Water Management Support Methodologies: State of the Art

WatManSup project

WatManSup Research Report No 1

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FutureWater Science for Solutions

Water Management Support Methodologies: State of the Art

WatManSup Research Report No 1

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Preface

This report is written in the context of the WatManSup project (Integrated Water Management Support Methodologies). The project is executed in three countries: The Netherlands, Kenya and Turkey. Financial support is provided by Partners for Water. For more information on the WatManSup project see the project website: http://www.futurewater.nl/watmansup.

The Dutch consortium:
- FutureWater (Wageningen)
- Institute for Environmental Studies (Amsterdam)
- Water Board Hunze en Aa's (Veendam)

Foreign clients:
- SASOL Foundation (Kitui, Kenya)
- Soil and Water Resources Research Institutes of the Turkish Ministry of Agricultural and Rural Affairs (Menemen, Turkey)
- SUMER (Izmir, Turkey)

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- EA-TEK (Izmir, Turkey)

Reports so far:
Research report No.1: Water Management Support Methodologies: State of the Art
Research report No.2: Water Evaluation and Planning System, Kitui - Kenya

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1 Introduction

Improved water management is highly required as water related disasters are on the rise. Population growth and climate change are likely to exacerbate those problems in the future and the number of people affected, total loss in lives, and economic damage is expected to increase. Moreover, people in developed societies expect that water is always available at the right moment and at the desired quantity and quality. It is clear that water managers are faced with enormous challenges to manage the scarce water resources in a sustainable and appropriate manner to meet demands of societies.

However, current water management practices are still focused on responding to events occurred in the past: the re-active approach. Some typical examples (amongst numerous others):

- The tsunami from December 2004 has led to a tsunami warning system
- The flooding in The Netherlands in 1953 was the starting point for the Delta-works
- After the devastating flooding in Bangladesh in 1991 (138,000 casualties) an early-warning system was established
- The critical situation of the Dutch dikes in 1995 and 1998 has led to a shift in water management policies (Nationaal Bestuursakkoord Water)

At many international high level ministerial and scientific meetings (i.e. World Water Forum 1997, 2000, 2003; World Water Council; World Summits) a call for more strategic oriented water management, the pro-active approach, has been advocated. Despite these calls such a pro-active approach is hardly adopted by water managers and policy makers.

Water managers and decisions makers are aware of the necessity of this paradigm shift, the change in thinking from a re-active towards a pro-active approach, but are confronted with the lack of appropriate methodologies. Instruments that are currently available are just tools on its own, while integrated instruments are required that cover the entire range leading from data to information to knowledge to policies: Integrated Water Management Support Methodologies (IWMSM).

To be prepared for the paradigm shift Integrated Water Management Support Methodologies (IWMSM) are needed that go beyond the traditional operational support tools. Note that these IWMSM are more than only tools, but include conceptual issues, theories, combining technical and socio-economic aspects. Moreover, demonstration and awareness raising regarding the opportunities these IWMSM offer are essential to ensure wider application.

IWMSM consist out of three components each with its own characteristics and purposes (Figure 1):

- Physical component. This part of the IWMSM relies on accurate description of the physical processes related to water.
- Allocation component. This component is mainly used to evaluate the impact of human interference in water distribution and allocation issues for water shortage as well as water excess.
- Multi-criteria component. This part of the IWMSMS is used widely for all kind of applications, but only to a very limited extent for water management issues so far. The multi-criteria approach is however of paramount importance in strategic decisions involving multiple-stakeholders.

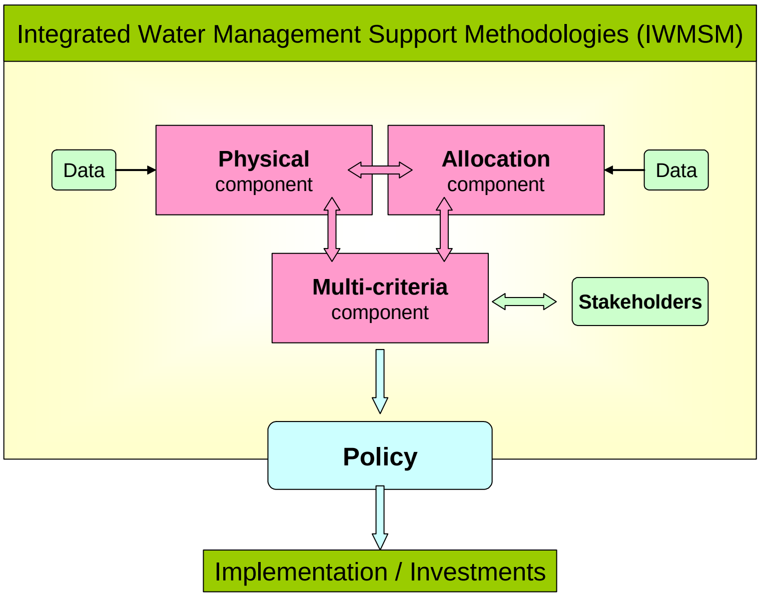


Figure 1. Conceptual framework of the Integrated Water Management Support Methodologies.

In summary IWMSM are a combination of methodologies that will support water managers in making decisions regarding strategic water management including investment decisions. In fact, they are the key to make the following steps: problem → data → information → knowledge → policies → implementation/ investments.

The focus of the project WatManSup (Water Management Support Methodologies) is to demonstrate how tools that form the core components of these IWMSM can be applied to take strategic pro-active decisions. This report provides a description of the state of the art of these tools.

