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Implications of sustainability in water resources management at catchment scale

Prof. Eng. Ezio Todini

Palermo, 8-9 October 2004



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Traditionally,

Water Resources Planning and Management

have been approached via

Deterministic or Stochastic Optimization

(Maas et al., 1962; James and Lee, 1971; Loucks et al., 1981)



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More recently,

Multi-criteria Techniques

have been extensively used, in order to account for a
wider variety of

Commensurable and Incommensurable Objectives



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The introduction of the

Sustainability Concept

(World Commission on Environment and Development, 1987)

which aims at fulfilling the so called "3 Es"
objectives:

- Environmental integrity
- Economic efficiency
- Equity for present and future generations

radically changed the traditional perspectives.



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SUSTAINABILITY EMERGING CONCEPTS

- **Water** must be considered as a **limiting factor** for economic growth and development
- **Environmental aspects** (especially water quality which may reduce **water availability** and **quality of life**) must be taken into consideration
- **Socio-economic** aspects must be taken into account
- **Legal and political** (local, national and international) issues (strategies, restrictions) must be considered
- **Uncertainty** (including hydrological stochasticity, climate change and future demand) has to be accounted for



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Planning sustainable resources exploitation requires to take into account:

- the present situation
- the socio-economic context
- the availability of resources
- the environmental carrying capacity

In addition it is also necessary:

- to place special attention on public requirements which implies strong interactions with population.



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EMERGING REQUIREMENTS

Sustainability requires studying problems in a **comprehensive way at catchment scale**.

Furthermore, with the introduction of the **sustainability concept** classical optimisation in water resources, has lost its leading role with respect to the integrated analysis of

environmental and **socio-economical impacts**

of **pre-defined development scenarios**.



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OTHER REQUIREMENTS FOR SUSTAINABLE PLANNING

- **Compatibility of technology with nature** and the physical, biological, ecological, social and cultural, political and sensual (including visual) environments,
- **Use, preservation and protection** of renewable resources,
- **Equitable allocation** and sharing of all benefits and costs,
- **Emphasis on service** as well as **profit** and financial feasibility,
- **Enhancement of local social institutions** and cultural traditions
- **Public involvement** in all aspects of planning and management and decision-making.



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THE NEED FOR INTEGRATED DECISION SUPPORTING TOOLS

From all these aspects the need emerges for **integrated planning and impact verification decision support tools**, integrating over a **geo-referenced database** all the required **models and tools** to be used by planners **to assess the consequences of measures on a multiplicity of aspects**, to navigate among the extremely large number of items and possibilities and to produce and implement development measures that will

keep track of the environmental and socio-economic interactions, of **public requirements** and of **administrative and legal viability**.



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Existing Decision Support Systems (DSS)

tend to be not sufficiently flexible or too detailed in the single models or restricted to some of the aspects of the problem, without taking into account the

complex interrelations

of all the

physical, socio-economical

and

environmental components



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Examples of Existing Decision Support Systems (DSS)

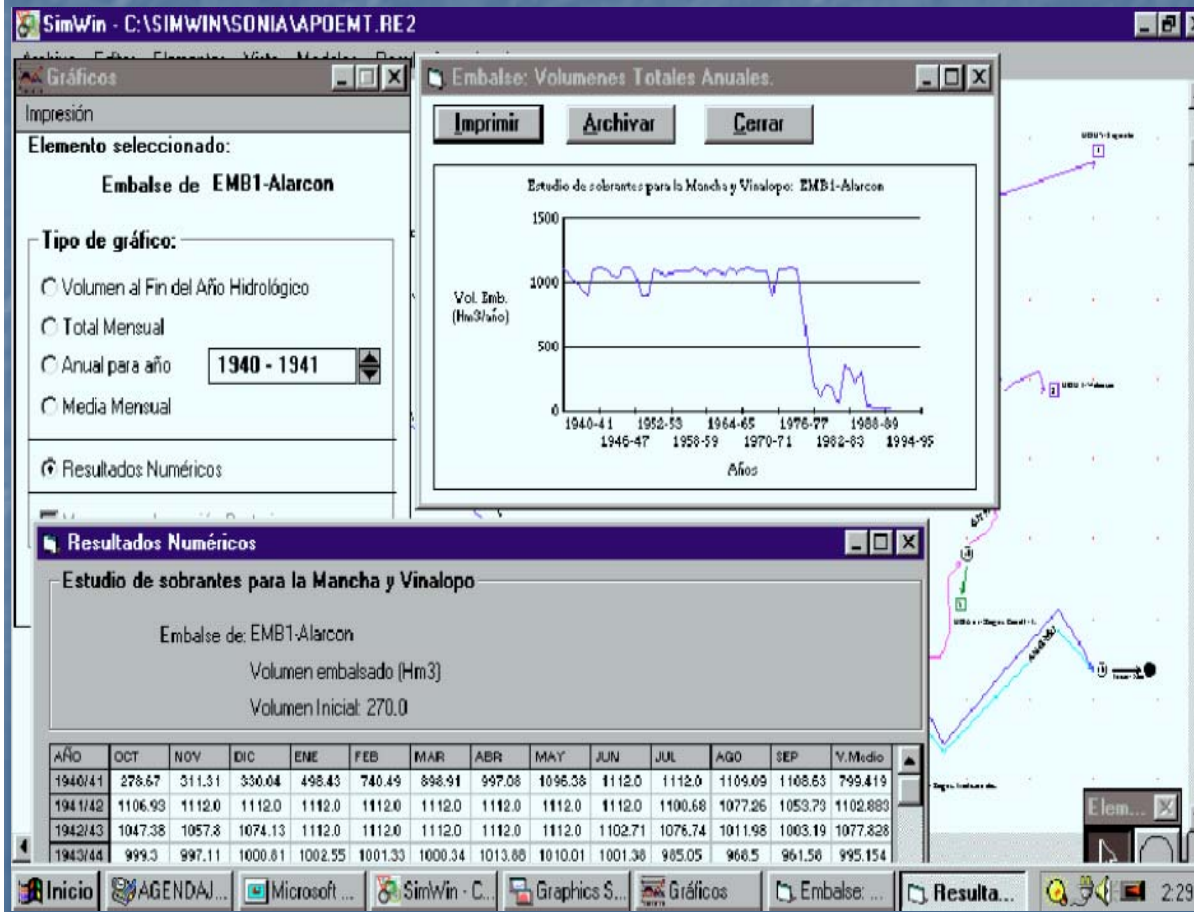
- **AQUATOOL – Polytechnical University Valencia**
- **BASINS - US EPA**
- **EGYPT DSS – ET&P**
- **ENSIS – NIVA**
- **IRAS – University of Cornell**
- **MIKE BASINS - DHI**
- **RIBASIM – Delft Hydraulics**
- **SPATIAL DSS – NTUA**
- **WATERWARE – Eureka 487**
- **WEAP – Stockholm Institute**



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AQUATOOL – Polytechnical University Valencia



PROS

General Water Resources
Management at catchment
scale

CONS

No economic and
environmental aspects

No link with GIS

Does not allow dynamic
inclusion of nodes



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BASINS - US EPA

BASINS 3.0

File Edit View Theme Analysis Surface Graphics Data Assess Window Help

Scale 591,702 1,392,940.39
2,105,894.99

Water Quality Targeting for NITRATE ...

