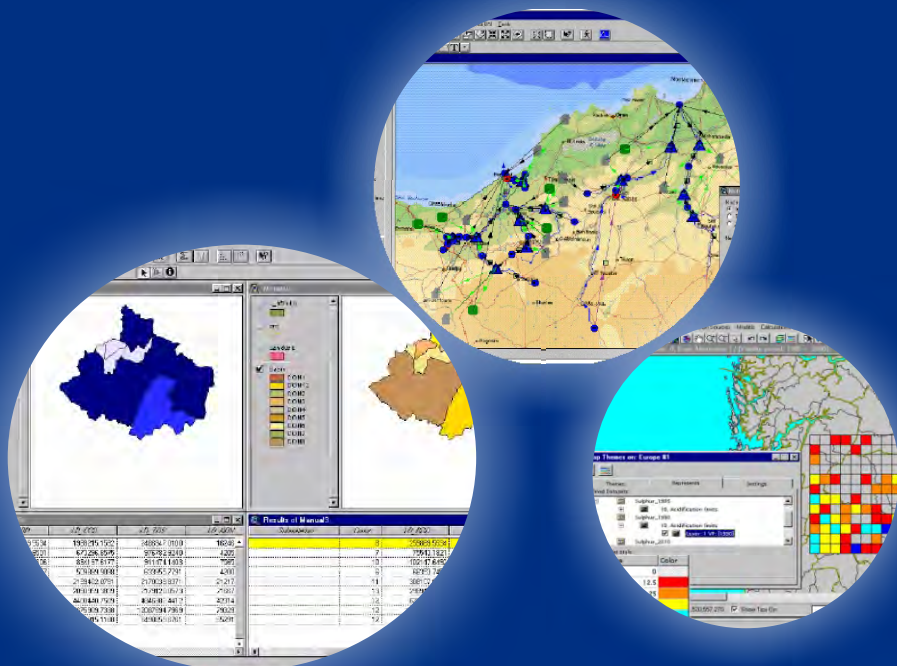




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IMPACT EVALUATION TOOLS & DECISION SUPPORT SYSTEM FOR ENVIRONMENTAL IMPACT ASSESSMENT (EIA)



Nile Basin Capacity Building Network



Impact Evaluation Tools & Decision Support System for Environmental Impact Assessment (EIA)

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NBCBN - BACKGROUND

Project Title**Knowledge Networks for the Nile Basin**

Using the innovative potential of Knowledge Networks and CoP's in strengthening human and institutional research capacity in the Nile region.

Implementing Leading Institute

UNESCO-IHE Institute for Water Education, Delft, The Netherlands (UNESCO-IHE)

Partner Institutes

Ten selected Universities and Ministries of Water Resources from Nile Basin Countries.

Project Secretariat Office

Hydraulics Research Institute – Cairo - Egypt

Beneficiaries

Water Sector Professionals and Institutions in the Nile Basin Countries

Short Description

The idea of establishing a Knowledge Network in the Nile region emerged after encouraging experiences with the first Regional Training Centre on River Engineering in Cairo since 1996. In January 2002 more than 50 representatives from all ten Nile basin countries signed the Cairo Declaration at the end of a kick-off workshop was held in Cairo. This declaration in which the main principles of the network were laid down marked the official start of the Nile Basin Capacity Building Network in River Engineering (NBCBN-RE) as an open network of national and regional capacity building institutions and professional sector organizations.

NBCBN is represented in the Nile basin countries through its nine nodes existing in Egypt, Sudan, Ethiopia, Tanzania, Uganda, Kenya, Rwanda, Burundi and D. R. Congo. The network includes six research clusters working on different research themes namely: Hydropower, Environmental Aspects, GIS and Modelling, River Morphology, flood Management, and River structures.

The remarkable contribution and impact of the network on both local and regional levels in the basin countries created the opportunity for the network to continue its mission for a second phase. The second phase was launched in Cairo in 2007 under the initiative of Knowledge Networks for the Nile Basin. New capacity building activities including knowledge sharing and dissemination tools specialised training courses and new collaborative research activities were initiated. The different new research modalities adopted by the network in its second phase include; (i) regional cluster research, (ii) integrated research, (iii) local action research and (iv) Multidisciplinary research.

By involving professionals, knowledge institutes and sector organisations from all Nile Basin countries, the network succeeded to create a solid passage from potential conflict to co-operation potential and confidence building between riparian states. More than 500 water professionals representing different disciplines of the water sector and coming from various governmental and private sector institutions selected to join NBCBN to enhance and build their capacities in order to be linked to the available career opportunities. In the last ten years the network succeeded to have both regional and international recognition, and to be the most successful and sustainable capacity building provider in the Nile Basin.

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FOREWORD

This report is one of the final outputs of the research activities under the second phase of the Nile Basin Capacity Building Network (NBCBN). The network was established with a main objective to build and strengthen the capacities of the Nile basin water professionals in the field of River Engineering. The first phase was officially launched in 2002. After this launch the network has become one of the most active groupings in generating and disseminating water related knowledge within the Nile region. At the moment it involves more than 500 water professionals who have teamed up in nine national networks (In-country network nodes) under the theme of “Knowledge Networks for the Nile Basin”. The main platform for capacity building adopted by NBCBN is “Collaborative Research” on both regional and local levels. The main aim of collaborative research is to strengthen the individual research capabilities of water professionals through collaboration at cluster/group level on a well-defined specialized research theme within the field of River and Hydraulic Engineering.

This research project was developed under the “Cluster Research Modality”. This research modality is activated through implementation of research proposals and topics under the NBCBN research clusters: Hydropower Development, Environmental Aspects of River Engineering, GIS and Modelling Applications in River Engineering, River Morphology, flood Management, and River structures.

This report is considered a joint achievement through collaboration and sincere commitment of all the research teams involved with participation of water professionals from all the Nile Basin countries, the Research Coordinators and the Scientific Advisors. Consequently the NBCBN Network Secretariat and Management Team would like to thank all members who contributed to the implementation of these research projects and the development of these valuable outputs.

Special thanks are due to UNESCO-IHE Project Team and NBCBN-Secretariat office staff for their contribution and effort done in the follow up and development of the different research projects activities.

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EXECUTIVE SUMMARY

Whenever a River Engineering (RE) project has to be undertaken, an Environmental Impact Assessment (EIA) must be carried out to identify the environmental impacts associated with the project so that the right mitigation measure can be put in place. Different processes are subjected to the project and impact analysis is one of those processes. The impact analysis starts with identification of impacts and later on prediction/evaluation of the impacts themselves. The last phase of impact analysis is impact significance to see the risks that impacts have on the environment. In Nile Basin countries, there is lack of impact prediction and unified tools for Environmental Impact Assessment for RE projects. Therefore, there was a need to conduct a survey of existing tools and methods for EIA plus their integrative nature to seek their application into Nile Basin Water Resources Management. The study was therefore carried out to identify and carry out the inventory of existing EIA tools, to set out the criteria for tools selection in Nile Basin Countries, to prioritize and select the identified EIA tools that can be used in Nile Basin Countries and to identify the risks (impact significance) assessment methods for EIA.

The study was desk study mainly focusing on literature review, but to achieve the above objectives the study did the literature search, identification and reviewing of existing models for integrated (environmental) assessments and evaluation, creation of an inventory of environmental assessment tools relevant for Water Resources Development (WRD) in the Nile Basin and Identification and reviewing of Risk Assessment Processes.

Several Decision Support Systems (DSS) EIA models were reviewed and have been presented as well as tools to aid predicting the impacts and thus in decision making addressing water resources issues. The majority of the software packages presented have been developed for and are currently applied to specific river basin case studies, but the features and approaches they use and the models they embed are general and can fit specific user-defined regions.

The report presents and discusses each model. The tools and models discussed include; **MIKE Basin** which aims at studying water allocation within a basin, **Basins** performs ecological and water quality studies at a watershed scale, **Integrated Quality and Quantity Model (IQQM)** a hydrologic modeling tool aiming at simulating river systems and supporting the planning and the evaluation of impacts of water resources management options, environmental monitoring and protection, **REALM** (REsource Allocation Model) is a package for the simulation of water supply systems and can be used to study different water resource options, **RIBASIM** (RIver BASin SIMulation) is a model package for water resource planning and management at the river basin level as it performs simulation of water allocation along a certain time horizon, **WEAP** (Water Evaluation And Planning System), a tool for water resources planning that assists the Decision Maker in storing and managing water demand and supply information, in forecasting water demands, water availability, waste generation and water costs and in evaluating water development and management options, **Waterware**, a DSS for integrated river basin planning and management as it integrates suites of models and tools aimed at comprehensive impact analyses,

Aqua tool, a generalized decision support system that consists of modules for simulation and optimization, modeling and risk assessment, for water resource planning and operational management at the watershed scale and **IRAS** (Interactive River-Aquifer Simulation) program, a tool for simulating surface and groundwater resources, their reciprocal interactions and flow exchanges over space and time.

Further the report presented the criteria for model selection which are data requirement, free or purchase, easy of use and accessibility. The scoring system and prioritisation based on the criteria was carried out from which WEAP score 4 points followed by RIBASIM 3 points the conclusion of which for Nile Basin region WEAP can be used as a DSS EIA tool.

The study further identified the processes of risk assessments as Identify risk, Assess risk, Reduce risk, and Document the results. However, due to time limitation and lack of coordination of the group it was not possible to apply the selected and prioritized DSS EIA tool and risk assessment processes for a particular case study in Nile Basin region. It is therefore recommended that the next phase has to concentrate in applying the selected tool for a given cases study in Nile Basin region.

ABBREVIATIONS & ACRONYMS

BOD	Biochemical oxygen demand
CoP	Community of Practice
DO	Dissolved oxygen
DSS	Decision Support Systems
EEA	European Environment Agency
EIA	Environmental Impact Assessment
FMEA	Failure Modes and Effect Analysis
GIS	Geographical Information System
HAZOP	Hazard and operability analysis
IQQM	Integrated Quality and Quantity Model
IRAS	Interactive River-Aquifer Simulation
IWRM	Integrated Water Resources Management in the Nile Basin.
MB	Mike Basin
MULINO	Multispectral Integrated and Operational
NBCBN-RE	Nile Basin Capacity Building Network for River Engineering
NBI	Nile Basin Initiative
NILU	Norwegian Institute for Air Research.
NIVA	Norwegian Institute for Water Research
OECD	Organization for Economic Cooperation and Development
PLOAD	Pollutant Load
PPE	Personal Protective Equipment
PSIR	Pressure/State/Impact/Response
QDNR	Queensland Department of Natural Resources
QUAL2	Enhanced Stream Water Quality Model
RE	River Engineering
REALM	Resource Allocation Model
RIBASIM	River Basin Simulation
RR	Rainfall-Runoff
TSEdit	Time Series Edit tool
UNESCO-IHE	United Nations Education and Scientific Organization – Institute of Hydraulics Education
WEAP	Water Evaluation and Planning System,
WinHSPF	Windows Hydrological Simulation Program-Fortran
WRD	Water Resources Development

1

INTRODUCTION

1.1 Background

The “Environmental Aspects of River Engineering” research cluster is one of the six research clusters that form the Nile Basin Capacity Building Network for River Engineering (NBCBN-RE). The node is hosted in Makerere University in Kampala, Uganda. Participants may come from all Nile Basin countries, but active inputs until the end of phase 1 of the NBCBN project were received from Sudan, Kenya, Rwanda and Uganda mainly. As for this phase, more inputs were also coming from other countries, like Tanzania and Egypt. The research cluster is globally made up of two research clusters namely:

- Group 1: Environmental Planning and Integrated Analysis
- Group 2: Impact Evaluation Tools and Monitoring

Group 2 has identified the following research area:

- Impact Evaluation Tools and decision support for EIA

The mentioned research topic is a priority area and in line with the research and development priorities of the riparian countries of the Nile Basin, who have organised themselves in the Nile Basin Initiative (NBI). The NBCBN activities are closely linked to and coordinated with the work of the NBI.

1.2 Evaluation Tools and DSS Group

At the 3rd Regional Workshop organized by Makerere University, Uganda and Nile Basin Capacity Building Network for River Engineering (NBCBN-RE), held in April 2005, at Makerere University, Kampala, the results of the first one year of research were reviewed and an outline of research activities for the 2nd phase of the project, which was scheduled to commence in June 2005, was discussed. However due to unavoidable circumstances, the activities did not take off. On August 26, 2006, a 1-day national meeting was held, facilitated by the scientific advisor, Dr. Boeriu Petru, to review progress and find a way forward. The outcomes of this meeting were several recommendations, one of which was to revise the cluster research activities to cover an initial period of two years, after which a new activity plan was drawn up based on the results of the first phase. Therefore, this report presents the results of phase 2 of the project activities which were over a period of three years (earlier on was supposed to be implemented over a period of one and a half years, starting January 2007 to July 2008), since 2007 to 2010.

The three-year research activities mainly focused on identification of existing tools for impact analysis, prioritising and selecting the tool(s) based on the criteria and identifying the risk assessment methods that can be used for RE Projects in Nile Basin Countries. The study was mainly a desk and literature review after the group had suffered from coordination for long time.

It is expected that the findings from this piece of work will enable high-ranking professionals in the water sector and decision-makers in the Nile Basin countries to address the problems in River Engineering projects to enhance best practices in the Integrated Water Resources Management and to ensure sustainability of service delivery in a dynamic environment. The problems to be addressed being trans-boundary in nature; they call for regional corporation and coordination to ensure the contribution and sharing of benefits is equitably done.

The —Environmental Impact Assessment and Decision Support Tools” research cluster aimed at becoming the leading community of practice (CoP) for EIA and RE research, development and utilize its experiences in contract research, training and development projects for EIA and RE in East Africa and the Nile Basin. It was also aimed at contributing scientific knowledge and tools towards Integrated Water Resources Management in the Nile Basin.

1.3 Study Rationale

Whenever a RE project has to be undertaken, an EIA must be carried out to the environmental impacts associated with the project so the right mitigation measure can be put in place. Different processes are subjected to the project and impact analysis is one of those processes. The impact analysis starts with identification of impacts and later on prediction/evaluation of the impacts themselves. The last phase is impact significance to see the risks of impacts on the environment. In Nile Basin countries, there is lack of impact prediction and unified tools for Environmental Impact Assessment for RE projects. Therefore, there was a need to conduct a survey of existing tools and methods plus their integrative nature to seek their application into Nile Basin Water Resources Management.

However, during the previous one year of research, concepts on scientific tools of analysis had been developed, providing an opportunity to further study and develop solutions to the prevailing problems.

The outcome of the present study is;

- Prioritised and Selected Impact Prediction Tools for EIA project with application of latest updates of Information Technology in the area of EIA
- A methodology for Environmental Risk Assessment, as an aid to Environmental Decision Making

The results have significantly contributed towards improvement of practices in Environmental Impact Assessment for River Engineering projects in the Nilotic Countries for sustainable and environmentally sound development and management of the River Nile Basin.

1.4 Problem Statement

Changes in the landscape are resulting from infrastructure; housing or industrial developments cause impacts on the natural environment with fragmentation and habitat loss being some of the main threats in Nile Basin countries. Environmental Impact Assessment (EIA) is an essential approach for minimizing the impact of physical and landscape plans and has a strong legislative basis. Despite its importance, the scientific knowledge of EIA in Nile basin countries is scarce and even the existing one is not well coordinated. In addition Nile basin countries lack unified tools for such assessment. There is need to conduct an inventory of existing tools and their integrative nature for all other environmental factors and suggest improvements of concepts, methods and techniques.

The descriptive and qualitative nature of many tools suggests a need to develop and implement quantitative and predictive methods to assess problems such as fragmentation and impacts on biodiversity. Such tools, from basic GIS applications to more advanced ecological models, already exist and have reached a level of development that allows practical implementation outside the research sphere. Although data requirements and the complexity of ecological models are limitations to their reproducibility and application range, the integration of landscape-ecology concepts in ecological assessment through the use of ecological models and GIS tools would contribute to the sustainable management of landscapes and their ecological resources.

1.5 Objectives

The aim of this study was, among others,

1.5.1 Long Term Objective

- To enhance Sustainable Environmental Management

1.5.2 Short Term Objectives

- To identify and carry out the inventory of existing EIA tools.
- To set out the criteria for tools selection in Nile Basin Countries
- To prioritize and select the identified EIA tools that can be used in Nile Basin Countries
- To identify the risks (impact significance) assessment methods for EIA

1.6 Significance

The inventory of existing evaluation and planning tools will increase the ability to present the quantified results from an EIA which will contribute tremendously towards improved practices in EIA in the River Nile Basin and will enhance the development of a common framework for Regional Corporation in river engineering projects. It will have the possibility of integration of biodiversity considerations in planning and thus helps the informed decision-making thereby reducing the possibility of regional conflicts related to management of shared waters.

2

METHODOLOGY

2.1 General Approach

The work was divided into the following major elements; identification and review of the existing, setting out the criteria for selection of, prioritizing and selecting EIA Tools and identification and reviewing of risks assessment methods. These elements allowed a wide spectrum of professionals with various expertises to effectively contribute to the activity. Participants from various countries in the Nile Basin; Uganda, Sudan, Egypt, and Tanzania participated to contribute. Communication among the researchers was expected to improve with increased use of the NBCBN platform and E-mail but didn't work out and ended up the group lacking coordination.

2.2 Detailed Methodology

The methodology focused on the following critical steps;

- Literature Search
- Identification and reviewing of existing models for integrated (environmental) assessments
- Creation of an inventory of environmental assessment tools relevant for WRD in the Nile Basin
- Identification and reviewing of Risk Assessment Processes

2.2.1 Literature Search

The earlier report which was compiled in June 2005 formed as one of sources of information for this stage due to the fact that lots of literature was gathered under phase I of this research work. Nevertheless, more research was conducted through Internet, and Libraries to collect more information on any method of impact evaluation and related concepts and tools. In appreciation of the existing knowledge, all existing tools and methods obtained are listed for future reference and probably application.

2.2.2 Review of Existing Concepts and Models of EIA

A detailed review of the existing models/methods for EIA was conducted to assess the suitability and reliability in water resources management of the Nile Basin.

2.2.3 Creation of EIA Tools Inventory

Based on the identified and reviewed EIA tools, an inventory of tools was created. The procedure followed the setting out of the criteria for model selection. The criteria set out were data requirement, whether it is free or it costs, easy of use, accessible, reliability and suitability. Then the criteria were weighted and summed up to get the highest scoring model. Different models had different scores and therefore the ranking and prioritisation of models was based on these criteria.

2.2.4 Identification of Environmental Risk Assessment Processes

The EIA processes have it that after the impacts have been predicted in a quantified manner, then follows the impact significance. This is normally carried out to see if the impacts have the significant impacts to the environments because not all impacts are normally significant to the environment. This requires that those impacts which have risks to the environment be identified and then a risk assessment is carried out on these impacts. A step was taken in finding appropriate processes for carrying out the risk assessment. Again to do this, literature search through the internet was carried out.

2.3 Preparation of Final Report

A final report was prepared by the appointed coordination unit towards the end of the project and submitted to the NBCBN secretariat for approval. Dissemination of the study findings was envisaged to be presented during the final workshop and in case the findings are approved, it will be disseminated in terms of training of EIA practitioners in the NB Countries.

2.4 Means of Verification

The prioritized EIA tools were supposed to be tested by applying them to earlier executed projects in various NB countries and comparing with the results of the earlier produced EIA's of these projects. However due to changing in coordination of the group, it was not possible to verify and apply the selected EIA tool to a particular case study due to a lack of time.

3

RESULTS

3.1 Identification, Reviewing and Inventory of EIA and DSS Tools

This section reviews the details of tools and models that can be used in making decisions concerning the management of River Nile by the Nile basin countries. Its purpose is to help identify the best available model or tool that can be used as a decision Support Tool for the sustainable management of the Nile Basin waters.

Several models have been presented as well as tools to aid in decision making addressing water resources issues. The majority of the software packages presented have been developed for and are currently applied to specific river basin case studies, but the features and approaches they use and the models they embed are general and can fit specific user-defined regions.

The models have been tabulated for its readability but the details of each model are annexed. The models in tabular format include; MIKE Basin which aims at studying water allocation within a basin, Basins performs ecological and water quality studies at a watershed scale, Integrated Quality and Quantity Model (IQQM) a hydrologic modeling tool aiming at simulating river systems and supporting the planning and the evaluation of impacts of water resources management options, environmental monitoring and protection, **REALM** (REsource Allocation Model) is a package for the simulation of water supply systems and can be used to study different water resource options, **RIBASIM** (River BASin SIMulation) is a model package for water resource planning and management at the river basin level as it performs simulation of water allocation along a certain time horizon, **WEAP** (Water Evaluation And Planning System), a tool for water resources planning that assists the Decision Maker in storing and managing water demand and supply information, in forecasting water demands, water availability, waste generation and water costs and in evaluating water development and management options, **Waterware**, a DSS for integrated river basin planning and management as it integrates suites of models and tools aimed at comprehensive impact analyses.

Aqua tool, a generalized decision support system that consists of modules for simulation and optimization, modeling and risk assessment, for water resource planning and operational management at the watershed scale and IRAS (Interactive River-Aquifer Simulation) program, a tool for simulating surface and groundwater resources, their reciprocal interactions and flow exchanges over space and time.

Table 1 below gives the summary of Tools and Models. For each model, the table defines what that model is all about, key features of the tool, data requirement, advantages and limitations.

Table 1: DSS EIA Tools and Models Summary

MIKE Basin	<ul style="list-style-type: none"> Developed by Danish Hydraulic Institute as a Versatile Decision Support Tool for Integrated Water Resources Management and Planning. Mike Basin aims at studying water allocation within a Basin (Inclusive of a water quality option and a ground water stimulating model)
Features	<ul style="list-style-type: none"> MIKE BASIN is integrated into the ArcView GIS environment to allow for maintaining full functionality of the ESRI software and applying its standard facilities to water resource modeling. By default Mike Basin aims at studying water allocation within a basin;

however a water quality option and a module for simulating groundwater can also be selected. This consists of **basin schematization** as a network of nodes and branches, the nodes should be placed in the following order: River nodes, Reservoirs, Hydropower nodes and Water Demand nodes.

- MB has an Access database, but data for each network element is easily edited or viewed from the *Network View*. The **Check Topology** tool can sweep the network connections and validate the basin schematization before running the simulation.
- The **Local Priority** principle is at the basis of the allocation algorithm of MB. MB has another principle for managing water allocation, the **Global Priority Rules**, whose concern is on abstractions, minimum flows, and reservoir storage and reservoir target levels.
- Simulation is required once schematization is completed. This involves defining required data and rules.
- MB simulates water quantity, water quality and groundwater. As far as water quantity is concerned, the calculation of water flows and their distribution in the basin is performed on the basis of the Local or Global Rules.
- MB, integrates a **rainfall-runoff (RR) module** that allows the computation of runoff time series given the initial conditions, a set of necessary parameters and time series of evaporation and precipitation. The models are NAM, SMAP and UHM which are part of another DHI software package named Mike 11.
- The NAM is a conceptual model that simulates the rainfall-runoff processes occurring at the catchment scale and in particular it calculates surface-overland flows, interflows and base-flows as a function of soil moisture content, surface storage, accumulation, and melting of snow. It treats each catchment as a single unit whose variables assume average weighted values for the entire area. NAM comprises the following modules: Basic modeling module, Extended Groundwater module, Snow module, and Irrigation module.
- The third model of Mike 11 included in the Rainfall-runoff module of MIKE BASIN is SMAP. It is a hydrological model simulating the runoff of a catchment area by accounting for moisture storage in the root zone and in aquifers.
- The **Water Quality module** of MIKE BASIN simulates transport and degradation of significant substances affecting water quality in reservoirs and rivers. The substances modeled are: Total Organic Matter expressed as Biological Oxygen Demand, Ammonia, Nitrates, Dissolved Oxygen, Chemical Oxygen Demand, Total Phosphorus and E. coli bacteria.

Required Data

- The input requirements of NAM consist of 1) basic meteorological data, such as rainfall and evapotranspiration 2) some additional data of temperature and radiation used for snow modeling 3) observed discharge data at the catchment outlet, to be compared with the model output for validation and calibration purposes 4) water used for irrigation and 5) pumping rates from aquifers. The time scale of meteorological data; rainfall depends on the time scale of the catchment response but usually daily values are sufficient; potential evapotranspiration can be provided as monthly values, while temperature is provided as daily mean values.
- The **Irrigation module** of NAM defines the conceptual approach for each large irrigation site as a sub-catchment described by its own individual parameters, such as irrigation losses to evaporation, seepage and overland flows. Monthly crop coefficients are also used to consider the proper evapotranspiration and stage of growth.
- Input data required by SMAP concern precipitation, evaporation, some specific parameters and the monthly mean discharge at the control outlet point of the basin, which is used for calibration purposes.
- The **Groundwater module** of MB requires the user to specify: 1) seepage loss fraction, to be multiplied by the simulated flow in the stream branch in order to obtain the water volume lost to the aquifer 2) groundwater recharge from the catchment area encompassing the stream and 3) pumping demand rates.

Advantages

- MIKE BASIN supports the definition of pollutant loads both at point and at non-point sources.

Limitations

- The system concentrates on the physical and optimization aspects of water resources, without taking into account socio-economic impacts and impact analysis techniques, such as PSIR (Pressure/State/Impact/Response) approach proposed by OECD, or the DPSIR approach (Driving forces, Pressures, State, Impacts and Responses) adopted by EEA, which links policy objectives to information and analysis in the context of management implementation.

BASINS MODEL

- BASINS MODEL is the Better Assessment Science integrating point and Non point Sources. BASINS model, developed by the U.S-Environmental Protection Agency, aims at facilitating the examination of environmental information, supports the analysis of environmental information and provides an integrated and modeling framework for examining point and non-point source management alternatives.

Features

- BASINS comprise a set of interrelated components that are integrated within the ESRI ArcView GIS environment. They are; GIS, National environmental databases, Assessment tools addressing both large- and small-scale analysis, Watershed delineation tools, Watershed characterization reports, Utilities for

importing, organizing, evaluating data, Utilities for classifying elevation, land use, soils, and water quality data, a suite of models concerning in-stream water quality and pollutant loads and their transport, and a scenario generator tool.

- The BASINS GIS, which is driven by the ArcView 3.1 or 3.2 GIS environments, provides built-in additional procedures for data query, spatial analysis, and map generation.
- The databases included in BASINS provide cartographic, environmental and water quality information, which have been selected on the basis of national availability and relevance to environmental analysis. **Base Cartographic Data** concern; Hydrographic boundaries associated with major U.S. river basins, networks of the major highways, populated and urbanized areas, and Administrative boundaries.
- **Environmental data** comprise background and monitoring information. The former describe watersheds in terms of soil characteristics, land use coverage, and stream hydrography, while the latter primarily concern water quality data.
- The **Assessment Tools**, (Target, Assess, and Data Mining) allow the regional assessment of in-stream water quality conditions, the identification of point source discharges on a watershed scale and the analysis and review of summary data for a specific site.
- The Watershed Delineation Tool permits the division of a watershed into one or more sub watersheds
- **Watershed Characterization Reports.** BASINS can assist the user to in creating customized maps and tables to summaries the overall conditions of the study area. BASINS version 3.0 generates six different types of **watershed reports**: Point Source Inventory Report, Water Quality Summary Report, Toxic Air Emission Report, Land Use Distribution Report, State Soil Characteristics Report, and watershed Topographic Report.
- BASINS has four utilities to reclassify, overlay, and update data. The **Land Use, Soils Class and Overlay** function is used to prepare data input for the SWAT and HSPF models. The **Land Use Reclassification** utility is used to change land use classifications within an existing data set.
- The Water Quality Observation Data Management supports the manipulation and addition of time series of water quality data observed at monitoring stations. The fourth basin utility is **DEM Reclassification** used to display large amounts of spatially distributed information.
- The models included in the BASINS package are Pollutant Load (PLOAD), Soil and Water Assessment Tool (SWAT), Windows Hydrological Simulation Program-Fortran (WinHSPF) and Enhanced Stream Water Quality Model (QUAL2).

	<ul style="list-style-type: none"> BASINS includes the program GenScn, GENeration and analysis of model simulation SCeNarios, and can be directly accessed from the GIS Interface. GenScn primarily serves as a pre- and post-processor for both the HSPF and SWAT models.
Required Data	<ul style="list-style-type: none"> General Data on Point Source/Loading Data that includes information on locations and type of facilities generating and discharging pollutant loads, such as: Industrial facilities discharge sites, Toxic release inventory Sites and pollutant release data, Location of transfer, storage, and disposal facilities for solid and hazardous waste. Data required by HSPF model comprise meteorological records of precipitation, estimates of potential evapo-transpiration, air temperature, wind, solar radiation, humidity and cloud cover. Data required by the Enhanced Stream Water Quality Model, QUAL2 concern hydrologic flows, water quality parameters and meteorological information. The latter includes monitored values of air temperature, atmospheric pressure, wind velocity, net solar radiation and cloud cover, all of which are involved in simulation of algae and temperature.
Advantages	<ul style="list-style-type: none"> BASINS is more environmentally oriented than MIKE BASIN The software can also be applied to other problems such as; wet weather combined with sewer overflows, storm water management, drinking water source protection, urban and rural land use evaluations, animal feeding operations and habitat management practices. The use of ArcView makes the architecture of BASINS open and flexible, so that each agency or a user can develop and customize their own utilities to better address specific needs and different applications.
Limitations	<ul style="list-style-type: none"> Physical aspects prevail over a comprehensive analysis and assessment of sustainability that can link policy options to information and analysis in an integrated water management context. The GenScn program allows the management of different scenarios; however the definition of a scenario is quite different from the one required for analysing water stress conditions.

INTEGRATED QUANTITY AND QUALITY MODEL (IQQM)

IQQM	<ul style="list-style-type: none"> The Integrated Quality and Quantity Model (IQQM) is a hydrologic modeling tool aiming at simulating river systems and at supporting the planning and the impacts evaluation of water resources management options, developed by the New South Wales Department of Land & Water Conservation, with collaborative assistance from the Queensland Department of Natural Resources (QDNR).
Features	<ul style="list-style-type: none"> IQQM is a windows-based software structured as a shell containing different modules linked together to form an integrated package. Its components are; river system model, rainfall-runoff model, gate operation model, climate

model, graphical output tools, statistical analysis tools, and data retrieval and utilities

- **River System Model** consists of the two sub-modules In-stream Water Quantity and In-stream Water Quality. The first concerns flow routing, reservoir operations, assessment of water resource availability, computation of urban, agricultural and environmental water requirements and the interaction between surface water and groundwater. The latter is based on the program QUAL2E, which can model the Nitrogen cycle, Dissolved oxygen (DO), Biochemical oxygen demand (BOD), the Phosphorus cycle, Coliforms, and Algae.
- The **Rainfall-runoff model** used within the tool is the Sacramento Model
- The **Gate Operation model** simulates extreme flood behaviour in gated storages with the aim of minimising flood discharges downstream the dam without endangering it.
- The **Climate Module** uses short-term daily climate data and long-term rainfall data to statistically generate long-term daily evaporation, minimum and maximum temperature and solar radiation.
- The **Statistical Tools** of IQQM are a set of routines that compute mean, standard deviation, coefficient of determination and efficiency and other statistics that are useful in the analysis of the daily, monthly or annual available data.
- The **Data Retrieval and Utilities** prepare the data files used by the software, check that the file format is correct and, if necessary, change it.

Required Data

- Data required includes; data on water demand for agricultural activities, industrial activities as well as urban and rural water demand. Data on precipitation, evapotranspiration, water harvesting and re-use, infiltration, soil moisture and crop types is required to aid in the simulation of Irrigation water demand.
- To be able to use the climate module, data on short-term daily climate and long-term rainfall is required.

Advantages

- IQQM allows the representation of the river system in node and link objects

Limitations

- The model does not integrate GIS software, and therefore lacks the related useful capabilities of data management and geo-referenced display.
- It also does not incorporate scenario management or conceptual scenario definition.

ENSIS

ENSIS	<ul style="list-style-type: none"> • ENSIS stands for —ENvironmental Surveillance and Information System” • It is a tool for the environmental monitoring and protection, and consists of two main Decision Support Systems, WaterQuis and AirQuis.
Features	<ul style="list-style-type: none"> • WaterQuis is concerned with water resources quality. WaterQuis DSS has models for calculation of pollution load. WaterQuis-specific features are; the definition and recording of information and data about catchments, rivers, lakes and coasts and the registration of discharge from domestic waste water, industries and diffuse sources. • AirQuis is concerned with air quality and pollution levels. It integrates atmospheric dispersion models, covering air pollution on all scales in the urban environment. • The GIS is programmed with MapObjects from ESRI, which makes it compatible with ArcView and ArcINFO. • ENSIS Internal Graphics Utility plots Time-series. • The ENSIS system has a report generator that is helpful in presenting analysis and results in an easy and clear manner and in disseminating them on the Internet.
Required Data	<ul style="list-style-type: none"> • water quality measurements
Advantages	<ul style="list-style-type: none"> • It is useful for creating and disseminating water quality reports and for time series visualization and analysis. • ENSIS embeds water quality models for calculation of pollution loads and proper routines showing their output
Limitations	<ul style="list-style-type: none"> • ENSIS is more a Surveillance and Information System based on GIS rather than a real Decision Support System. • The package does not provide capabilities for the management and comparison of alternative simulation scenarios. Water allocation in the area under surveillance is not considered, and water availability and demand evaluation are not included.

WATERWARE

WATERWARE	<ul style="list-style-type: none"> • WATERWARE is a DSS for integrated river basin planning and management, main objective of the European research program Eureka-EU487. • WATERWARE is one of the first examples of systems integrating suites of models and tools aimed at comprehensive impact analyses.
Features	<ul style="list-style-type: none"> • WATERWARE is coded in C/C++ but it is capable of integrating

models written in the FORTRAN programming language. Its developed as an open, object-oriented architecture running on UNIX servers and compatible with ArcInfo and Grass.

- WATERWARE consists; User interface, a GIS providing hierarchical map layers for spatial reference and direct data input for the simulation models.
- It is integrated with the database, the models, and http servers supporting remote access through the Internet, geo-referenced database with HTML documents and control technologies
- WATERWARE works with a variety of geographic, hydrological, meteorological, and economic data.
- The models embedded in WATERWARE simulate the behavior of the basin objects, providing their input from the geo-referenced database and displaying their output on GIS maps.
- Rivers are represented in WATERWARE as classes of River Node, Reach and Cross Section objects linked together to form the River Network Object.

Required Data

- WATERWARE works with a variety of geographic, hydrological, meteorological, and economic data.