2 Water Management Support Tools

2.1 Introduction

Water related problems are very diverse, but water shortage is considered as the most pressing issue. The increasing water scarcity, the growing demand for food, and the need to link those two in a sustainable way is the challenge for the next decades. Seckler et al. (1999) estimated that by 2025 cereal production will have to increase by 38% to meet world food demands. The World Water Vision, as outcome from the Second World Water Forum in The Hague in 2000, estimated a similar figure of 40% based on various projections and modelling exercises (Cosgrove and Rijsberman, 2000). These figures were more or less confirmed by projections based on an econometric model which showed that the rate of increase of grain production will be about 2% per year for the 2000-2020 period (Koyama, 1998).

To produce this increasing amount of food substantial amounts of water are required. Global estimates of water consumption per sector indicate that irrigated agriculture consumes 85% from all the withdrawals and that this consumptive use will increase by 20% in 2025 (Shiklomanov, 1998). Gleick (2000) presented estimates on the amount of water required to produce daily food diets per region. According to his figures large differences can be found between regions ranging from 1,760 liters per day per person for Sub-Saharan Africa to 5,020 for North America. Differences come from the larger number of calories consumed and the higher fraction of water-intensive meat in the diet of a North American.

This increase in food, and therefore water, requirements coincide with a growing water scarcity at an alarming rate. Recently, a study by the United Nations (UN, 1997) revealed that one-third of the world's total population of 5.7 billion lives under conditions of relative water scarcity and 450 million people are under severe water stress. This relative water scarcity and severe water scarcity are defined using the Relative Water Demand (RWD) expressed as the fraction water demand over water supply. A RWD greater then 0.2 is classified as relative water scarce, while a RWD greater then 0.4 as severe water stress. However, these values as mentioned by the UN are based on national-level totals, ignoring the fact that especially in bigger countries, huge spatial differences can occur. Vörösmarty et al. (2000) showed that including these in-country differences 1.8 billion people live in areas with sever water stress. Using their global water model and some projections for climate change, population growth and economic growth, they concluded that the number of people living in sever water stress will have grown to 2.2 billion by the year 2025.

A study published by the International Water Management Institute (Seckler et al., 1999), based on country analysis, indicated that by the year 2025 8 percent of the population of countries studied (India and China where treated separately, because of their extreme variations within the country) will have major water scarcity problems. Most countries, which contain 80% of the study population, need to increase withdrawals to meet future requirements, and only for 12% of the population no actions are required.

Although the exact numbers on how severe water stress actually is, or will be in the near future, and how much more food we should produce, differ to a certain extent, the main trend is unambiguous: more water for food and water will be scarcer.

References given before are related to the global scale, but it is very clear that at smaller scales, such as basins, extreme variations will occur and many basins with tremendous water problems can be found. This, in combination with the "think globally, act locally" principle, makes the basin the most appropriate scale to focus on.

Data is essential to assess the current conditions of water resources and to explore trends in the past. However, to explore options for the future tools are required that are able to see the impact of future trends and how we can adapt to these in the most sustainable way. Simulation models are the appropriate tools to do these analyses. R.K Linsley, a pioneer in the development of hydrologic simulation at Stanford University wrote already in 1976:
"In summary then it can be said that the answer to 'Why simulate?' is given by the following points:

1. Simulation is generally more adequate because it involves fewer approximations than conventional methods.
2. Simulation gives a more useful answer because it gives a more complete answer.
3. Simulation allows adjustment for change which conventional methods cannot do effectively.
4. Simulation costs no more than the use of reliable conventional methods (excluding empirical formulae which should not be used in any case).
5. Data for simulation is easily obtained on magnetic tape from the Climatic Data Service or the Geological Survey.
6. No more work or time is required to complete a simulation study than for a thorough hydrologic analysis with conventional methods. Often the time and cost requirements are less.
7. In any case, if the time and cost are measured against the quality and completeness of the results, simulation is far ahead of the conventional techniques.
8. Even though the available data are limited, simulation can still be useful because the data are used in a physically rational computational program."

These points are still valid nowadays and can be more or less summarised by the two main objectives of model application: (i) understanding processes and (ii) scenarios analyses. Understanding processes is something that starts right from the beginning during model development. In order to build our models we must have a clear picture on how processes in the real world function and how we can mimic these in our models. The main challenge is not in trying to build in all processes we understand, which is in fact impossible, but lies in our capabilities to simplify things and concentrate on the most relevant processes of the model under construction.

The main reason for the success of models in understanding processes is that models can provide output over an unlimited time-scale, in an unlimited spatial resolution, and for difficult to observe sub-processes (e.g. Droogers and Bastiaanssen, 2002). These three items are the weak point in experiments, but are at the same time exactly the components in the concept of sustainable water resources management.

The most important aspect of applying models, however, is in the use to explore different scenarios. These scenarios can refer to aspects that cannot directly be influenced, such as population growth and climate change (Droogers and Aerts, 2005). These are often referred to as projections. Contrary to this are the so-called management scenarios where water managers and policy makers can make decisions that will have a direct impact. Examples are changes in reservoir operations, water allocation and agricultural/irrigation practices. In other words: models enable to change focus from a re-active towards a pro-active approach. (Figure 2).