Average Monitoring

- <0
- 0 - 1.19388 (M)
- 1.19388 - 5.96938 (M)
- 5.96938 - 23.8775 (M)

Permit Compliance

Industrial Facilities

Water Quality Targeting for NITRATE ...

Targeted Cataloging Units by No. of Stations Exceeding Threshold

Total Stations in Project Area: 12603

Category	No. of Stations Exceeding Threshold
1 Stat.	~1000
2 - 9 Stat.	~11000
10 - 28 Stat.	~500

Water Quality Targeting for NITRATE ...

Targeted Cataloging Units by Avg. Monitoring Value

Total Cataloging Units in Project Area: 58

Category	Avg. Monitoring Value (M)	Cat. Units
0 - 1.19388 (MG/L AS)	0 - 1.19388	~35
1.19388 - 5.96938 (M)	1.19388 - 5.96938	~15
5.96938 - 23.8775 (M)	5.96938 - 23.8775	~2

tutorial.apr

New Open Print

Tables

Charts

Water Quality Targeting for NITRATE NIT

Water Quality Targeting for NITRATE NIT

PROS
Environmentally oriented

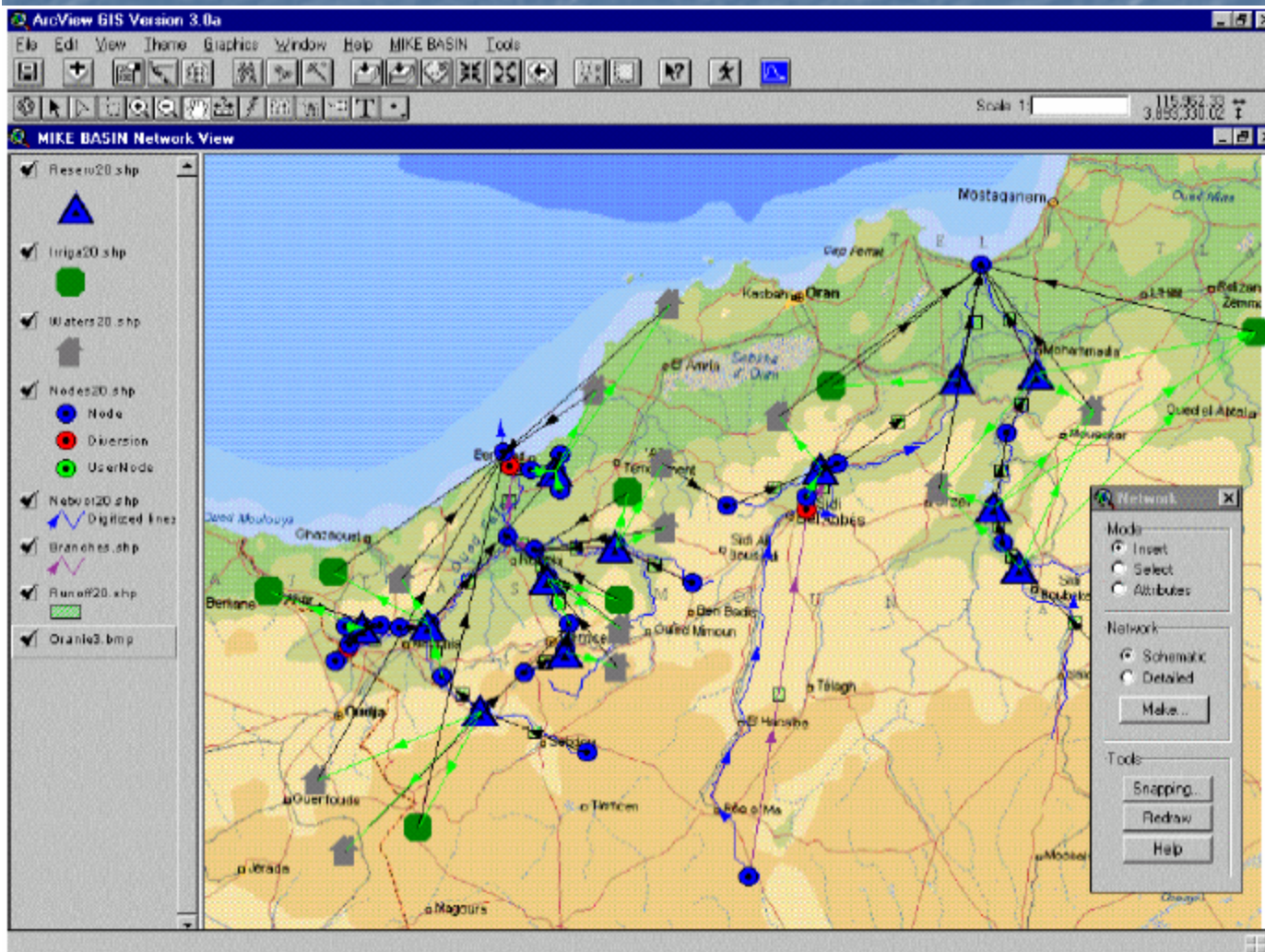
CONS
Physical aspects description prevails over socio-economical impacts



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MIKE BASINS - DHI



PROS
Integrated GIS-DB

Physical simulation
and optimisation

CONS
No socio-economic
and environmental
impact



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EGYPT DSS – ET&P

The screenshot displays the GIS software interface for the Egypt DSS. The main window shows a map of Egypt with a river network and a data menu. The menu options are: LoadDBMap, View Data, GU Reagregation, and Isoline to Raster. The interface includes a menu bar (File, Database, Analisi, Modifica, Models, Database, GisDB), a toolbar, and a status bar. The status bar shows the time 19:08.