Advantages

- WATERWARE is certainly a comprehensive DSS; it has been developed using an open architecture that integrates water quantity and quality models.
- It is linked to a geo-referenced database; it has a graphical network editor and uses geographical layers that are compatible with ArcInfo and Grass. It has more the role of an information system

Limitations

- Models used within WATERWARE are all conceptually linked together in a sort of data processing chain: during the simulation they are launched according to a predefined sequence, and the output of a model represents the input of the next ones. This is not an unusual way to perform the simulation. However, it surely can represent an obstacle if new modules are added or the existing ones are modified.
 - WATERWARE does not operate with economic, hydrologic or meteorological scenarios and does not integrate a framework for result comparison and definition of strategies or options to improve the water availability or to solve water pollution.
 - The system can support decision making under an integrated and multi-objective analysis.
-

AQUATOOL**AQUATOOL**

- AQUATOOL is a generalized decision support system for water resource planning and operational management at the watershed scale.

Features

- It's a Windows-based DSS that consists of modules for the basin management simulation and optimization, for modeling of water flows in aquifers, risk assessment, analysis and reporting of results. These components have been coded in different programming languages such as C++, Visual Basic and Fortran
- The **SIMGES** Fortran-coded mathematical model performs the simulation of the operational management of the system on a monthly basis.
- **OPTIGES** is the optimisation module of AQUATOOL. OPTIGES is based on mass conservation within the network of nodes and links
- **SIMRISK** is a module for risk assessment in real operational management of the system. It simulates the basin under several series of synthesized future hydrological inflows consistent with the initial conditions of the system and calculates the probability distribution function of water deficits, volumes of reservoirs, deficit in ecological flows and water quality indices
- The **Graphical Analysis Module** of AQUATOOL provides graphs, tables and report files, helpful for investigating the values of decision variables that result from simulations and optimizations, and for displaying hydrologic time series and parameters.

Required Data

- Data on storage capacity of for example on lakes and reservoirs, diversions and junctions, natural channels and aquifers.
- Data on evaporation and infiltration losses and water uses such as irrigated zones, municipal and industrial supply and hydroelectric plants is used.

Advantages

- AQUATOOL permits the simulation and comparison of different operating policies and hydrological data in order to analyze planning decisions and determine tradeoffs between different hydrological scenarios. Moreover, it provides risk assessment and evaluation. AQUATOOL is a running project at the department of Hydraulic and Environment
- AQUATOOL is basically an optimisation frame for water resources allocation.

Limitations

- AQUATOOL is not linked to GIS software and, moreover, the current version does not have an approach that integrates economic and ecological aspects, while management options, such as construction of new supply nodes, are not considered.

RESOURCES ALLOCATION MODEL

RESOURCE ALLOCATION MODEL(REALM) +	<ul style="list-style-type: none"> Package for the simulation of water supply systems, developed in 1997 by the Victoria University of Technology and the Department Of Natural Resources and Environment, in the State of Victoria, Australia. It was originally developed to run under the DOS operating system and it has been converted to run under Windows in 1999.
FEATURE	<p>-simulates simple as well as large and complex water supply systems, both under drought and normal conditions with high stream flows.</p> <p>-It can be used to study different water resource options, as for example new operating rules or physical system modifications and graphically compare them.</p> <p>-comprises a program manager, a graphical editor, a group of routines for listing, plotting and text editing, and the simulation core.</p> <p>- Has a graphical editor, which allows the user to draw the system network and to define the features of nodes, links and their operating rules.</p> <p>-The eight node types considered are: Reservoir, Demand, Irrigation demand, Diversion, Pipe junction, Stream junction,</p> <p>Groundwater, Stream terminator:</p> <p>-The entire network can be properly viewed and zoomed with the Network Plotting utility.</p> <p>-The user can introduce the carriers connecting the demand nodes to suppliers with the same drag & drop procedure</p> <p>- Carriers can be RIV type, representing river sections, and PIP type, representing pipes, aqueducts and general carriers that are not river sections.</p> <p>-The user can access and introduce each carrier's characteristics through the "pipe-river editing" window.</p> <p>-Attributes include: cost or penalty, used in the allocation process, transmission losses, and annual volume limit, capacity sharing among different demand sites both connected at the same carrier, minimum and maximum capacities and water quality parameters.</p> <p>-Carrier capacity can be expressed as a function of many system variables and edited by the user from a dedicated menu.</p> <p>Demand Restriction Curves</p> <p>- Manages the periods of low storage and stream flow through the; those determine the manner with which each demand is restricted and the degree of severity of this restriction.</p> <p>-The package considers two types of demand restrictions, namely urban restrictions, applied to urban and industrial demand zones, and irrigation restrictions, applied to irrigation demand zones.</p> <p>Simulation Scenario</p> <p>-Before running the water allocation simulation, the user has to define the simulation scenario.</p> <p>-In REALM the scenario refers to the set of run-time parameters such as simulation period, inputs of stream flows and demand, initial reservoir volumes, initial irrigation deliveries, water quality initialization data and output options.</p> <p>- The definition of parameters is conducted through the relevant dialog windows of the REALM setup program.</p> <p>-Category and Output</p> <p>Reservoirs: Storage volume, spills, targets, inflows, evaporation, storage level</p> <p>Supplied demand: Unrestricted demand, restricted demand, demand shortfall, rationed demand, restriction level, supplied demand</p> <p>Gravity diversions: intake ,spills, inflows</p> <p>Pump diversions: intake, spills, inflow</p> <p>Groundwater: storage volume, spills, inflows, evaporation</p> <p>Stream junctions: Inflows</p> <p>Carriers: flows, capacities, losses</p>
DATA REQUIRED	<p>-It uses water stream flows and demands as input.</p> <p>- The former consists of unregulated inflows entering the system and available at reservoirs, gravity diversions, stream junctions, and harvesting nodes.</p> <p>-These data can be organized on a monthly, weekly or daily basis.</p> <p>-Stream flows also include meteorological variables, such as temperature and rainfall.</p>

	-Water demand consists of time series data specific to determined demand zones in the area under study and can represent historic water usage or forecasted needs.
ADVANTAGES	-Has the possibility to choose some nodes or carriers of the system network from a list and highlight them in red. -This can be very helpful in finding specific nodes and carriers in large networks. -Has a network editor that allows the user to schematize the system of water users
LIMITATION	-The elements of the network are not geo-referenced, since the tool does not integrate GIS software and GIS maps cannot be imported, even to be used as a network background. -The economic aspect of water resources is reduced to the simple estimation of costs for conveying water through the carriers. As mentioned, these costs are actually the parameter that defines the priority of water uses in the water allocation algorithm.
MULTi-sectoral, INtegrated and Operational(MULINO)	-The acronym MULINO stands for “MULTi-sectoral, INtegrated and Operational decision support system for sustainable use of water resource at the catchement scale”. -It is the main objective of the related Mulino Project funded within the European Fifth Framework Programme for Research and Technological Development and Demonstration. -The project started in January 2001 and has duration of three years. This review concerns the first of the three planned intermediate versions of the tool. -The Mulino consortium consists of specialists in hydrologic modelling, software development, economy, geography, sociology, agronomy and GIS coming from various European countries and co-ordinated by The Fondazione ENI Enrico Mattei in Venice, Italy.
Features	-MULINO DSS integrates social, economic and environmental modeling techniques with GIS capabilities -A proposed series of “ <i>decision steps</i> ” has been encapsulated in the Mulino DSS and defined at the user interface level by the three Conceptual, Design, Choice Views: - Conceptual View : the Decision Maker (DM) is directly involved, and requested to define the water resource problem and choose the decisional criteria which will be used to measure and evaluate the river basin status and the effectiveness of the actions conceptualized to improve it. - Design View : the role of technicians is prevalent since they have to implement the problem formulated by the DM and find practical solutions that will constitute the set of possible options to be investigated. - Choice View : DM and technicians assign weights to the options so as to select the preferred one. - Spatial View and explore geo-referenced data on the GIS layers that describe the river catchment. Decision process is based on D-P-S-I-R indicators and the cause-effect relationship existing among them: Decision Maker; -describes the problem in terms of a set of Driving Forces that lead to specific Pressures exerted on the basin, so determining its State, and propose alternate options to improve the status itself. -builds up the D-PS chains in the Conceptual View of the interface, where a list of Driving Forces-Pressure- State indicators is already available from the database. -choose those which are relevant to the particular water resource problem and linked by cause-effect relationships. The first version of Mulino DSS has been applied to the Vela catchment, near Venice. In this case the two following D-P-S chains have been defined: - use of fertilizers in agriculture and livestock production (Driving Forces), leading to production of nitrogen (Pressure), which increases the nitrogen concentration in the water basin (State), - wastewater production, (Driving Forces) that leads to production of nitrogen (Pressure), which in turn increases nitrogen concentrations in the water basin (State).

	<p>The Design view consists of two parts.</p> <ul style="list-style-type: none"> -the first allows for the creation and definition of the alternative options: the DSS user can edit a new option, delete an existing one from the list of those available and display the related chains of D-P-S indicators. - the other part, the user accesses the geo-referenced database through the GIS layers and extracts the numeric values of the D-P-S indicators for each associated option. <p>The result is an Analysis Matrix with the status indices as rows and the different options as columns. The options designed for the Vela catchment are the following:</p> <ul style="list-style-type: none"> - EXCAV_MEO: excavation of a tributary, in order to increase the water retention time and as a consequence the potential self-purification effects for nutrient (N and P) discharges. - DIV_CANDE: redirection of the discharge of an area (153ha) from the Vallio River into the Candellara canal that drains outside the lagoon. - BUF_VALLIO: plantation of a wooden buffer strip along one of the main rivers of the catchment, the Vallio River, to improve the phyto-remediation effect. <p>Analysis Matrix is the starting point of the Choice Phase in which the Decision Maker manipulates the numeric values of the indicators, so as to investigate which option is more effective.</p> <ul style="list-style-type: none"> -First of all, the values of the matrix are normalised through Value Functions described by the user, in order to make the options comparable. - Different types of state indicators are assigned a weight and are aggregated in just one value per option. -Finally the aggregated values, each one being representative of the global effect of a certain action on the basin status, are plotted on a graph and the Decision-Maker can choose the best alternative.
Data Required	Geo-referenced data on the GIS layers that describe the river catchment
Advantages	<ul style="list-style-type: none"> -The system has been conceived as an operational tool aiming at supporting and guiding the Decision Makers in each step of the overall decision making process, , from problem conceptualization to the choice of the best policy to solve it. -The first version of MULINO DSS suggests an interesting approach to problem definition and evaluation that focuses on ; -defining the subject of water resource analysis, in terms of D-PS chains, -defining available options to change the status and -evaluating proper state indicators for each strategic option.
Limitations	A network editor and simple hydrological models not integrated in this version but are going to be integrated in the DSS in the next versions.

RIBASIM The River Basin SIMulation	<ul style="list-style-type: none"> -Model package for water resource planning and management at the river basin level. -It has been developed over the years since 1985 by Delft Hydraulics, Netherlands, and it is currently used by many national and regional agencies all over the world. -Allows to describe a basin in terms of water sources and uses and to perform a simulation of the water allocation along a certain time horizon.
Features	<ul style="list-style-type: none"> -Windows-based software with a graphical user interface, a database, a simulation program and a tool for the analysis of results. -The main view of the User Interface shows a flow chart aiming to guide the user in the application of models to the river basin under analysis: the blocks of the chart change their colour, so as to show which step the user is currently performing and which are those already performed. -The macro-steps are: <ul style="list-style-type: none"> -The creation of the network of nodes and branches as schematisation of the basin users, water sources and specific features, - The data entry of the necessary information in the geo-referenced database, - The preparation of input such as hydrological time series, operational rules for reservoirs,

	<p>hydro biological and crop requirements</p> <ul style="list-style-type: none"> - The simulation, -The post processing of results and - Their analysis. <p>-The schematization of the basin consists of a network of nodes connected by branches.</p> <p>-The user creates the scheme from the interface tool called Netter.</p> <ul style="list-style-type: none"> - Netter has a window where all node types are listed. -Users can choose the types they want and place them on the geographical layer of the basin. - The geographic layer can be imported from ArcView or MapInfo. <p>Models embedded in the Ribasim Tool</p> <p>Samo, AgwatFishwat, Demes,Ribasim,Wadis,Delwaq,Wlm,Stratif</p> <p>RIBASIM enables the user to simulate and evaluate various measures and to compare their results.</p> <p>Measures can involve</p> <ul style="list-style-type: none"> - network infrastructure, with the building of new dams, reservoirs; irrigation systems - water management, with the specification of new priorities or rule curves of reservoirs - laws and water use regulations which can influence the demand.
Data Required	Network infrastructure data, reservoir data, law and water use regulation data
Advantages	<ul style="list-style-type: none"> - Helpful in identifying possible water use conflicts among different types of uses, such as farmers or industries - In studying the sustainable development of the river basin itself and in planning the adequate measures to solve conflicts or generally improve the water resource status. - The water balance and the flow composition are the basis for further water quality analysis to be performed by external models or by the Delft DeltaQ water quality model - RIBASIM allows defining different hydrological scenarios as inflows input to the water resource system, as well as strategies or groups of strategies (<i>cases</i>).
Limitations	<ul style="list-style-type: none"> -RIBASIM does not integrate GIS software. -There is not a real multi criteria evaluation procedure based on a comprehensive set of indicators.

WEAP <i>The Water Evaluation And Planning System</i> (WEAP)	<ul style="list-style-type: none"> - Tool for water resources planning developed by the Stockholm Environment Institute's Boston Center at the Tellus Institute, USA. -It aims at assisting the Decision Maker in storing and managing water demand and supply information, in forecasting water demands, water availability, waste generation and water costs and in evaluating water development and management options.
Features	<p>-Weap21 is the latest release of the software. It is windows-based and has been developed in the Delphi programming environment by Borland. The graphical user interface consists of four different views, namely Schematic, Data, Results and Overviews. They are accessed by specific buttons on the View Bar placed at the left of the interface main screen, where each view is displayed</p> <p>-Schematic View the user finds a GIS layer of the area of interest and can build the network of nodes and links representing the water resource system of the area.</p> <p>-WEAP is usually applied to river watersheds but the area can also be a larger or smaller geographic region.</p> <p>-The user draws the node system directly on the GIS layer by dragging and dropping the desired types of nodes and transmission links from a list window at the upper-left, to the specific position on the map in the centre of the interface.</p> <p>-After dropping the node type on the map, a pop-up window requests some minimum general information about the new node, such as the name and whether the node will be included in the simulation of the default scenario.</p> <ul style="list-style-type: none"> - Additional required data depend on the specific element type -Network elements can represent rivers, diversions, reservoirs, groundwater pumping stations, demand sites, wastewater treatment plants, hydropower stations and flow requirements.

	<ul style="list-style-type: none"> - Nodes are linked by transmission links and return flows. -The former carry water from the water resource nodes to the demand sites nodes, while the latter exit the demand sites towards treatment plants or river locations. - A small window, under the node types list, lists the GIS layers that can be loaded over the basic river basin map so as to add geographical information such as rivers, aquifers, lakes, seas. -Both network elements and maps are loaded by ticking the list elements with the mouse left button. -The GIS map can be navigated by moving the little hand cursor over it, and a specific part of the map can be selected and zoomed.
Data Requirements	GIS map, Watershed data, rivers, diversions, reservoirs, groundwater pumping stations, demand sites, wastewater treatment plants, hydropower stations and flow requirements data.
Advantages	-WEAP could certainly represent a good starting point for the development of a comprehensive decision support system
Limitations	<ul style="list-style-type: none"> -Unfortunately, it does not integrate GIS software and a formalized data base. This is certainly a limitation. -In addition no feedback in terms of water demand can be accounted for, which limits its real interest for the analysis of interventions such as for instance demand management.

Iras Interactive River-Aquifer Simulation	<p>-IRAS is the acronym for <i>Interactive River-Aquifer Simulation</i> program. It is a tool for simulating surface and groundwater resources, their reciprocal interactions and flow exchanges over space and time. IRAS was first released in 1994 and updated in 1998 by the Civil and Environmental Engineering Department of Cornell University and the Resources Planning Associates Inc of Ithaca, New York State.</p>
Features	<p>IRAS is Windows-based and has a graphical user interface supporting the user to study the generic water resource system. Through the interface, the user can:</p> <ul style="list-style-type: none"> -draw and define the features of the WR system components as a network of nodes and links - edit data and operating rules characterizing each type of network element -prepare input files and parameters of the simulation modules - plot input and output time-series over time and space - display simulation results geographically - calculate and view statistics of simulation results <p>IRAS network</p> <ul style="list-style-type: none"> -The IRAS network elements can model various components of any interacting surface groundwater system. -Nodes represent components or points of interest where simulated variable values are recorded, and where inflow, outflow, consumption, diversion, or storage events can take place. -The user of IRAS can choose among the following types of nodes: <ul style="list-style-type: none"> - Artificial reservoirs, whose release or discharge are governed by operating policies accounting for target volume, satisfaction of downstream demands, etc; - Natural lakes, whose outflow or discharge is determined by the topography of the basin and hence is a function of its volume or surface-water elevation; - Wetlands; - Confined or unconfined aquifers, distributed either horizontally or in multiple layers; - Groundwater withdrawal or recharge sites; - Gauging stations where time series of flow, natural recharge or quality parameters are available; - Demand sites, either consumptive or non-consumptive; - waste water discharge sites; - Hydropower plants, connected either to rivers or reservoirs. They are not real nodes but are conceived in IRAS as items featuring river links. Hydropower can be placed on any link and the flow entering the link is assumed to be available for the production of energy; - Confluences and diversions. <p>Links represent the transfer of water between two nodes and can be uni-directional or</p>

	<p>bidirectional if water goes respectively one direction only or both.</p> <p>Uni-directional links are:</p> <ul style="list-style-type: none"> - Natural streams or river reaches, connecting two surface-water nodes. River reaches are stretches of river that may be connected to hydroelectric power plants or pumping stations, - Diversion canals, drainage ditches or pipelines. <p>Bi-directional links are:</p> <ul style="list-style-type: none"> - Generic links transferring water between two nodes, in particular links connecting aquifer or wetland nodes. The schematic network is drawn by the user in a blank Iras window. - A digitized geographic map of the area can be loaded as a black and white image in order to facilitate a consistent placement of nodes.
Data Required	<p>All Nodes</p> <p>-Gauge-flow multipliers. Each node in the network may assume the role of a gauging station monitoring natural water flows. However, in case data time series are not really monitored or available in a newly defined <i>gauging node</i>, this latter is treated and described as a <i>fictitious station</i> that is conceptually associated to a real neighbouring monitoring point. The fictitious node generates its own data series from the associated real station by multiplying each real value by a proper calibrated factor, namely Gauge-Flow Multiplier, accounting for spatial interpolation or extrapolation.</p> <p>On the other hand, Gauge-Flow Multipliers can also be defined for all node types, here for converting the measurement units of monitored flows from the user-defined ones to those needed by simulation modules.</p> <p>-Quality parameters. If the node is a storage node and water quality is to be simulated, the user must define the values of the average daily growth or decay rate constants and the transformation rate constants for each water quality constituent being simulated and for each within-year time period.</p> <p>- Elevation data. Elevation data at a node are needed anytime hydropower or pumping may be considered on any of its incoming or outgoing links. If the node is a storage node, storage volume elevation functions should be defined. Elevation data are also required to define storage-area-discharge-seepage data at all storage nodes.</p> <p>- Loss functions. Water can be lost due to evaporation or seepage at any storage node and the user must define the appropriate loss functions at each applicable node for each within-year time period.</p> <p>Demand Node</p> <ul style="list-style-type: none"> - Water demand targets for each within-year period must be specified for each demand node. They are the water requirements of the node to be met by simulated water inflows. - Water sources identifiers and factors. Each demand node can have a set of assigned possible sources of water, either a reservoir or a release-rule site. <p>Reservoir and Natural Lake</p> <ul style="list-style-type: none"> - Storage volume capacity and initial storage volume, -Minimum release or discharge as a function of storage volume, - Elevation-storage, volume-surface area functions and daily evaporation loss rates, -Daily seepage volume loss as a function of storage volume, and - Values of growth, decay and transformation rate constants of water quality constituents. <p>Aquifer and Wetland Node</p> <ul style="list-style-type: none"> - Initial storage volume, - Evaporation and seepage loss as a function of surface area or storage volume, - Storage-elevation (head) functions if energy consumption from pumping is to be calculated on any of the connecting links. <p>Gauging stations</p> <ul style="list-style-type: none"> - Gauging stations are placed along rivers or in every site where natural uncontrolled inflows are calculated, for example based on measurements of precipitation and evaporation to get the net recharge. -These natural uncontrolled inflows represent the water input to the river system. Stations can also observe wastewater flows at treatment plant sites. <p>Waste Water Discharge Node</p>

	<p>-Number and type of waste or water quality constituents and their average initial concentrations for each discharge node and for each within-year period.</p> <p>-Concentrations of natural inflows entering the system at the discharge nodes must also be defined.</p> <p>Surface-Water Link Data</p> <ul style="list-style-type: none"> - Detention storage (volume in link if flow is 0) and initial link volume if flow routing and/or water quality simulation are implemented; - Flow losses as a function of flow in the link; - Values of water quality constituent growth, decay and transformation rate constants for each water quality constituent being simulated, and for each within-year time period; - Hydropower capacity, minimum turbine flow, plant factors and energy production constant, if hydroelectric energy is produced on the link; - Energy consumption constant, if pumping can occur on the link; - Link flow capacity, if it is designated as a diversion link. <p>Aquifer and Wetland-Area Link</p> <ul style="list-style-type: none"> - Links connected to aquifer nodes are named <i>groundwater links</i> and links connected to wetland-area nodes are named <i>wetland links</i>. Flow pumping policies as function of current storage volumes in the aquifer or wetland nodes are to be defined. <p>Diversion Link</p> <ul style="list-style-type: none"> - Maximum link flow capacity. <p><i>Simulation</i></p> <p>The IRAS simulation takes place in a separate program module, namely IRAS_s that reads database files, containing the data entered for each network element, and files with monitored natural flows and their relevant concentrations.</p>
Limitations	<ul style="list-style-type: none"> - Does not use geo-referenced data and GIS software - It seems that economic analysis and relevant indicators are not taken into account does not include a definition of scenarios and related management options and strategies - The high number of different link types connecting the nodes may lead to confusion.

3.2 Criteria for Model/Tools Selection and Scoring System

Much of modern scientific enterprise is concerned with the question of model choice. An experimenter or researcher collects data, often in the form of measurements on many different aspects of the observed units, and wants to study how these variables affect some outcome of interest. This is the question of model choice. Like it has been explained in section 3.1, different models were identified and reviewed. Since there are quite a lot of models, it was felt important that model should be selected based on the certain criteria. These criteria are relevant to the application of the model in Nile Basin Countries. The study set out criteria for model section includes data requirement, whether it is free or it costs, easy of use and accessibility

3.2.1 Data Requirement

Most of the models/tools require such type of data as spatial data (DEM, land use and soil type), hydro-climatic data (streams flows, temperature, precipitation, evaporation, wind speed, humidity etc), water quality data (e.g. BOD, sediment data etc). It is well known fact that most of the countries in the Nile Basin region don't have access to reliable data. There is a both spatial and temporal data gap both for hydrology and water quality. That is to say the data in this region is scare. So the model that is going to be selected should not require a lot of data, or data intensity should be low. The model that showed little data requirement scored 1 while the one that requires a lot of data scored 0.

3.2.2 Free or Purchase

The identified and reviewed model may sometimes call for resources (money) in order for one to buy them. The fact about the region is that some projects may not have enough resources to buy and therefore the

selection of the model will depend whether the model is free or needs to be purchased. The model that needs money to buy it scored 0 while the free one scored 1.

3.2.3 Ease of Model to Use

Another criterion that was used for model selection is it's easy to use. Ease of use of model means, how quickly someone can understand how to use a model and how easily they can use it. The primary notion of ease of use of model is that a model/tool designed with a generalized users' psychology and physiology in mind is, for example:

- More efficient to use—takes less time to accomplish a particular task
- Easier to learn—operation can be learned by observing
- More satisfying to use

The models reviewed may be complex to be used by the scientists from the region and therefore the model that will be easy to use scored 1 while the difficult one scored 0.

3.2.4 Accessibility

Accessibility was also another criterion for selection of the model. This comes from the fact the models identified and reviewed not all can be easily accessible. Some may be accessible even from the internet while others may need to be ordered from the manufacturers/dealers/suppliers. The model that was easily accessible scored 1 while the difficult ones scored 0.

Based on the above selection criteria and its scoring system, the following summarizes how each model scored and this led to prioritization of models for application in the Nile Basin regions, table (2).

Table 2: Scoring and Prioritization for Different DSS EIA Tools and Models

Criteria	Model										
	MIKE Basin	Basis Model	Integrated Quantity and Quality Model (IQQM)	ENSIS –Environmental Surveillance and Information System	Water ware	Aqu atool	Resource Allocation Model (REAL M	Multi-Sectoral, Integrated And Operational (Mulino)	RIBASIM (The River Basin Simulation)	The Water Evaluation and Planning System (WEAP)	IRAS (Interactive River-Aquifer Simulation)
Data Requirements	0	1	0	0	0	1	1	0	1	1	0
Free or Purchase	0	0	0	0	0	0	0	1	0	1	0
Easy to Use	0	0	0	0	0	0	1	1	1	1	0
Accessibility	0	0	0	0	0	0	0	0	0	1	0
Total	0	1	0	0	0	1	2	2	2	4	0

The above table shows that the model with highest score based on criteria set is WEAP scoring 4 points followed by RIBASIN with 3 points and REAM and MULINO each 2 points. Based on the scoring systems the tools that can be used in Nile Basin region is WEAP followed by RIBASIM and REAM and MULINO.

Because of time limitation and lack of group coordination for long time, the study was not able to proceed to apply the chosen model to a particular case study in the region.

3.3 Risk Assessment Processes

As it has been already explained that the predictions of the impacts is normally followed by impact significance, that means to see if the impacts have the risks to the environment. There is where now the processes for assessing the risks were called for. Again the following sections only gives the theoretical descriptions of the processes to take into account when assessing the risks. Due to time limitation and lack of coordination of the group it was not possible to apply the processes for a particular case study.

3.3.1 Defining Risk Assessment

The term “risk assessment” can mean the specific steps related to calculating a risk level, an overall term for the entire process, or to refer to any method that assesses risks. However a broadly accepted definition of risk assessment has not emerged (Manuele, 2005). Clearly, simplicity is needed in defining risk. The following statements (Manuele, 2005) are used to help build that definition.

- Hazards are defined as the potential for harm. The dual nature of hazards must be understood. Hazards include any aspect of technology or activity that produces risk. Hazards include the characteristics of things and the actions or inactions of people.
- Risk is defined as a combination of the probability of a hazard-related incident occurring and the severity of harm or damage that could result.
- Probability is defined as the likelihood of a hazard being realized and initiating an incident or series of incidents that could result in harm or damage-for the selected unit of time, events, population, items or activity being considered.
- Severity is defined as the extent of harm or damage that could result from a hazard-related incident.
- The entirety of purpose of those accountable for safety, whatever their titles, is to manage their endeavors with respect to hazards so that their associated risks are acceptable.

Risk assessment commences with hazard identification and analysis, through which the probable severity of harm is established (assuming that a hazard's potential is realized and a hazard-related incident occurs); it concludes with an estimate of the probability of the hazard-related incident occurring. An appropriate statement indicating risk level must include both the probability of a hazard-related incident occurring (related to some statistical base) and the severity of harm or damage that could result. If a risk assessment establishes that risks are not acceptable, appropriate abatement actions would taken.

3.3.2 Steps of Risk Assessment

The following steps are taken in risk assessment process (Main, 2004).

- Identify risk,
- Assess risk,
- Reduce risk, and
- Document the results.

A general risk assessment process describes the seven basic steps (Main, 2004) in completing a risk assessment. One step in particular, identifying hazards, is critical because if hazards are omitted the associated risks will remain unknown. Main (2004) noted that a task-based approach to identifying hazards has shown to be very effective and is recommended where applicable.

Integrating risk assessment in an organization is a process that generally follows a sequence of phases. Engineering design needs to change to include the risk assessment process to more effectively move safety into design. Only by changing the design process will risk assessment efforts succeed. Issues such as changing the design process to include risk assessment are critical to address for the risk assessment effort to be successful in a company. As with any new process or substantive change, people may resist. Guidance is shared on how to change the design process to include risk assessment, and what resistance may be encountered in doing so.

A team of interested persons should conduct the risk assessment. The team members can be drawn from several areas such as engineering, operations, safety, users and others. They may include different participants as the assessment evolves. To integrate risk assessment into the design process engineers will likely need education and training on risk assessment in some form.

Unfortunately, most engineering design efforts do not currently include formal risk assessments. Engineering design must include the risk assessment process to more effectively move safety into design. Introducing the risk assessment process will explicitly change the design process, allowing hazards to be identified and risk reduction methods to be incorporated early in the design process. If the design process does not change, long term efforts to improve worker and product user safety will fail even if risk assessments are deployed (Main, 2004)

Risk assessment does have limitations. Several limitations are discussed in order to minimize unrealistic expectations. Successfully integrating the risk assessment process into an organization requires time and effort. In industrial product or process applications, both equipment suppliers and users should perform risk assessments and be involved in the risk assessment process.

—Riskscoring system” is the term that describes how risks are assessed. There are many variables, factors and combinations that must be considered in selecting a risk scoring system. The three most common types of risk scoring systems are qualitative, semi-quantitative and quantitative.

3.3.3 Hazard Analysis & Risk Assessment Methods

Many methodologies are used to perform a hazard analysis and a risk assessment. For example, the System Safety Handbook describes 101 analytical methods (Stephans and Talso, 1997). Commonly used techniques include (Main, 2004; Manuele, 2005);

1. FMEA (Failure Modes and Effect Analysis),
2. What if analysis,
3. HAZOP (Hazard and operability analysis)
HAZOP investigates deviations from the intent of engineering design. A multidisciplinary team identifies all credible accident scenarios using detailed design information, operating characteristics, and actual operating experience with engineering components and systems.
4. Operational analysis
5. Fault Tree Analysis,

The Fault Tree procedure begins with an accident and determines with —reverseanalysis” the equipment failures or events that could have led to it. The Event Tree procedure begins with a component failure and follows a —forward analysis” to determine if a major accident could result. During hazard analysis the sequence of events which could lead to hazardous incidents is set out. The likelihood of the incident is then quantified. Fault tree analysis plays a key role in this part of the risk assessment. Fault tree analysis is normally used to evaluate failures in engineering systems. The analysis provides a graphical representation of the relationships between specific events and the ultimate undesired event. Fault tree analysis allows systematic examination of various materials, personnel, and environmental factors influencing the rate of system failure. The method also allows for the recognition of combinations of failures, which may not otherwise be easily discovered. The fault tree analysis is sufficiently general to allow both qualitative and quantitative estimates of failure probabilities within the analysis.

6. Checklist analysis
7. Safety reviews
8. Management oversight and risk tree

3.3.4 Thought- and Action Process for Risk Assessment

Whatever the simplicity or complexity of the hazard/risk situation, and whatever the risk assessment methodology used, the following thought-and action process is applicable (Manuele, 2005).

1) Establish analysis parameters. Select a manageable task, system, process or product to be analyzed, and establish its boundaries and operating phase (e.g., standard operation, maintenance, and startup). Determine the scope of the analysis in terms of what can be harmed or damaged: People (the public, employees), property, equipment, productivity and the environment.

2) Identify the hazards. The frame of thinking adopted should get to the bases of causal factors, which are hazards. These questions should be asked: What characteristics of things or the actions or inactions of people present a potential for harm? What aspects of the activity or technology produce risk?

Depending on the complexity of the situation, some or all of the following may apply.

- Use intuitive engineering and operational sense. This is paramount throughout.
- Examine system specifications and expectations.
- Review relevant codes, regulations and consensus standards.
- Interview current or intended system users or operators.
- Consult checklists.
- Review studies from similar systems.
- Consider the potential for unwanted energy releases and exposure to hazardous substances.
- Review historical data such as industry experience, incident investigation reports, OSHA and National Safety Council data, and manufacturers' literature.
- Brainstorm.

3) Consider the failure modes. Define possible failure modes that would result in the realization of the potentials of the hazards. Consider how an undesirable event could occur and what controls are in place to mitigate its occurrence.

4) Determine exposure frequency and duration. For each harm or damage category selected in Step 1 for the scope of the analysis, estimate the frequency and duration of exposure to the hazard (i.e., the frequency and duration of vulnerability or endangerment). For example, for workers, consider how often the task is performed, the duration of exposure and the number of people affected.

5) Assess the severity of consequences. What is the magnitude of harm or damage that could result? Learned speculations must be made regarding the consequences of an occurrence: The number of resulting injuries and illnesses or fatalities; the value of property or equipment damaged; the duration of lost productivity; or the extent of environmental damage. Historical data can establish a baseline. On a subjective basis, the goal is to determine the worst credible consequences should an incident occur, not the worst-conceivable consequences. When the severity of consequences is determined, the hazard analysis is complete.

6) Determine occurrence probability. Consider the likelihood that a hazardous event will occur. This process is also subjective. For more-complex hazardous scenarios, it is best to brainstorm with people knowledgeable of the issues involved. Probability is to be related to an interval base of some sort, such as a unit of time or activity, events, units produced, or the life cycle of a facility, equipment, process or product.

7) Define the risk. Conclude with a statement that addresses both the probability of an incident occurring and the expected severity of harm or damage. Categorize each risk in accord with agreed upon terms, such as high, serious, moderate or low.

8) Rank risks in priority order. Risks should be ranked in order to establish priorities. Since the hazard analysis and risk assessment exercise is subjective, the risk-ranking system will also be subjective.

9) Develop remediation proposals. When required by the results of the risk assessment, alternate proposals for design and operational changes that are needed to achieve an acceptable risk level would be recommended.

10) Take action. Action should be taken as necessary, as should follow-up activities to determine whether the action was effective.

3.3.5 Risk Assessment Process Flow Chart

Figure 1 presents the risk assessment process as given by (Main, 2004). This figure simplifies the process and reflects how risk assessment is conducted in industrial practice.