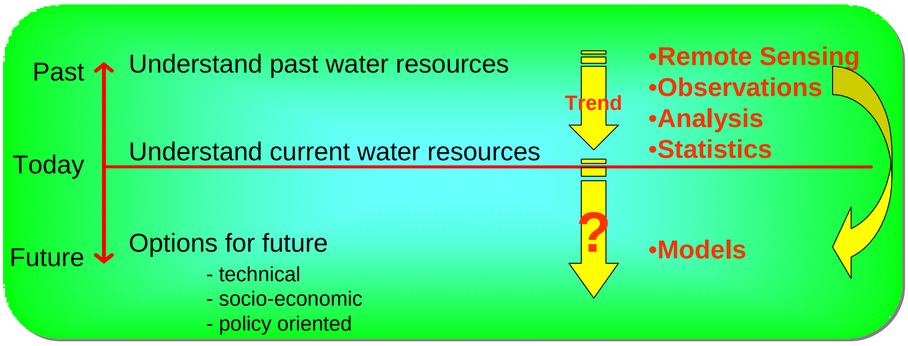


Figure 2. The concept of using simulation models in scenario analysis.

2.2 *Concepts of modelling*

The term modelling is very broad and includes everything where reality is imitated. The Webster dictionary distinguishes 13 different meanings for the word "model": where the following definition is most close to the one this study is focusing on: "a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs". However, we will restrict our definition here to computer models and that a model should have a certain degree of process oriented approach, excluding statistical, regression oriented models. This leads to the following definition: "a model is a computer based mathematical representation of dynamic processes".

The history of hydrological and agro-hydrological models, based on this somewhat restricted definition, is relatively short. One of the first models is the so-called Stanford Watershed Model (SWM) developed by Crawford and Linsley in 1966, but the main principles are still used in nowadays catchment models to convert rainfall in runoff. SWM did not have much physics included as the catchment was just represented by a set of storage reservoirs linked to each other. The value of parameters describing the interaction between these different reservoirs was obtained by trying to optimise the simulated with the observed streamflows. At the other end of the spectrum are the field scale models describing unsaturated flow processes in the soil and root water uptake. One of the first to be developed was the SWATR model by Feddes et al. (1978) based on Richards' equation. Since these models are based on points and use the concept that unsaturated flow is dominated only by vertical transport of water, much more physics could be built in from the beginning.

A huge number of hydrological models exits and applications are growing rapidly. The number of pages on the Internet including "hydrological model" is over 1.2 million (using Google on January 2007). Using the same search engine with "water resources model" provides 86 million pages found (Figure 3). A relevant question for hydrological model studies is therefore related to the selection of the most appropriate model. One of the most important issues to consider is the spatial scale to be incorporated in the study and how much physical detail to be included. Figure 4 illustrates the negative correlation between the physical detail of the model applied and spatial scale of application. The figure indicates also the position of commonly used models in this continuum.

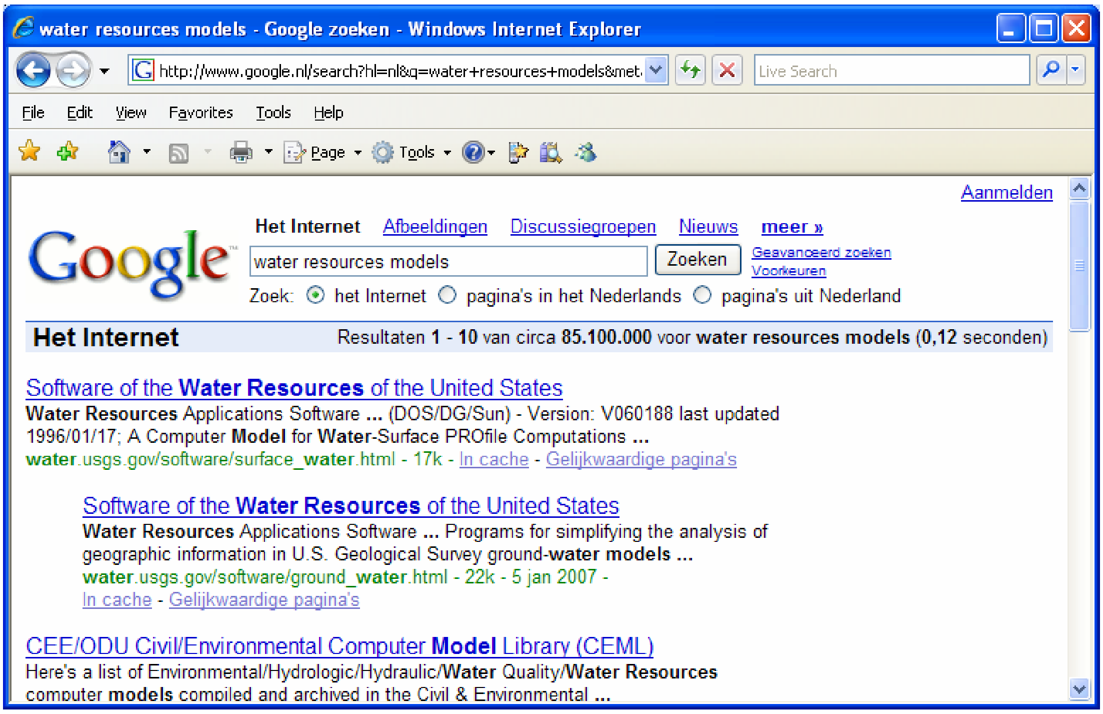


Figure 3. Number of pages returned with "water resources model" (January 2007).

