Irrigation method improvements;
- 4) Process change in industry;
- 5) Introduction of new crop types, and
- 6) 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 up 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 in August.

In order to modify the demand pattern of irrigation sites, the option improving the current irrigation methods can 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 used originally in management scheme. New methods and corresponding irrigation efficiencies can be set, starting from the *Year of Implementation* of the action.

Importing-1

Quantity and Cost:

Maximum Quantity (m³/month):

Implementation Year:

Infrastructure Construction Cost (€): Water Transfer Cost (€/m³):

Infrastructure Lifetime:

Location and Connections:

Maximum distance from region boundary (m):

Maximum distance from demand nodes (m):

Lower priorities for all incoming links that have the same (and lower) supply priority

Demand Sites	Connect?	Supply Priority
+ Settlements	<input type="checkbox"/>	
+ Irrigation Sites	<input type="checkbox"/>	
+ Industrial Sites	<input type="checkbox"/>	
- Animal Breeding Sites	<input checked="" type="checkbox"/>	
Pig breeding in Albufeira (185)	<input checked="" type="checkbox"/>	1
Pig breeding in Aljezur (350)	<input type="checkbox"/>	

Apply Action

Figure 43. 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 market value: arrangements have to be accepted between cultivating crops that require less water and those which have a higher market 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. A replacement cost can also be specified.

Reduction of Network Losses-1

Target:

Select Task: Internal network replac

Targeted Loss Coefficient: 0.40

Parameters:

Replacement Year: 2007

New Loss Coefficient: 0.25

Location:

Settlement	Distribution Losses at year 2007	Replace?	Replacement Cost
Menfi (4)	0.43	<input checked="" type="checkbox"/>	5500
S. Margherita Belice (14)	0.43	<input type="checkbox"/>	
Sambuca di Sicilia (8)	0.43	<input checked="" type="checkbox"/>	7200

Select All

Deselect All

Apply Action




Figure 44. 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.

4.6. Simulation Results and Cost Analysis

The *Simulation* menu in the tree view of water management schemes, in the Manager Panel, is made up of three sub-menus: Overview, Cost Analysis and Detailed Results. By clicking on one of them, without distinction, the simulation of the WSM DSS runs, thus allocating the 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, each type of node or link having its own, which are both plotted and presented in tabular form. The Detailed Results window comprises of four panels which allow the DSS user to navigate among the indicators 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 at 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.