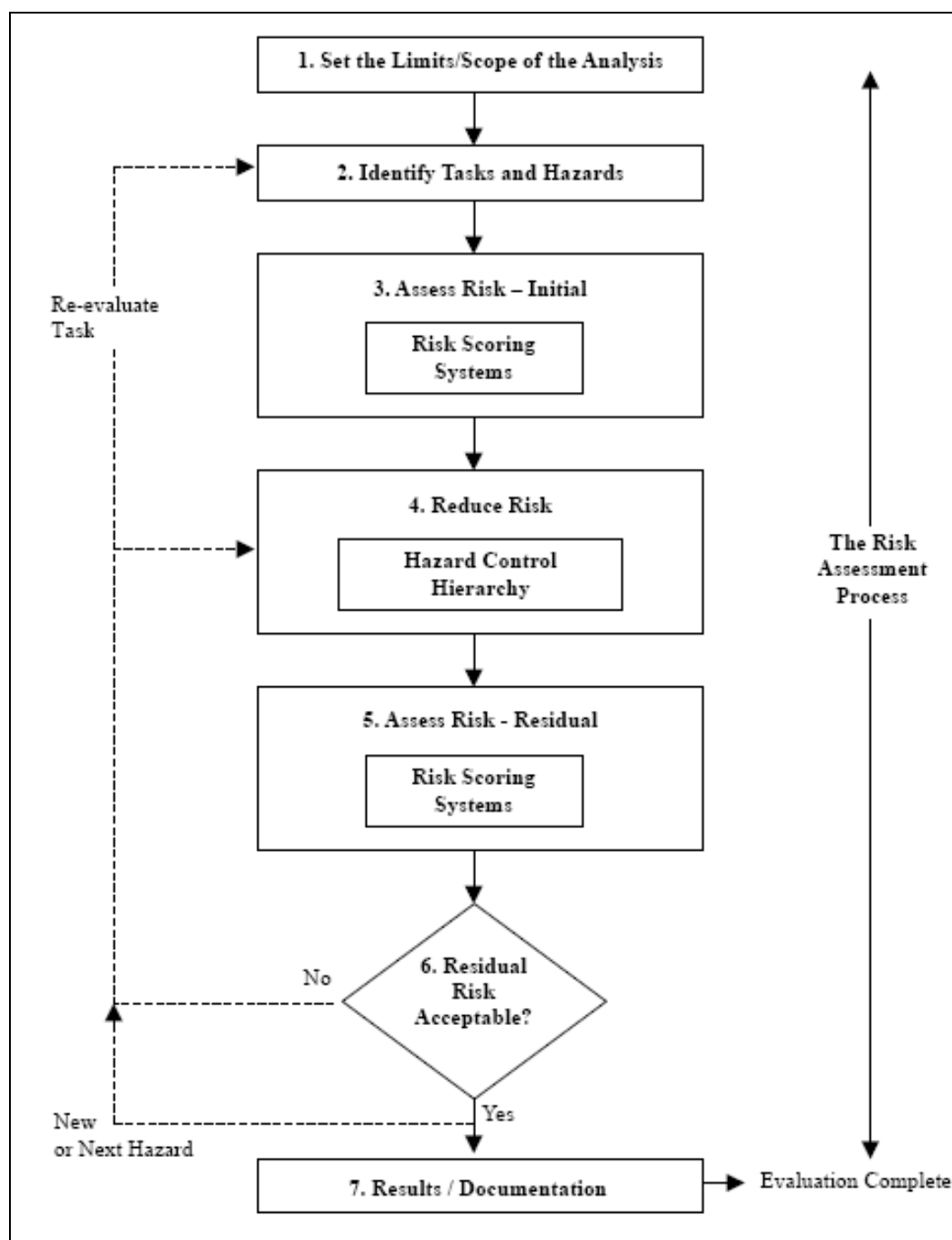


Figure 1 : The Risk Assessment Process (Source: Main, 2004)

3.3.6 Risk Assessment matrix

A risk assessment matrix (table 3) is a method that displays the combinations of probability and severity of harm or damage that could result and categorizes those combinations. Such a matrix also helps the SH&E professional communicate with and influence decision makers (table 4).

Table 3: Risk Assessment Matrix (Source: Manuele, 2005)

Occurrence Probability	Severity of Consequences			
	Catastrophic	Critical	Medium	Minimal
Frequent	High	High	Serious	Moderate
Likely	High	High	Serious	Moderate
Occasional	Serious	Serious	Moderate	Low
Remote	Moderate	Moderate	Moderate	Low
Improbable	Low	Low	Low	Low

Table 4: Management Decision Levels (Source: Manuele, 2005)

Risk Category	Remedial Action or Acceptance
High	Operation not permissible
Serious	Remedial action to have high priority
Moderate	Remedial action to be taken in appropriate time
Low	Risk is acceptable; remedial action is discretionary

3.3.7 Hazard Control hierarchy

A hierarchy is any system of action ranked one above the other. For SH&E practitioners, a hierarchy of controls establishes the actions to be considered in an order of effectiveness to resolve unacceptable hazardous situations. Achieving an understanding of the significance and the rationale for this order is an important step in the continuing evolution of the practice of safety.

The hierarchical control process is applied in the following order of preference:

- Eliminate the hazard and risk through system design
- Reduce risks by substituting less-hazardous methods or materials
- Use engineered safeguards (safety devices)
- Use warning and alerting techniques
- Use administrative controls (e.g. safe work procedures, training);
- Use Personal Protective Equipment (PPE).

For many situations, a combination of the risk management methods included in a hierarchy of controls may be applied. However, the expectation is that sequential consideration will be given to each method in a descending order, and that reasonable attempts will be made to eliminate or reduce the hazards and their associated risks by taking the more effective steps higher in the hierarchy before lower steps are considered. A lower step is not to be chosen until practical applications of the preceding higher levels are exhausted.

3.3.8 Common Hazards on a Hydro Power Project

- Flooding
- Explosions and/or Flammable materials (oil leaks and spills)
- Carrying heavy loads
- Exposure to harmful substances (toxic chemicals)
- Extreme Conditions of Temperature or Pressure
- Large Mechanical Equipment or controls
- Transportation accidents (Collision)
- Equipment and structural failure
- Noise and Vibration

Noise and vibration

Most noise and vibration arises during construction, especially when blasting is necessary. Substations and transformers are another source of noise (‘‘humming’’). If air blast switch gears are used, occasional loud noises can be produced. Noise levels from substations can be considerable, occasionally reaching 100dB close to the station.

4

CONCLUSIONS AND RECOMMENDATIONS

The study has identified and reviewed a number of DSS tools though there were developed for other purposes, they can be used for EIA. The reviewed tools include; **Mike Basin** which aims at studying water allocation within a basin, **Basins** performs ecological and water quality studies at a watershed scale, **Integrated Quality and Quantity Model (IQQM)** a hydrologic modeling tool aiming at simulating river systems and supporting the planning and the evaluation of impacts of water resources management options, environmental monitoring and protection, **REALM** (REsource Allocation Model) is a package for the simulation of water supply systems and can be used to study different water resource options, **RIBASIM** (RIVER BASin SIMulation) is a model package for water resource planning and management at the river basin level as it performs simulation of water allocation along a certain time horizon, **WEAP** (Water Evaluation And Planning System), a tool for water resources planning that assists the Decision Maker in storing and managing water demand and supply information, in forecasting water demands, water availability, waste generation and water costs and in evaluating water development and management options, **Waterware**, a DSS for integrated river basin planning and management as it integrates suites of models and tools aimed at comprehensive impact analyses,

Aqua tool, a generalized decision support system that consists of modules for simulation and optimization, modeling and risk assessment, for water resource planning and operational management at the watershed scale and **IRAS** (Interactive River-Aquifer Simulation) program, a tool for simulating surface and groundwater resources, their reciprocal interactions and flow exchanges over space and time.

Further the report presented the criteria for model selection which are data requirement, free or purchase, easy of use and accessibility. The scoring system and prioritisation based on the criteria was carried out from which WEAP score 4 points followed by RIBASIM 3 points. From the scoring, it can be concluded that WEAP can be used as a DSS EIA tool for Nile Basin region.

The study further identified the processes of risk assessments as Identify risk, Assess risk, Reduce risk, and Document the results. Due to time limitation and lack of coordination of the group it was not possible to apply the selected and prioritized DSS EIA tool and risk assessment processes for a particular case study in Nile Basin region and it thus recommended that for verifications of the DSS EIA tool and risk assessments processes identified a particular case study from Nile Basin region has to be selected and put into application.

5

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ANNEX:
Detailed DSS EIA Tools Descriptions

2.1 Review of Existing Tools and Models for Decision Support Systems

Introduction

The following Sections aim at providing an overview of Decision Support Systems for water management. The review aimed at analyzing the characteristics of available tools as well as at evaluating their applicability to the Nile Basin Countries. The criteria used for determining the applicability of reviewed tools were identified within the definition of the appropriate methodologies for a comprehensive, integrated and sustainable water resource management, adapted to the Nile basin countries regional context. The first criterion was the functionality of a Windows-based Graphical User Interface, connected with a Geographical Information System (GIS), which would have to allow for: (a) the graphical schematization of water resource systems, and (b) the active user-interaction in their construction and/or modification. The second criterion was the integration of a framework of indicators able to cover a wide range of aspects, such as water quantity and water quality, climatic driving forces, demographic pressures, sustainable exploitation, full water cost components and environmental demand. The third criterion concerned the capability to create and manage scenarios of driving forces such as rainfall and population growth, and the possibility to simulate multiple alternative cases and compare them through appropriate multi-criteria approaches, taking into account economic, social and environmental indicators. Last but not least, a vital criterion for the assessment was the ability to perform comprehensive economic analyses, in light of the requirements imposed by the Nile Basin Initiatives (NBI). The satisfaction of those requirements is shortly discussed at the end of each tool review.

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

Tools and Models Reviewed

The tools reviewed were the following:

Mike Basin, by the Danish Hydraulic Institute (DHI);

□ **Basins**, by the U.S.- Environmental Protection Agency;

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

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

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

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

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

□ **Mulino**, main objective of the related EU funded Mulino Project;

□ **Ribasim**, by Delft Hydraulics;

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

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

□ **Aquatool**, by the Universidad Politecnica de Valencia, Spain;

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

2.1.1 Mike Basin

In terms of actual Decision Support Systems, one may consider MIKE BASIN to be a first example of a comprehensive tool. Developed by the Danish Hydraulic Institute (DHI) as a *Versatile Decision Support Tool for Integrated Water Resources Management and Planning*, MIKE BASIN has been integrated into the ArcView GIS environment. This allows for maintaining the full functionality of the ESRI software and applying its standard facilities to water resource modeling.

Main Interface and Basin Schematization

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

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

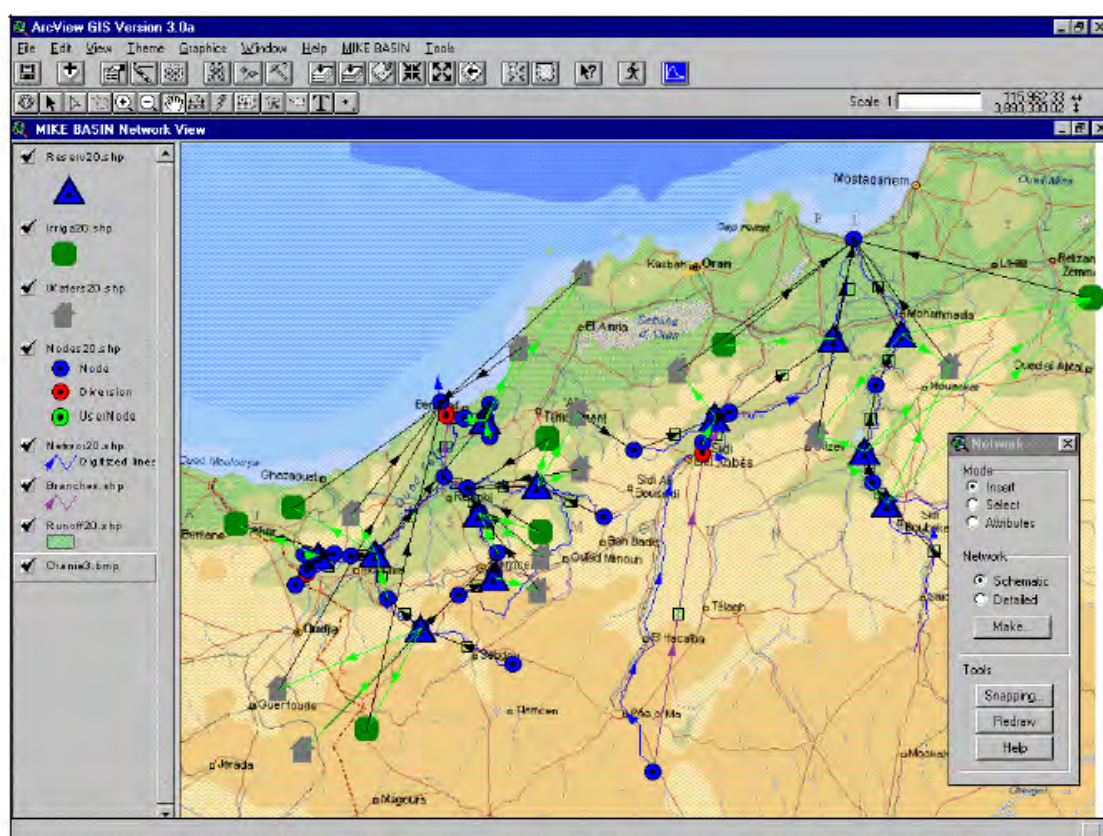


Figure 1: An example of Basin Schematisation in the Network View of MB

The **Schematic network** can be drawn on a geographic map showing the hydrography of the area of interest. At first, the user digitises manually the main river and his tributaries in terms of a polyline following the trace on the map. Then the nodes should be placed in the following order: River nodes, Reservoirs, Hydropower nodes and Water Demand nodes. River nodes are placed on the river polyline and are of *Simple* or *Catchment* type. *Simple* river nodes define confluences, diversions, upstream end of tributaries and the outlet of the river

system, while *Catchment* river nodes represent the outlets of upstream catchment areas. These areas are depicted hatched in green colour in the specific *Runoff* layer. A *Simple* or *Catchment* node can assume the further role of *Offtake Node*, when it is connected to demand nodes. Reservoir nodes are placed on top of river nodes, whereas Hydropower nodes are placed out of it. Water demand nodes are placed in the end and represent irrigation sites and water supply systems conveying water to cities or industries.

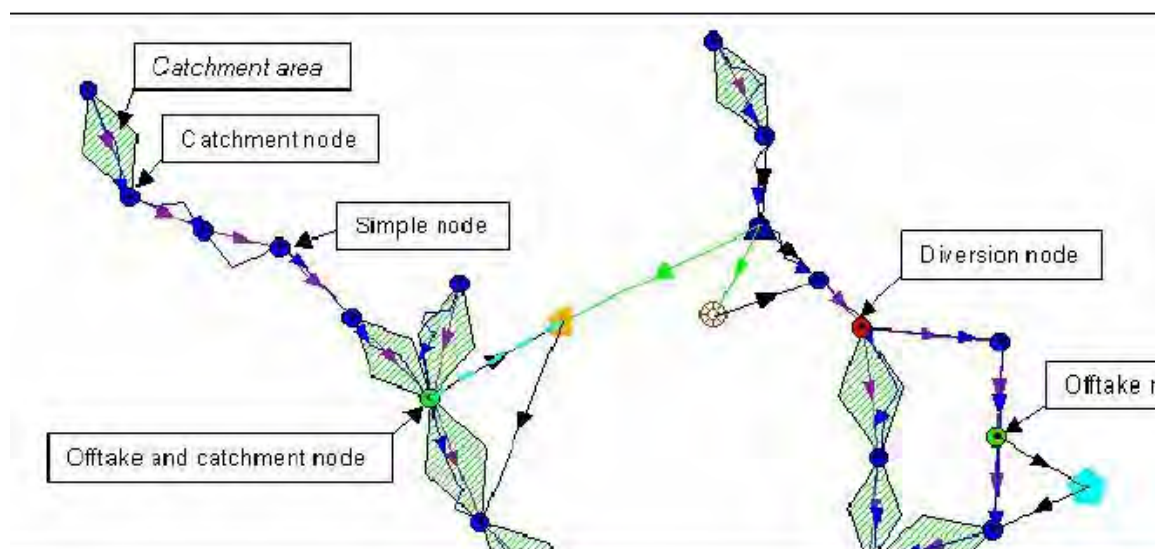


Figure 2: Definition of Catchment areas and Off take nodes

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

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

When the user edits the attributes of a Demand Node in the relevant boxes, he browses and specifies the files with the water demand and the return flow data for the node. Additionally, he has to define the water sources supplying water to the node and the *sink nodes* receiving his *return flows*. The nodes connected to the demand node are defined on the network map by dragging a little square around each selected water source (river or reservoir nodes), and each sink node that is usually of a River node type. Then the Identifier number of the selected source or sink node appears automatically in the property box of the demand node. The same operation is performed when editing the properties of off take nodes, which are River nodes with the additional role of water source. The user specifies the demand nodes served by the offtake node; however these connections should be consistent with the ones previously defined in the demand node boxes. In fact, each connection between a user node and a source node must be consistently defined in the property boxes of both of them. This means that whenever a use is specified for a source node, the same node must be specified for that use.

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

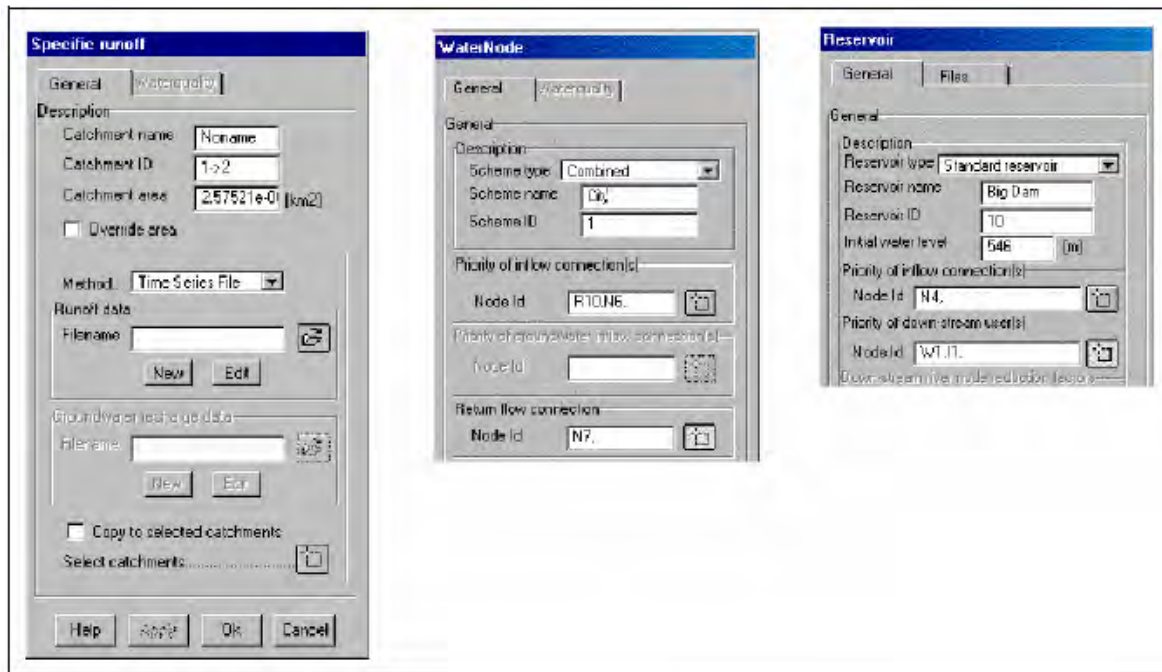


Figure 3: Dialog boxes for data editing concerning Catchments nodes, Water Supply System nodes and Reservoir nodes

Priorities for water allocation

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

MB has another principle for managing water allocation, the *Global Priority Rules*. This option can be selected along with the overall simulation options in the first window of the MB interface and consists of a set of rules affecting any node in the network that is involved in the water allocation process. Multiple rules can be defined with a priority rank given to each.

With the **Global Priority** algorithm any allocation of water is governed by rules only, thus implying some restrictions to the basin schematisation:

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

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

Global Priority Rules concern abstractions, minimum flows, reservoir storage and reservoir target levels. Table 1 presents the types of rules, their purpose, nodes and data affected.

Table 1 : Global Priority Rules of Mike Basins

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

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

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

Figure 4: The MB Rules Window, summarizing Global Priority Rules

Simulation and models

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

Water Quantity

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

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

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

NAM comprises the following modules:

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

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

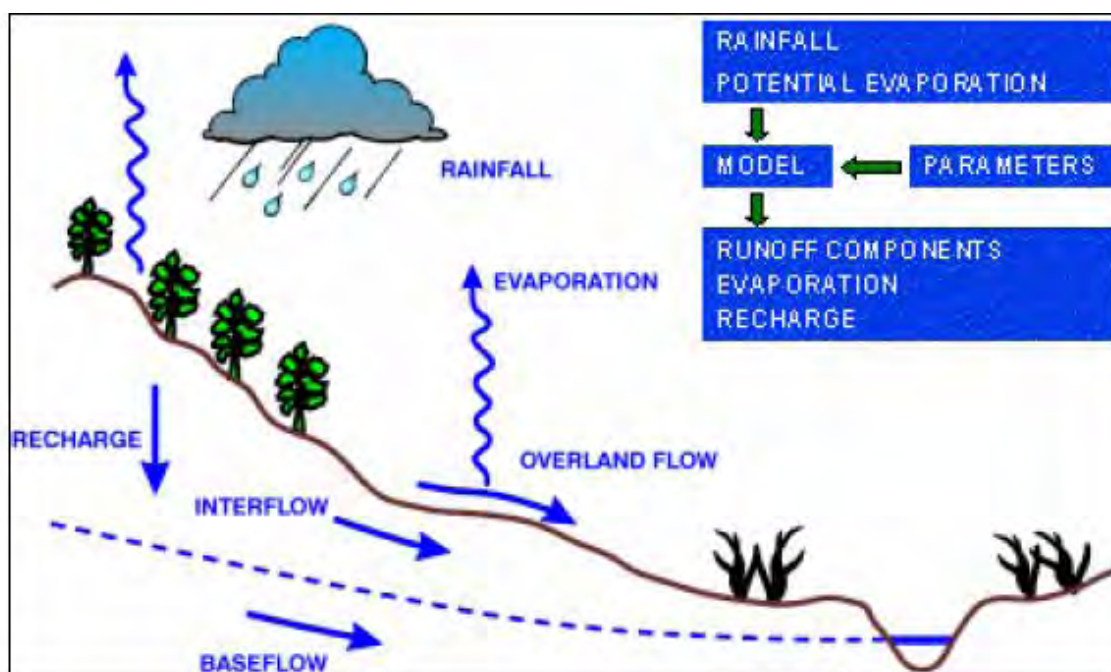


Figure 5: The schematisation of natural phenomena in the NAM model

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

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

The **Irrigation module** of NAM takes into account the weight of large agricultural areas in the global water balance of the catchment. Those affect the runoff distribution in terms of local water abstractions (from aquifers and rivers), and increased local infiltration and groundwater recharge. Increased evapotranspiration, as well as possible external water transfers for irrigation may significantly influence catchment hydrology. The conceptual approach is to define each large irrigation site as a sub-catchment described by its own individual parameters, such as irrigation losses to evaporation, seepage and overland flows. Monthly crop coefficients are also used to consider the proper evapotranspiration and stage of growth.

The **Unit Hydrograph Module (UHM)** is a hydrological model of the Mike 11 package which simulates the runoff from a single storm event using unit hydrograph methodology. The total rainfall subtracting the amount that infiltrates in the root zone gives the volume of precipitation that generates the land-flows. Infiltration can

be calculated through (a) a hortonian approach, (b) a loss rate proportional to the rainfall intensity (Rational Method), or (c) determined by the Soil Conservation Service curve number method. The third model of Mike 11 included in the Rainfall-runoff module of MIKE BASIN is SMAP. It is a hydrological model simulating the runoff of a catchment area by accounting for moisture storage in the root zone and in aquifers. These two types of storage are schematized as linear reservoirs, as in the NAM model. The model works on a monthly basis and updates the storage of both reservoirs at each time step according to the calculated terms of the balance, such as surface runoff, groundwater recharge, evaporation and base flows. Input data required by SMAP concern precipitation, evaporation, some specific parameters and the monthly mean discharge at the control outlet point of the basin, which is used for calibration purposes. Since it uses monthly data, SMAP can be used instead of NAM when daily data are not available.

Water Quality

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

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

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

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

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

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

Groundwater

The **Groundwater module** of MIKE BASIN can be activated in the first window together with the other simulation modules and the choice of a local or global rule approach. This module consists of a simple physical model of an aquifer that is conceptualised as a linear reservoir that exchanges water with water users and surface water bodies. Water balance is analysed according to pumping, recharge, seepage from rivers and discharge to rivers. The first three are assigned by the user as time series. This type of information is defined in the property box of the respective network elements (catchment areas and river branches) since groundwater is conceptually linked to them. In more detail, the user specifies: 1) seepage loss fraction, to be multiplied by the simulated flow in the stream branch in order to obtain the water volume lost to the aquifer 2) groundwater recharge from the catchment area encompassing the stream 3) pumping demand rates, which

Mike Basin will try to cover on the basis of actual groundwater availability. Groundwater discharge represents the water flows from the shallow and deep outlet levels (Figure 83) feeding rivers and it is proportional to the water level of the aquifer and also to its storage. Being a hydraulic response, discharge is not assigned by the user but computed by the groundwater module.

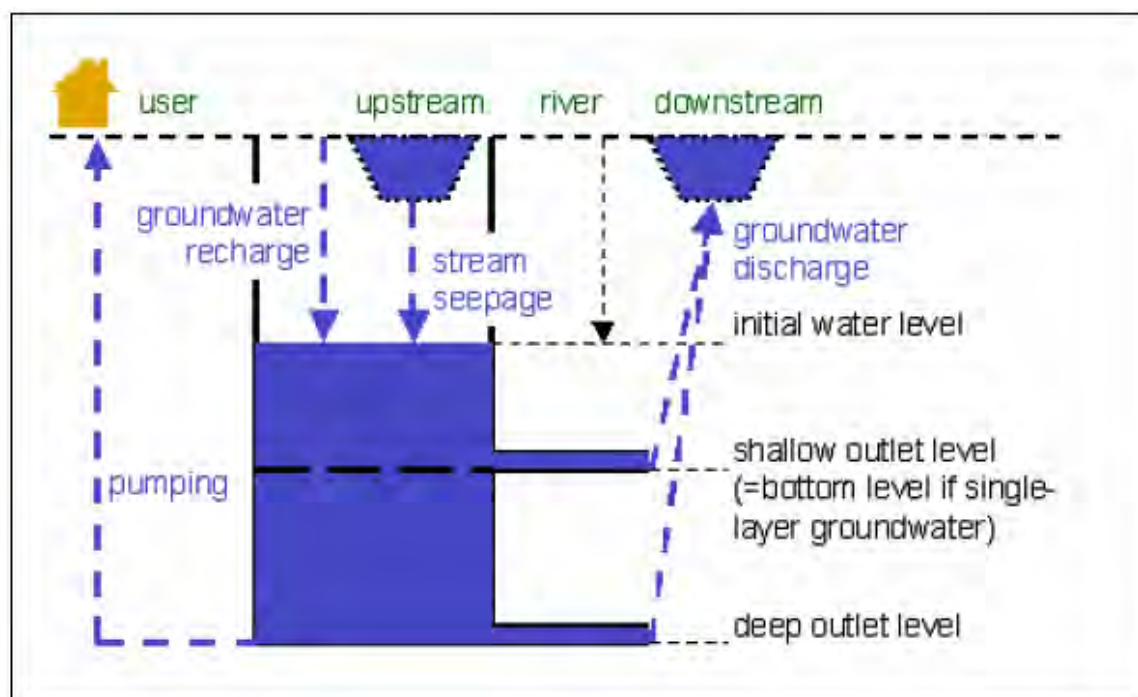


Figure 6: Aquifer schematisation and exchanged flows

Viewing Results

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

- ☐ **Time series** and related **graphs**,
- ☐ **Summary HTML tables**, and
- ☐ **Animated Features** on the geographic layer.

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

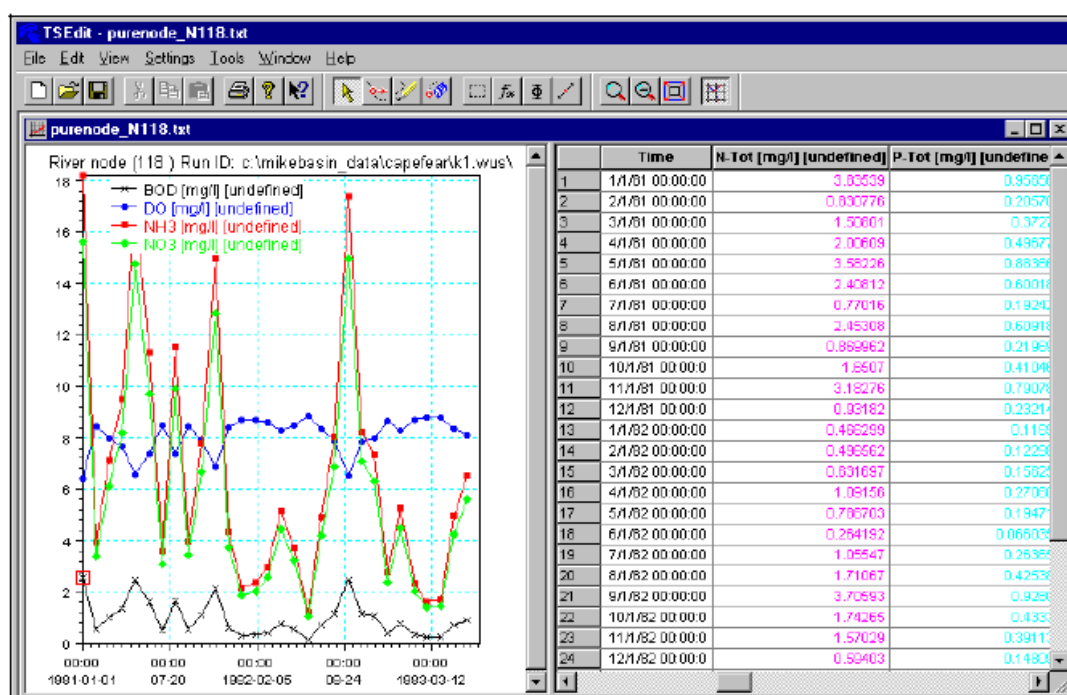


Figure 7: The TSEdit tool displaying results



Figure 8: An HTML table for a river node

HTML tables contain the same output but the presence of “go to” links to the various sections of the file gives the advantage of an easy navigation. Links to HTML files associated with the neighbouring nodes, actually the upstream and downstream ones, are also provided. The HTML file also contains descriptive statistics of results, such as minimum, maximum and mean values for each data series. As a third option, the MB User can visualise the behaviour of the water resource system through an animated view on the geographic layer. Dimensions and colours of the network elements change at each time step according to the values assumed by output variables. On the left of the map there is a list of legends describing the range of values each output

type can assume and the associated colours and sizes. A dedicated bar displays the time steps and the time position within the simulation horizon.

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

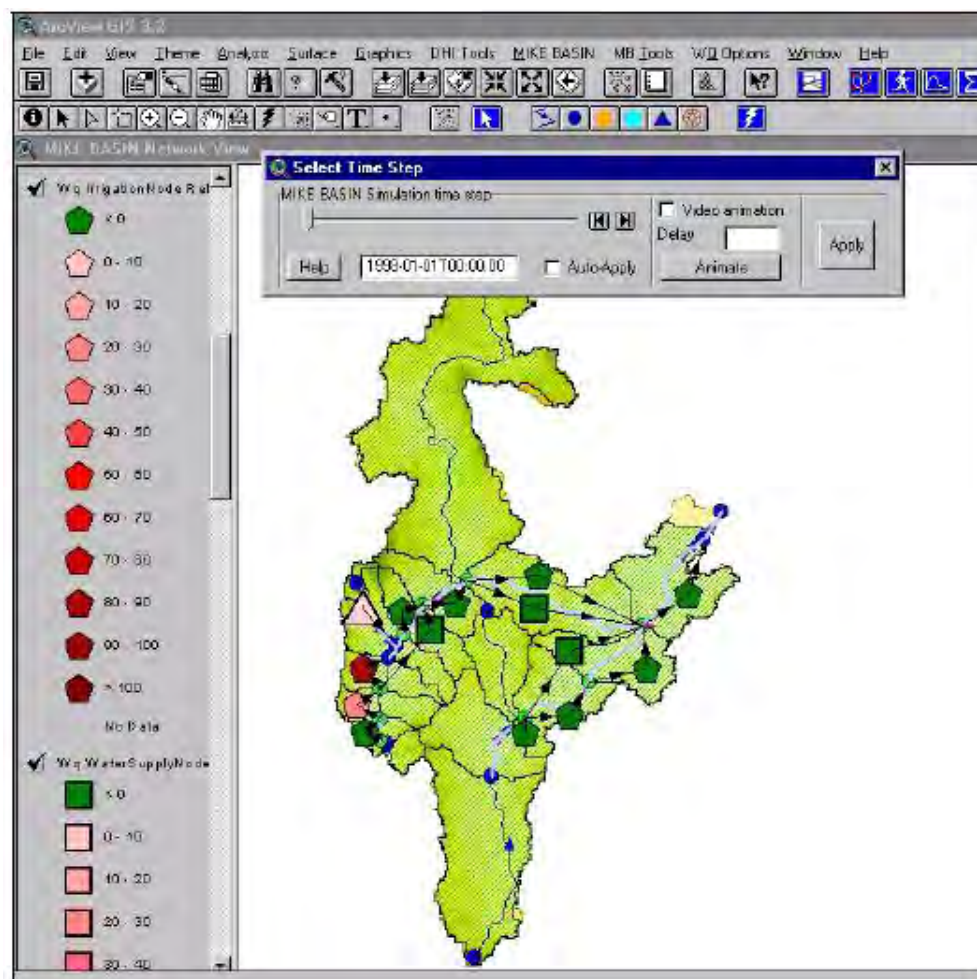


Figure 9: The Animated View displaying simulation results

Summary of Pros and Cons

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

2.1.2 Basins

Another DSS example for Water Resources Modelling is the Better Assessment Science Integrating point and Non point Sources – BASINS, developed by the U.S.- Environmental Protection Agency. After the first release in 1996 and the upgrade in 1998, BASINS is now at the third version, dated June 2001. It has been originally conceived to meet the needs of local, regional and state Environmental and Pollution Control Agencies in performing ecological and water quality studies at the watershed scale.

Objectives

The main objectives of Basins are to:

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

alternatives; Although the software package is mainly used for analysing the maximum daily pollutant loads from point and non-point sources, it has also been applied to other problems: wet weather combined with sewer overflows, storm water management, drinking water source protection, urban and rural land use evaluations, animal feeding operations and habitat management practices.

Components

BASINS comprise a set of interrelated components that are integrated within the ESRI ArcView GIS environment. They are:

- ☐ GIS,
- ☐ National environmental databases,
- ☐ Assessment tools addressing both large- and small-scale analysis,
- ☐ Watershed delineation tools,
- ☐ Watershed characterisation reports,
- ☐ Utilities for importing, organising, evaluating data,
- ☐ Utilities for classifying elevation, land use, soils, and water quality data,
- ☐ A suite of models concerning in-stream water quality and pollutant loads and their transport, and
- ☐ A scenario generator tool.

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

GIS

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

Database

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

Base Cartographic Data concern:

- ☐ Hydrographic boundaries associated with major U.S. river basins,
- ☐ networks of the major highways,
- ☐ populated and urbanized areas, and

- ☐ Administrative boundaries.