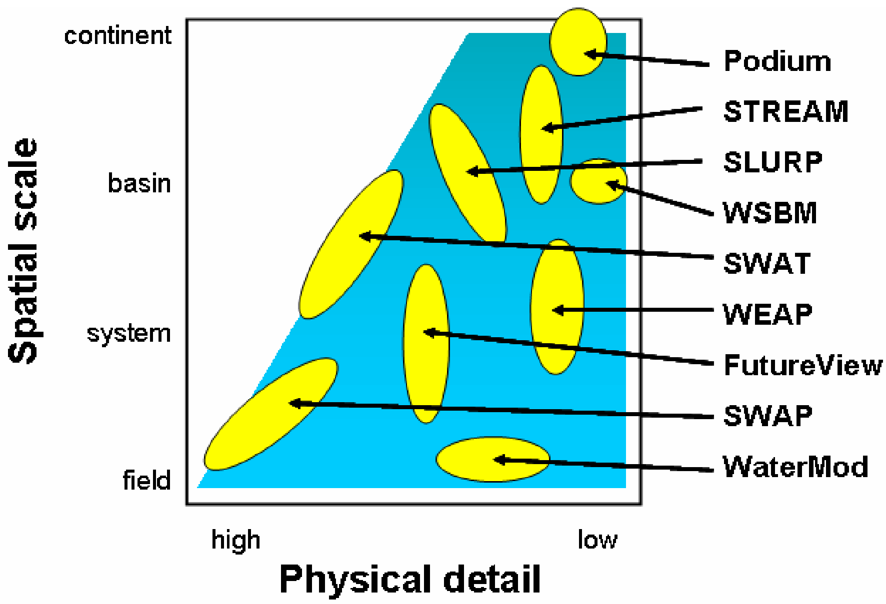


Figure 4. Spatial and physical detail of hydrological models.

2.3 Model classification

The number of hydrological simulation models is unknown, but must exceed ten thousand. Even if we exclude the one-time models developed for a specific study and count only the more generic and more applied models it must exceed thousand. Some existing model overviews include numerous models: IRRISOFT (2000): 105, USBR (2002): 100, CAMASE (2005): 211, and REM (2006): 675, amongst others. Interesting is that there seems to be no standard model or models emerging in catchment modelling, contrary to for example in groundwater modelling where ModFlow is the de-facto standard. Two hypotheses for this lack of standard can be brought forward. The first one is that model development is still in its initial phase, despite the about 25 years of history, and therefore it is easy to start developing one's own model that can compete with similar existing ones in a reasonable amount of time and effort. A stimulating factor related to this is that a serious scientist is considered to have his/her own model or has at least developed one during his or her PhD studies. A second reason for the large number of models is a more fundamental one saying that hydrological processes are so complex and diverse that each case requires its specific model or set of models.

It is therefore interesting to see how models can be classified and see whether such a classification might be helpful in selecting the appropriate model given a certain question or problem to be solved. Probably, the most generally used classification is the spatial scale the model deals with and the amount of physics included (Figure 4). These two characteristics determine other model behaviour as data need, expected accuracy, required expertise, user-friendliness amongst others.

2.4 Existing model overviews

A substantial number of overviews exist listing available models and providing a short summary. Most of this information is provided by the developers of the model themselves and tends therefore to be biased towards the capabilities of the model. The most commonly used model overviews are discussed briefly here, keeping in mind that these overviews are changing rapidly, in size and number, since the Internet provides almost unlimited options to start and update such an overview in a automatic or semi-automatic way. A clear example is the Hydrologic Modelling Inventory project from the United States Bureau of Reclamation, where about 100 mainly river basin models are registered by model developers (USBR, 2002).

An overview of agro-ecosystem models is provided by a consortium named CAMASE (Concerted Action for the development and testing of quantitative Methods for research on Agricultural Systems and the Environment; CAMASE, 2005). The following types of models are distinguished: crop science, soil science, crop protection, forestry, farming systems, and land use studies, environmental science, and agricultural economics. A total of 211 models are included and for each model a nice general overview is provided. Unfortunately the last update of the register was in 1996 and advancements in model development over the last years are not taken into account.

The United States Geological Survey (USGS, 2006) provides an overview of all their own models, about 50, divided in five categories: geochemical, groundwater, surface water, water quality, and general. Some of the models are somewhat outdated, but some commonly used ones are included too. All the models are in the public domain and can be used without restrictions. For most of the models source code is provided as well.

The United States Department of Agriculture also provides models to be used in crop-water related issues. The National Water and Climate Center of the USDA has an irrigation page (NWCC, 2006) with some water management tools related to field scale irrigation.

United States Environmental Protection Agency is very active in supporting model development. The SWAT model, originating from their research programs, might have the potential to become the de-facto standard in basin scale modelling, and has been included in the BASINS package (BASINS, 2006). More linkages to models and other model overviews are provided too (EPA, 2006).

Modelling efforts of USGS, USDA, USACE, and EPA, combined with some other models, are brought together by the USGS Surface water quality and flow Modelling Interest Group (SMIG, 2006a). SMIG has setup the most complete link to model archives nowadays including links to 40 archives (SMIG, 2006b).

The most up-to-date overview of models using crop growth modelling is the Register of Ecological Models (REM, 2006), with 675 models as per 12-Dec-2005. Besides this overview of models the same website provides general concepts and links to other websites about modelling.

2.5 Model reviews

In the previous section an overview of existing model inventories has been given. Although useful as a catalogue it does not provide any independent judgment of model quality. The best model does not exist, but is a function of the application and questions to be answered. Few studies have been undertaken where a limited amount of models have been thoroughly tested and reviewed. The majority of these studies focus on two or three models that are almost similar in nature and in most cases it was concluded that these models perform comparably.