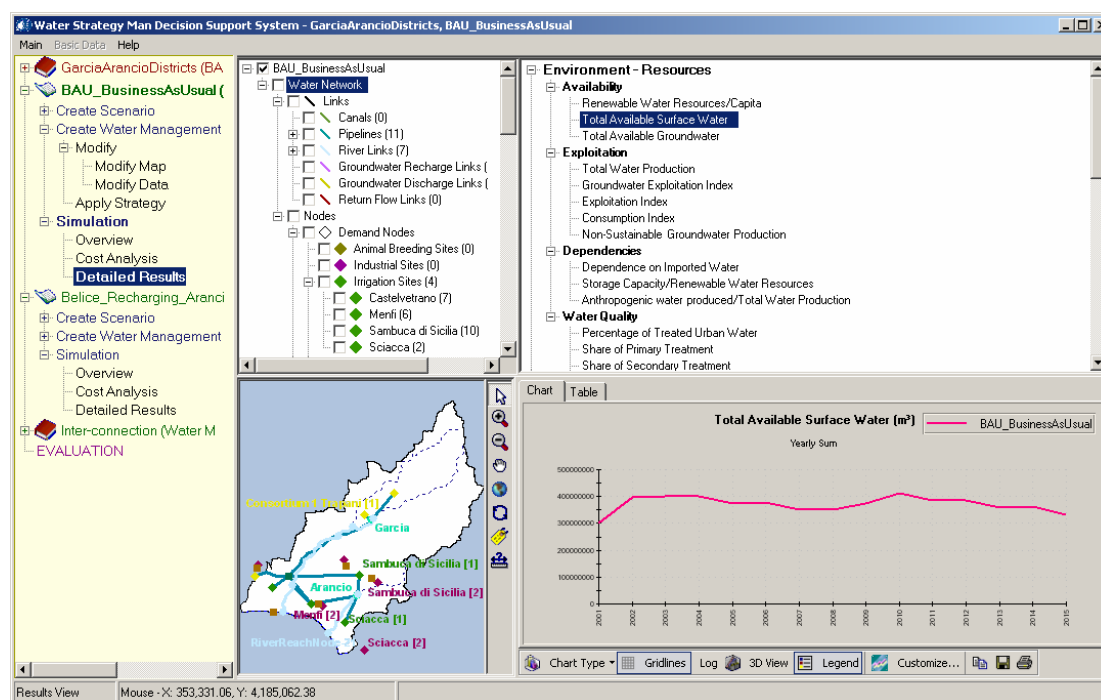


Figure 45. Opening the Detailed Results View

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 or for some or for all the nodes of the same type that exist in the case study region. 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 the 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, *Social 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 customization of the plot of indicators: it is possible to change the graph type, from lines to bars, or 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 *Customize* button has an important role as it modifies the time steps plotted: the DSS user can decide to show the detailed simulation output, monthly time series, or show yearly aggregation only. 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.

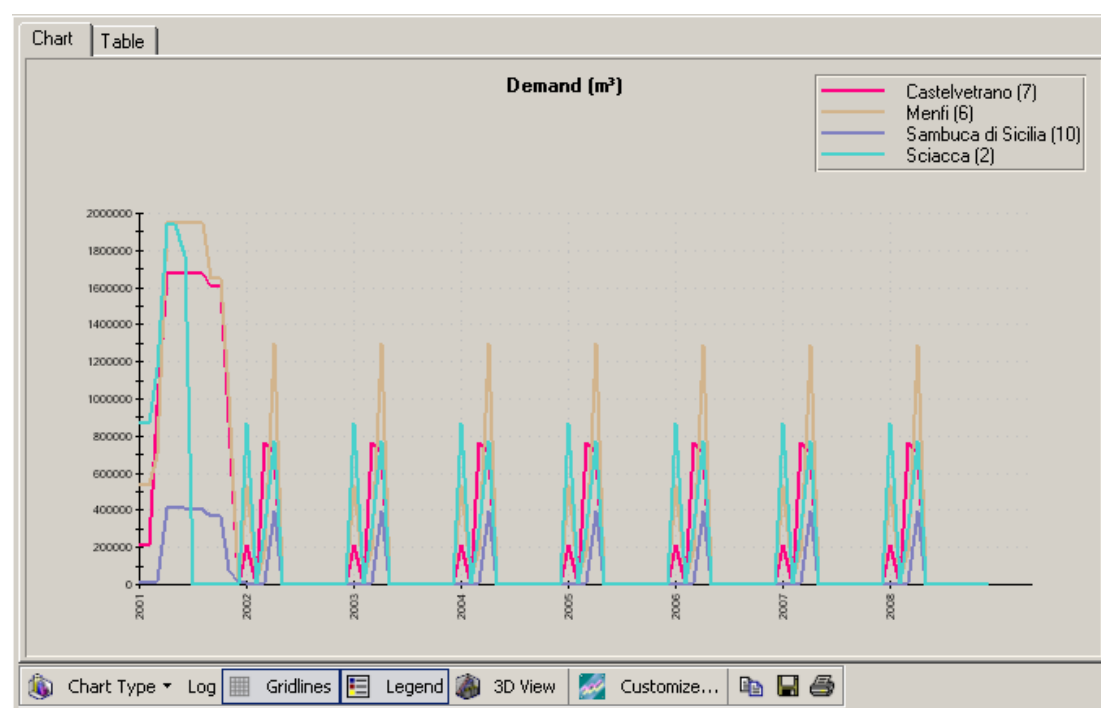


Figure 46. The Chart View displaying indicators

At the right side of the graphical 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 in many network users, to find inter-relations and causal effects

between them, and it is important to look simultaneously at the behaviour of many indicators.