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

In more detail, Environmental Background Data consist of:

- ☐ Delineation of the Eco-regions defined by the U.S. EPA and of the study areas,
- ☐ Soil information,
- ☐ results of the wastewater control,
- ☐ Stream networks,
- ☐ Drainage networks,
- ☐ Digital Elevation Model,
- ☐ land Use and land Cover, and
- ☐ National inventory of dams and associated information.

Environmental Monitoring Data concern:

- ☐ Historical water quality data for physical and chemical parameters and bacteria registered at monitoring stations,
- ☐ observed data at monitoring stations,
- ☐ Freshwater and coastal sediments and amount of nutrients,
- ☐ Locations with advisories for fishing,
- ☐ Inventory of surface water gauging station data,
- ☐ Meteorological station sites,
- ☐ Location of public water supplies, their intakes, and sources of surface water supply, and
- ☐ location and extent of shellfish areas.

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

- ☐ industrial facilities discharge sites,
- ☐ toxic release inventory Sites and pollutant release data,
- ☐ location of transfer, storage, and disposal facilities for solid and hazardous waste, and
- ☐ location and characteristics of mining sites.

Environmental Assessment Tools

The **Assessment Tools**, *Target*, *Assess*, and *Data Mining*, constitute three of the useful extensions of Basins. They allow the regional assessment of in-stream water quality conditions, the identification of point source discharges on a watershed scale and the analysis and review of summary data for a specific site.

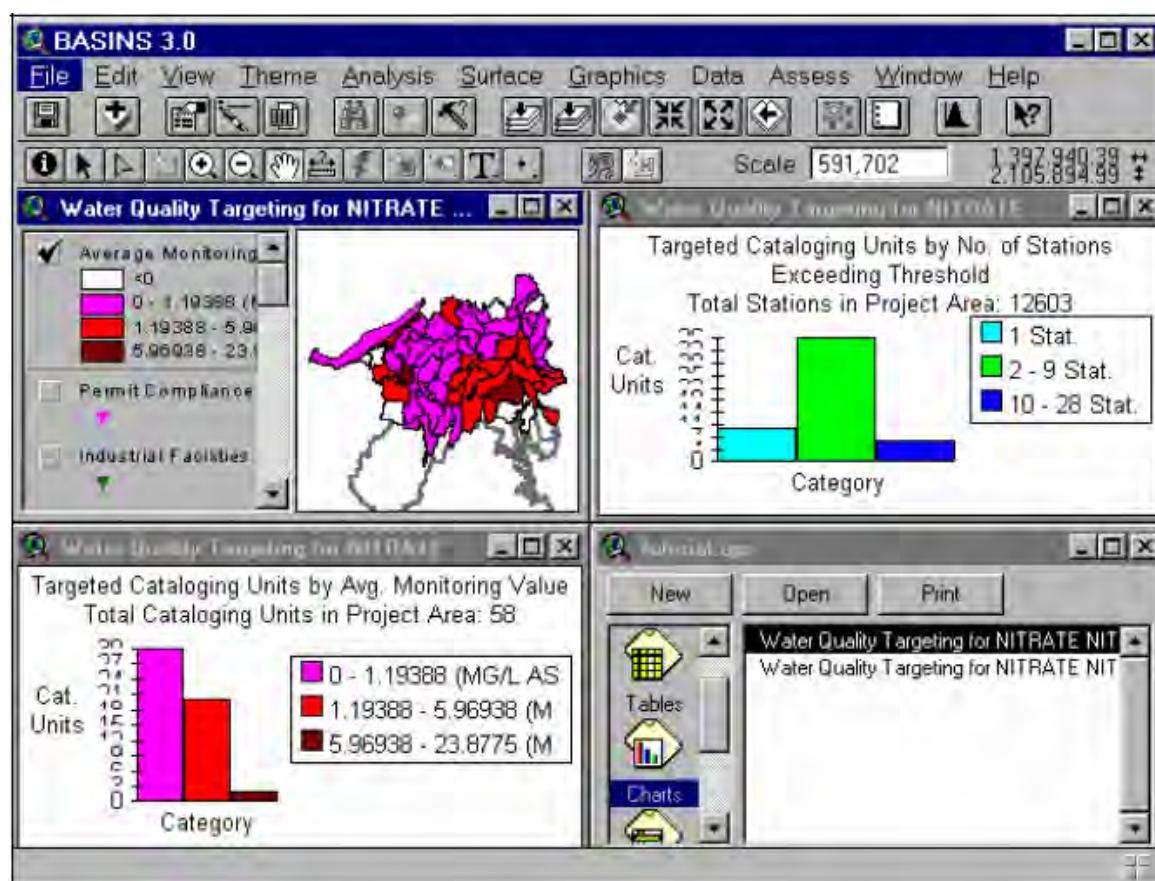


Figure 10: The Target tool of BASINS

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

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

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

The results of **Assess** are summarised in the following views:

- A geographic layer displaying water quality stations ranked according to the average monitoring value for the selected time period and selected water quality parameter;
- A bar chart displaying the distribution of the stations based on the monitoring value; The Assess tool can be used for various purposes such as evaluation of stream conditions, establishment of relationships between in-stream water quality conditions and potential sources and causes, and evaluation of monitoring programs.

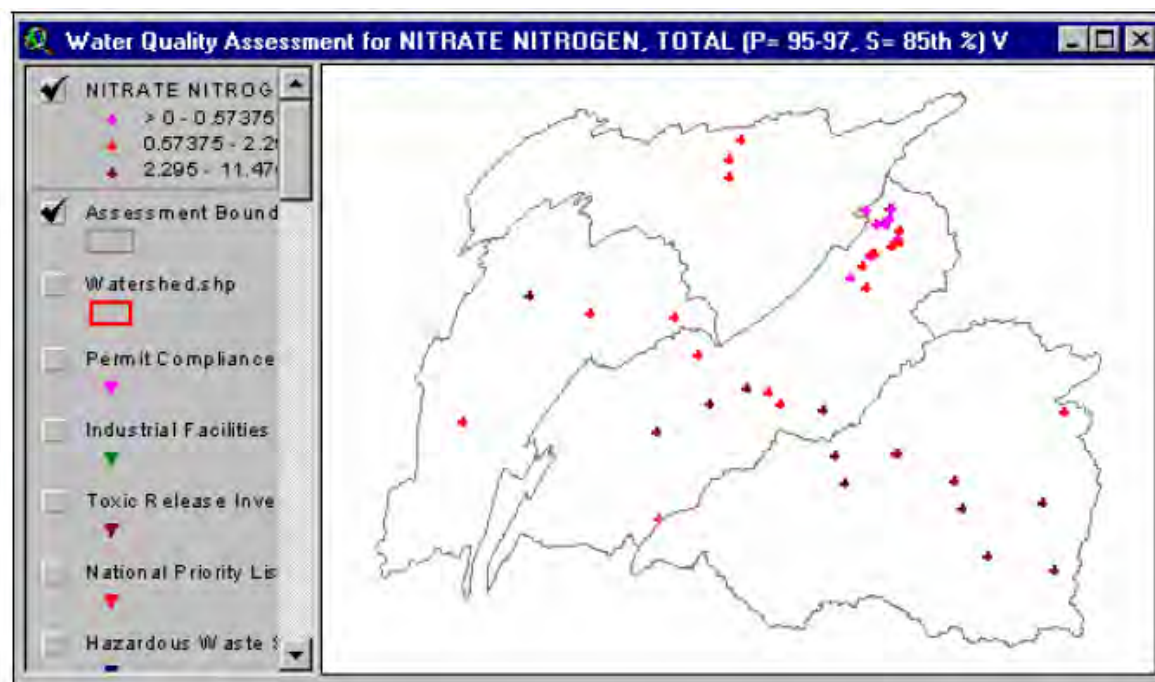


Figure 11: The Assess tool of BASINS

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

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

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

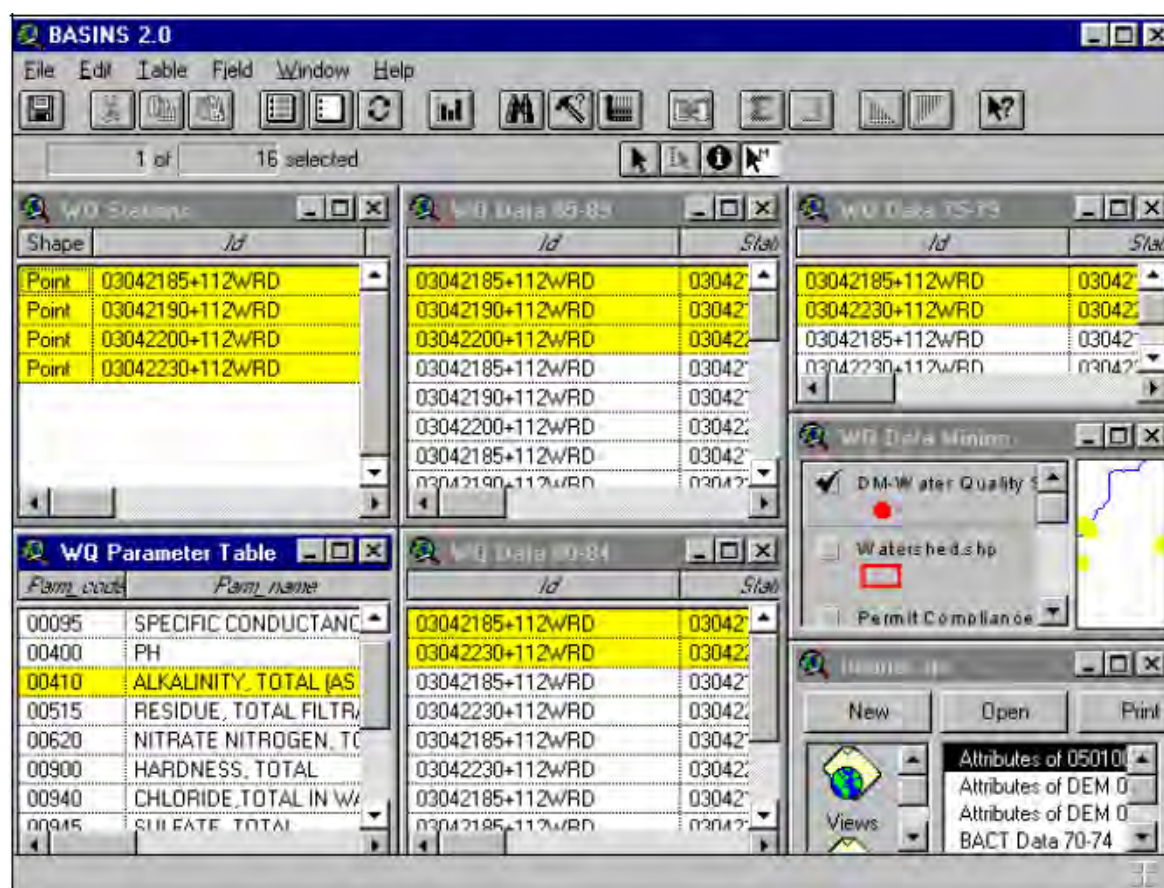


Figure 12: Water Quality View

Watershed Delineation tool

The Watershed Delineation Tool permits the division of a watershed into one or more subwatersheds. The boundary of a sub-basin is drawn directly on the GIS layer as a set of segments through a point-and-click process. Watershed modelling and analysis can be performed on a single delineated watershed or multiple watersheds by using HSPF or SWAT models and the Watershed Characterisation Report tools integrated in BASINS.

Watershed Characterization Reports

BASINS can assist the user to in creating customized maps and tables to summaries the overall conditions of the study area. BASINS version 3.0 generates six different types of **watershed reports**:

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

BASINS Utilities

BASINS has four utilities to reclassify, overlay, and update data. The **Land Use, Soils Class and Overlay** function is used to prepare data input for the SWAT and HSPF models. These models use combinations of land use and soil themes to determine the area and the distribution of hydrologic response units of each land-soil category considered in the simulation. The **Land Use Reclassification** utility is used to change land use classifications within an existing data set. Reclassification allows the user to update land use data or simply to change them, in order to evaluate alternative water quality impacts based on changes of land use over time. Land Use Reclassification simplifies the non-point source modelling as well, by grouping detailed land use classes with similar characteristics into broad categories.

The **Water Quality Observation Data Management** supports the user to manipulate and add the time series of water quality data observed at monitoring stations, as well as to add, delete and relocate stations. The fourth basin utility is **DEM Reclassification**. This is used to display large amounts of spatially distributed information in appropriate detail by modifying default colours and the range of values.

Models used in BASINS

The models included in the BASINS package are Pollutant Load (PLOAD), Soil and Water Assessment Tool (SWAT), Windows Hydrological Simulation Program-Fortran (WinHSPF) and Enhanced Stream Water Quality Model (QUAL2). A short description of each model is given in the paragraphs that follow.

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

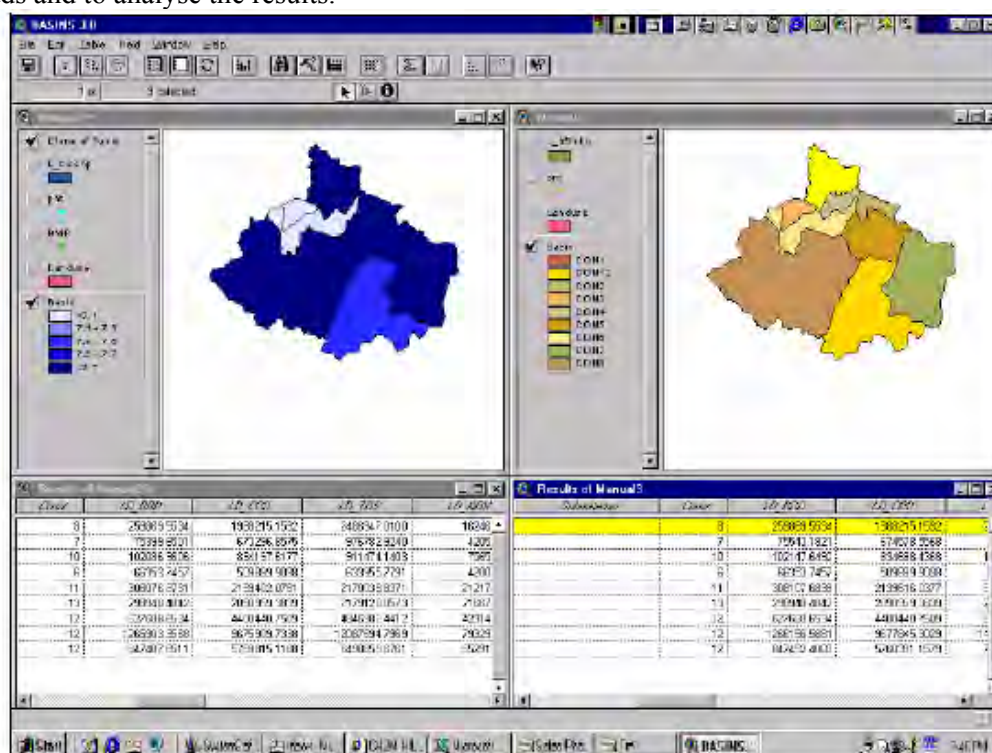


Figure 13: A comparison of two calculations with the View Sessions

Results can be displayed on maps, together with the corresponding tables of values, and in two different spatial scales: the user can visualise the pollutant loads aggregated by watershed, expressed in lb/year, or per unit of watershed area, expressed in lb/acre-year. Additionally, a *View Sessions* option allows viewing simultaneously up to three different outputs, resulting from three different calculation sessions, in order to compare different situations.

The Soil and Water Assessment Tool, **SWAT**, is a watershed-scale model developed by the Agricultural Research Service of the US Department of Agriculture. It is physically based and simulates hydrology, pesticide and nutrient cycling, bacteria transport, erosion and sediment transport on a daily time step. It is particularly suitable for predicting the effects of land use management, as well as climatic and vegetative changes on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions for a long time horizon (up to a hundred years). As SWAT describes physical processes associated with water, it requires specific information on meteorological parameters, soil properties, topography, vegetation, and land management practices occurring in the watershed. Moreover, Swat includes five databases concerning specific pollutant loads generated from agricultural practices and municipalities:

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

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

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

Scenario generator tool

BASINS includes the program **GenScn**, *GENeration and analysis of model simulation SCeNarios*, that was originally developed by the U.S. Geological Survey. This tool has been integrated within BASINS as an extension and can be directly accessed from the GIS Interface. GenScn primarily serves as a pre- and post-

processor for both the HSPF and SWAT models, as it allows changes in input data and display of output reports in graphical and tabular form. On the other hand, the definition of input data describes a Scenario that can be evaluated through the simulation results and compared against others. Therefore, GenScn is said to be a Scenario Generator. Moreover, this tool can also be used for visualising observed time series data, for making comparisons with modelled data and for performing statistic analyses.

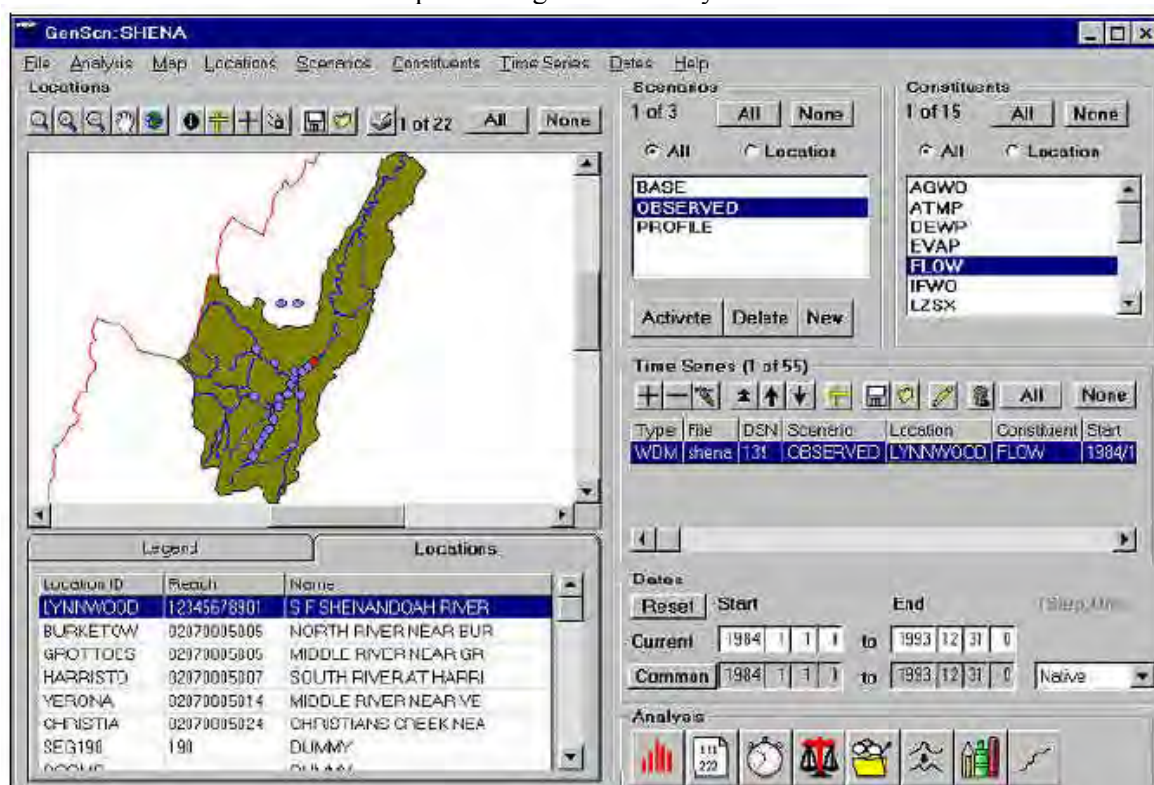


Figure 14: The main form of GenScn Graphical User Interface

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

- A **locations** frame consisting of 1) a map of the basin, displaying boundaries and locations to be analyzed 2) a toolbar containing map handling commands 3) a table with a legend and summary of information found on the map. A location can be selected both by clicking the corresponding point on the map and by selecting its entry in the table. In both cases entry and point are highlighted;
- A **scenarios** frame, containing a list of simulated or monitored scenarios available in the project. A preferred scenario for the chosen location can be selected by clicking on it;
- A **list of items**, named *constituents*, such as atmospheric pressure, water flows, dew and evaporation for which observed time-series are available;
- The **time-series** frame, summarizing information about the available time-series of selected scenario, constituents and highlighted location;
- The **dates** frame, containing information about available ranges for the currently selected time series and the default time step.
- The **analysis** frame, containing a toolbar that links to the tools of GenScn for generating and editing various types of plots, tables and statistical text reports useful to compare various data series.

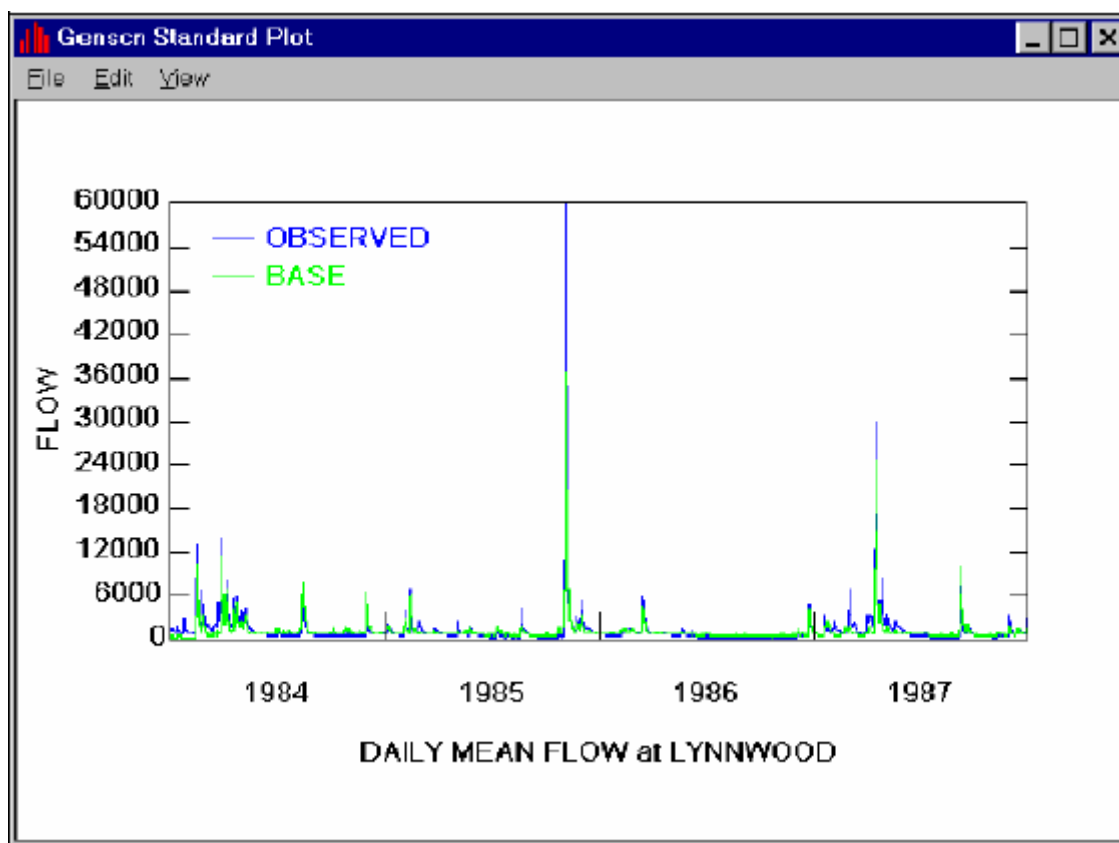


Figure 15: Comparison of time series of flow item in the selected Lynnwood location

Summary of Pros and Cons

BASINS is more environmentally oriented than MIKE BASIN; nonetheless, the physical aspects prevail over a comprehensive analysis and assessment of sustainability that can link policy options to information and analysis in an integrated water management context. The *GenScn* program allows the management of different scenarios; however the definition of a scenario is quite different from the one required for analysing water stress conditions. In BASINS the word “*scenario*” refers to a set of data series that are model inputs and to the relevant outputs. A scenario is in more general terms defined as a group of *developments which can not be directly influenced by the decision maker, such as weather, market prices etc*”. According to this interpretation, a scenario should be formed by choosing from predefined climatic or economic scenarios, which consist of the exogenous background in the simulation of water quantity and quality and indicator computation. The variables assuming the data values of time series that define a scenario are used by models but are not updated at each time step.

2.1.3 Integrated Quantity and Quality Model –(IQQM)

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

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

- ☐ river system model,
- ☐ rainfall-runoff model,
- ☐ gate operation model,

- ☐ climate model,
- ☐ graphical output tools,
- ☐ statistical analysis tools, and
- ☐ data retrieval and utilities.

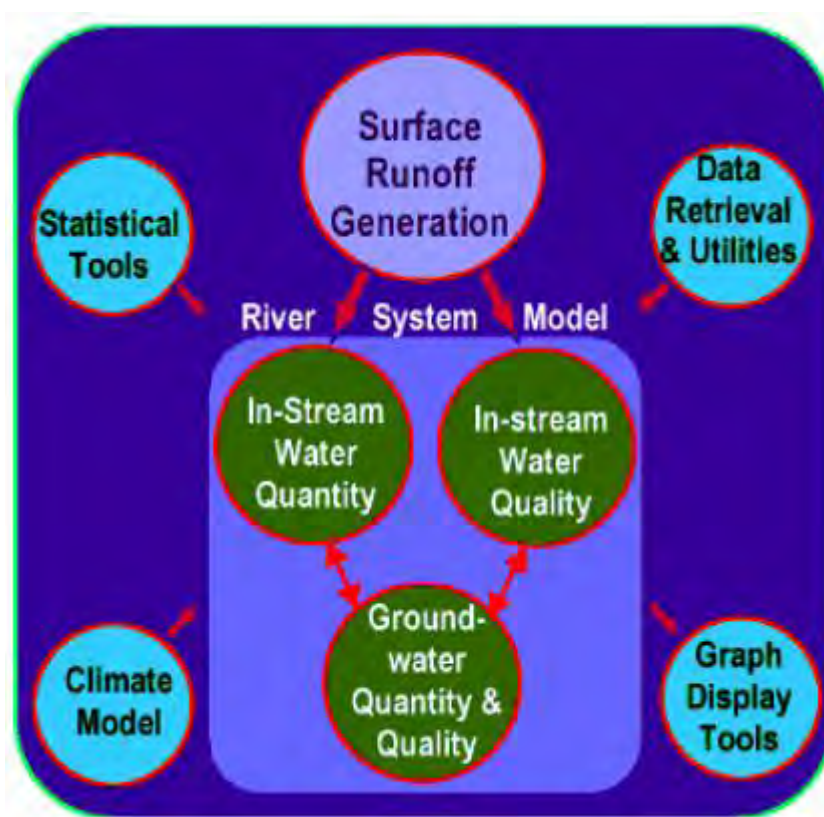


Figure 16: Main IQQM Components

Graphical Interface and Models

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

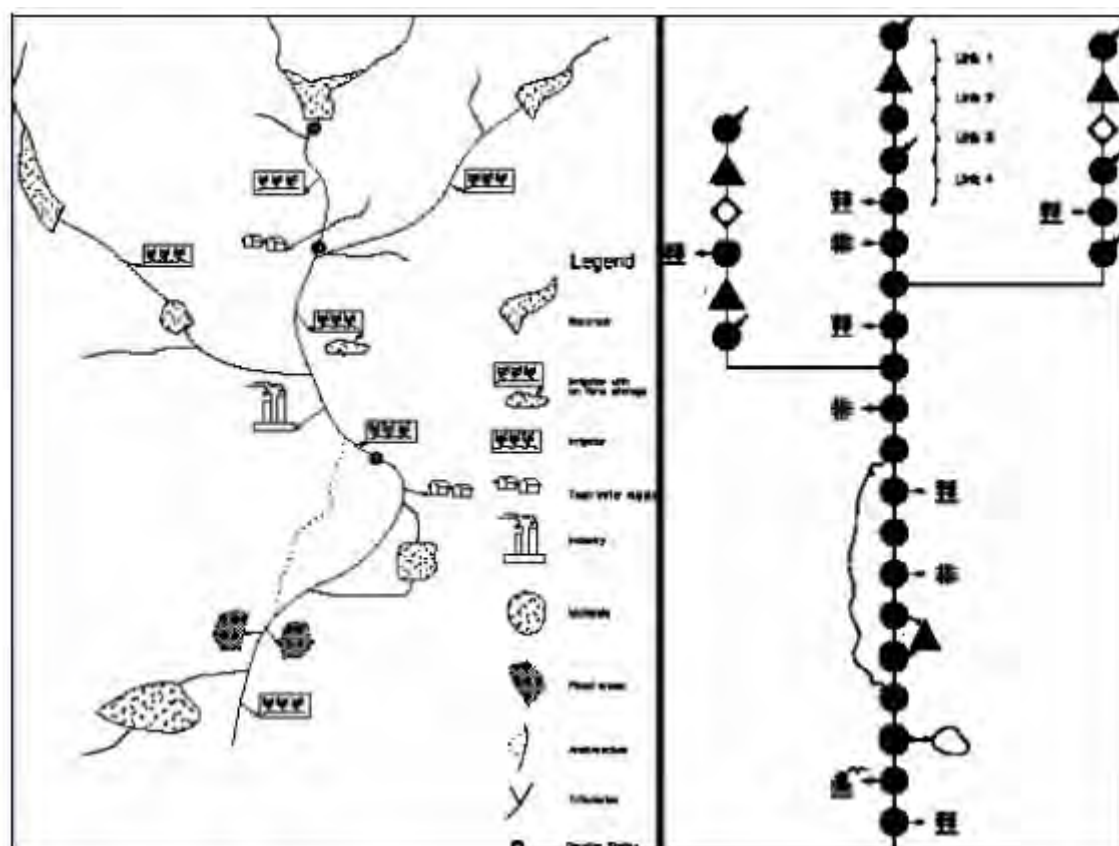


Figure 17: Representation of a typical river system in IQQM

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

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

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

An **irrigation module** is used to consider all the processes driving the agricultural needs, such as precipitation, evapotranspiration, water harvesting and re-use, infiltration and planting decisions and to calculate the relevant water demands. Features modelled by the irrigation module include:

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

The **Rainfall-runoff model** used within the tool is the *Sacramento Model* developed by the US National Weather Service and California Department of Water Resources, and adapted to use standard IQQM file input and output formats. The calibration of parameters has also been improved. The following figure presents a schematisation of the physical phenomena studied by the models.

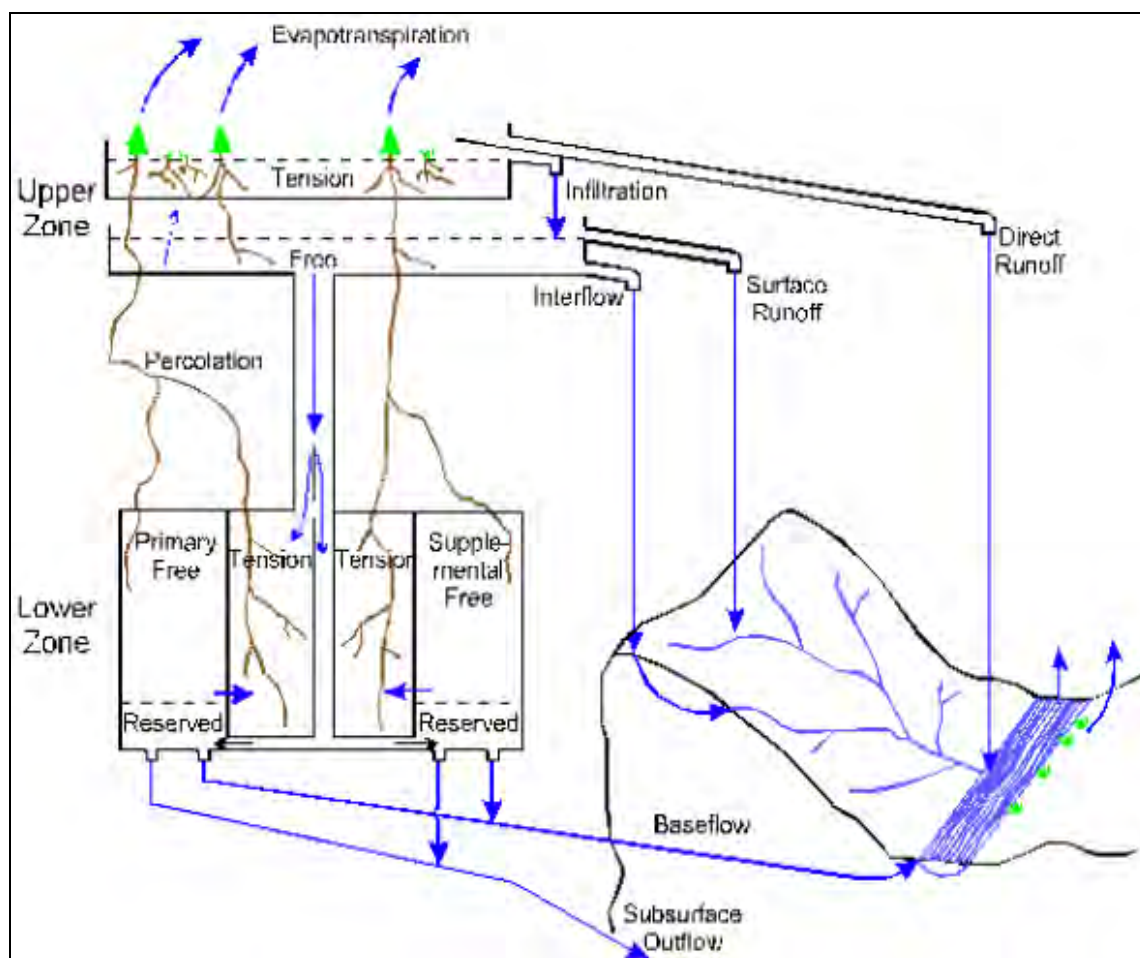


Figure 18: Schematization of the physical phenomena studied within the Sacramento Model

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

The **Climate Module** uses short-term daily climate data and long-term rainfall data to statistically generate long-term daily evaporation, minimum and maximum temperature and solar radiation. The results of simulations, as well as observed time series, can be plotted in different types of graphs (e.g. continuous line graphs, histograms, cumulative and frequency curves). A specific toolbar supports the building of graphical displays and customisation of graphs. The time interval of the data plotted can be an hour, a day, a month or a year. Over one hundred years of daily data can be graphed for up to five parameters simultaneously.