A survey of Australian catchment managers, model users and model developers revealed the following conclusions about the state of catchment modelling in the late 1990's (http://www.catchment.crc.org.au/toolkit/current.htm):

- There are almost as many models as there are modellers, and there is significant duplication of effort in model building.
- The standard of computer code employed in these models, and their supporting documentation is generally poor.
- User interfaces are generally poor and inconsistent in their design and function.
- There are no agreed standards on how to code, document and deliver the models to end-users.
- Virtually no holistic modelling is being undertaken at large spatial scales, partly due to the lack of a suitable paradigm for linking models.
- Access to many catchment models is restricted.

This negative viewpoint is to a certain extent still valid nowadays, although a couple of modelling tools have overcome most of these shortcomings. However, the perspective of many water managers is still quite suspicious about model application and only by examples of projects such as WatManSup can those views change.

Texas Natural Resource Conservation Commission evaluated 19 river basin models, referred to as Water Availability Models, in order to select the most suitable model used for management of water resources, including issuing new water right permits (TNRCC, 1998). A total of 26 evaluative criteria were identified as important functions and characteristics for selecting a model that fits the need for the 23 river basins in Texas. Most important was the ability of the model to support water rights simulation. During the evaluation process, each model was assessed and ranked in order of its ability to meet each criterion. The 19 models were in the first phase narrowed down to five: WRAP, MODSIM, STATEMOD, MIKE BASIN, OASIS. Models not selected included WEAP (no appropriation doctrine) and SWAT (not intuitive and user-friendly). The final conclusion was to use the WRAP model with the HEC-PREPRO GUI. As mentioned, the study focused only on models able to assist in water rights questions.

A similar study was performed to select an appropriate river basin model to be used by the Mekong River Commission (MRC, 2000). In fact, it was already decided that considering the requirements of the MRC not one single model could fulfil the needs, but three different types of model were necessary: hydrological (rainfall-runoff), basin water resources, hydrodynamic. Three main criteria were used to select the most appropriate model: technical capability, user friendliness, and sustainability. Considering the hydrological models 11 were evaluated and the SWAT model was considered as the most suitable one. Since water quality and sediment processes were required models like SLURP were not selected. Interesting is that grid based models were not recommended as they were considered as relatively new. The selected basin simulation model was IQQM. ISIS was reviewed as the best model to be used to simulate the hydrodynamic processes.

An actual model comparison, where models are really tested using existing data, is initiated by the Hydrology Laboratory (HL) of the National Weather Service (NWS), USA. The comparison is limited to hydrological models and their ability to reproduce hydrographs, based on detailed radar rainfall data. This model comparison, referred to as DMIP (Distributed Model Intercomparison Project, 2002) has the intention to invite the academic community and other researchers to help guide the NWS's distributed modelling research by participating in a comparison of distributed models applied to test data sets. Results have been published recently, but no distinct conclusions were drawn (Reed et al., 2004).

2.6 Model selection in WatManSup

Based on the previous discussions model selection was done for the WatManSup project. The most important aspect considered in the model selection was that for each type of application one tool would be selected: water allocation based, physical based, and multi criteria based. Other aspects considered were: familiarity with the tool, acceptance of the tool in the water resources community, contacts with developers, and options to expand to other areas.

Based on those criteria the following three tools have been selected to form the complete Water Management Support Methodologies as displayed in Figure 1:

- **WEAP**. An integrated approach to water development which places water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis. WEAP places demand-side issues such as water use patterns, equipment efficiencies, re-use strategies, costs, and water allocation schemes on an equal footing with supply-side topics such as stream flow, groundwater resources, reservoirs, and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g. evapotranspirative demands, runoff, baseflow) and engineered components (e.g. reservoirs, groundwater pumping) of water systems, allowing the planner access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use. WEAP can be summarised as an effective tool for examining alternative water development and management options.

- **SWAT** (Soil and Water Assessment Tool) is developed to predict the impact of land management practices on water, sediment and agricultural yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, etc.) on water quality or other variables of interest can be quantified using readily available inputs.

- **DEFINITE** (decisions on a finite set of alternatives) is a decision support software package that has been developed to improve the quality of environmental decision making. DEFINITE is, in fact, a whole tool kit of methods that can be used on a wide variety of problems. DEFINITE can weigh up the alternative solutions and assess the most reasonable alternative. The program contains a number of methods for supporting problem definition as well as graphical methods to support representation. To be able to deal with all types of information DEFINITE includes five different multicriteria methods, as well as Cost-Benefit and Cost-Effectiveness analysis. Related procedures such as weight assessment, standardisation, discounting and a large variety of methods for sensitivity analysis are also available.

3 Water Allocation Tools

3.1 Background

WEAP is short for Water Evaluation and Planning System. It is a microcomputer tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for policy analysis (SEI, 2005).

Many regions are facing formidable freshwater management challenges. Allocation of limited water resources, environmental quality, and policies for sustainable water use are issues of increasing concern. Conventional supply-oriented simulation models are not always adequate. Over the last decade, an integrated approach to water development has emerged that places water supply projects in the context of demand-side issues, water quality and ecosystem preservation. WEAP aims to incorporate these values into a practical tool for water resources planning.

WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP is a laboratory for examining alternative water development and management strategies (SEI, 2005).