E.T.&P.
Environmental Technologies & Products

DB Grass corrente

DB: x:\cbrasscos

Location: egypt

Mapset: new

- Load Levels -
U\optionMenu: Load Vector

Exit

PROS

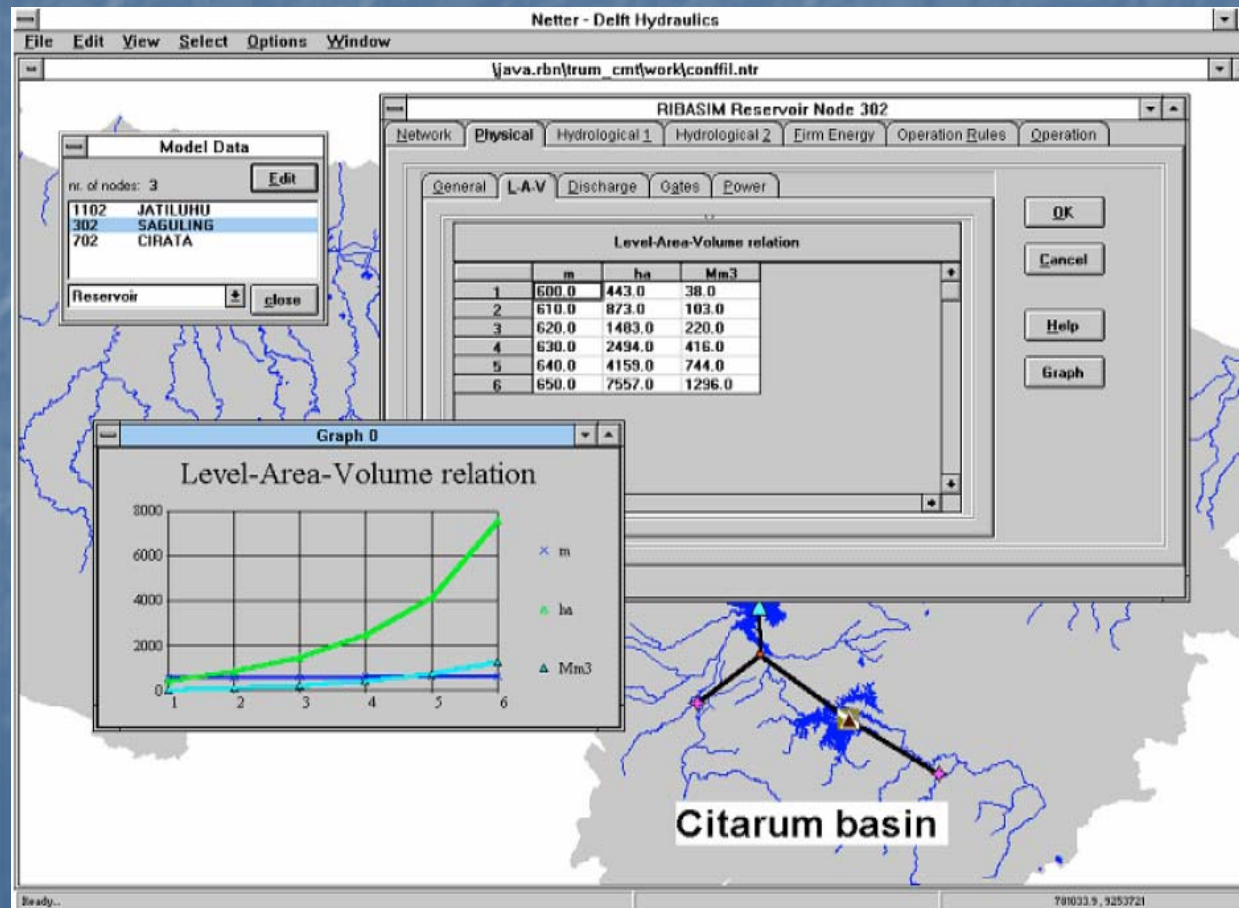
Comprehensive
Includes
Socio-economical,
Environmental and
Quality of Life
indicators

CONS

Too complex as a
generic tool



RIBASIM – Delft Hydraulics



PROS

Includes several models
Performs water allocation

CONS

Does not allow for
Environmental and
Socio-Economical
impacts

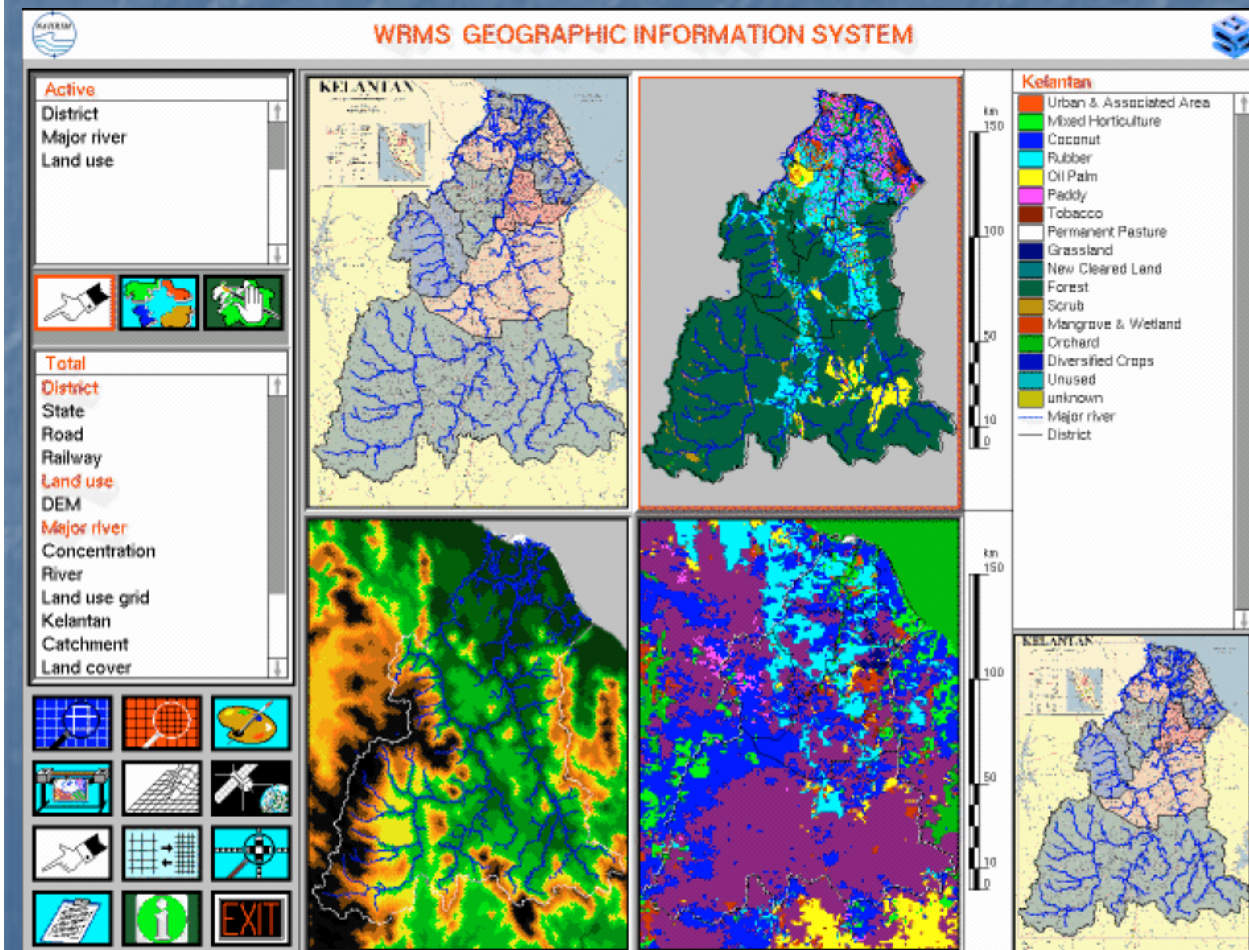
Can import maps but
does not provide GIS
facilities