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

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

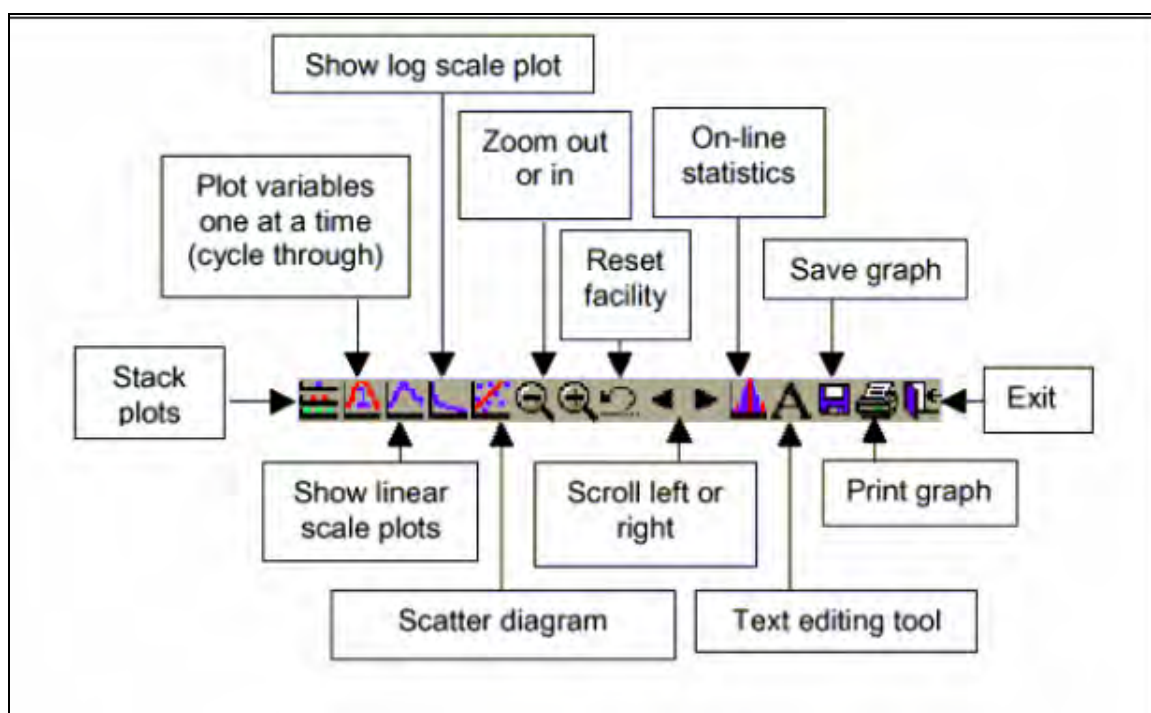


Figure 19: Graphical display toolbar for all plot types

Summary of Pros and Cons

IQQM allows the representation of the river system in node and link objects; however those are not geographically referenced. A GIS map can be imported in IQQM but it is used only as a visual reference for drawing the schematic. The model does not integrate GIS software, and therefore lacks the related useful capabilities of data management and geo-referenced display. It also does not incorporate scenario management or conceptual scenario definition.

2.1.4 Ensis

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

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

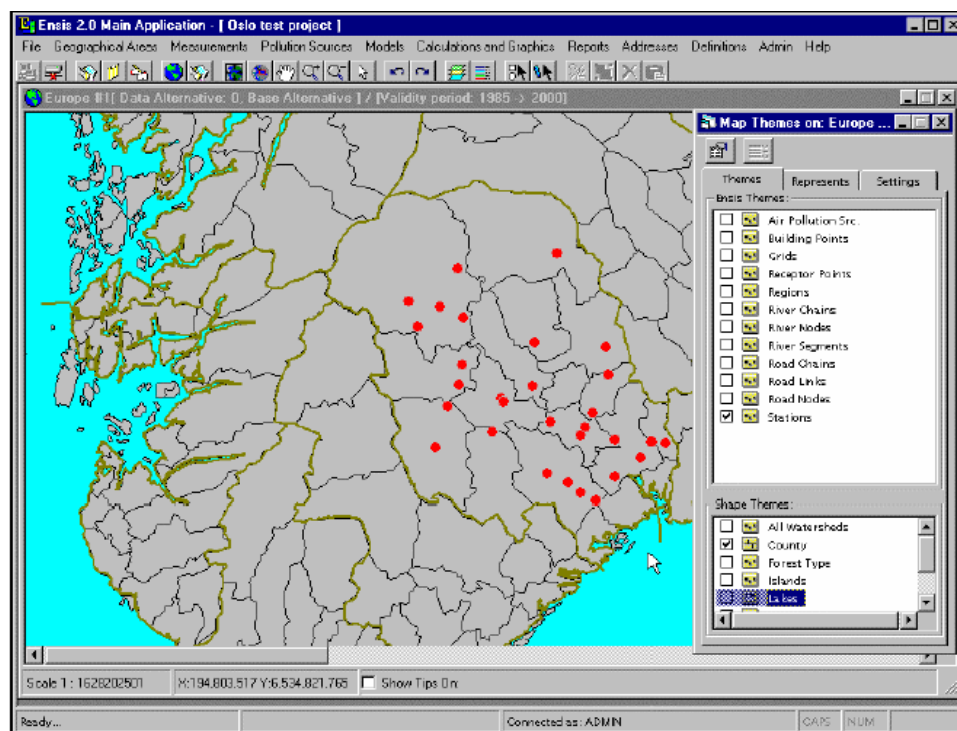


Figure 20: Ensiv GIS

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

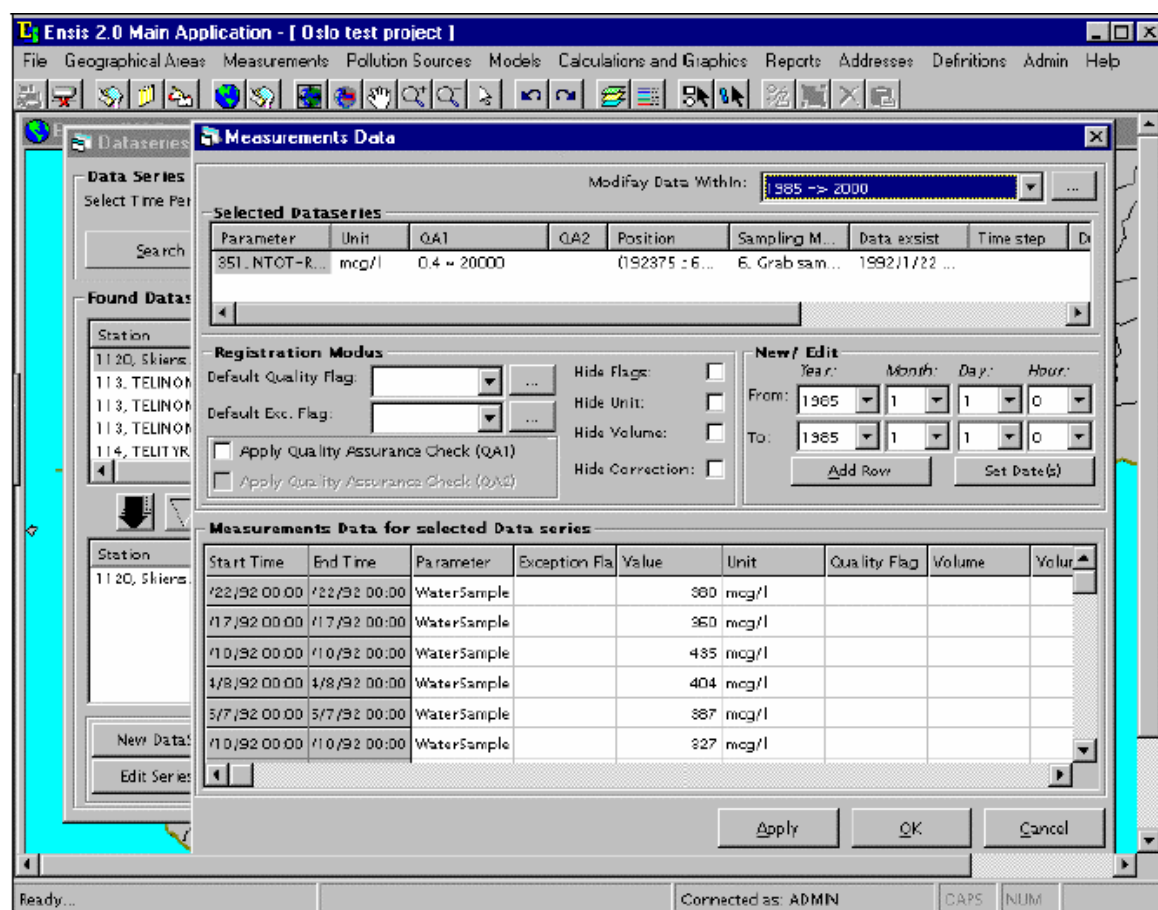


Figure 21: Viewing the measurement values

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

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

The ENSIS system can encapsulate programs for environmental modelling and can show their output both graphically or as numeric tables, or process them statistically. WaterQuis DSS has models for **calculation of pollution load** whereas the air-related AirQuis integrates **atmospheric dispersion models**, covering air pollution on all scales in the urban environment. Further, WaterQuis-specific features are: the definition and recording of information and data about catchments, rivers, lakes and coasts and the registration of discharge from domestic waste water, industries and diffuse sources.

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

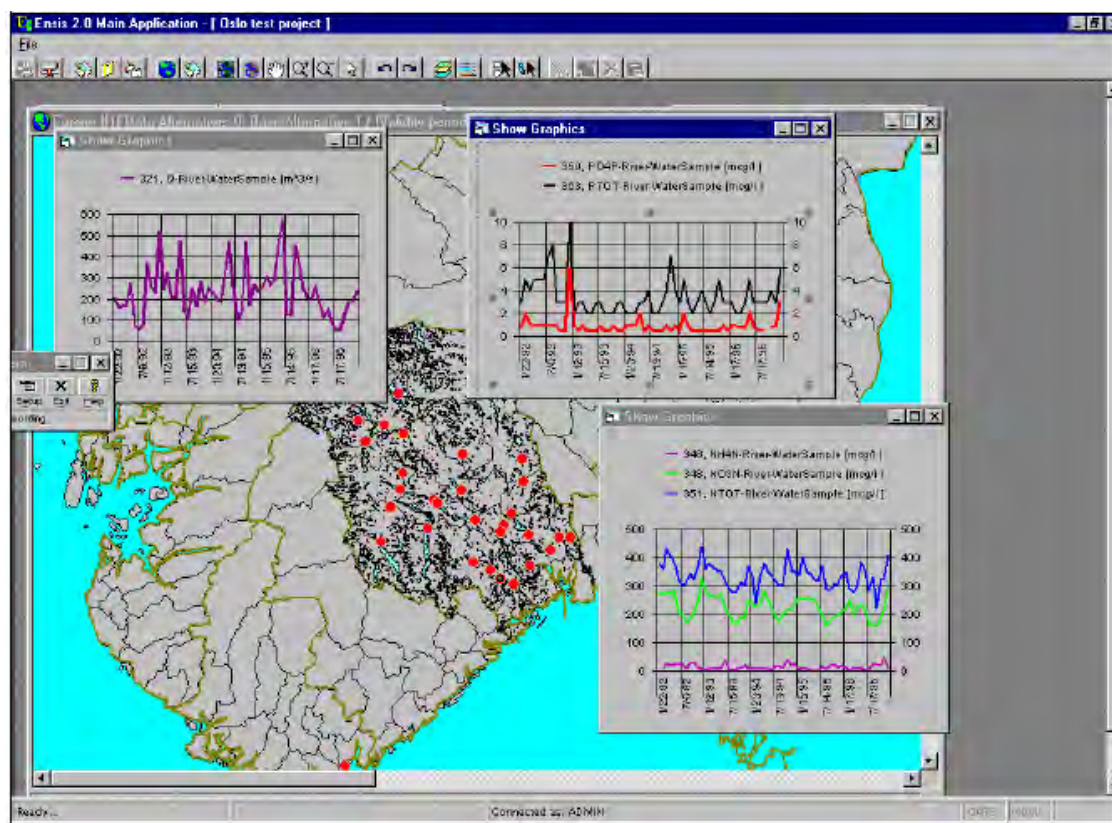


Figure 22: Comparison of time-series

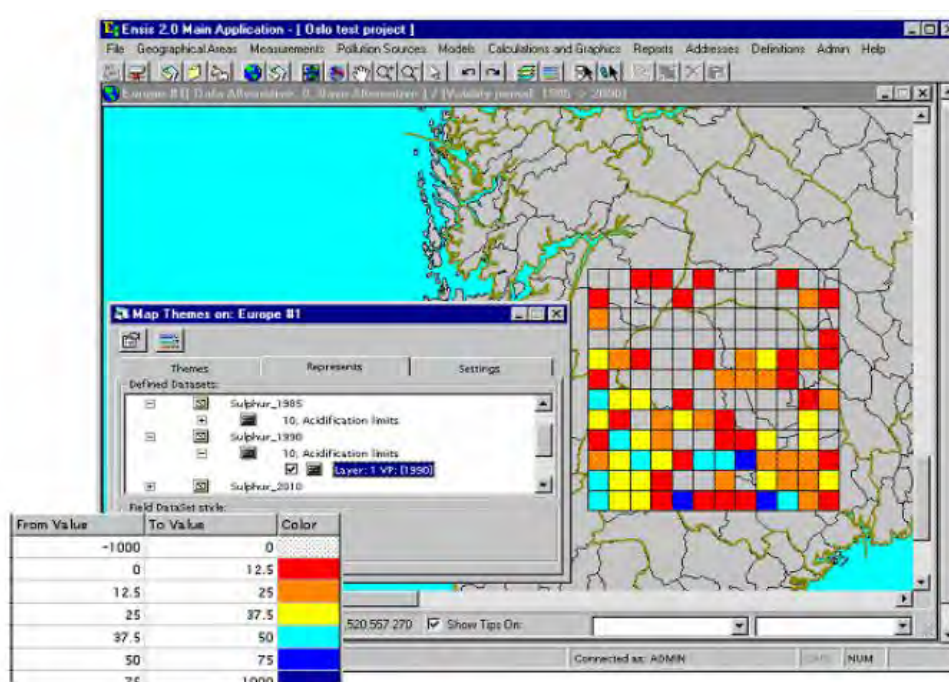


Figure 23: Acidification limits displayed on GIS layers

Summary of Pros and Cons

As derived from the acronym, ENSIS is more a Surveillance and Information System based on GIS rather than a real Decision Support System. It is useful for creating and disseminating water quality reports and for time series visualization and analysis. Although ENSIS embeds water quality models for calculation of pollution loads and proper routines showing their output, the package does not provide capabilities for the management and comparison of alternative simulation scenarios. Moreover, water allocation in the area under surveillance is not considered, and water availability and demand evaluation are not included. Those aspects are considered of fundamental importance in identifying possible deficit conditions and building appropriate strategies to face them.

2.1.5 Realm

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

REALM simulates simple as well as large and complex water supply systems, both under drought and normal conditions with high stream flows. It can be used to study different water resource options, as for example new operating rules or physical system modifications and graphically compare them. The water allocation is performed by a fast network linear programming algorithm that runs at each simulation time step. This algorithm **optimizes** water allocation on the basis of the carrier costs: if a demand node is connected to the supply node through multiple different carriers, the one with the lowest cost is used first and if its maximum capacity does not completely satisfy the demand then the next lowest cost carrier is used. The program allocates water to as many carriers as needed to meet the demand, always following the order mentioned above.

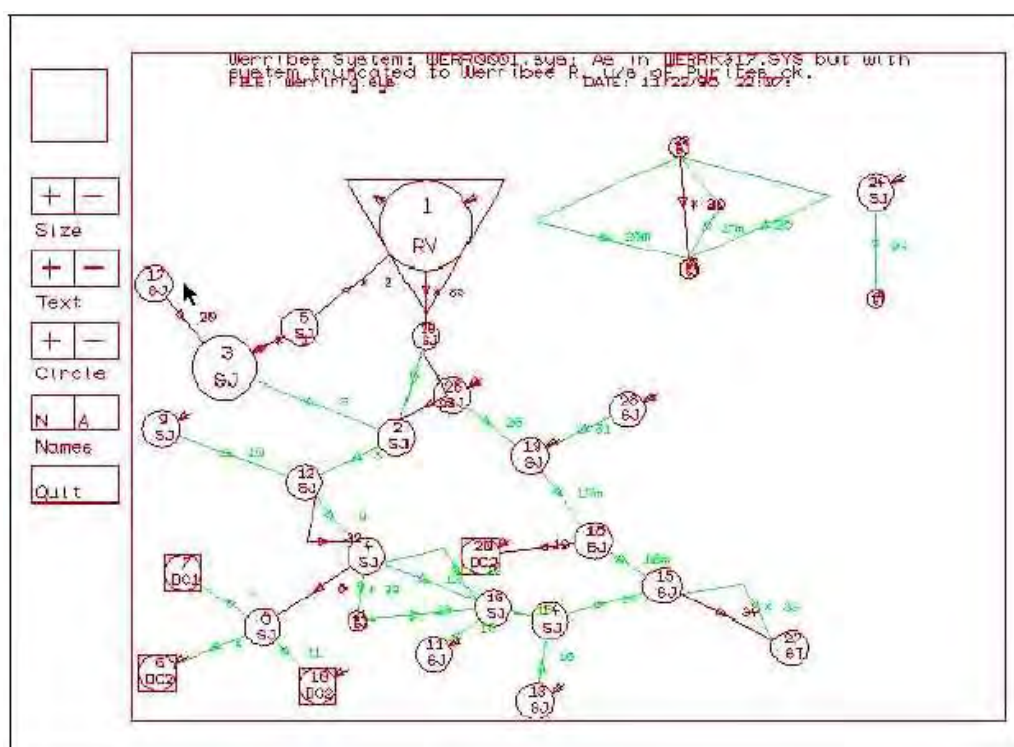


Figure 24: REALM Screen Plot3

REALM comprises a program manager, a graphical editor, a group of routines for listing, plotting and text editing, and the simulation core. It uses water stream flows and demands as input. The former consists of unregulated inflows entering the system and available at reservoirs, gravity diversions, stream junctions, and harvesting nodes. These data can be organised on a monthly, weekly or daily basis. Stream flows also include meteorological variables, such as temperature and rainfall. Water demand consists of time series data specific to determined demand zones in the area under study and can represent historic water usage or forecasted needs.

REALM has a graphical editor, which allows the user to draw the system network and to define the features of nodes (reservoirs, demand sites), links (here mentioned as “carriers”) and their operating rules. The system network can be drawn just by choosing specific types of node or carrier from a palette of buttons at the left and at the bottom of the System Network Screen and positioning those to its centre with a simple “drag & drop” operation. The eight node types considered are: Reservoir, Demand, Irrigation demand, Diversion, Pipe junction, Stream junction,

Groundwater, Stream terminator. Later the entire network can be properly viewed and zoomed with the **Network Plotting utility**. The user can introduce the carriers connecting the demand nodes to suppliers with the same drag & drop procedure. Carriers can be RIV type, representing river sections, and PIP type, representing pipes, aqueducts and general carriers that are not river sections. The user can access and introduce each carrier’s characteristics through the “pipe-river editing” window. Attributes include: cost or penalty, used in the allocation process, transmission losses, and annual volume limit, capacity sharing among different demand sites both connected at the same carrier, minimum and maximum capacities and water quality parameters. Carrier capacity can be expressed as a function of many system variables and edited by the user from a dedicated menu.

EDITING PIPE/RIVER SECTION

Arc Desc

Cost Offset Loss Annual Vol Limit Capacity Sharing:-
Gp= ZShare=

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

Edit Water Quality parameters Y/N

Figure 25: Editing Capacity Type 1 Pipe/River Section Menu

REALM manages the periods of low storage and stream flow through the *demand restriction curves*; those determine the manner with which each demand is restricted and the degree of severity of this restriction. The

package considers two types of demand restrictions, namely urban restrictions, applied to urban and industrial demand zones, and irrigation restrictions, applied to irrigation demand zones.

An interesting feature of the software is the possibility to choose some nodes or carriers of the system network from a list and highlight them in red. This can be very helpful in finding specific nodes and carriers in large networks. Before running the water allocation simulation, the user has to define the “*simulation scenario*”. In REALM the scenario refers to the set of run-time parameters such as simulation period, inputs of stream flows and demand, initial reservoir volumes, initial irrigation deliveries, water quality initialisation data and output options. The definition of parameters is conducted through the relevant dialog windows of the REALM setup program.

Figure 26: Restriction Parameters for Irrigation Demand Group Menu

REALM can generate several outputs, which are grouped into different categories (Table 2)

Table 2. Categories and outputs

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

The REALM package contains some output utilities that can be used to perform basic processing of input-output data such as **graphical plotting**, **data ranking** from highest to lowest value, **statistics computation** (total, mean, minimum and maximum value, standard deviation etc). REALM is currently used for all major water supply schemes in the State of Victoria, Australia.

Summary of Pros and Cons

REALM has a network editor that allows the user to schematise the system of water users; however, the elements of the network are not geo-referenced, since the tool does not integrate GIS software and GIS maps cannot be imported, even to be used as a network background. The economic aspect of water resources is reduced to the simple estimation of costs for conveying water through the carriers. As mentioned, these costs are actually the parameter that defines the priority of water uses in the water allocation algorithm.

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

2.1.6 Mulino

The acronym MULINO stands for *–MULTi-sectoral, INtegrated and Operational decision support system for sustainable use of water resource at the catchment scale–*. It is the main objective of the related Mulino Project funded within the European Fifth Framework Programme for Research and Technological Development and Demonstration. The project started in January 2001 and has duration of three years. This review concerns the first of the three planned intermediate versions of the tool. The Mulino consortium consists of specialists in hydrologic modelling, software development, economy, geography, sociology, agronomy and GIS coming from various European countries and co-ordinated by The Fondazione ENI Enrico Mattei in Venice, Italy.

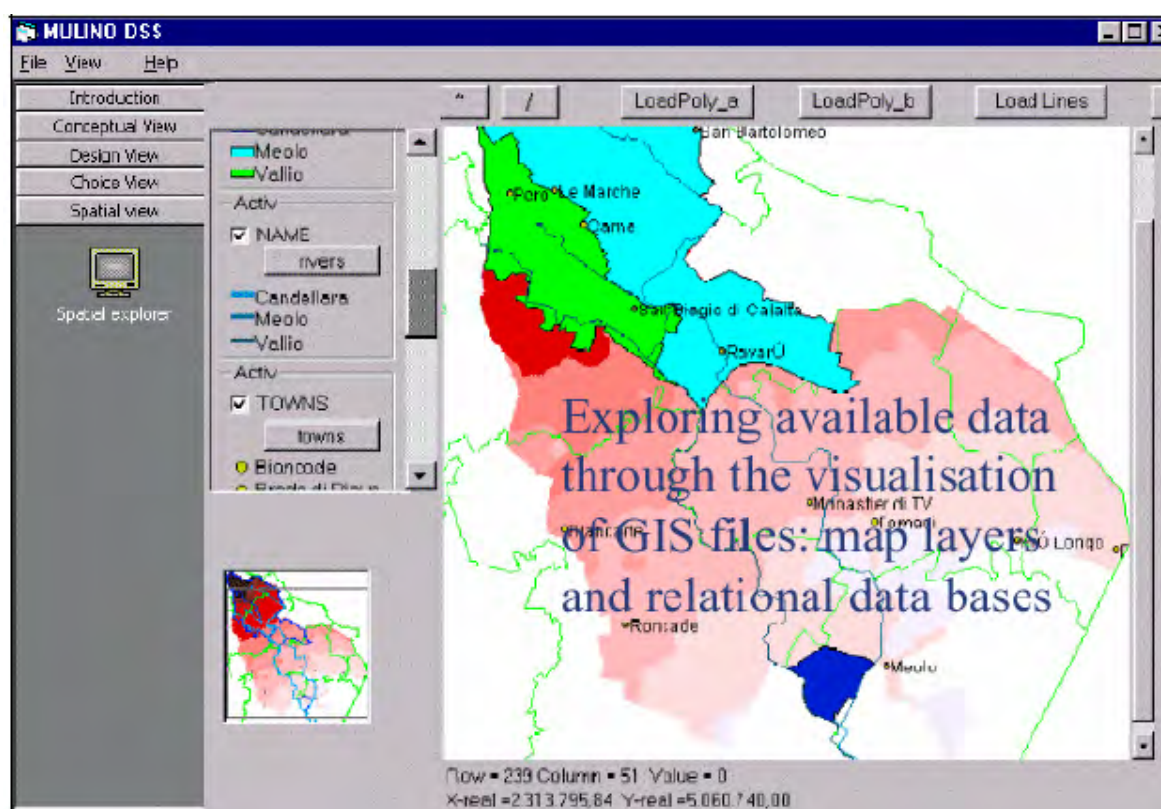


Figure 27: The Spatial View of MULINO DSS

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

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

□ In the **Conceptual View**, the Decision Maker (DM) is directly involved, and requested to define the water resource problem and choose the decisional criteria which will be used to measure and evaluate the river basin status and the effectiveness of the actions conceptualized to improve it.

□ In the **Design View**, the role of technicians is prevalent since they have to implement the problem formulated by the DM and find practical solutions that will constitute the set of possible options to be investigated.

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

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

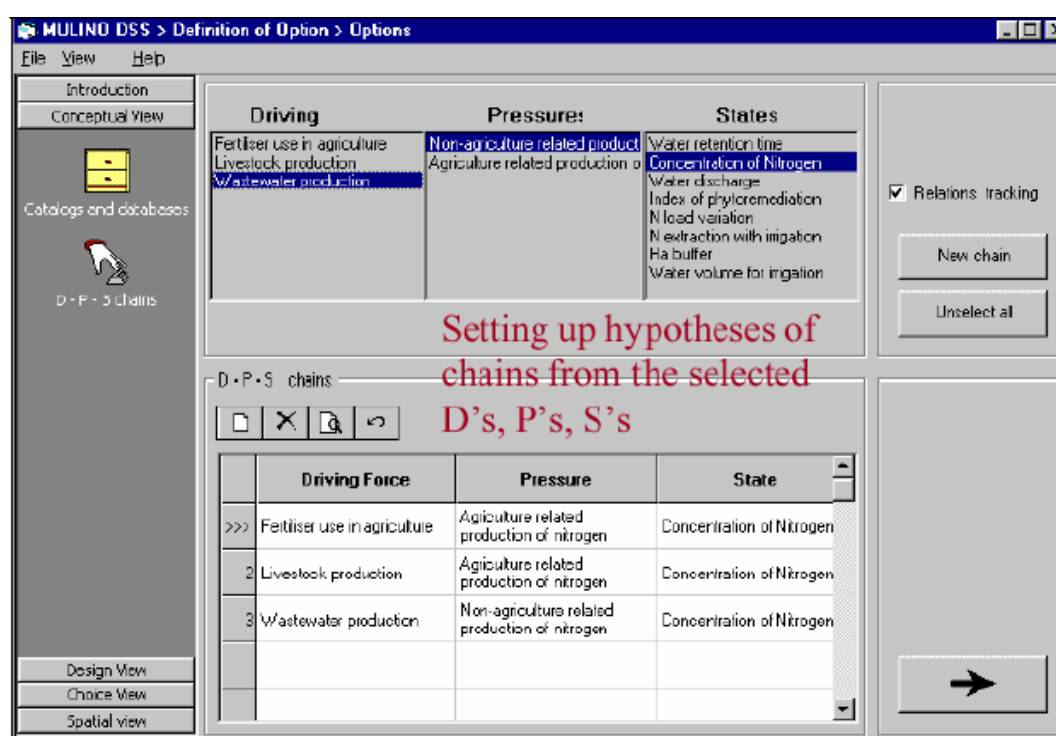


Figure 28: The Conceptual View and the D-P-S Chains

The entire decision process is based on D-P-S-I-R indicators and the cause-effect relationship existing among them: the Decision Maker describes the problem in terms of a set of Driving Forces that lead to specific Pressures exerted on the basin, so determining its State, and propose alternate options to improve the status itself. The Decision Maker builds up the D-PS chains in the Conceptual View of the interface, where a list of Driving Forces-Pressure- State indicators is already available from the database. Then they choose those which are relevant to the particular water resource problem and linked by cause-effect relationships. The first version of Mulino DSS has been applied to the Vela catchment, near Venice. In this case the two following D-P-S chains have been defined: 1) use of fertilizers in agriculture and livestock production (Driving Forces), leading to production of nitrogen (Pressure), which increases the nitrogen concentration in the water basin (State), 2) wastewater production, (Driving Forces) that leads to production of nitrogen (Pressure), which in turn increases nitrogen concentrations in the water basin (State).

The Design view consists of two parts. The first allows for the creation and definition of the alternative options: the DSS user can edit a new option, delete an existing one from the list of those available and display the related chains of D-P-S indicators. In the other part, the user accesses the geo-referenced database through the GIS layers and extracts the numeric values of the D-P-S indicators for each associated option. The result is

an Analysis Matrix with the status indices as rows and the different options as columns. The options designed for the Vela catchment are the following:

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

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

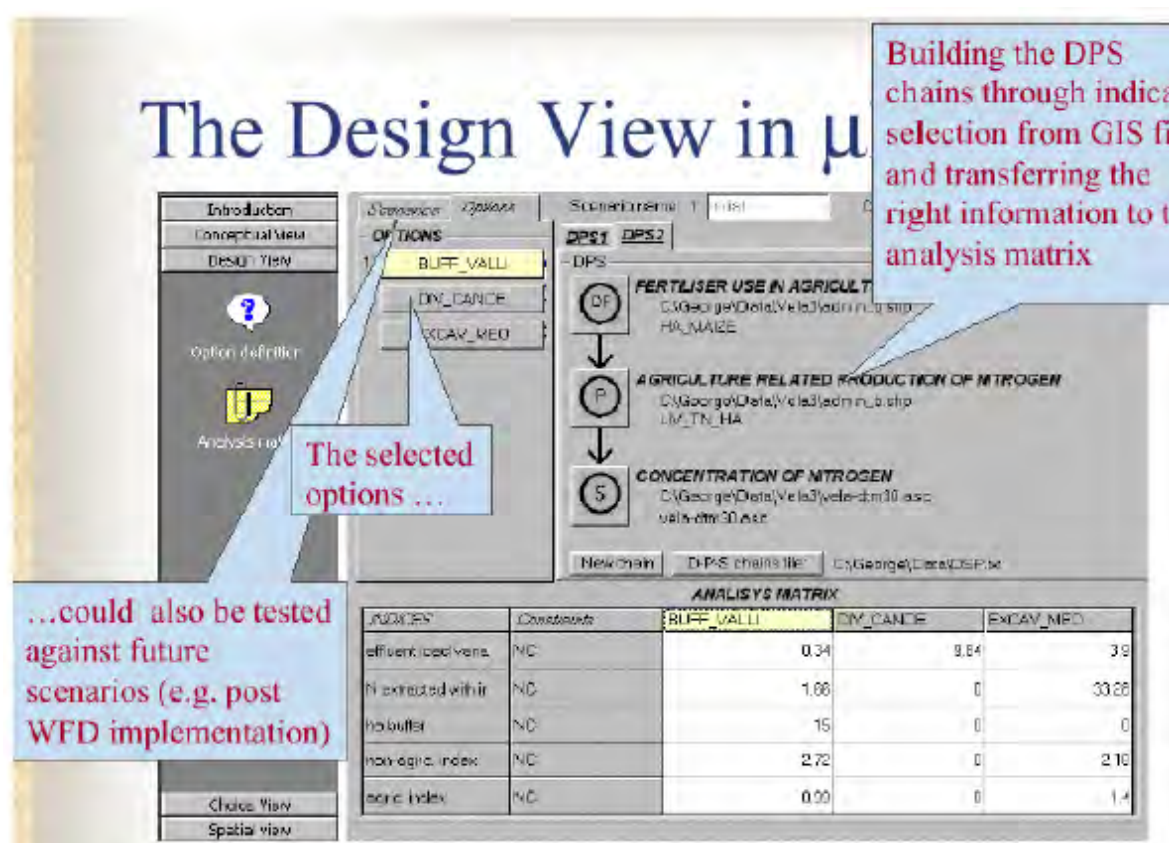


Figure 29: The Design View and the Analysis Matrix

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

MULINO DSS first version does not have its own dynamic modeling routines and works on top of external models; however the full integration of simple hydrological models has been planned for the next two releases.

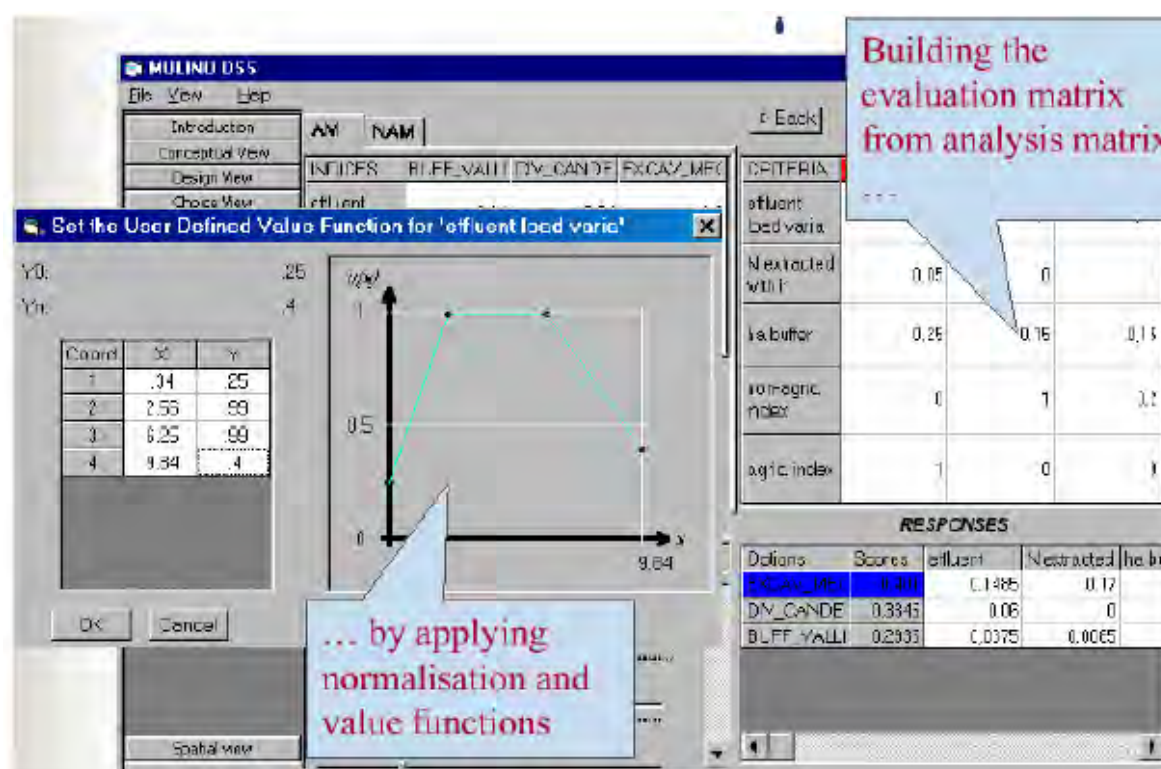


Figure 30: The Choice View and the Value Functions

Summary of Pros and Cons

The first version of MULINO DSS suggests an interesting approach to problem definition and evaluation that focuses on 1) defining the subject of water resource analysis, in terms of D-PS chains, 2) defining available options to change the status and 3) evaluating proper state indicators for each strategic option. A network editor and simple hydrological models are going to be integrated in the DSS in the next versions.