3.2 WEAP approach

WEAP is operating on the basic principles of a water balance. The analyst represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customised to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

Operating on these basic principles WEAP is applicable to many scales; municipal and agricultural systems, single catchments or complex transboundary river systems. WEAP does not only incorporate water allocation but also water quality and ecosystem preservation modules. This makes the model suitable for simulating many of the fresh water problems that exist in the world nowadays (SEI, 2005).

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts, which can be viewed as a calibration step in the development of an application, provide a snapshot of the actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. Scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (SEI, 2005).

WEAP calculates a water and pollution mass balance for every node and link in the system. Water is dispatched to meet instream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints. Point loads of pollution into receiving bodies of water are computed, and instream concentrations of polluting elements are calculated.

WEAP operates on a monthly time step, from the first month of the Current Accounts year through the last month of the last scenario year. Each month is independent of the previous month, except for reservoir and aquifer storage. Thus, all of the water entering the system in a month (e.g. head flow, groundwater recharge, or runoff into reaches) is either stored in an aquifer or reservoir, or leaves the system by the end of the month (e.g. outflow from end of river, demand site consumption, reservoir or river reach evaporation, transmission and return flow link losses). Because the time scale is relatively long (monthly), all flows are assumed to occur instantaneously. Thus, a demand site can withdraw water from the river, consume some, return the rest to a wastewater treatment plant that treats it and returns it to the river. This return flow is available for use in the same month to downstream demands (SEI, 2005).

Each month the calculations (algorithms) follow this order (SEI, 2005):

1. Annual demand and monthly supply requirements for each demand site and flow requirement.
2. Runoff and infiltration from catchments, assuming no irrigation inflow (yet).
3. Inflows and outflows of water for every node and link in the system. This includes calculating withdrawals from supply sources to meet demand, and dispatching reservoirs. This step is solved by a linear program (LP), which attempts to optimise coverage of demand site and instream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints.
4. Pollution generation by demand sites, flows and treatment of pollutants, and loadings on receiving bodies, concentrations in rivers.
5. Hydropower generation.
6. Capital and operating costs and revenues.

3.3 Program structure

WEAP consists of five main views: (i) schematic, (ii) data, (iii) results, (iv) overviews and (v) notes. These views are listed as graphical icons on the "View Bar", located on the left of the screen. Click an icon in the View Bar to select one of the views. For the Results and Overviews view, WEAP will calculate scenarios before the view is displayed, if any changes have been made to the system or the scenarios.

3.3.1 Schematic view

In the Schematic view the basic structure of the model is created (Figure 5). Objects from the item menu are dragged and dropped in the system. First the river stream is created and the demand sites and supply sites are positioned in the system. Vector or raster files can be added as a background layer. The river, demand sites and supply sites are linked to each other by transmission links, runoff/infiltration links or return flow links.

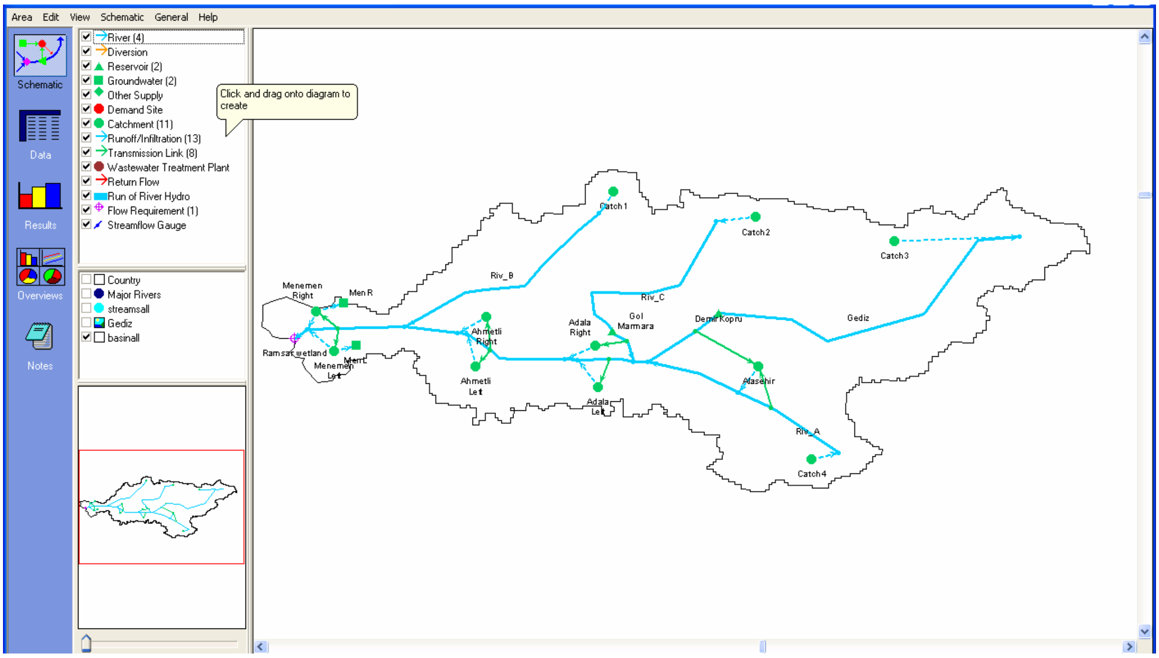


Figure 5. Example of the WEAP Schematic view.

3.3.2 Data view

Adding data to the model is done in the Data view. The Data view is structured as a data tree with branches. The main branches are named Key assumptions, Demand sites, Hydrology, Supply and Resources and Water quality.