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WATERWARE – Eureka 487



PROS

Incorporates GIS and DB
Open architecture

CONS

More information system
than DSS

Integration of components
very expensive

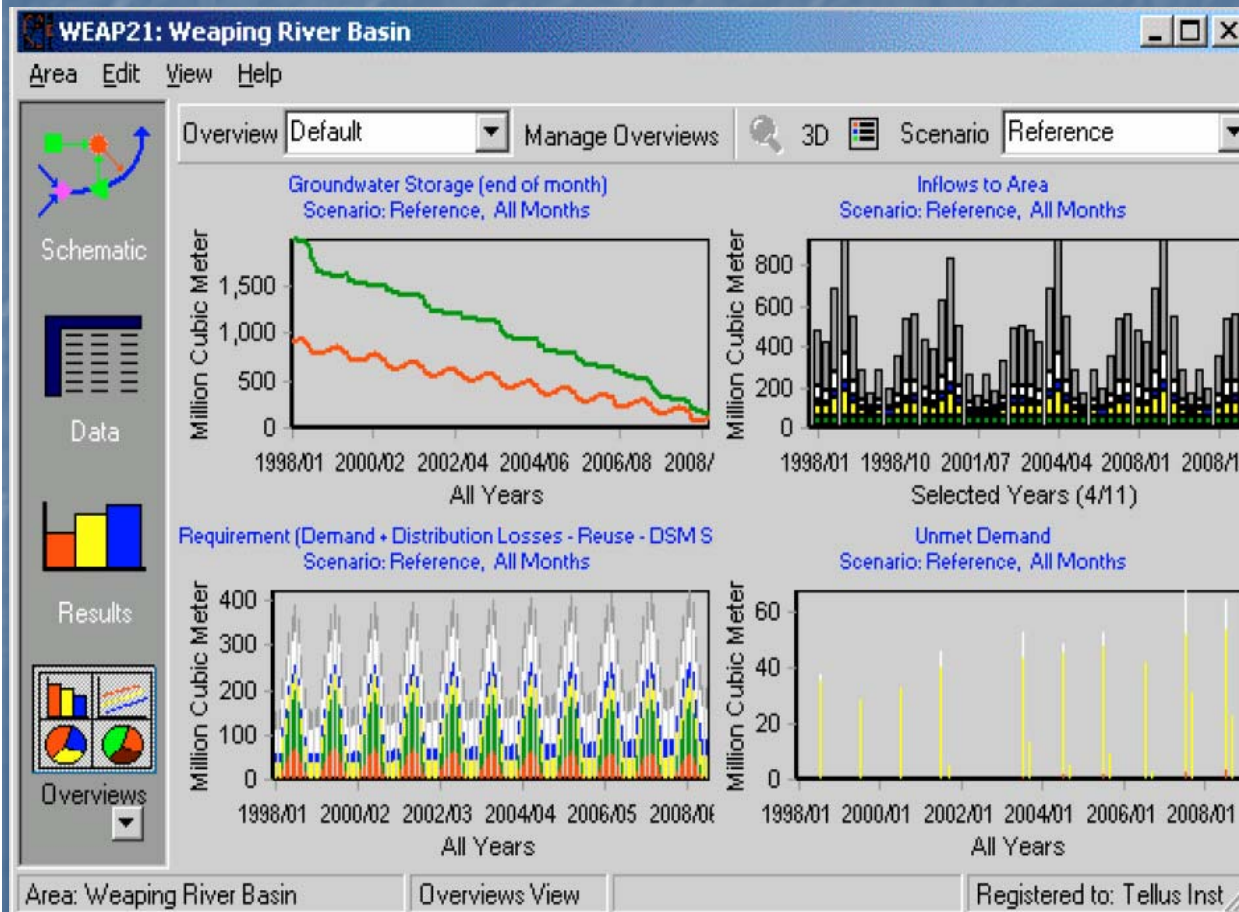
Scant documentation
available



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WEAP – Stockholm Institute



PROS

Comprehensive
Based on DPSIR concepts

CONS

Does not include GIS/DB

Water Demand cannot
be updated through
feedbacks at each
time step



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A new tool: the WaterStrategyMan DSS

- A comprehensive Decision Support Tool
- Uses WFD and DPSIR concepts and approaches
- Fully imbedded in ARC-GIS
- Uses the ARC-GIS Geo-Database
- Includes interactive and user friendly graphical tools
- Includes default data, such as:
 - 1x1 km Geotopo30
 - 1x1 km FAO Soil Map of the World
 - 1x1 km Global Land Cover Characteristics Data Base
 - 10x10 km Monthly average climatology
- Allows for multicriteria analysis of indicators



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The Water Strategy Man Team

National Technical University of Athens (Greece)
ProGeA – Protezione e Gestione Ambientale (Italy)
Ruhr University of Bochum (Germany)
Office International de l'Eau (France)
The Hebrew University of Jerusalem (Israel)
The Water Development Department (Cyprus)
INSULA (Spain)
The University of Porto (Portugal)



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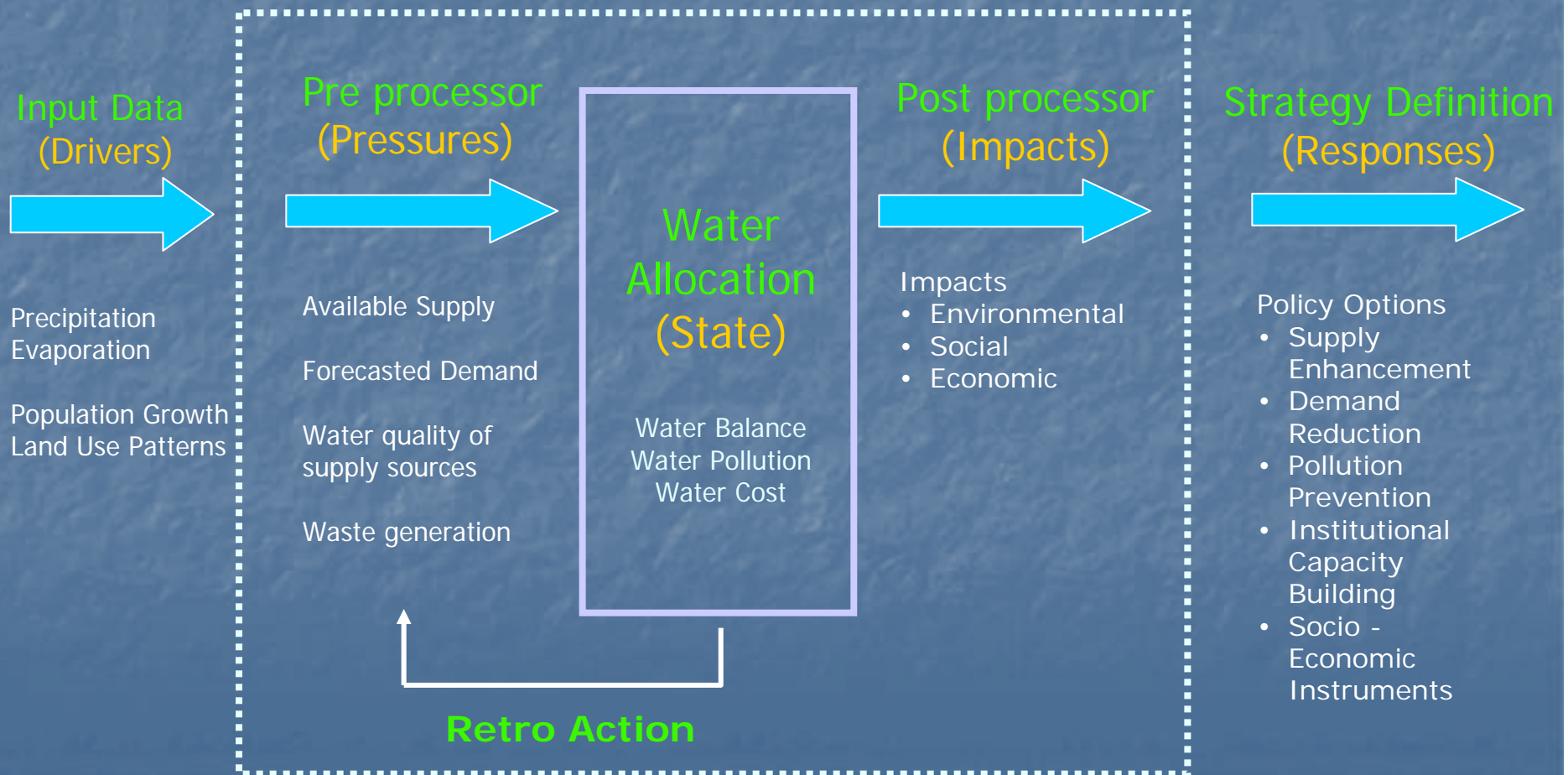