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 on the tabular data as well.

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

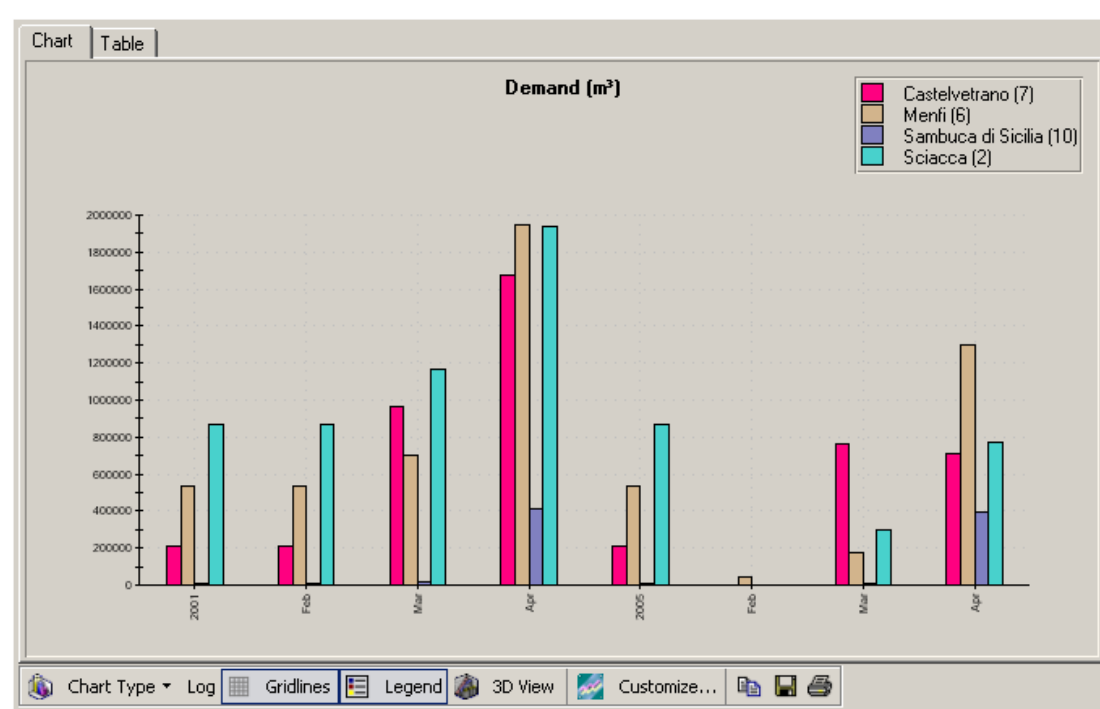


Figure 47. The Customize functionality: comparing results for January-April seasons of years 2001 and 2005

The *Simulation-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 stations. The 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.