2.1.7 Ribasim

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

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

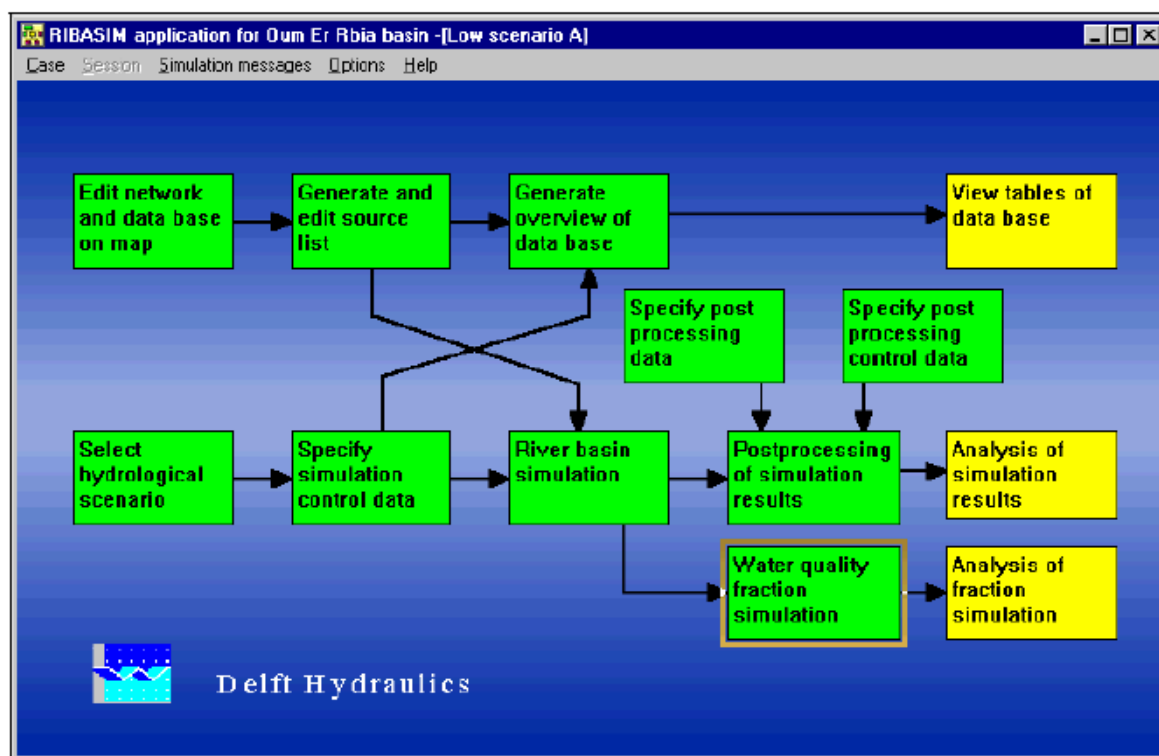


Figure 31. The main view of the RIBASIM interface with the application steps.

RIBASIM is a Windows-based software with a graphical user interface, a database, a simulation program and a tool for the analysis of results. The main view of the User Interface shows a flow chart aiming to guide the user in the application of models to the river basin under analysis: the blocks of the chart change their colour, so as to show which step the user is currently performing and which are those already performed. The macro-steps are: 1) the creation of the network of nodes and branches as schematisation of the basin users, water sources and specific features, 2) the data entry of the necessary information in the geo-referenced database, 3) the preparation of input such as hydrological time series, operational rules for reservoirs, hydrobiological and crop requirements etc., 4) the simulation, 5) the post processing of results and 6) their analysis.

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

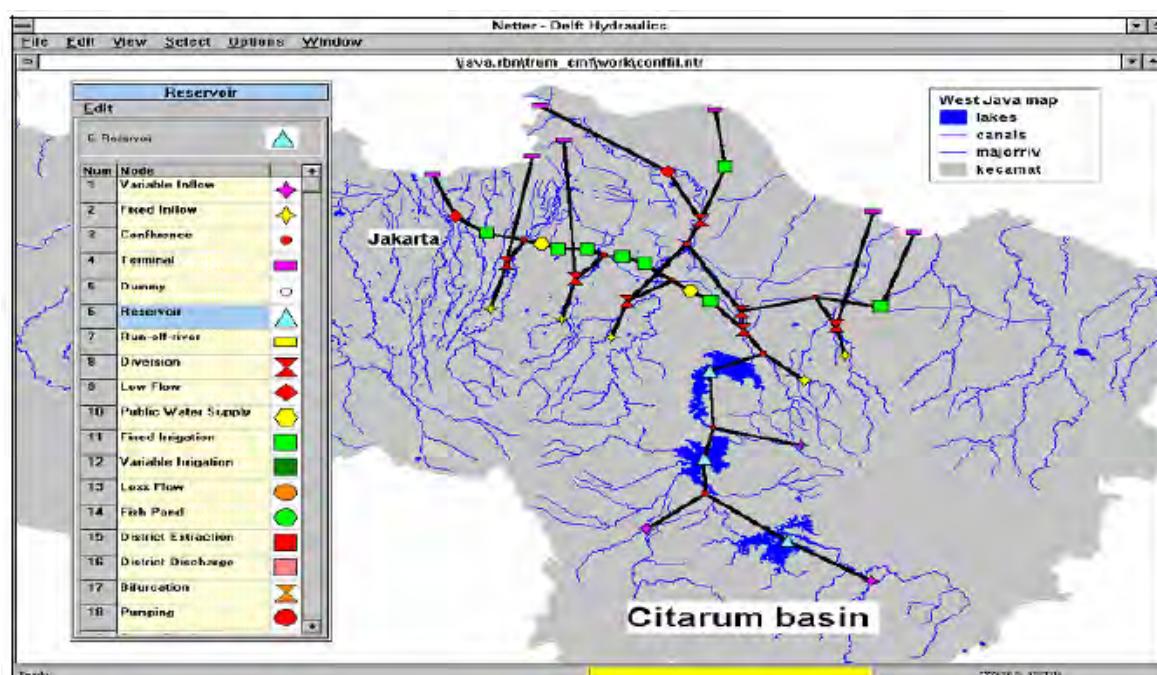


Figure 32: The Netter and the network building

As far as the simulation is concerned, it is usually run over time series of many years to include dry and wet periods. Time steps are not fixed but variable and defined by the user: they can be for instance a day, a number of days or a month. It must be noted that the RIBASIM package is a tool that embeds many models among which the main one has the same name of the tool, RIBASIM, and is used for water allocation both at the basin level and within the district nodes. In particular, at the node level it is coupled with other models such as *Demes* and *Agwat* that estimate a more detailed demand for irrigation, industries and municipalities. Table 3 lists the models used in Ribasim.

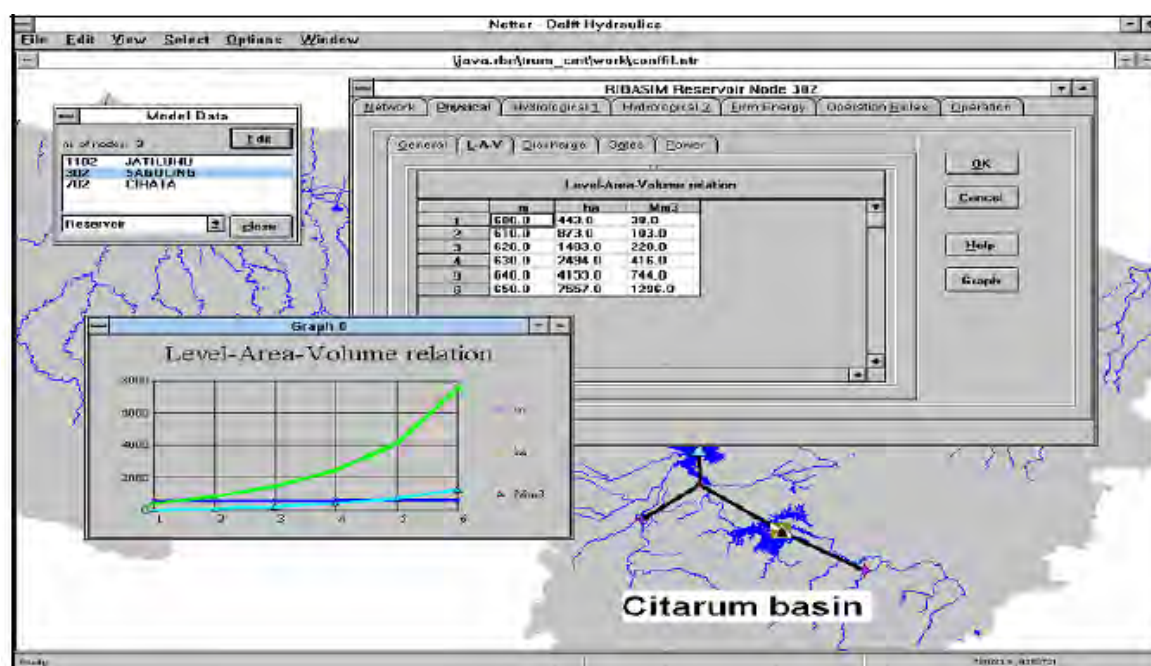


Figure 33. Data entry and related graphs

Table 3. Models embedded in the Ribasim Tool (Description from the Delft Hydraulics Web Site)

Model	Short description
Samo	Determines per water district and per time step the runoff of non-irrigated areas, based on time series of potential evapotranspiration and rainfall.
Agwat	Determines per water district and per time step the irrigation water requirements and return flows under full supply condition for a variety of cropping patterns, taking into account farming and irrigation practices, and physical parameters related to soils and hydro-meteorological characteristics.
Fishwat	Determines per water district and per time step the fresh and saline water requirements of brackish water fish ponds (tambaks) under full supply conditions, taking into account various species to be cultivated, production technology (type of tambaks, required pond salinity's), climatological characteristics, and salinity's of the supplied water. Water demands are derived from water and salt balances.
Demes	Estimates the demand for domestic, municipal and industrial water supply based on projections of population and water using activities, a mode split between surface and groundwater, losses during transport and treatment, the applied level of technology, maintenance and management.
Ribasim	Computes the water allocation in the main distribution network and inside the water district by simulating the river and canal flows, operation of reservoirs (including hydropower production) and diversion structures. The model simulates water allocation within the water districts and within a river basin.
Wadis	Determines the potential and actual crop yield and production costs of irrigated and rainfed agriculture per crop and brackish water aquaculture in each water district.
Delwaq	Determines the composition of the flow in any location of the main distribution network (river- and canal system) which forms a first insight in the quality of the water at that location. The model can be used as well to predict the water quality in the main distribution network under various hydrological conditions, pollution and sanitation scenario's.
Wlm	WLM (waste load model): estimation of the actual and future waste loads (point and non-point sources) on surface water. WLM provides direct input to the delwaq simulation model.
Stratif	Simulation of stratification layers in reservoirs.

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

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

The evaluation of the case results and the comparison of different cases are supported by graphs, thematic maps, tables or spreadsheets. Graphs of specific node parameters can be accessed directly on the GIS layer by clicking the node and by selecting the desired parameters themselves. Among the output parameters, are the applied cropping pattern, water allocation, shortages per user, the actual surface or groundwater reservoir storage, the overall water balance of the basin and the energy production. Default tables summarise the main results, such as the success rate, allocated amounts of water, water shortages, water utilization rate, failure

year percentage and energy production, whilst user-defined tables can display detailed results per time step for specific variables per node or link. Among the postprocessing options, the user can choose an animated view where the amount of water carried by the branches of the network is represented by the thickness of their lines. This view can be displayed for different times of the simulation period just by moving a proper time bar.

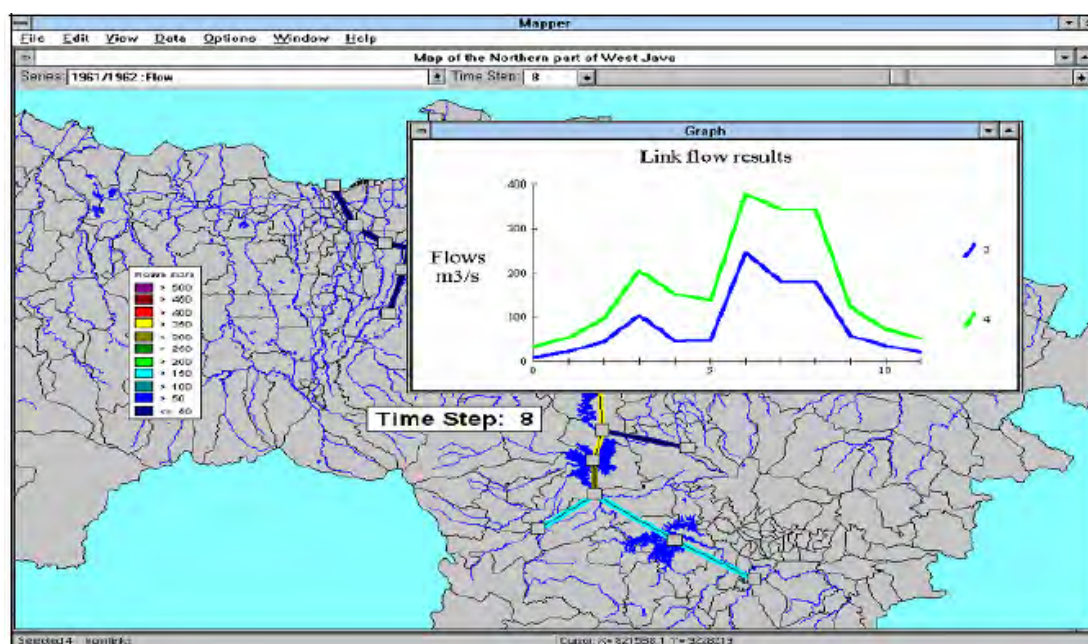


Figure 34: The plotted results

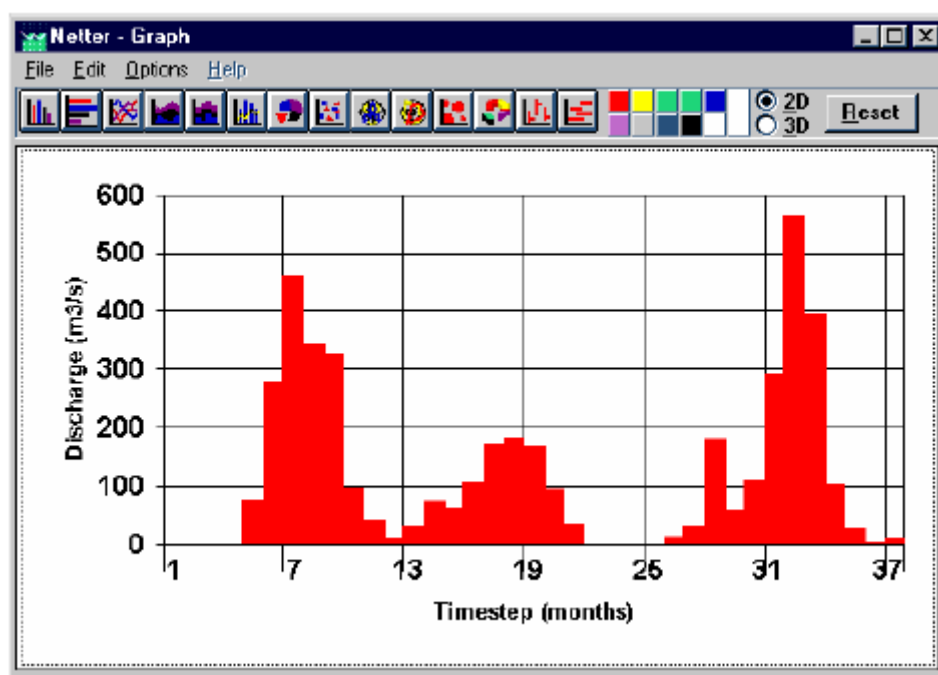


Figure 35: A specific output can be plotted over the simulation period

Summary of Pros and Cons

The user can draw the river basin schematisation on a geographic layer imported from ArcView or MapInfo. However, RIBASIM does not integrate GIS software. RIBASIM allows defining different hydrological scenarios as inflows input to the water resource system, as well as strategies or groups of strategies (*cases*). However, there is not a real multi criteria evaluation procedure based on a comprehensive set of indicators.

2.1.8 Weap

The *Water Evaluation And Planning System* (WEAP) is a tool for **water resources planning** developed by the Stockholm Environment Institute's Boston Center at the Tellus Institute, USA. It aims at assisting the Decision Maker in storing and managing water demand and supply information, in forecasting water demands, water availability, waste generation and water costs and in evaluating water development and management options.

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

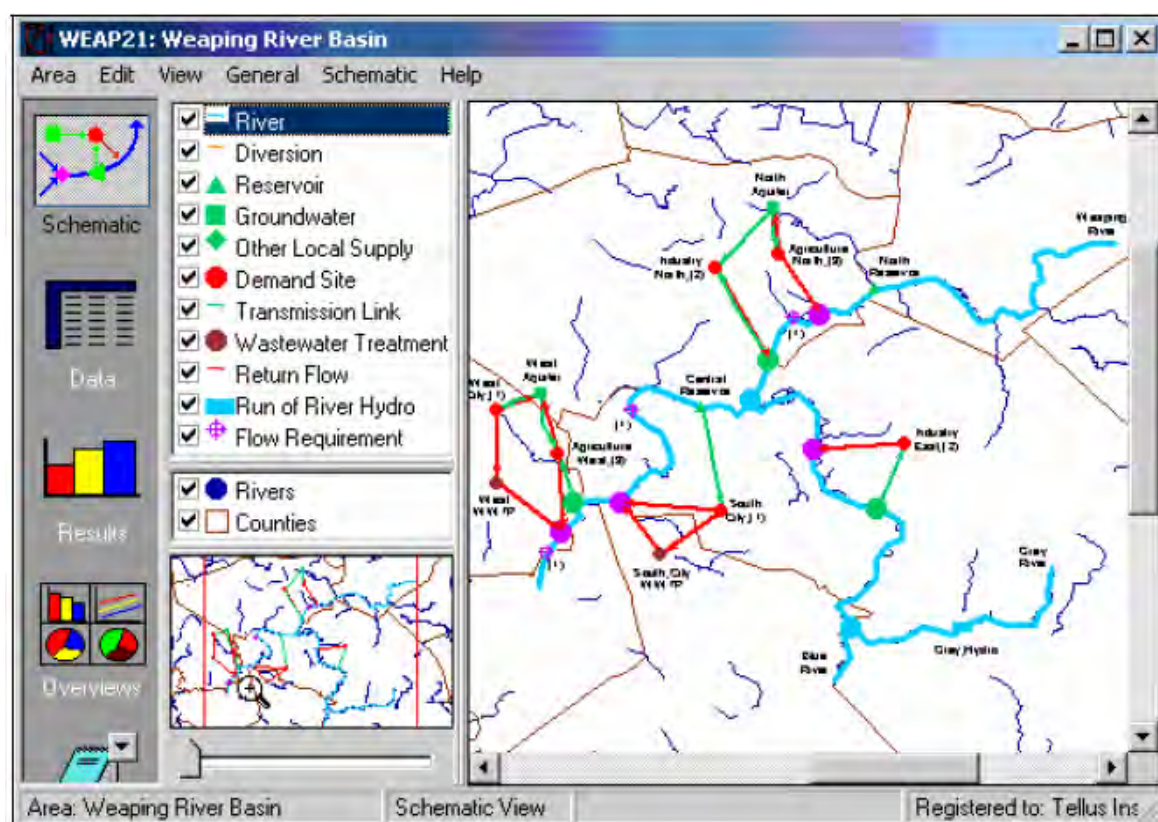


Figure 36: The Schematic view of Weap

In the **Schematic View** the user finds a GIS layer of the area of interest and can build the network of nodes and links representing the water resource system of the area. WEAP is usually applied to river watersheds but the area can also be a larger or smaller geographic region. The user draws the node system directly on the GIS layer by dragging and dropping the desired types of nodes and transmission links from a list window at the upper-left, to the specific position on the map in the centre of the interface. After dropping the node type on the map, a pop-up window requests some minimum general information about the new node, such as the name and whether the node will be included in the simulation of the default scenario. Additional required data depend on the specific element type and will be described later on. Network elements can represent rivers, diversions, reservoirs, groundwater pumping stations, demand sites, wastewater treatment plants, hydropower stations and flow requirements. Nodes are linked by transmission links and return flows. The former carry water from the water resource nodes to the demand sites nodes, while the latter exit the demand sites towards treatment plants or river locations. A small window, under the node types list, lists the GIS layers that can be loaded over the basic river basin map so as to add geographical information such as rivers, aquifers, lakes,

seas. Both network elements and maps are loaded by ticking the list elements with the mouse left button. The GIS map can be navigated by moving the little hand cursor over it, and a specific part of the map can be selected and zoomed.

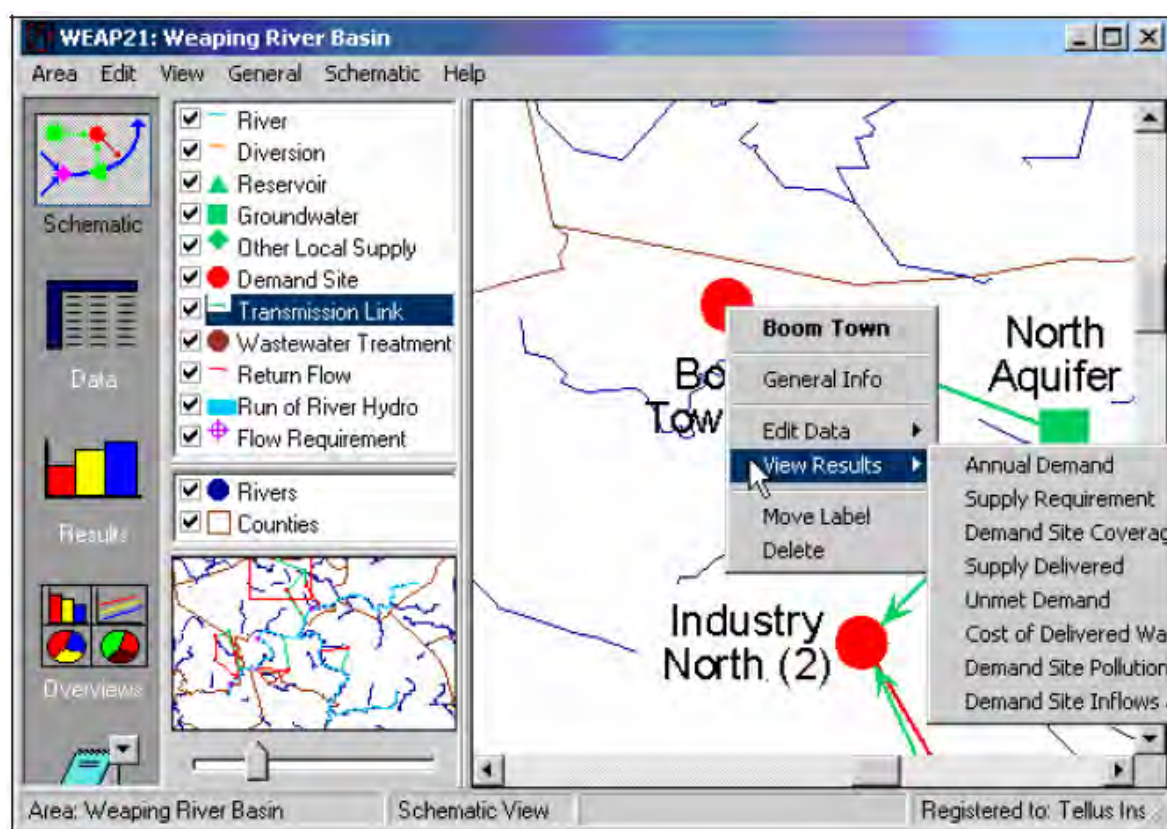


Figure 37: The user can access data and results by clicking the network elements in the Schematic view

The **Data View** is used to organise, edit and model data associated with network elements. This view consists of four panels: the Tree on the top left, the Inset Schematic on the bottom left, the Data Entry Tables on the top right and the Data Entry Results on the bottom right. The Data Entry Tables panel is the main subject of the view, where data can be accessed. In order to display information for a specific node in the data entry, the node itself must be selected by clicking in the inset schematic. The inset schematic is a small map of the area that can be navigated and zoomed, whereas the tree is a hierarchical outline similar to the folder structure of Windows Explorer that is used to organise the data under predefined categories. The data entered in the Data Entry Tables appear in the Data Entry Results either as graphical charts or as tables listing the corresponding plotted values. In more detail, the Data Entry Tables concern the variables describing the nodes and their trends over time. These latter are easily built by the user through a dedicated set of integrated functions, where the simple specification of parameters allows for defining the variable behaviour. Examples are the *Growth* and the *Interp* functions that calculate a value in any given year using a growth rate from the base year value or a linear interpolation of a time series of year/value pairs respectively. Variable trends can also be built through dedicated wizards for monthly and yearly time-series construction. Once data have been filled-in, the user can convert and display them in different measurement units and scales. The list of units depends on the category of network elements data refer to. Data Entry Tables also concern the management of scenarios, which in WEAP are defined as *self-consistent story lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions*. The default one-year scenario is called *Current Accounts* and the corresponding data represent the status of the system in the specified year.

This year is the starting point for all the simulated and alternative scenarios which are formulated from that year on. As previously mentioned, the behaviour of variables is built through mathematical expressions that can either be constant or generate time series of values. These expressions can be exported from one scenario to another; in this way it is possible to minimise the amount of data entries and to facilitate the scenario editing and management. The Data View Tree is organised into six major categories, Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment and Other Assumptions. The **Key and Other Assumptions** are user-defined intermediate variables that can be referenced in any expression or function used in data and scenario definition. Examples of such variables are the Gross Domestic Product (GDP) and water price. **Demand sites** include cities, industries and agricultural area demanding for water. They are described in terms of annual water use, monthly share of annual demand among all the sites of the same category, loss and re-use rates within a demand site and the costs and savings due to the application demand management options. The **Supply and Resource** category groups all water sources and network links. These latter are featured by the maximum flow volume, loss rate and cost per unit of water delivered while each source type has its own specific variables. The **Hydrology** category refers to future time series of inflows to supply resources, specified via mathematical expressions or entered on a monthly basis. The **Environment** category concerns pollutant generation, concentrations, decay rates and removal within the treatment plants.

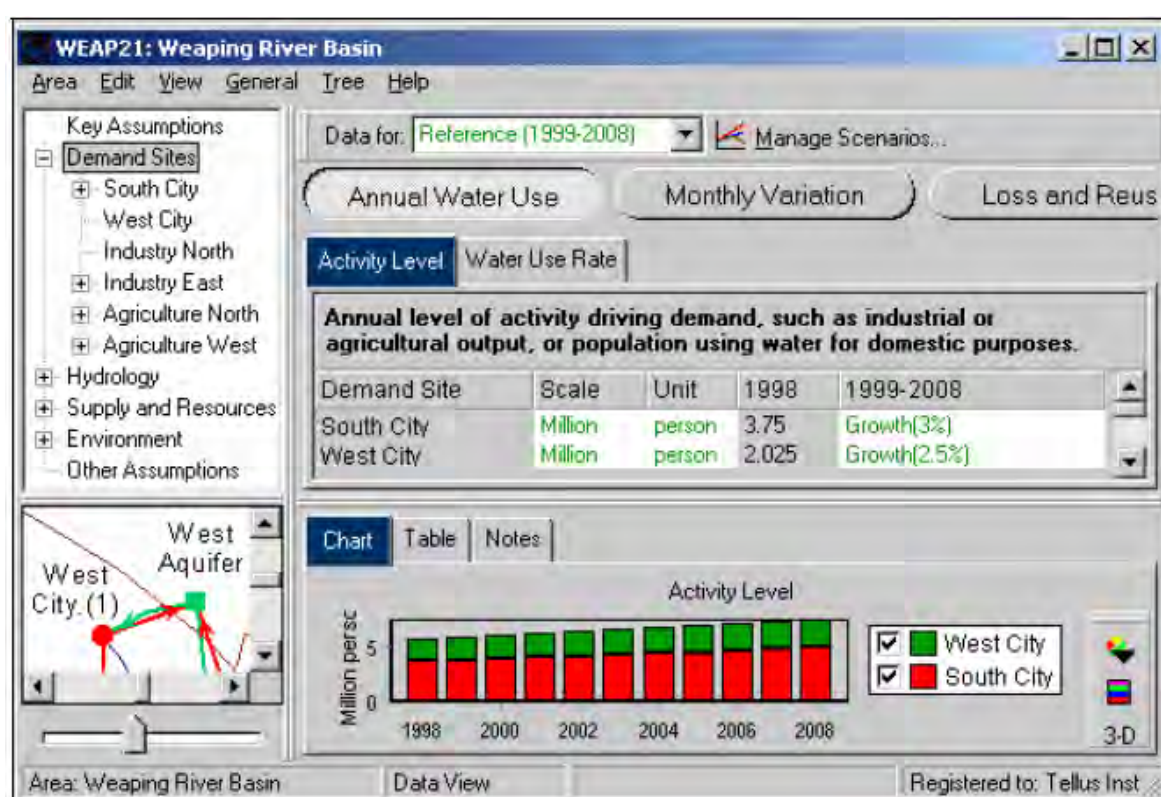


Figure 38: The Data View of Weap

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

basin map in the Schematic View by right-clicking on the desired demand site or transmission link and selecting “General Information”.

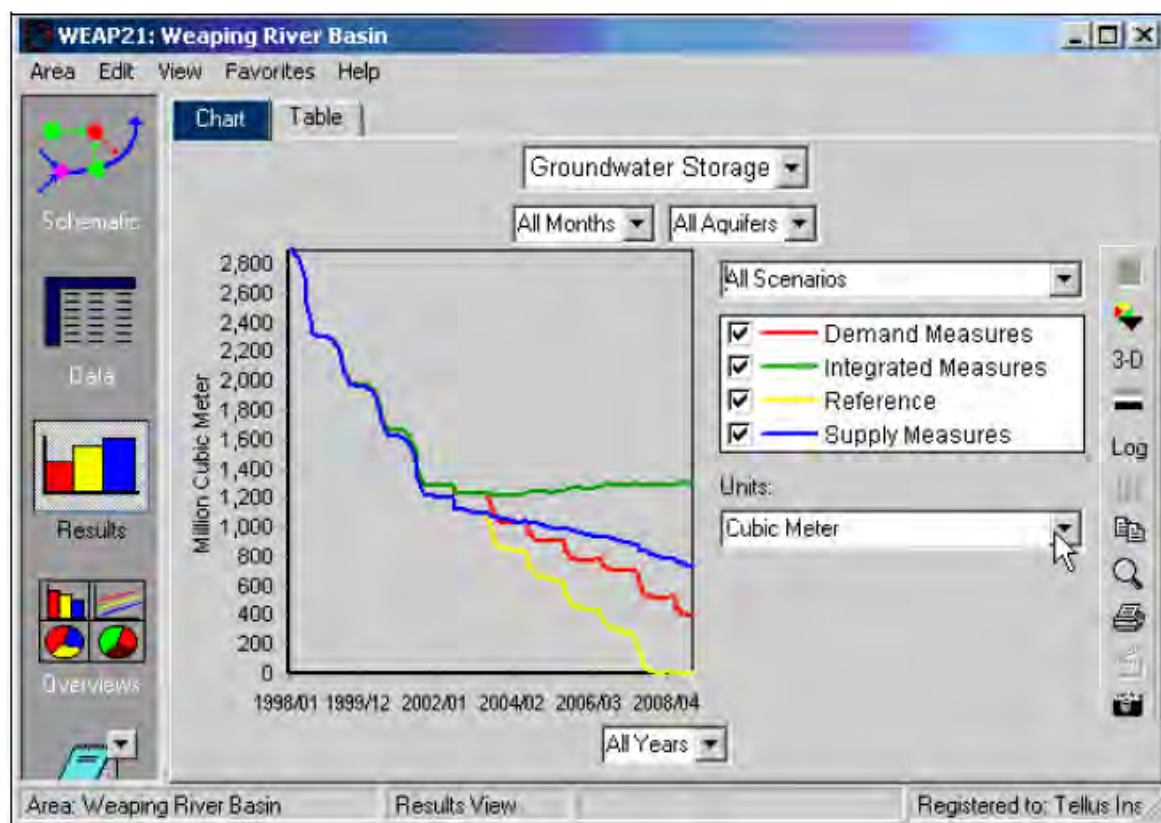


Figure 39: The Result View of Weap

After the simulation is performed, results can be plotted in the same *Result View* or investigated in the associated data tables. The user can customize graphs and save them as favorites, choose the variables to plot, choose a specific month or display the entire time series, and plot information associated with just one network node or with all the nodes of the same type (e.g. groundwater storage for all aquifers). Moreover, the user can choose and change the graph type, select a scenario, and change the display units. Data tables can be exported to Excel by clicking on the dedicated button; while graphs can be copied and printed. Graphs previously saved as favorites can be viewed simultaneously in the *Overview*, in order to compare different aspects of the river basin, such as water demand and coverage, storage levels, pollutant generation and costs. The user can build and save up to 16 charts or tables per overview, and create multiple overviews. Each single graph of one overview can be further modified and saved again.

A fifth tool that appears in the View Bar —Note3 is a word processor for writing documentation on the network elements, trends built or expression used WEAP has been applied in water assessments in the United States, Mexico, China, Central Asia, Africa, Egypt, Israel and India. The main objectives of those applications were:

- The identification and evaluation of the impacts of climate change on water for agriculture, recreation, hydropower generation, water for municipal and industrial use, habitat function and health, biodiversity, water purification.
- The representation of alternative water development and allocation scenarios.
- The assessment of water supply augmentation through an inter-basin transfer within firm yield analysis.
- The resolution of water use conflicts in river basins.
- The development of supply and demand balances and alternative strategies to study the water costs in watersheds.