The objects created in the Schematic view are shown in the branches. Further subdivision of a demand site can be created by the analyst. The example in Figure 6 shows further sub-division of the demand sites into land use classes.

The Data view allows creating variables and relationships, entering assumptions and projections using mathematical expressions, and dynamically linking to input files (SEI, 2005).

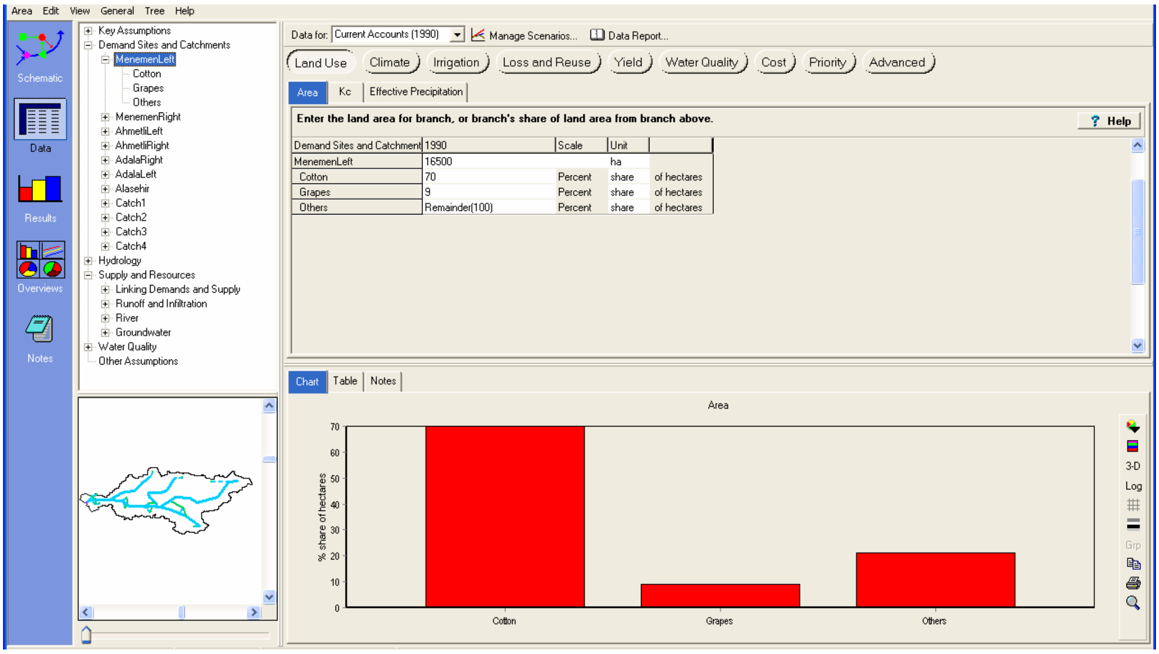


Figure 6. Example of the WEAP Data view.

3.3.3 Result view

Clicking the Results view will force WEAP to run its monthly simulation and report projections of all aspects of the system, including demand site requirements and coverage, streamflow, instream flow requirement satisfaction, reservoir and groundwater storage, hydropower generation, evaporation, transmission losses, wastewater treatment, pollution loads, and costs.

The Results view is a general purpose reporting tool for reviewing the results of scenario calculations in either chart or table form, or displayed schematically (Figure 7). Monthly or yearly results can be displayed for any time period within the study horizon. The reports are available either as graphs, tables or maps and can be saved as text, graphic or spreadsheet files. Each report can be customised by changing: the list of nodes displayed (e.g. demand sites), scenarios, time period, graph type, unit, gridlines, color, or background image. Customised reports can be saved as a "favorite" for later retrieval. Up to 25 "favorites" can be displayed side by side by grouping them into an "overview". Using favorites and overviews, can easily assemble a customised set of reports that highlight the key results of the analysis (Figure 8).

In addition to its role as WEAP's main reporting tool, the Results view is also important as the main place where intermediate results can be analysed to ensure that data, assumptions and models are valid and consistent.

The reports are grouped into five main categories:

- Demand
- Supply and Resources
- Catchments
- Water Quality
- Financial

Details about output generated by WEAP can be found in Table 1. This Table indicates also the processes that are included in WEAP and to which level of detail output can be obtained.

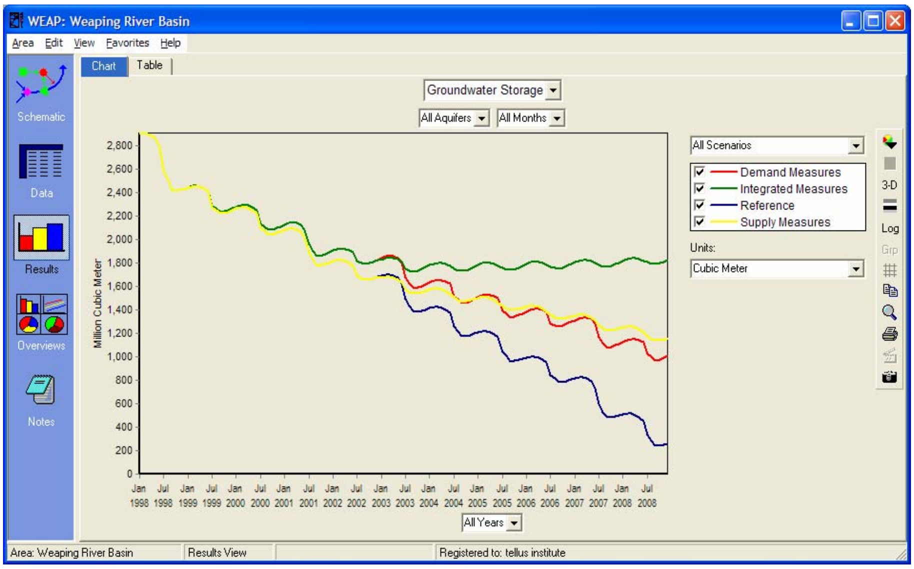


Figure 7. Example of the WEAP Results view.