	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

Figure 48. The Table View shows the data that are plotted in the Chart View

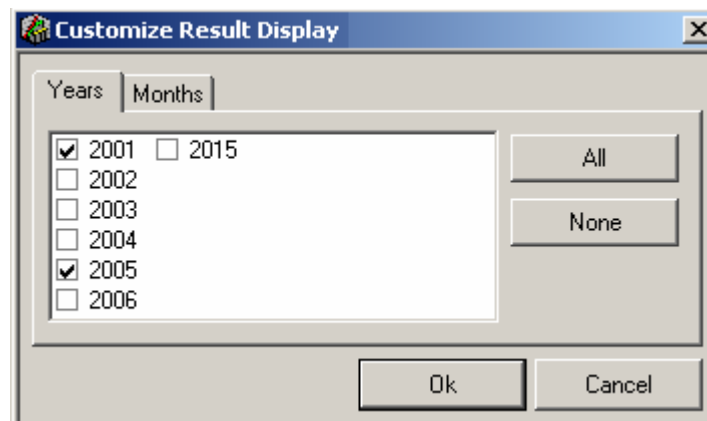


Figure 49. The Customize Dialog Box

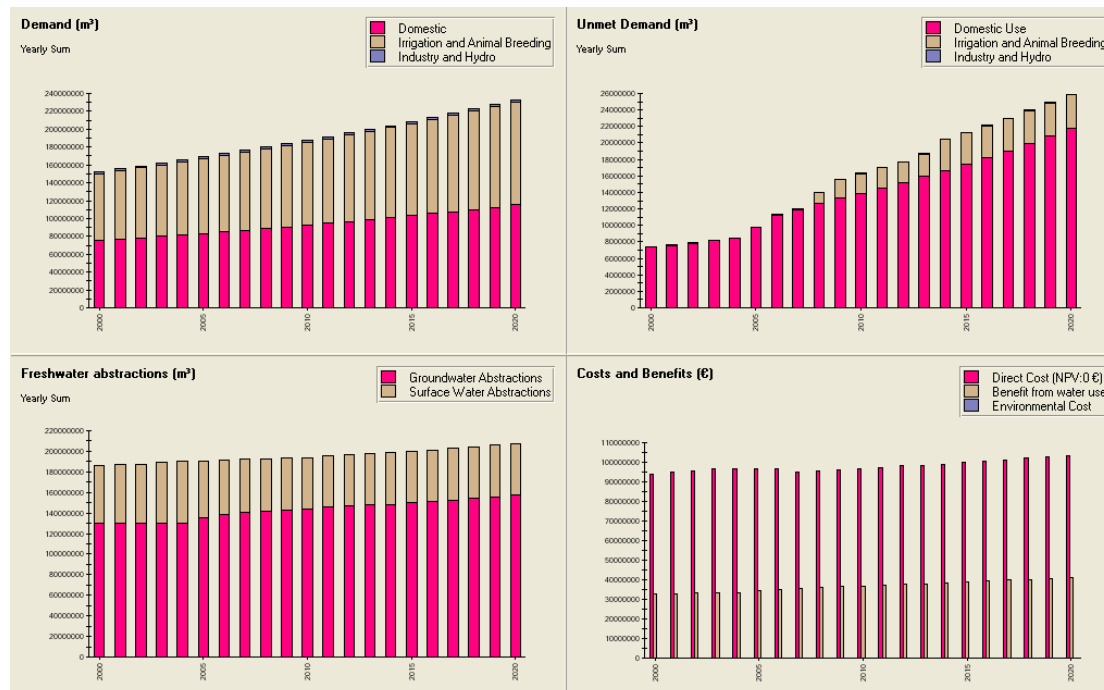


Figure 50. The Overview window of the WSM DSS

The economic analysis is performed 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 Cost Analysis Window, and

the costs can be updated as freestanding, without the need of running again the water allocation. The Cost 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, or choose the way the environmental cost is obtained, either relating aquifer abstractions or using the charge model, or 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.