Objectives of the WSM DSS

- To support the strategy analysis at regional level
- To compare strategies on the basis of different indicators
- To help decision-makers to decide upon the best strategy, taking into account:
 - Regional development priorities
 - Social and economic constraints
 - Environmental constraints
 - Local, national or international legal constraints and directives



The WSM DSS Framework





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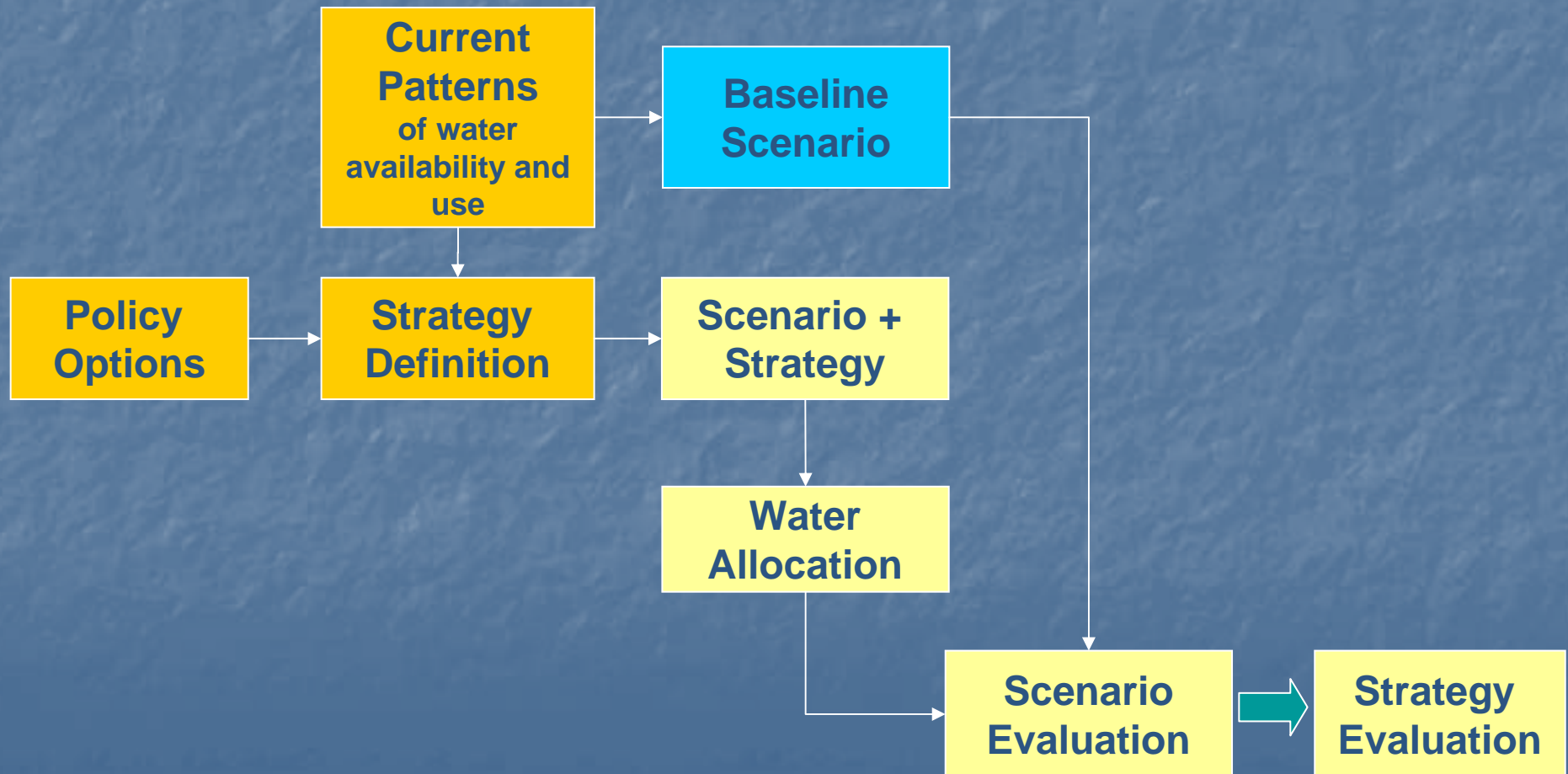


The Four Main Functions of the DSS

- **Describe** the existing **state** of the water system
- **Assess state** in terms of:
 - Sources
 - Usage
 - Water cycles
 - Environmental quality
- **Forecast state** on the basis of:
 - Assumed or envisaged scenarios
 - Technical alternatives
 - Management policies and actions
- **Evaluate impacts** of actions



The Analysis Procedure





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Water Strategy Man Decision Support System - GarciaArancioDistricts

Main Basic Data Help

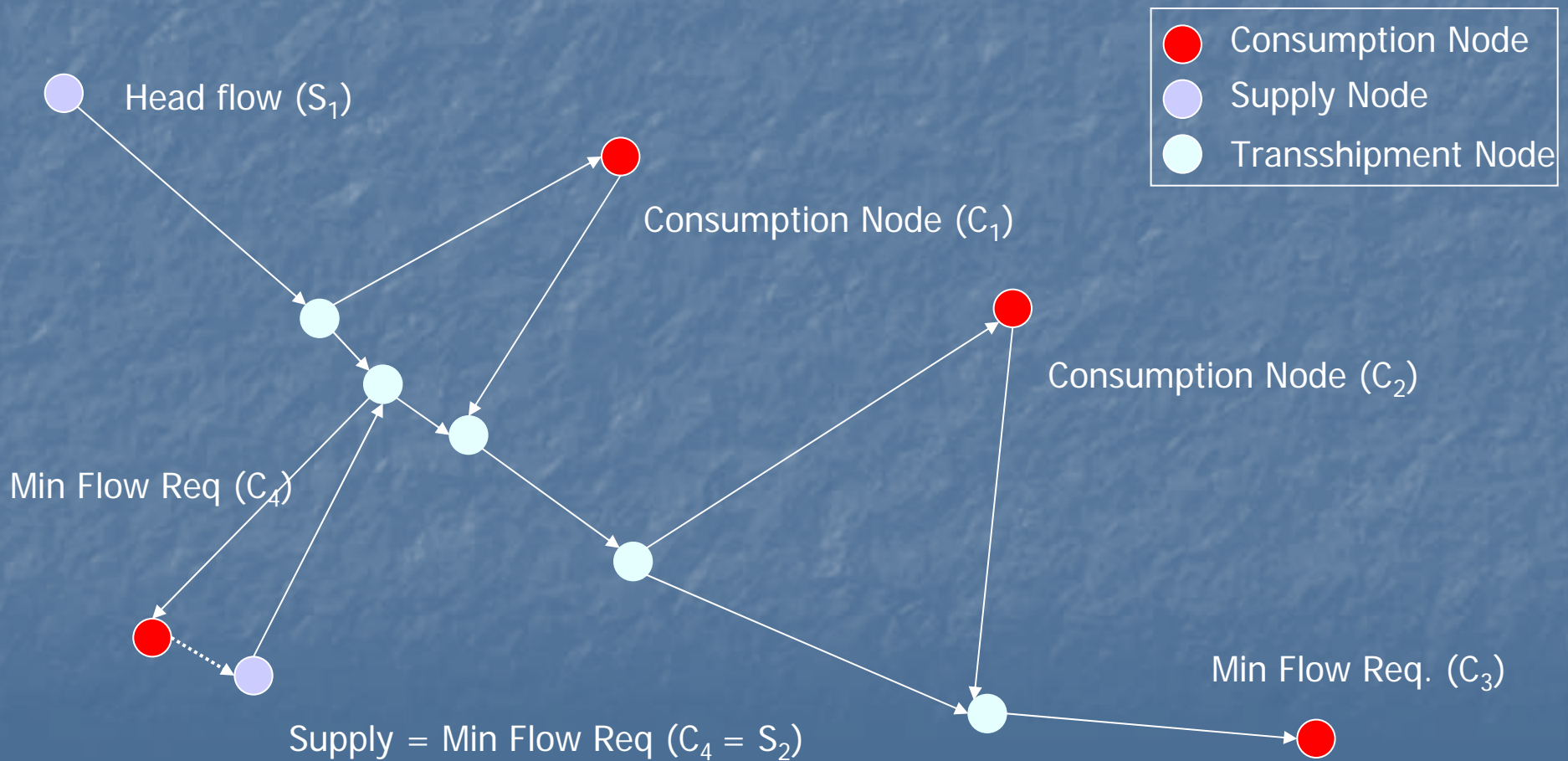
- GarciaArancioDistricts (BASE CASE)**
 - Edit Base Case Data**
 - Map Editor**
 - Data Editor
 - Discharge Scenario Base Data
 - BAU-Business As Usual (Water Management Schem**
 - Create Scenario
 - Water Availability
 - Demand
 - Create Water Management Scheme
 - Modify
 - Modify Map
 - Modify Data
 - Apply Strategy
 - Analysis
 - Overview
 - Economic Analysis
 - Detailed Results
 - Reservoir inter-connection (Water Management Sche**
 - Additional River Reach (Water Management Scheme)**
 - Create Scenario
 - Create Water Management Scheme
 - Analysis
 - EVALUATION**