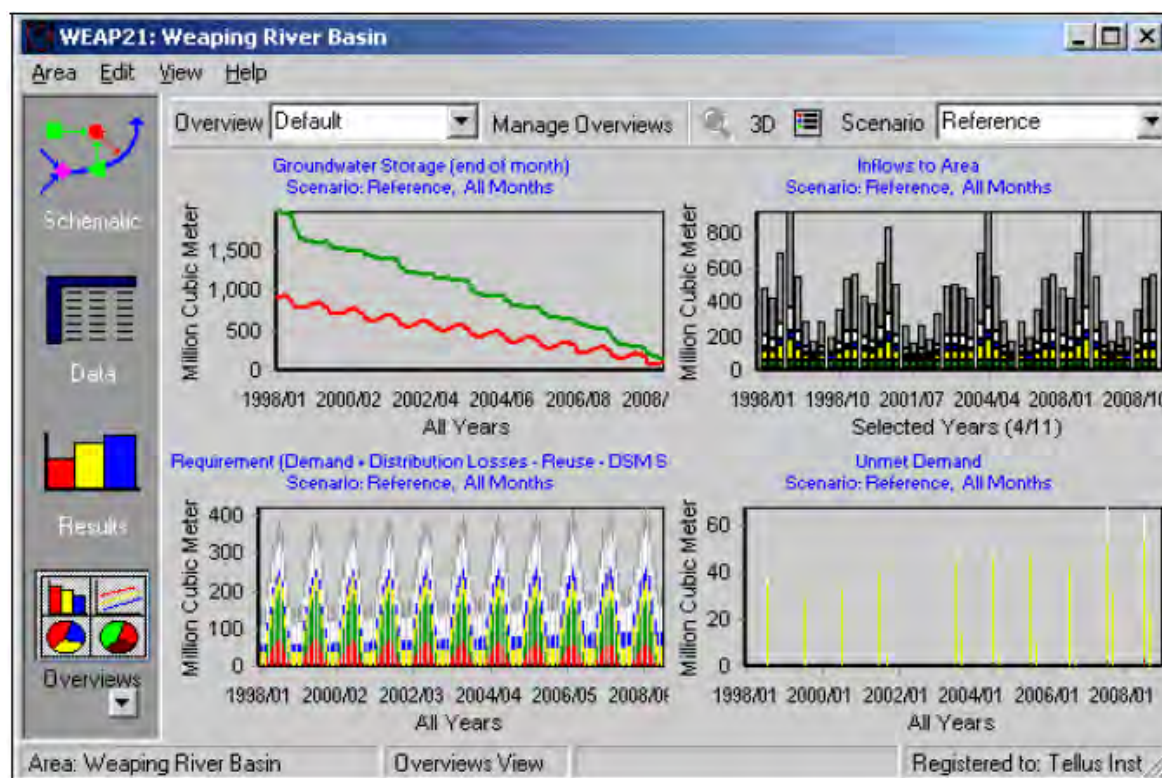


Figure 40: The Overview of Weap

Summary of Pros and Cons

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

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

2.1.9 Waterware

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

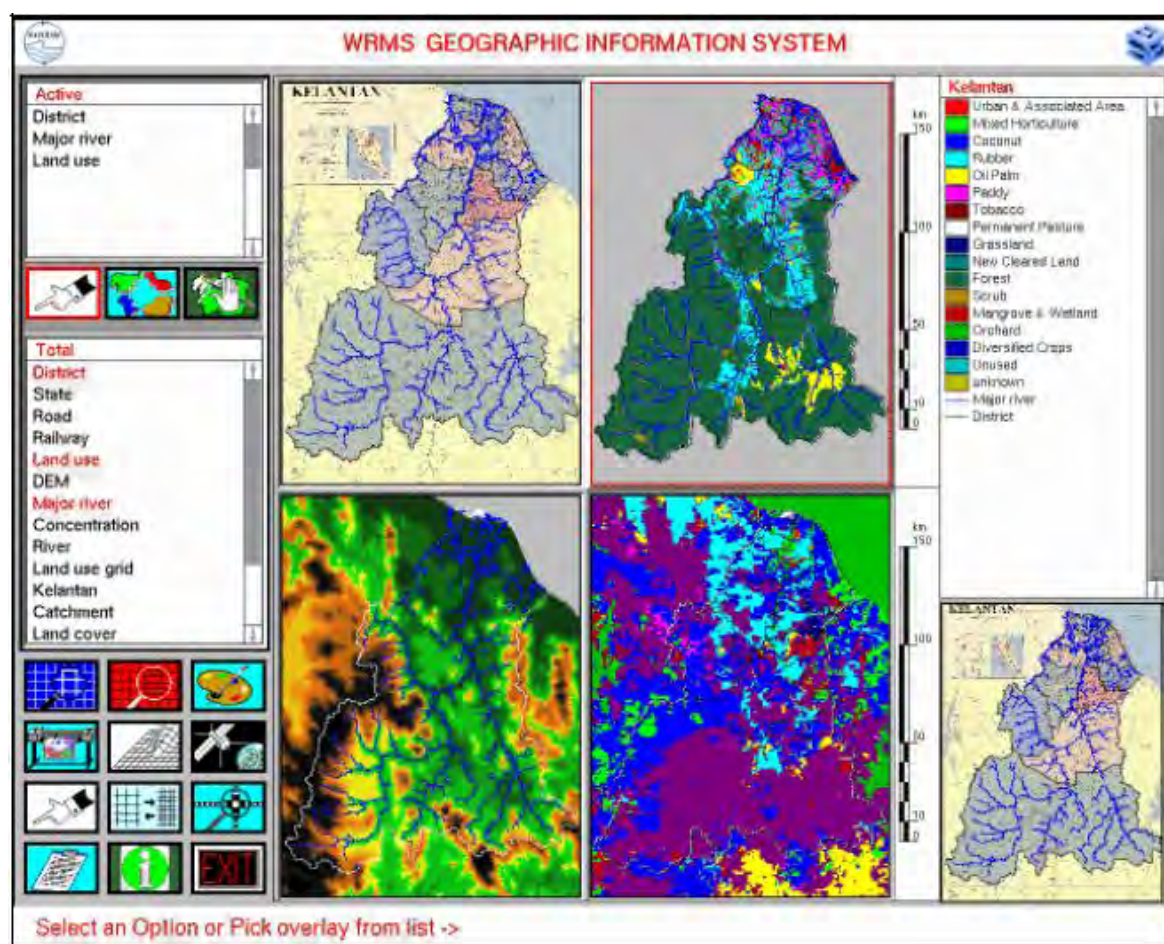


Figure 41: GIS layers drainage network, land use, soil, and DEM

Among the Water resource issues considered by Waterware are:

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

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

- ☐ User interface,
- ☐ a GIS providing hierarchical map layers for spatial reference and direct data input for the simulation models. It is integrated with the database, the models, and other utilities as well as http servers supporting remote access through the Internet,
- ☐ geo-referenced database with HTML documents to easily navigate through background information on legislation, pollutants, emission sources and coefficients, models, health effects, and control technologies,
- ☐ a graphical river network editor,
- ☐ a suite of simulation models:
 - ☐ mono-dimensional stochastic river water-quality model
 - ☐ bi-dimensional finite-difference model of groundwater flow and contaminant transport
 - ☐ UN Food and Agriculture Organisation's CROPWAT model to estimate the crops water requirements

- ☐ rainfall/runoff model
- ☐ water resources planning model
- ☐ utilities for time series analysis and reporting, and
- ☐ a rule-based expert system for Environmental Impact Assessment.

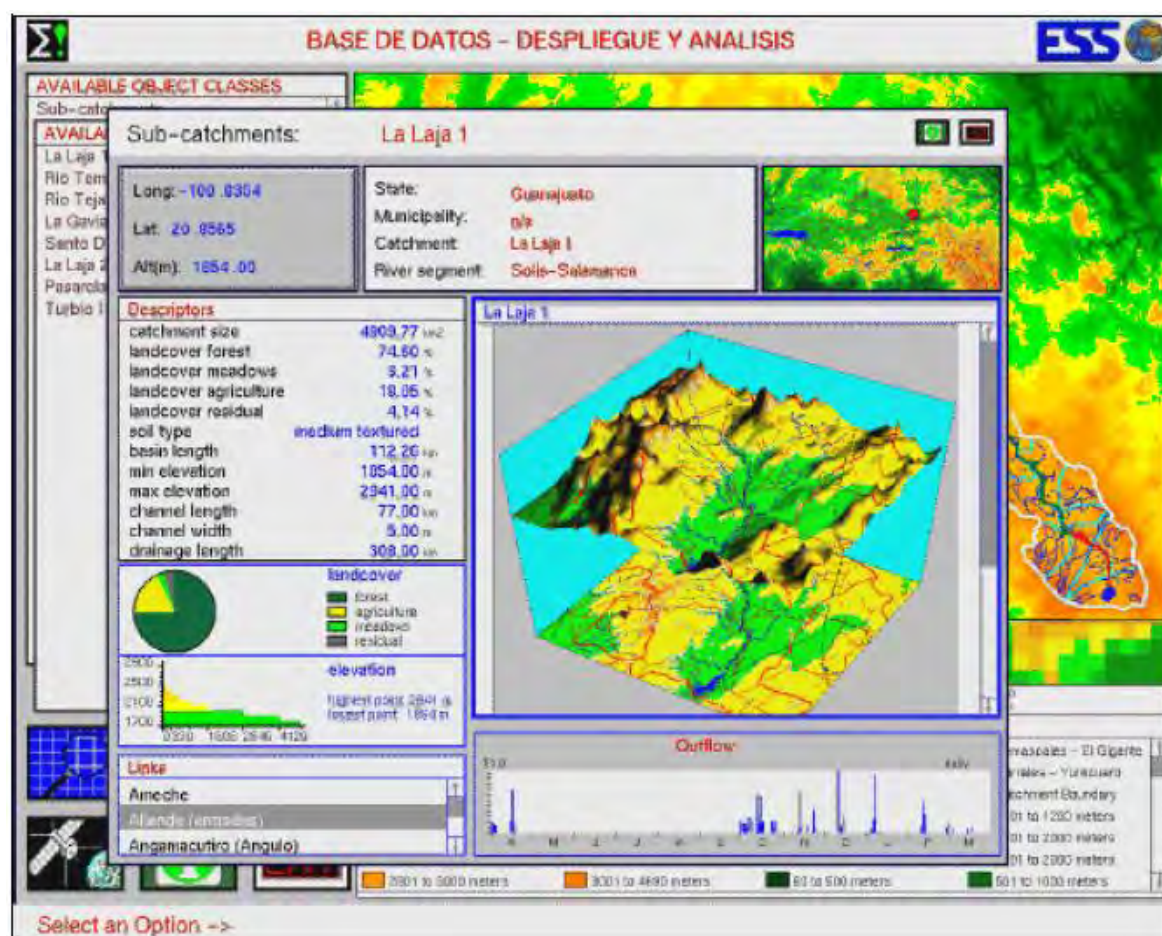


Figure 42: The window for a sub-catchment object

WATERWARE works with a variety of geographic, hydrological, meteorological, and economic data. Examples are: maps with administrative boundaries, land-use, DEMs, the parameters specific to each simulation model. The river basin is schematized according to a set of **River Basin Objects** that are: meteorological stations, flow stations, water quality stations, observation time series, abstractions, settlements, industries, irrigation districts, animal farms, treatment plants, water works, sub-catchments, dams and reservoirs, natural lakes, aquifers, wells, weirs and falls, gates and sluices, cross-sections, boreholes, and scenic sites. Each type of object represents a *class* of elements that have been assigned a common set of properties and functions.

Properties, describe the status of the element while functions drive their behaviour in time.

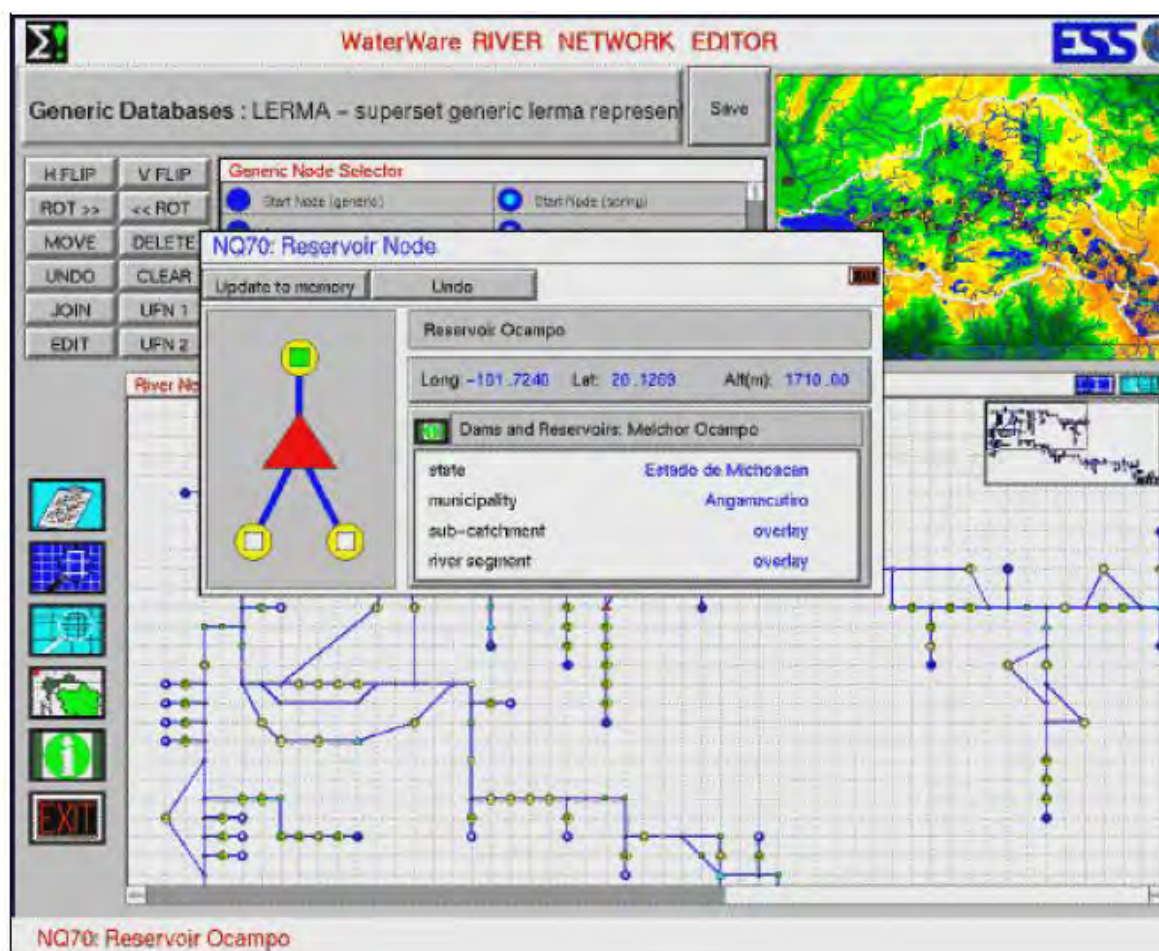


Figure 43: The Interactive River network editor of Waterware

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

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

The user can access each model and river basin object through a dedicated windows and menus. Examples are presented in the figures that follow.

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

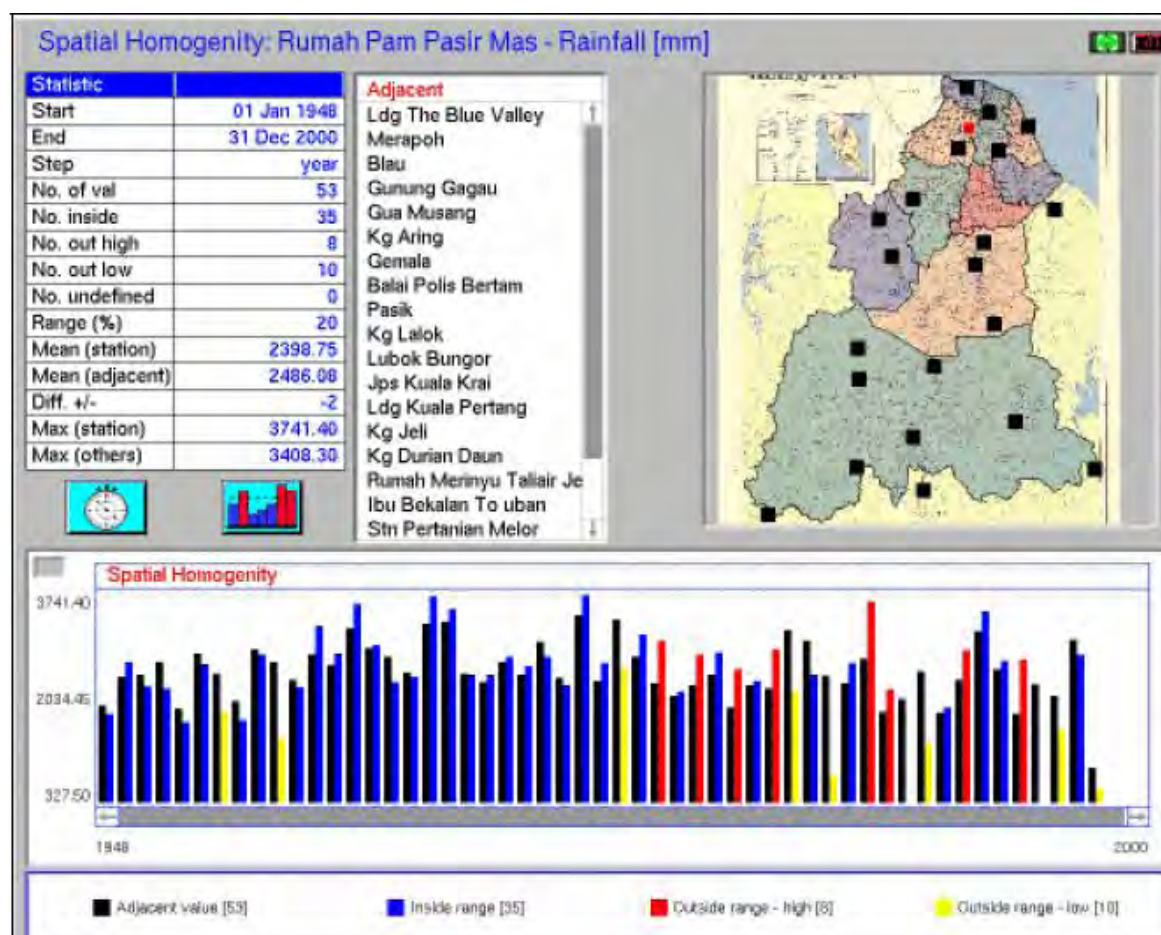


Figure 44: Examples of time series analysis: selection of stations and spatial homogeneity

Data analysis utilities go beyond the basic functionality of displaying time series data, scrolling, zooming, data aggregation and unit converting. Data associated with individual gauging stations can be accessed through selection from a list of stations or from maps and are analysed in the spatial context of the station itself. There are functions that allow the selection of sub-periods of time-series, their interpolation and the search for the maximum common temporal coverage for a set of stations. Moreover, data can be tested in terms of spatial homogeneity and seasonality of specific values and the cumulative distributions of time-series of different neighbouring stations can be compared.

Summary of Pros and Cons

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

WATERWARE does not operate with economic, hydrologic or meteorological scenarios and does not integrate a framework for result comparison and definition of strategies or options to improve the water

availability or to solve water pollution. It has more the role of an information system rather than of a system that can support decision making under an integrated and multi-objective analysis.

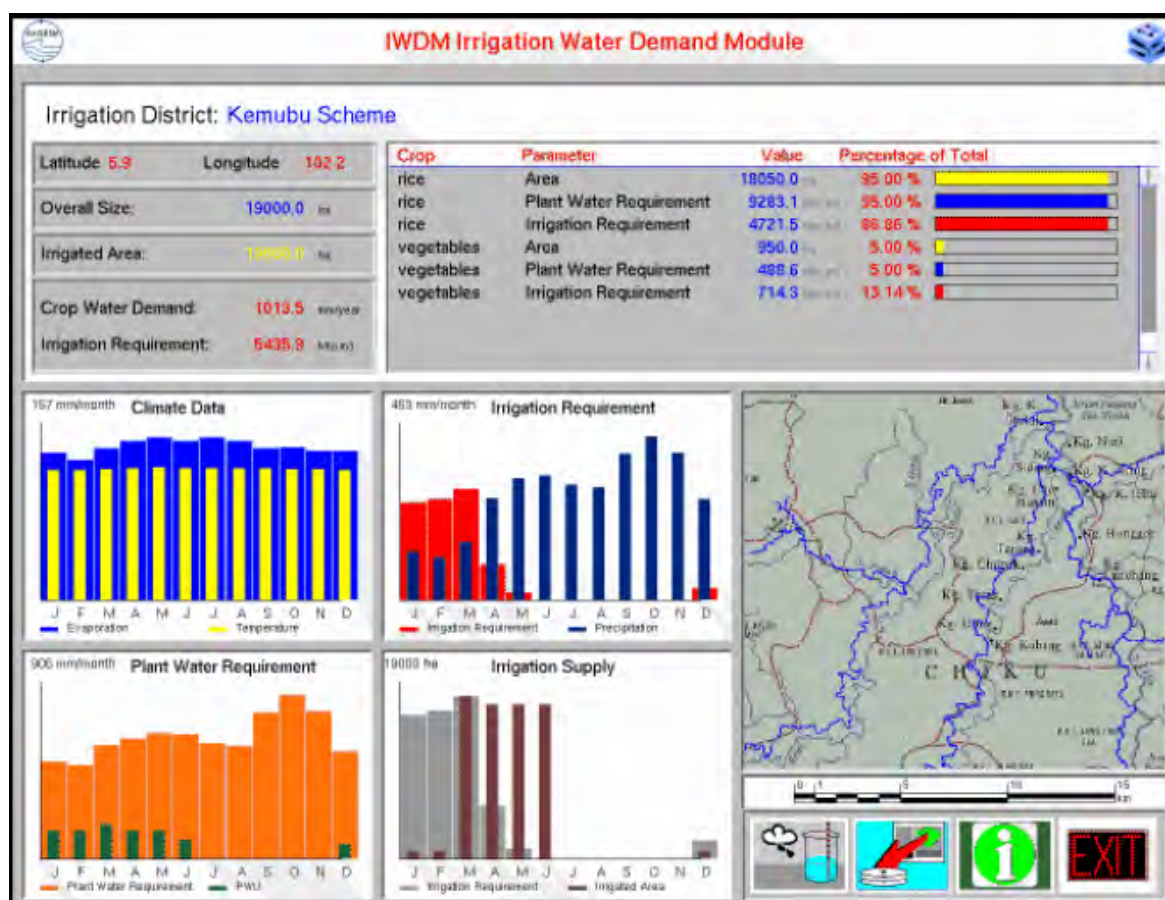


Figure 45: The Irrigation Water Demand Model window

2.1.10 Aquatool

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

This Windows-based DSS consists of modules for the basin management **simulation** and **optimisation**, for **modelling** of water flows in aquifers, **risk assessment**, analysis and reporting of results. These components have been coded in different programming languages such as C++, Visual Basic and Fortran, as they have been developed in different periods and have not been integrated in one package; this makes AQUATOOL highly flexible to work with, to upgrade and further develop.

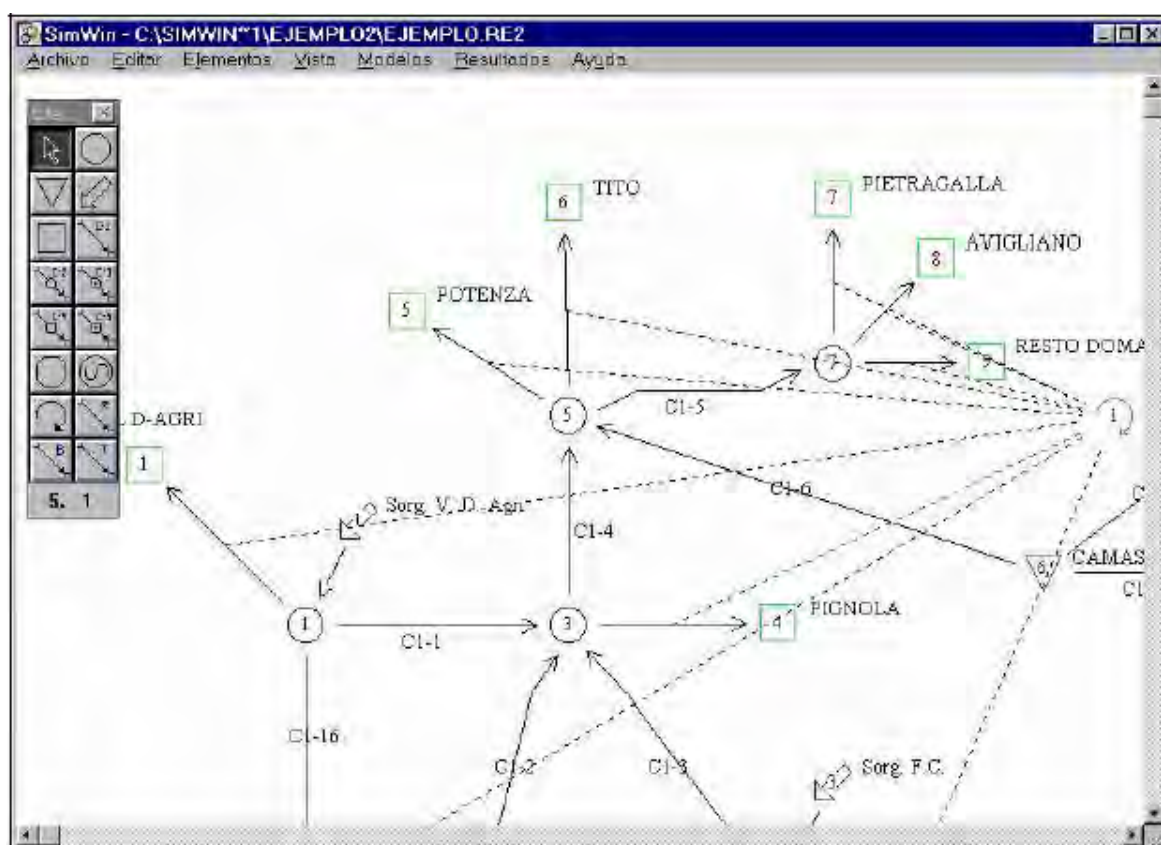


Figure 46: Building the river basin schematisation

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

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

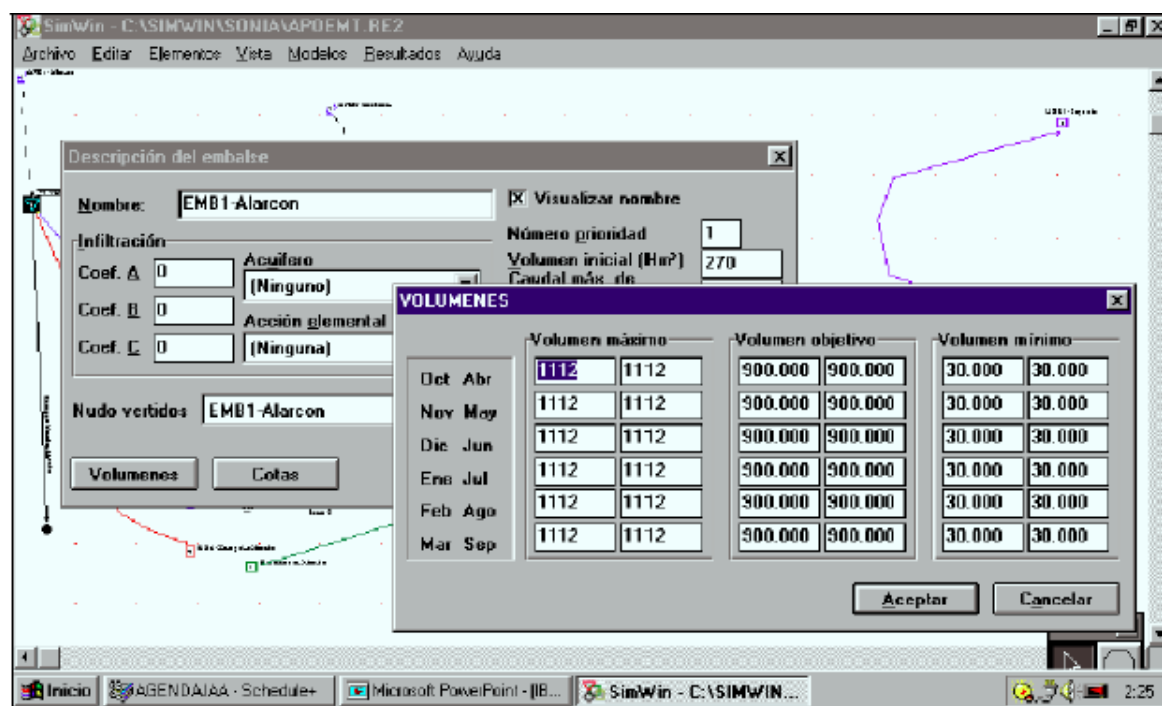


Figure 47: Accessing the geo-referenced database from the basin scheme

The **SIMGES** Fortran-coded mathematical model performs the simulation of the operational management of the system on a monthly basis. It is responsible for the water allocation to water uses and considers the conjunctive use of surface water and groundwater. This issue is of particular importance, since in most Spanish basins aquifer exploitation helps considerably in facing water scarcity and competition between conflicting uses. For that reason, the model takes into account detailed relationships between the surface water source and the aquifers and includes a broad spectrum of approaches for modelling groundwater:

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

Of course the choice of one approach instead of another can depend on the amount of data available from hydrological and geological studies and the desired level of detail for a realistic representation of the aquifer.

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

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

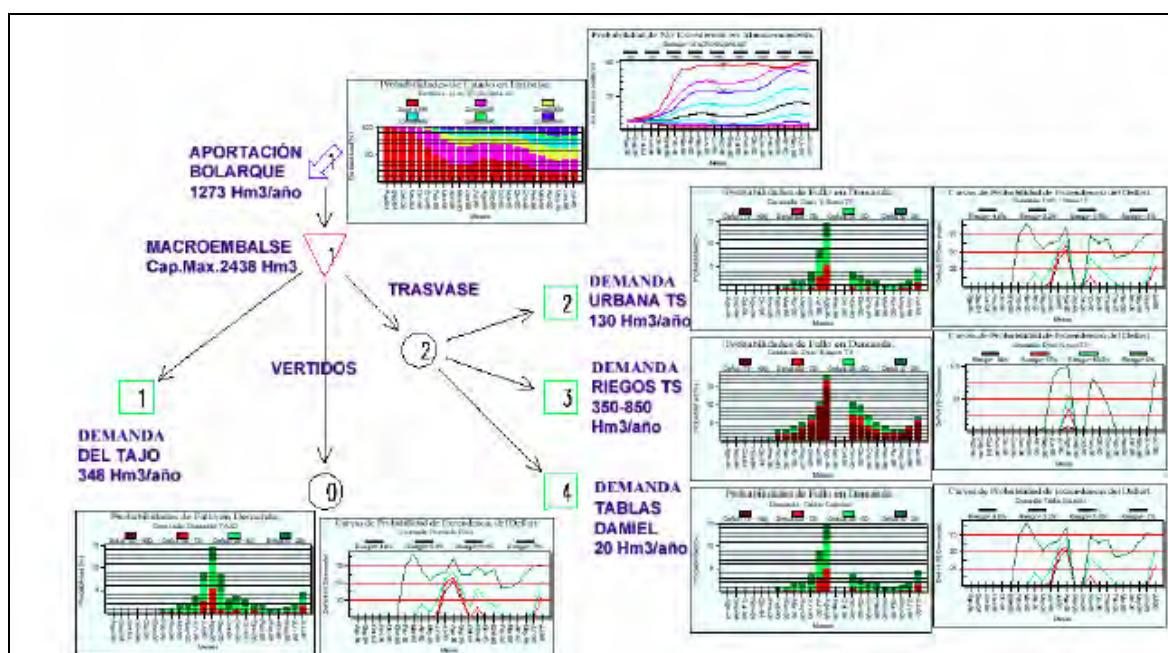


Figure 48: Risk assessment analysis for a sub-watershed of the Tagus Basin

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

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

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

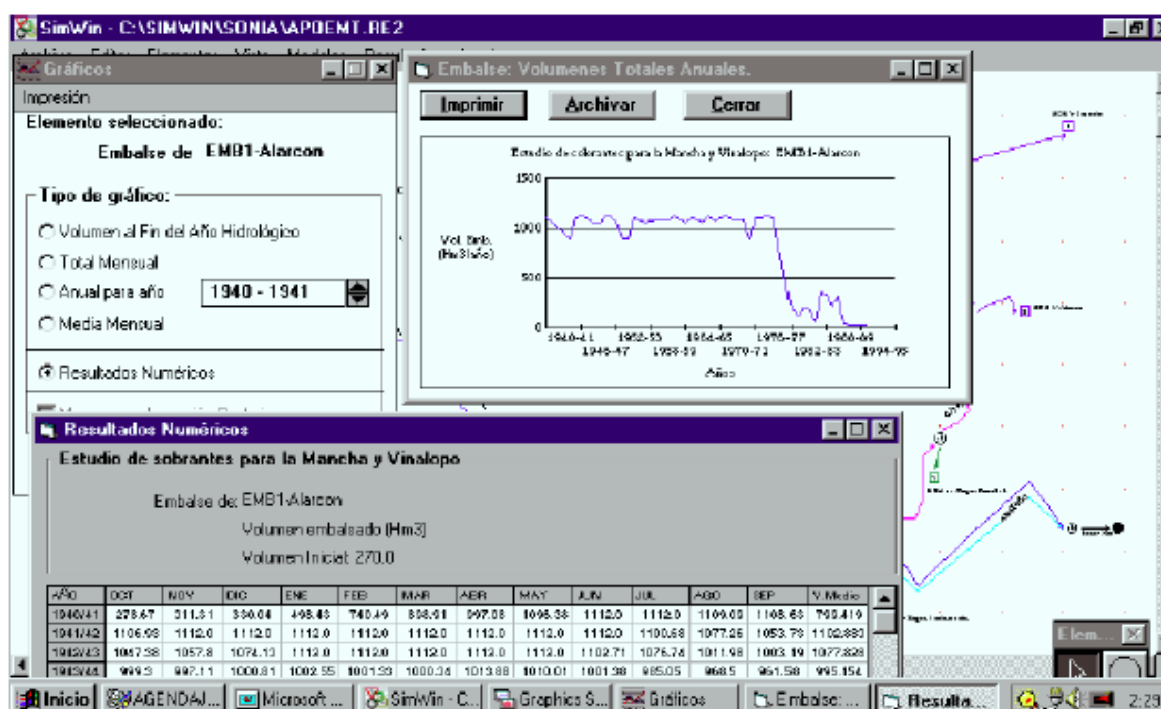


Figure 49: Example of tabular and graphical display of results for a specific reservoir of the system

Summary of Pros and Cons

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

2.1.11 Iras

IRAS is the acronym for *Interactive River-Aquifer Simulation* program. It is a tool for **simulating surface and groundwater resources**, their reciprocal interactions and flow exchanges over space and time. IRAS was first released in 1994 and updated in 1998 by the Civil and Environmental Engineering Department of Cornell University and the Resources Planning Associates Inc of Ithaca, New York State.