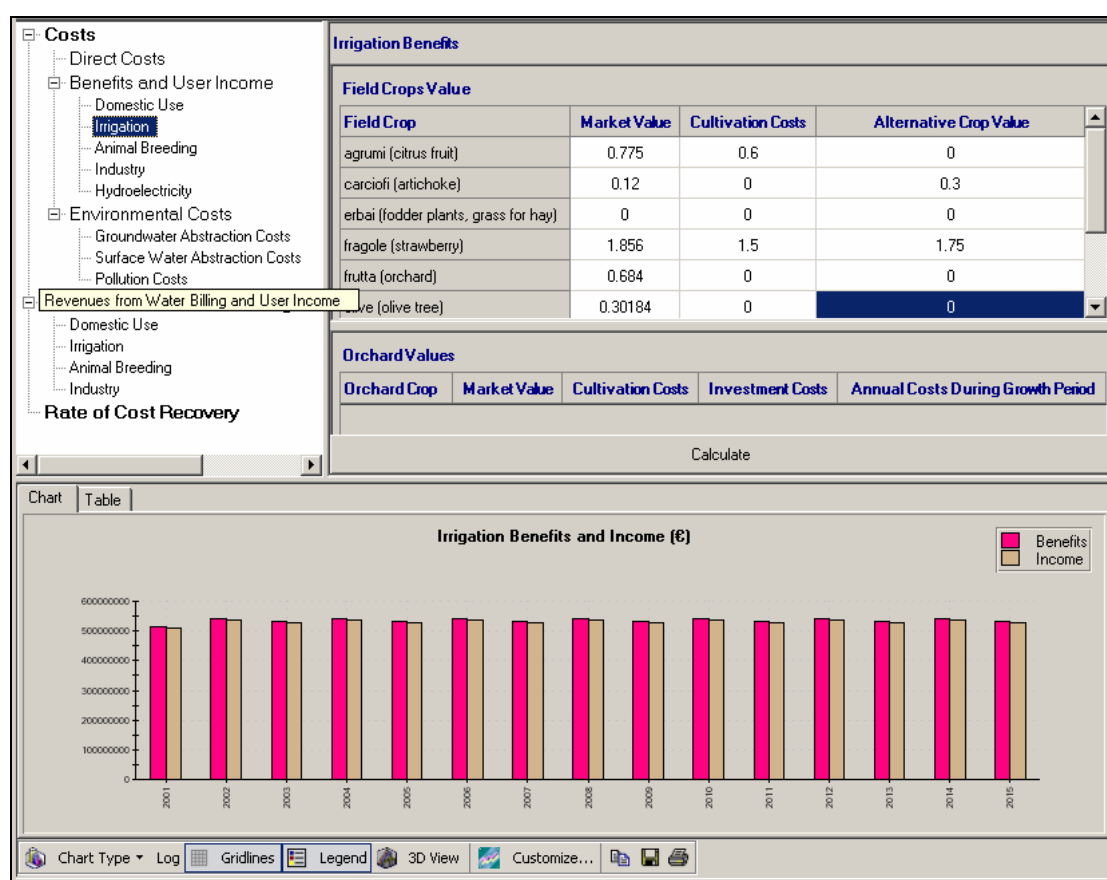


Figure 51. Setting the Benefits and Income data for irrigation in the Cost Analysis Window

As a sort of appendix to the simulation chapter, 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 6. 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 inflow), Hydroelectricity Production (only inflow), Drinking Plant	
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	Region Irrigation,

Category	Indicator	Network Element
	abstractions and pollution	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, 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,

Category	Indicator	Network Element	
		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, 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	

4.7. Evaluation of Water Management Schemes

The Graphical User Interface of the Evaluation Module (EM), as described in section 3.5, 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 for the case study region 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.