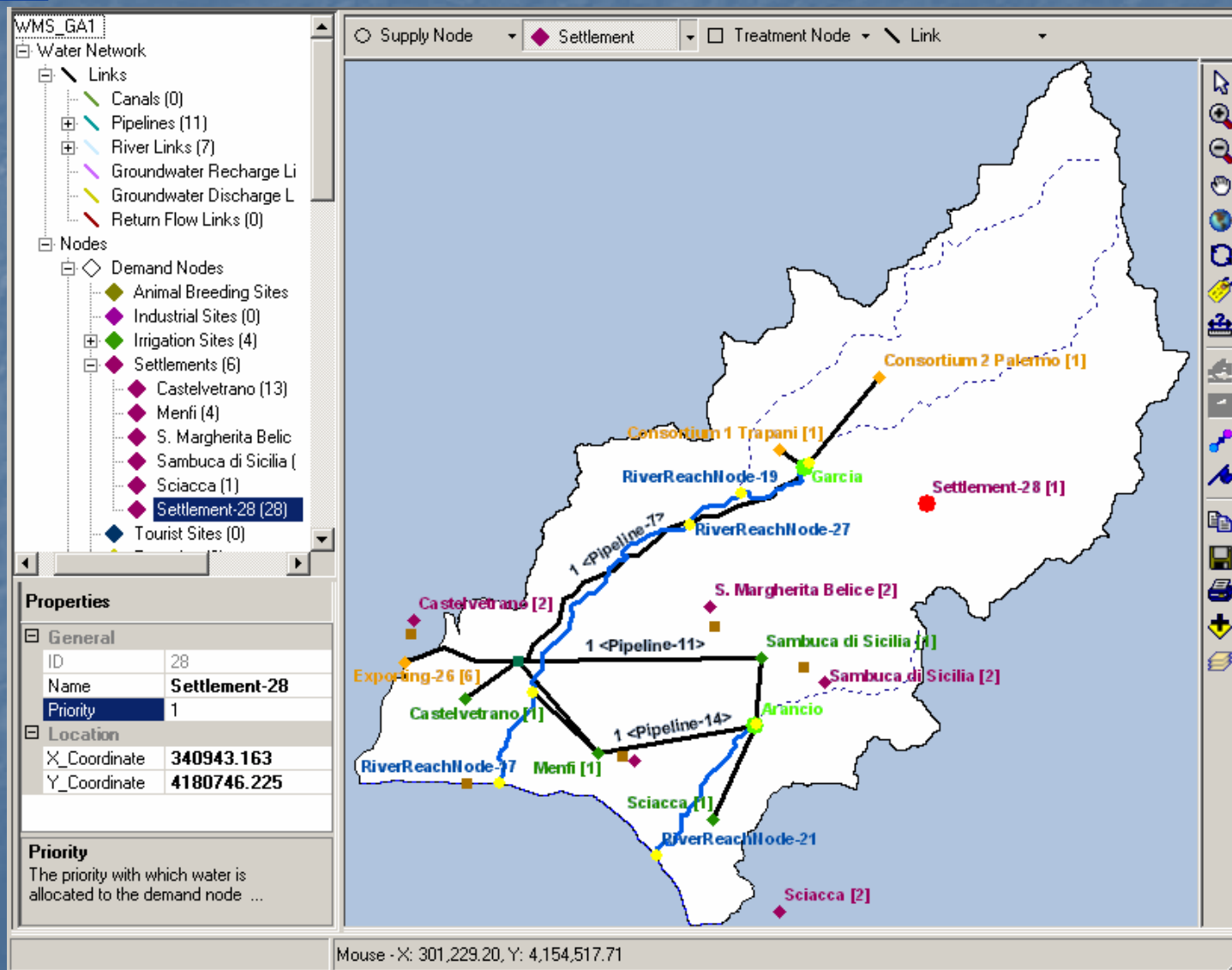
GarciaArancioDistricts

- Water Network
 - Links
 - Nodes
 - Demand Nodes
 - Animal Breeding Sites (0)
 - Industrial Sites (0)
 - Irrigation Sites (4)
 - Castelvetrano (7)
 - Menfi (6)
 - Sambuca di Sicilia (10)
 - Sciacca (2)
 - Settlements (10)
 - Tourist Sites (2)
 - Menfi (34)
 - Sciacca (35)
 - Exporting (6)
 - Consortium 1 Trapani (15)
 - Consortium 2 Palermo (16)
 - IrrigationTrapani (26)
 - Urban_Agrigento (38)
 - Urban_Favara di Burgio (59)
 - Urban_Trapani (39)
 - Environmental Demand (0)
 - Recreation (0)
 - Navigation (0)
 - Hydroelectricity Production (1)
 - Supply Nodes
 - Treatment Nodes
 - Transshipment Nodes



River Basin Schematization







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Generating hydrological scenarios

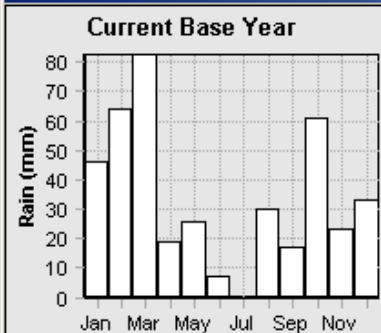
Hydrological scenarios can be directly generated from available hydrological data or by processing hydro-meteorological observations such as rainfall, temperature, evapotranspiration.