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

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

The Iras Network

The IRAS network elements can model various components of any interacting surface groundwater system. Nodes represent components or points of interest where simulated variable values are recorded, and where

inflow, outflow, consumption, diversion, or storage events can take place. The user of IRAS can choose among the following types of nodes:

- ☐ Artificial reservoirs, whose release or discharge are governed by operating policies accounting for target volume, satisfaction of downstream demands, etc;
- ☐ Natural lakes, whose outflow or discharge is determined by the topography of the basin and hence is a function of its volume or surface-water elevation;
- ☐ Wetlands;
- ☐ Confined or unconfined aquifers, distributed either horizontally or in multiple layers;
- ☐ Groundwater withdrawal or recharge sites;
- ☐ Gauging stations where time series of flow, natural recharge or quality parameters are available;
- ☐ Demand sites, either consumptive or non-consumptive;
- ☐ waste water discharge sites;
- ☐ Hydropower plants, connected either to rivers or reservoirs. They are not real nodes but are conceived in IRAS as items featuring river links. Hydropower can be placed on any link and the flow entering the link is assumed to be available for the production of energy;
- ☐ Confluences and diversions.

Links represent the transfer of water between two nodes and can be uni-directional or bidirectional if water goes respectively one direction only or both. Uni-directional links are:

- ☐ Natural streams or river reaches, connecting two surface-water nodes. River reaches are stretches of river that may be connected to hydroelectric power plants or pumping stations,
- ☐ Diversion canals, drainage ditches or pipelines.

Bi-directional links are:

- ☐ Generic links transferring water between two nodes, in particular links connecting aquifer or wetland nodes.

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

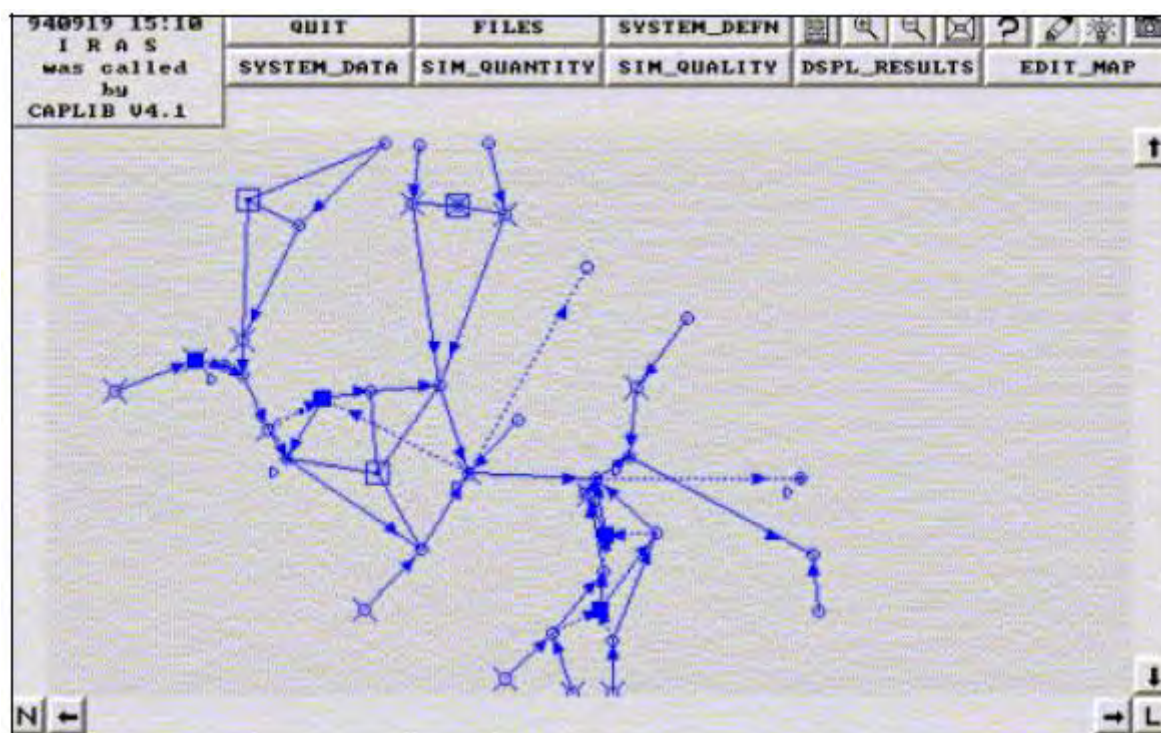


Figure 50: An example of schematic representation without background mapping: the Raritan River-Aquifer system in New Jersey

Data Enter and requirements

The type of nodes and links determines the data required for simulating their behaviour. When the user adds a new network element in the drawing network window, the IRAS program automatically recognises its type and creates the appropriate dialog box and data slots for entering all the needed data. Node and link dialog boxes for data entry or modification can be displayed by clicking on the node or link. Data requirements for some type of nodes and links are listed below:

All Nodes

□ **Gauge-flow multipliers.** Each node in the network may assume the role of a gauging station monitoring natural water flows. However, in case data time series are not really monitored or available in a newly defined *gauging node*, this latter is treated and described as a *fictitious station* that is conceptually associated to a real neighbouring monitoring point. The fictitious node generates its own data series from the associated real station by multiplying each real value by a proper calibrated factor, namely **Gauge-Flow Multiplier**, accounting for spatial interpolation or extrapolation.

On the other hand, Gauge-Flow Multipliers can also be defined for all node types, here for converting the measurement units of monitored flows from the user-defined ones to those needed by simulation modules.

□ **Quality parameters.** If the node is a storage node and water quality is to be simulated, the user must define the values of the average daily growth or decay rate constants and the transformation rate constants for each water quality constituent being simulated and for each within-year time period.

□ **Elevation data.** Elevation data at a node are needed anytime hydropower or pumping may be considered on any of its incoming or outgoing links. If the node is a storage node, storage volume elevation functions should be defined. Elevation data are also required to define storage-area-discharge-seepage data at all storage nodes.

□ **Loss functions.** Water can be lost due to evaporation or seepage at any storage node and the user must define the appropriate loss functions at each applicable node for each within-year time period. Note that the word *losses* in IRAS mean amounts of water exiting the water system definitively. According to that, seepage volumes from surface water bodies or adjacent aquifers entering other aquifers are not defined as losses and their transfer should be represented through a proper link connecting these two related nodes.

Demand Node

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

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

Reservoir and Natural Lake

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

Aquifer and Wetland Node

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

Gauging stations

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

Waste Water Discharge Node

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

Surface-Water Link Data

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

Aquifer and Wetland-Area Link

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

Diversion Link

- ☐ Maximum link flow capacity.

Simulation

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

The IRAS program simulates water resource systems over multiple within-year time periods that can be months, weeks, days, or time periods of different duration. The *within-year time periods* can be up to 60 and could cover an entire year, even if this is not necessary; in this case many years can be simulated, each one with different within-year time periods. All inflows, consumption rates, evaporation and seepage loss rates, and wastewater input data are considered constant within each within-year period. The within-year periods should be defined in a manner that captures the significant changes in inflows, wastewater discharges,

demands, and parameter values affecting water quality, as applicable, for the particular system being simulated. Each within-year period is divided into a number of simulation time steps of equal duration, at least 12, a day being the minimum time step.

RELEASE RULE NODE 4

OK ?

NODE NAME: Reservoir

INIT. STOR.: 400.0

CAPACITY: 700.0

LENGTH: 0.0000

ELEVATION: 0.0000

GAGE TABLE ALLOCATIONS

EVAPORATION RATE TABLE

QUALITY FUNCTIONS

RELEASE RULE

ALLOCATIONS

OK ?

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

LAKE NODE 3

OK ?

NODE NAME: Lake

INIT. STOR.: 0.0000

CAPACITY: 100.0

LENGTH: 0.0000

ELEVATION: 0.0000

GAGE TABLE ALLOCATIONS

EVAPORATION RATE TABLE

QUALITY FUNCTIONS

RELEASE RULE FOR Reservoir

OK ?

	Initial	Final
Max. Storage	550.00	600.00
Release	70.000	60.000
Min. Storage	350.00	400.00
Release	45.000	45.000
ZONE: 3		PERIOD: 2

RATING TABLE FOR Lake

OK ?

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

Figure 51: Dialog boxes with entered data for selected nodes and links. They are accessed by right clicking on the relevant network node or link.

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

4) **Inflows, Losses and Reservoir Release Targets.** In this first step the natural inflows (recharge flows) at aquifer and wetland-area nodes and the estimated evaporation and seepage losses at each storage node are calculated. These losses at each node are based on the current storage volume at the node and are calculated from the elevation storage area or storage volume-area functions, from daily evaporation rates and from daily seepage loss functions, entered by the user. Reservoir release targets, which are not necessarily the actual reservoir releases, are also computed according to current reservoir storage volumes and capacity, downstream demand target deficits and a specified minimum required release. The discharge from each natural lake node is calculated as the storage volume less evaporation and seepage losses plus inflows;

5) **Initial volume and inflow** at all nodes, surface-water node consumption and outflows, and surface-water link inflows and outflows. If hydropower production or pumping occurs on surface-water link, then the energy produced or consumed is computed based on the link inflow and the storage heads at the two nodes the link connects;

6) **Bi-directional link flows** between aquifers and/or wetlands. These flows are functions of current storage volumes, groundwater physics, overland flow and pumping policies. If hydropower and/or pumping is defined for any of the bidirectional links, the energy produced or consumed is also computed;

7) **Groundwater and wetland inflows**, outflows and storage volume. Water exchange with neighbouring rivers is also taken into account. Water flows within aquifers are calculated with the Darcy's Law for saturated flows in at least semi pervious material. This law assumes that the flow is laminar and proportional to the difference in pressure heads between the two water bodies multiplied by the area through which the flow travels divided by the length of the flow path;

8) **Water quality**. The simulation of water quality in storage nodes representing natural lakes, reservoirs, groundwater aquifers, or wetland areas, and in links representing stream reaches or surface water diversions, is based on the simulated flows and storage volumes. Water quality constituent inputs at each node are defined by the concentration of each constituent in the uncontrolled flows entering each node. For water quality simulation, storage nodes and surface-water links can be subdivided into a series of storage elements of equal volume, where complete mixing is assumed.

The volume in each element of a node or link is the total node or link volume divided by the number of user-defined volume elements. The instantaneous rate of change in mass of a water quality constituent in a storage element equals the incoming mass less the outgoing mass less the decay or consumption of that constituent mass plus its growth or increase in mass resulting from the transformation of other quality constituents in the storage element. The differential equation defining the rate of change in the mass of a constituent in a storage volume element can be approximated by the finite difference equation for each simulation time step. IRAS bases the change in constituent masses due to growth, decay and transformation only on the initial constituent concentrations rather than average concentrations in each simulation time step. Errors caused by that assumption may be reduced by adjusting the values of the rate constants of growth, decay or consumption of constituents during the calibration process.

Displaying Simulation Results

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

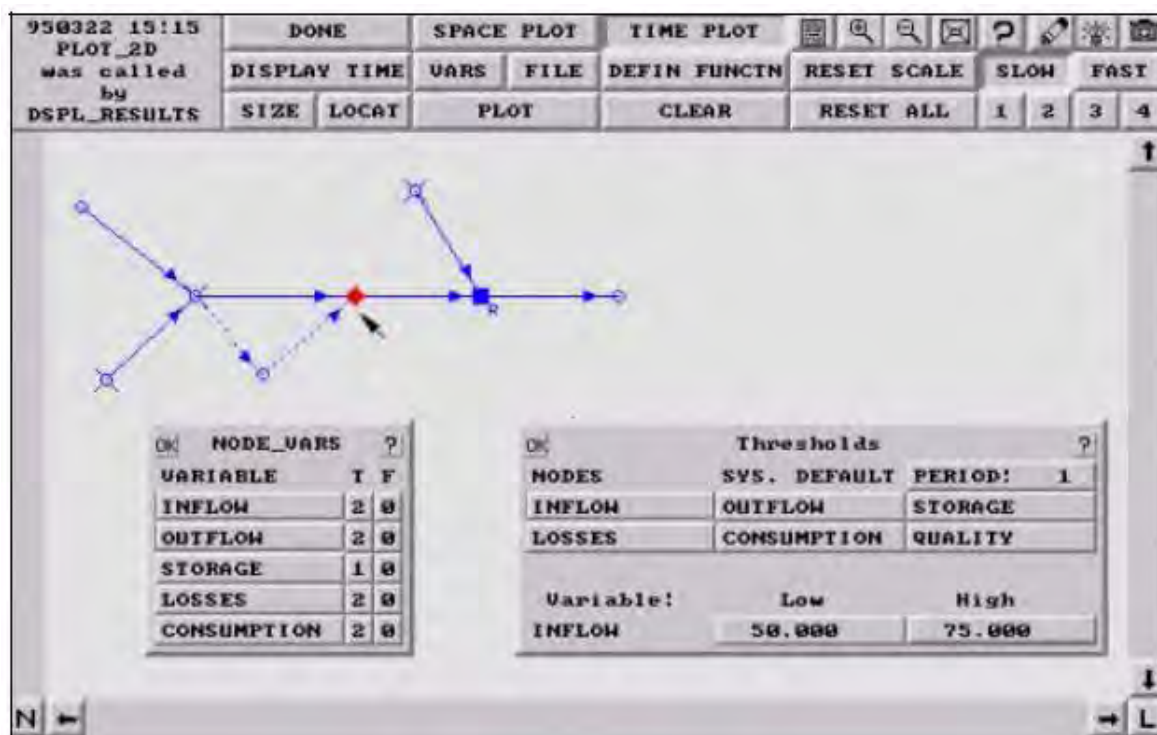


Figure 52: Assigning thresholds values to variables permits to check visually their behaviour over the simulation time steps: nodes in the network scheme change colour according to the range of values assumed by the variables. This type of visualisation may be performed for each simulation variable.

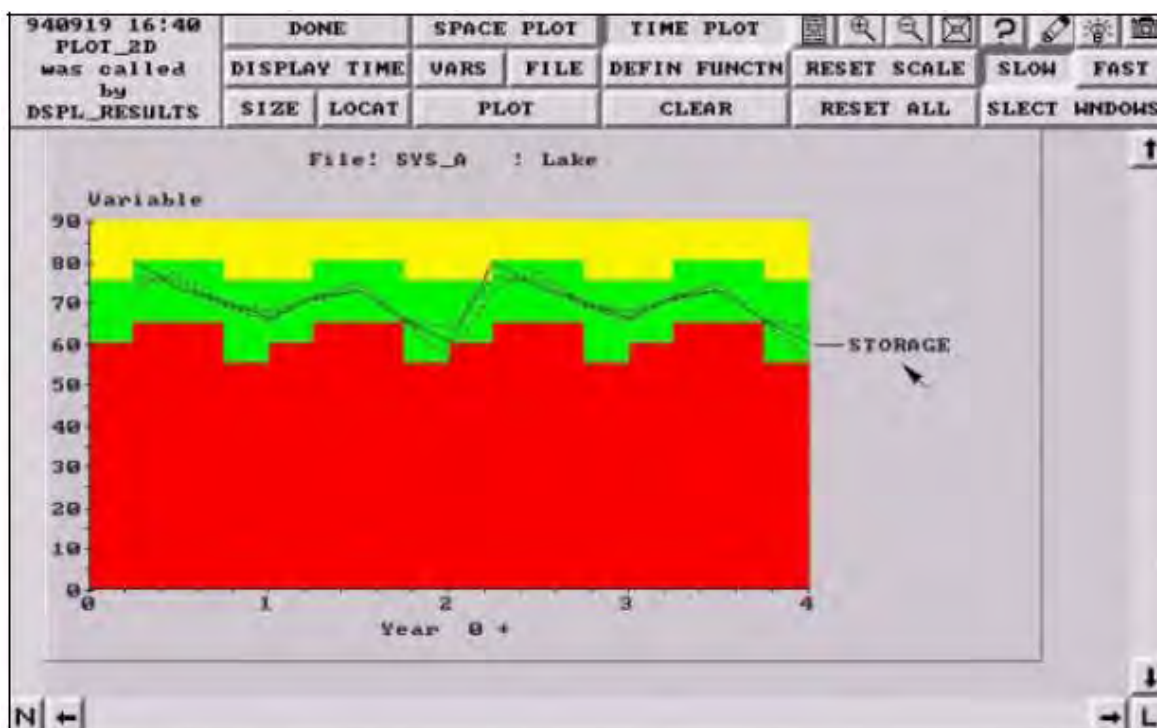


Figure 53: Coloured display of a lake storage over years

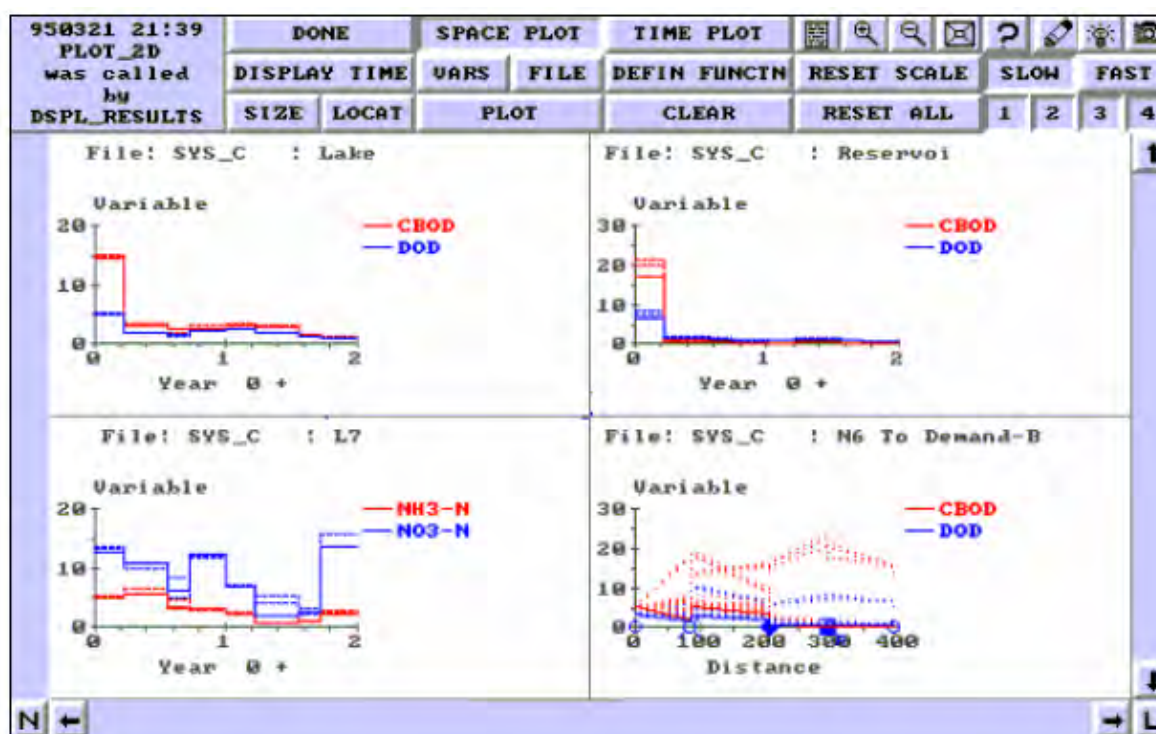


Figure 54: Displays water quality output data

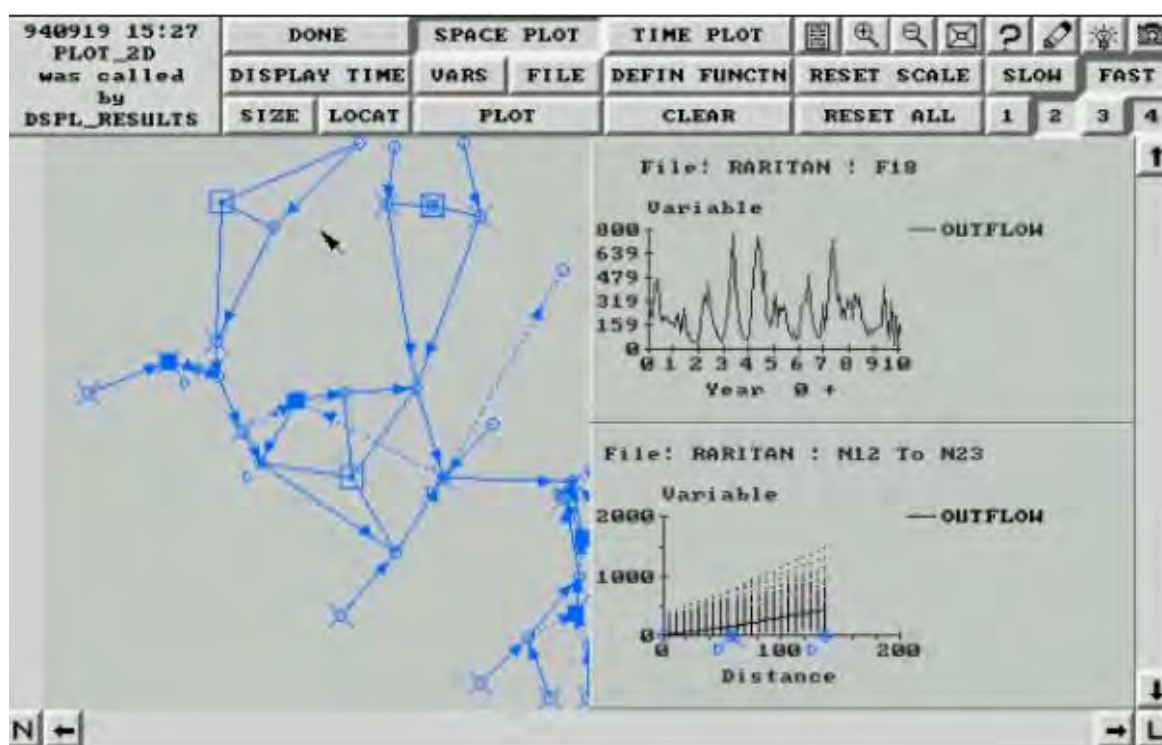


Figure 55: Displaying outflows from a node

Summary of Pros and Cons

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

2.2 Model Development for Quantifying Impacts

2.2.1 Tools (Models) Development

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

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

The set of quality variables simulated comprises:

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

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

2.2.2 Methodology Outline

The concentration of each quality parameter is updated at each time step and for each supply node using two different algorithms, according to the quality parameter type. For some the **continuity equation on the loads** is applied: the variation of load in the volume stored in the supply node (where load is concentration multiplied by the water volume) equals the difference between the incoming load and the outgoing load. The incoming load is equal to the sum of loads of the links carrying water to the supply node, while the outgoing load is computed from the current concentration at the supply node. Concentration is estimated at each time step by the equation. In these equations, additional terms are added to take into consideration the generation or decay of load i.e. the presence of algae and the nitrogen cycle.

Moreover, some of the water quality variables, such as Chlorophyll alpha, ammonia nitrogen and nitrate nitrogen are strictly inter-related and their equations are solved following a computation sequence or iterations. This approach requires the user to specify the initial concentrations of the quality variables (referring to the first month in the simulation period).

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

2.2.3 Tools Development Procedures

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

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

With an analytical solution of the type:

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

The specific equations for each quality variable are presented below.

Volume V of the water body:

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

Where:

I = water flow entering the water body;

O = water flow exiting the water body.

Salinity S:

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

Where:

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

O = water flow exiting the water body;

$in Load(S)$ = 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 conversion factor.

$$Chl\alpha = \alpha_0 * A$$

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

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

Where:

in $Load(A)$ = 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 1 N:

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

With

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

Where:

in $Load(N_1)$ = 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 = preference factor for ammonia nitrogen.

Nitrates:

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

With

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

Where:

in) $Load(N_1)$ = nitrate nitrogen load entering the water body;

O = water outflow;

$3 N$ = concentration of nitrate nitrogen;

$1 N$ = concentration of ammonia nitrogen;

V = water volume;

$1 F$ = fraction of algal nitrogen uptake from ammonia pool;

1α =

fraction of algal biomass that is nitrogen;

A = concentration of algal biomass;

1β =

rate constant for the biological oxidation of ammonia nitrogen;

μ = algal growth rate;

$N P$ = preference factor for ammonia nitrogen.

Coliform bacteria:

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

Where:

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

O = water outflow;

E = concentration of coliform bacteria;

V = water volume;

$5 k$ = coliform die-off rate.

Biochemical Oxygen Demand (BOD):

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

Where:

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

O = water outflow;

BOD = concentration of Biochemical Oxygen Demand;

V = water volume;

1 k = deoxygenation rate coefficient;

3 k = rate of BOD loss due to settling.

Dissolved Oxygen (DO):

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

Where:

$in DO Load$) (= 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;

1 N = concentration of ammonia nitrogen;

A = concentration of algal biomass;

1 k = de-oxygenation rate coefficient;

2 k = re-aeration rate;

μ = algal growth rate;

ρ = algal respiration rate;

3 α = rate of oxygen production per unit of algal photo-synthesis;

4 α = rate of oxygen uptake per unit of algae respired;

5 α = rate of oxygen uptake per unit of ammonia nitrogen oxidation.

Table 5 : 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
Definition	Notation	Range of values	Units
Rate of oxygen uptake per unit of algae respired	α_4	1.6 - 2.3	dimensionless
Rate of oxygen uptake per unit of ammonia nitrogen oxidation	α_5	3.0 - 4.0	dimensionless
Ratio of chlorophyll alpha to algal biomass	α_0	10 - 100	µg-Chla/mg-A
Saturation concentration of Dissolved Oxygen	DO^*	-	mg/l

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

□ **For Dissolved Oxygen:** the rate of oxygen involved in oxidation of ammonia to nitrite has been disregarded, since nitrification-oxidation of ammonia to nitrate in one-stage process has been considered. Benthic oxygen uptake has not been considered.

□ **For Ammonia Nitrogen:** benthos source rates have been disregarded.

□ **For Nitrate Nitrogen:** nitrification-oxidation of ammonia to nitrate has been considered a one-stage process. Contribution of organic nitrogen has not been considered.

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

The equation used is the following:

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

Where:

X = Concentration of the quality variable;

$o X$ = Reference concentration of the quality variable;

$(X Load$ = Load of the quality variable;

$(o X Load$ = Reference Load of the quality variable.

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

Water quality at supply nodes changes at each time step due to incoming loads from return flows generated by demand nodes and treatment plants. The loads at the exit of each wastewater treatment plant are computed according to removal rates assigned to each quality variable. The same stands for drinking treatment plants. However, in this case instead of removal rates, concentrations after process are set. The loads generated from demand nodes are also user-defined: a rate per unit of activity level is specified for each quality variable (Table 6).

Table 6. 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

2.2.3 Development of Decision Support System (DSS) for Environmental Impact Assessment (EIA)

2.2.3.1 Issues, disciplines and stakeholders

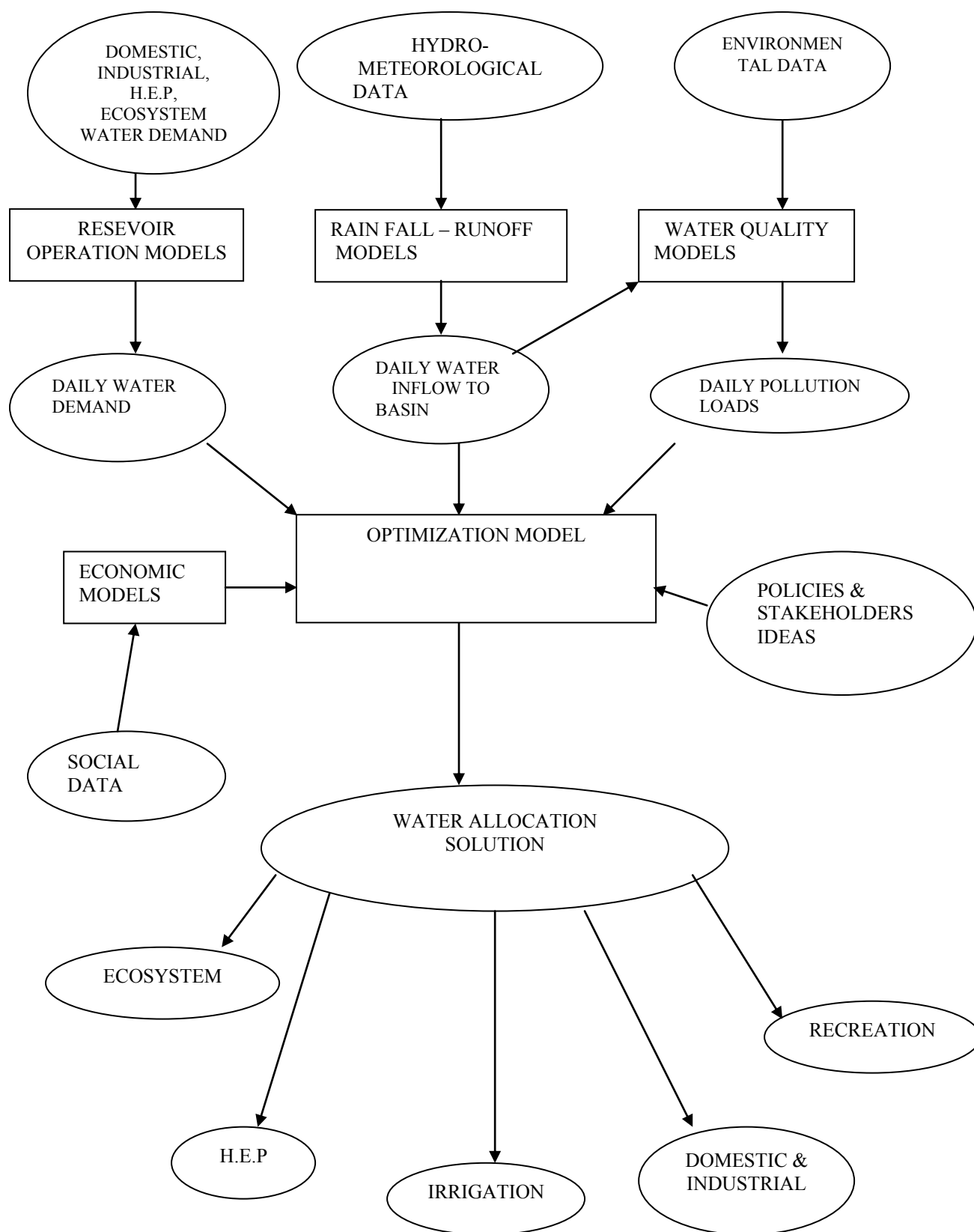
Throughout the world, deforestation, agricultural expansion and the associated competition for water resources produce environmental, economic and social impacts. In parts of the developing world these problems are often more striking because of fast growing populations and the associated rapidity of the manifested problems. Ghassemi et al. (1995) provides information on the extent and distribution of the world's water and arable land resources and land degradation types.

Water Resources Projects, e.g. agricultural expansion and hydropower produces competition for water at various scales and has resulted in erosion problems, downstream water quality deterioration, groundwater depletion, biodiversity loss, and shifts in the distribution of economic and social well-being and equity. These projects also intensifies demand for water in the dry season and, with the seasonal shift in flow regimes especially at larger scales where dam regulation is more considerable, exacerbates in-stream biodiversity and habitat.

Necessarily the toolkit requires integration of various disciplinary contributions including agronomy, climatology, economics, and hydrology and soil science. In order to enhance the utility, interactivity and transparency of the approach, the toolkit will be imbedded within a decision support system that allows scenarios to be generated as inputs to the toolkit and a range of biophysical and socioeconomic indicators as outputs. The main stakeholder focus for the DSS will be the Land Development Department, which aims to utilize the DSS to assist its land-use planning activities. However, other agencies and groups will be involved. Adoption will be facilitated by training workshops on the individual model components and the DSS itself.

2.2.3.2 Models and scales

The model components to be embedded in the DSS will be biophysical model, a rainfall-runoff model, a sheet erosion model and an economic model. The links between these models are indicated in DSS Framework shown in Fig.56.



PROPOSED STRUCTURE OF THE DSS

Figure 56 . DSS Framework

Time steps of the models range from daily to 10 days whilst outputs may be aggregated up to seasonal, annual and higher depending on the length of simulation. The spatial scale of the economic modelling in the initial project is at the level of the household, where activities are optimised with respect to income and constraints subject to the land and water resources available and external drivers mentioned before. The temporal scale of the economic modeling is seasonal.

A unifying spatial scale for the modelling is the node. Nodes are identified through the stream network as distinct zones of activity in catchments between which tradeoff of indicators is required. Thus, the time clocks of the various models are synchronised at these nodes. Despite the apparent availability of model component candidates from the literature, much innovation will be required in modelling. All of the models integrated into the toolkit and DSS will require some development to take into account data inadequacies, either in the form of inputs and parameters to drive the models or as outputs to assist in the calibration of models. Least modification will be required for the erosion model where the inputs, rainfall erosivity factor and topographic factor, will be adjusted for the higher rainfall and steeper slopes in Nile Basin countries compared to the original areas in the USA where the USLE was developed. The crop model will require simplification of the detail in infiltration, runoff and percolation processes to circumvent the lack of detailed field measurements in the catchments. The simulation of discharge will provide perhaps the greatest challenge because of the need to predict flows at nodal sites that are ungauged, and to predict nodal flows under changes in landcover conditions. This will require a regionalisation approach to relate the ratio of parameters of the IHACRES model (from gauged calibrated nodes to ungauged and/or landcover modified nodes) to the ratios of either runoff, deep drainage or runoff plus deep drainage inferred by the crop model.

2.3 Models and Methods Application/Demonstration

Having reviewed and developed the DSS framework, the application/demonstration of the appropriate models or tools will be based on conducting workshop to agree on;

- (i) Selection of study site in one of the Nile Basin Countries
- (ii) Data availability as required by the tool/model

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IMPACT EVALUATION TOOLS & DECISION SUPPORT SYSTEM FOR ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

Whenever a River Engineering (RE) project has to be undertaken, an Environmental Impact Assessment (EIA) must be carried out to identify the environmental impacts associated with the project so that the right mitigation measure can be put in place. Different processes are subjected to the project and impact analysis is one of those processes. The impact analysis starts with identification of impacts and later on prediction/evaluation of the impacts themselves. The last phase of impact analysis is impact significance to see the risks that impacts have on the environment. In Nile Basin countries, there is lack of impact prediction and unified tools for Environmental Impact Assessment for RE projects. Therefore, there was a need to conduct a survey of existing tools and methods for EIA plus their integrative nature to seek their application into Nile Basin Water Resources Management. The study was therefore carried out to identify and carry out the inventory of existing EIA tools, to set out the criteria for tools selection in Nile Basin Countries, to prioritize and select the identified EIA tools that can be used in Nile Basin Countries and to identify the risks (impact significance) assessment methods for EIA. The study was desk study mainly focusing on literature review, but to achieve the above objectives the study did the literature search, identification and reviewing of existing models for integrated (environmental) assessments and evaluation, creation of an inventory of environmental assessment tools relevant for Water Resources Development (WRD) in the Nile Basin and Identification and reviewing of Risk Assessment Processes.