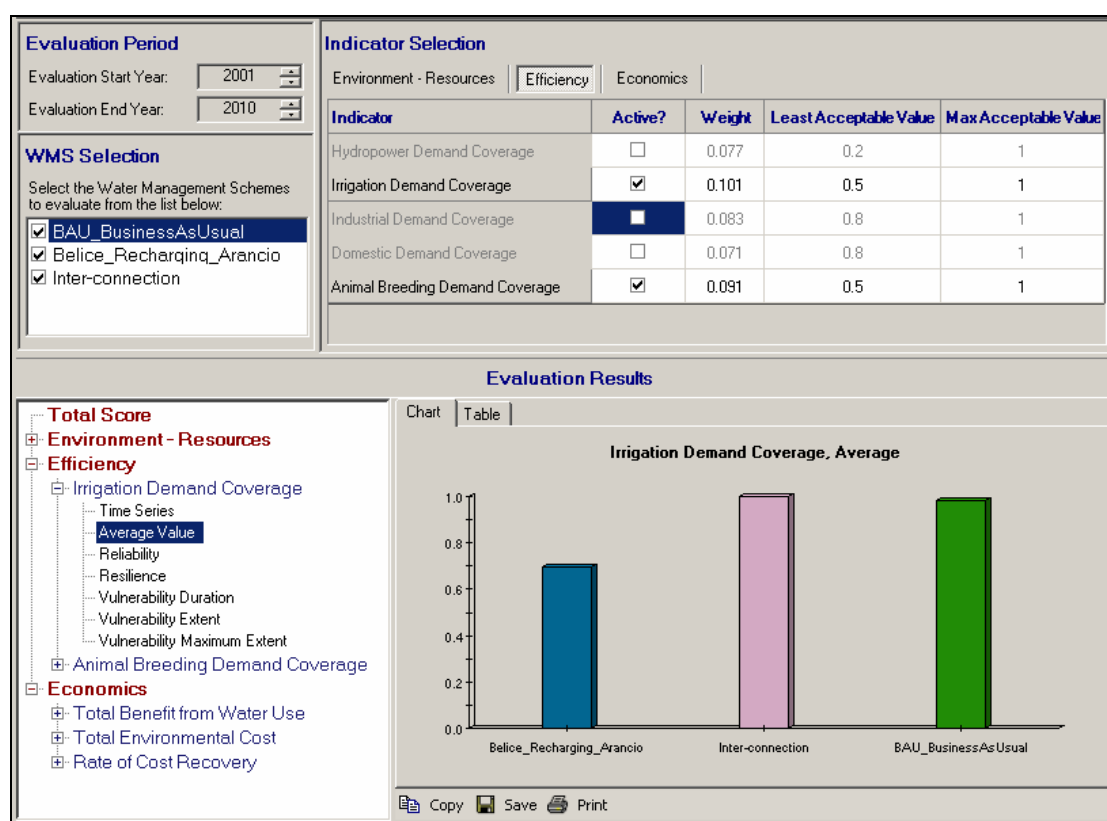


Figure 52. The Evaluation Module's window

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.

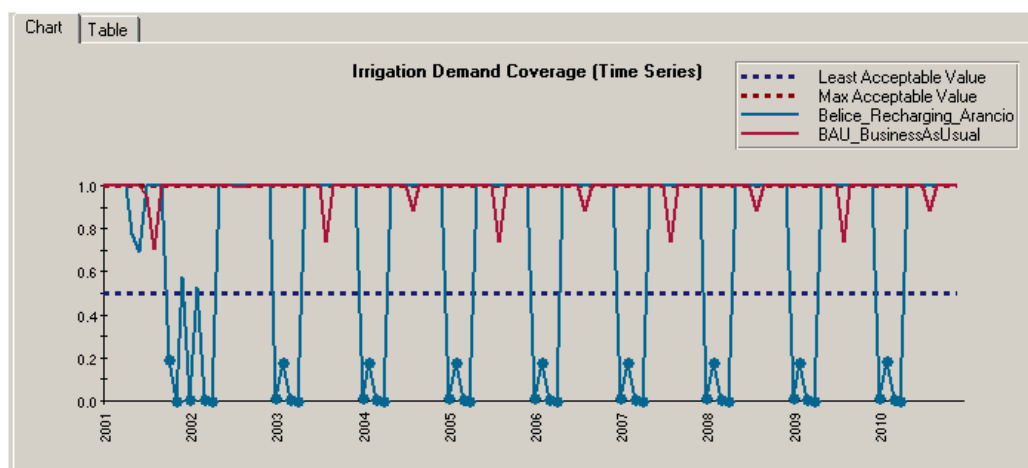


Figure 53. Comparing time series of irrigation demand coverage

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 chapter 3.6 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.

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.

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 54. The Evaluation Table of the WSM DSS

Appendix – The Basic WSM Glossary of Technical Terms Used

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- $AI = \text{Precipitation} / \text{Potential Evapotranspiration}$. 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 [1]

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 - 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 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

DRIVERS - they reflect pressures exerted by natural phenomena and anthropogenic activities.

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 - 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 - 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
- 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 Directive 79/409/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 - 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 - 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

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.

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).