Scenarios can then be generated by:

- **repeating the base year** for the entire duration of the scenario,
- **defining a monthly or yearly trend** over the entire period,
- **building up a sequence** of previously created base years.



Rain Scenario Generation - Step 3: Selected Mode Parameters - Trend Definition



The third step of generating a scenario of rainfall allows you to specify the parameters for the selected mode.

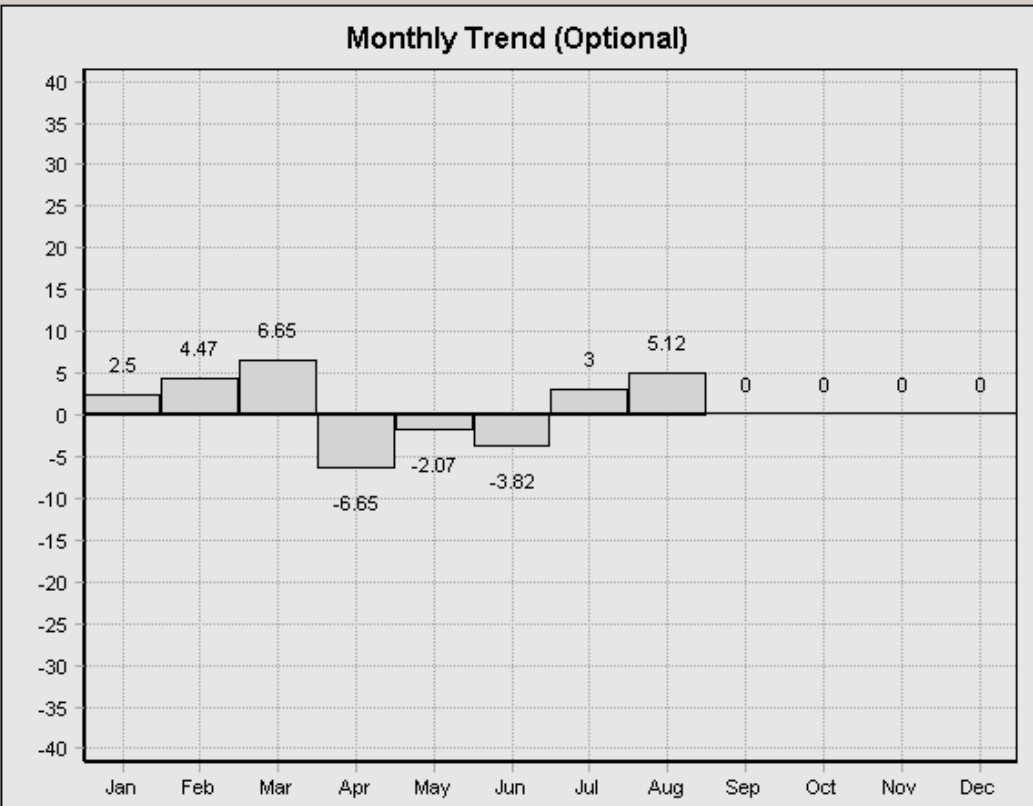
In this window you can assign a trend in two ways:

- a) Define a total increment of rain (Rainfall Trend) in terms of percentage over the entire duration of the scenario. The monthly variation within the year is derived proportionally.
- b) Define directly an increment of rainfall over the period for each month of the base year. In this case the "Rainfall Trend" you may have previously specified is ignored.

In both cases you can change the initial percentage of the base year (optional).

Current base year that has been previously selected is visualised in the top left corner of the window.

Rainfall Trend in the period: Percentage of base year:



< Back

Next >



Hydrological Balance - Geodatabase Results Visualization

Type
Sub-Basins

Element
RiverReachNode-17
RiverReachNode-18
RiverReachNode-19
RiverReachNode-20
RiverReachNode-21
RiverReachNode-22
RiverReachNode-27
RiverReachNode-28

Selected Rainfall Scenario:

Selected Evapotranspiration Scenario:

This window allows you to visualise the water balance results for each subbasin, aquifer, lake and reservoir in the case study area. In particular, the graph shows the computed runoff for sub-basins, lakes and reservoirs and the infiltration for aquifers.

Chart Table

Runoff Time Series

Year	Element 1	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	Element 8	Element 9	Element 10
2015	1.6	2.1	3.0	2.4	0.7	0	0.1	0.4	1.4	1.6
2016	2.0	3.0	2.3	0.6	0	0.1	0.2	0.4	0.4	0.4

Highlight Year



Generation of demand scenarios on population growth rates

Water Strategy Man Decision Support System - Demo, Demo WMS 2

Main Basic Data Help

- [-] Demo (BASE CASE)
 - [-] Edit Base Case Data
 - Map Editor
 - Data Editor
 - Discharge Scenario Base Data
 - [+] Demo WMS 1 (Water Management)
 - [+] Demo WMS 2 (Water Management)
 - [-] Create Scenario
 - Water Availability
 - Demand**
 - [-] Create Water Management Scheme
 - [-] Modify
 - Modify Map
 - Modify Data
 - Apply Strategy
 - [-] Analysis
 - Overview
 - Economic Analysis
 - Detailed Results
 - EVALUATION

Use	Growth Rate Expression
[-] Domestic Use	
Permanent population (in settlements)	0.015
Seasonal population (in settlements and tourist sites)	0.017
[-] Agricultural Uses	
Cultivable area growth (in irrigation sites)	0.02
Livestock number increase (in animal breeding sites)	0.05
[-] Industry And Energy	
Industrial production growth	<Not Set>
Growth of energy requirements from hydropower	<Not Set>
[-] Other	
Growth of demand for exporting to other regions	<Not Set>

Apply Growth Rates



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or on seasonal patterns

Settlements

The screenshot shows a software interface for configuring 'Settlements'. On the left is a tree view under 'Nodes' with 'Demand Nodes' expanded to show a list of settlements including 'Alte (356)'. The main panel has tabs for 'General', 'Population Data', 'Demand Data', 'Distribution Losses and Cost', 'Sewage Network', and 'Return flow quality'. The 'Population Data' tab is active, showing a table with columns 'Property', 'Value', and 'Description / Units'.

Property	Value	Description / Units
Residential Population		
Residential Population Growth	If{Year>=2010,GrowthRate(636,0.03,Year-1998)}	Residential population growth expression.
Month Variation	<Click to edit>	Click to edit residential population month variation.
Seasonal Population		
Tourist Population Growth	GrowthRate(36142,0.017,Year-1998)	Overnight stays growth expression.
Month Variation	<Click to edit>	Click to edit overnight stays' month variation.

Irrigation Sites

The screenshot shows a software interface for configuring 'Irrigation Sites'. On the left is a tree view under 'Nodes' with 'Demand Nodes' expanded to show a list of irrigation sites including 'Balaia Village (104)'. The main panel has tabs for 'General', 'Irrigation Activities', 'Irrigation Methods', 'Return flow quality', and 'Demand Economics'. The 'General' tab is active, showing a table with columns 'Property', 'Value', and 'Description / Units'.

Property	Value	Description / Units
General		
Area and employees		
Number Of Employees	1	Number of people employed at the irrigation site.
Maximum Cultivable Area	GrowthRate(333500,0,Year-1998)	Maximum cultivable area growth expression (area in m²).



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Policy Options and 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)



The Strategy Definition

ACTIONS	Strategy OPTIONS							
	Demand Management		Supply Enhancement		Institutional Capacity Building		Socio-Economic Instruments	
1	Household conservation	<input type="checkbox"/>	Importing water	<input type="checkbox"/>	Organizational mobilization	<input type="checkbox"/>	Cost recovery	<input type="checkbox"/>
2	Losses reduction	<input type="checkbox"/>	Surface storage	<input type="checkbox"/>	Institutional/ Legal amendments	<input type="checkbox"/>	...	<input type="checkbox"/>
3	...	<input type="checkbox"/>	Reuse	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>
...	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>





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Scenario + Strategy Evaluation

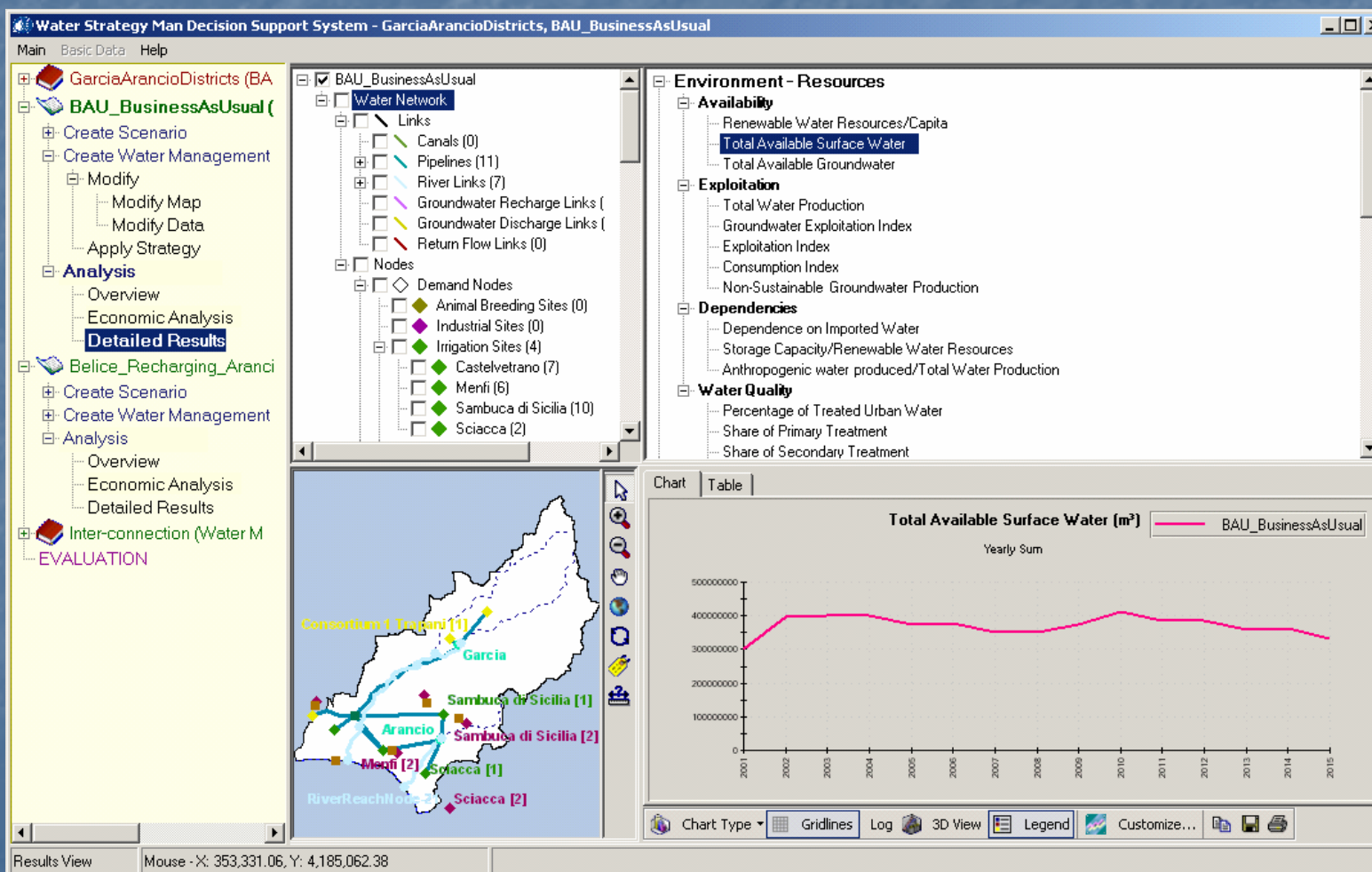
- Evaluation is based on indicators for:
 - Sustainability of water resources
 - Social/Economic benefits for water uses
 - Environmental impacts on water resources
 - Compliance with legal, economic and environmental constraints



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Analysis of results with reference to BAU





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Performance at node level

- **Pollution**
 - Concentrations of fecal coliform counts in water bodies
 - Concentrations of BOD / COD in water bodies
 - Heavy metal concentrations in water bodies
 - Decrease in effluent volume (%)
 - Reduced pollution levels in water bodies after wastewater treatment
- **Demand**
 - Increase in potable water (%)
 - Reduction of actual water consumption (%)
- **Economics**
 - Increase of income (%)



Performance at regional level (1)

- **Sustainability of resources**
 - Increased water availability with respect to baseline scenario (%)
 - Amount of groundwater reserves vs annual groundwater withdrawals
 - Annual regional water consumption (m³/cap)
 - Exploitation index
- **Demand**
 - Consumption Index
 - Dependence on importing (%) – on upstream
 - Coverage of water demand per sector
- **Water quality**
 - Increased amount of treated wastewater (%)
 - Area irrigated with treated effluent (%)
 - Improved drinking water quality (% of population)



Performance at regional level (2)

- **Economics**
 - Rate of cost recovery
 - Increased tourism revenues (%)
 - Increased revenues from agriculture
 - Increased revenues from industry etc
 - Total Cost
 - Direct Cost
 - Opportunity Cost
 - Environmental Cost
- **Environment**
 - Average monthly BOD in freshwater resources
 - Average monthly nitrogen in freshwater resources
 - Average monthly phosphorus in freshwater resources



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	Supply Nodes	User Nodes	Treatment Plants
Drivers	X	X	
Pressures			
Supply	X		X
Demand		X	
State			
Shortage		X	
Quality	X	X	X
Availability	X	X	
Impacts			
Social			
Health etc		X	X
Economic Impact		X	
Ecosystems	X		

Scenario

Evaluation

Matrix



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Strategy Evaluation Matrix

Impacts	Baseline Scenario	Scenario 1	Scenario 2
Social Impacts
Health etc
Economic Impact
Ecosystems
OVERALL PERFORMANCE



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CONCLUSIONS

The concept of sustainability radically changed the IWR planning approaches from **optimisation** to **scenario simulation analysis**

The **WaterStrategyMan Project** has produced a new **Comprehensive Decision Supporting Tool** aimed at coping with the emerging requirements.

It is hoped that the new tool, already tested on several European case studies, **will be extensively applied and evaluated** over several other catchments for further improvements based on users experience.



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Detailed description of the WSM DSS

was distributed to all the participants

Full project description can be found at

<http://environ.chemeng.ntua.gr/wsm/>

Thank you for your attention