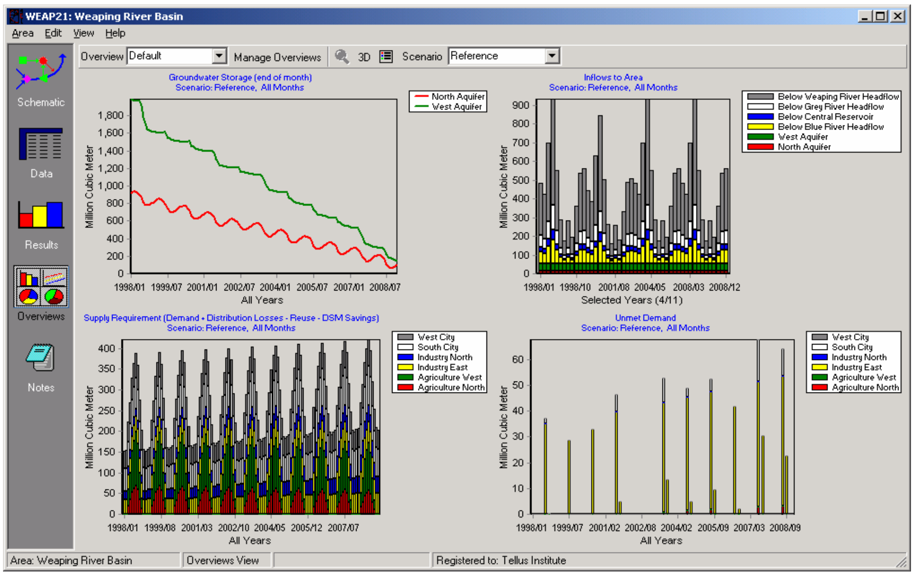


Figure 8. Example of the WEAP Overviews view.

Table 1. WEAP output organised in five groups.

Demand Results
- Water Demand
- Supply Requirement
- Supply Delivered
- Unmet Demand
- Coverage
- Demand Site Inflow and Outflow
- Instream Flow Requirement
- Instream Flow Requirement Delivered
- Unmet Instream Flow Requirement
- Instream Flow Requirement Coverage

Supply and Resources Results
- Inflows to Area
- Outflows to Area
- River
  - Streamflow:
  - Streamflow Relative to Gauge (absolute)
  - Streamflow Relative to Gauge (%)
  - Stage
  - Velocity
  - Reach Length
- Groundwater
  - Storage
  - Inflows and Outflows
  - Overflow
  - Height Above River
  - Outflow to River
- Reservoir
  - Storage Volume
  - Storage Elevation
  - Inflows and Outflows
  - Hydropower:
- Transmission Link
  - Flow
  - Inflows and Outflows
- Other Supply
  - Inflows and Outflows
- Return Link
  - Flow
  - Inflows and Outflows

Catchment Results
- FAO method results
  - Runoff from Precipitation
  - Observed Precipitation
  - Infiltration/Runoff Flow
  - ETPotential
  - ETActual (including irrigation)
  - ET Shortfall
  - Total Yield
  - Total Market Value
- Soil Moisture Method Results
  - Land Class Inflows and Outflows
  - Observed Precipitation
  - Snow Accumulation
  - Infiltration/Runoff Flow
  - Effective Monthly Precipitation for ET (including snowmelt)
  - Area
  - Temperature
  - Net Solar Radiation
  - Reference Monthly PET
  - ETPotential
  - ETActual (including irrigation)
  - Relative Soil Moisture 1 (%)
  - Relative Soil Moisture 2 (%)
  - Flow to River No Irrigation
  - Flow to River Full Irrigation
  - Flow to GW No Irrigation
  - Flow to GW Full Irrigation
  - Irrigation Return Flow Fraction to Surface Water
  - Irrigation Return Flow Fraction to Groundwater

Water Quality Results • Pollution Generation • Pollution Loads • Pollution Inflow to Treatment Plants • Wastewater Treatment Plant Inflows and Outflows • Surface Water Quality
Financial Results • Net Cost Report • Net Present Value Report • Average Cost of Water Report

4 Physical Based Tools

4.1 Introduction

Physical based water management support methodologies are in their most basic forms referred to as rainfall-runoff model. For the WatManSup project the physical based tool should include some specific features to be used for water managers in their pro-active approach:

- All components of the water balance included
- Applicable in data scarce environments
- Spatially distributed model
- Based on physical processes
- Possibility of modelling of land management practices and land use changes
- Outputs must include data on the water balance
- GIS based
- Continuous time and long term simulations

A model that does comply with these requirements is the SWAT model. SWAT is the acronym for Soil and Water Assessment Tool, a river basin model developed originally by the USDA Agricultural Research Service (ARS) and Texas A&M University that is currently one of the worlds leading spatially distributed hydrological models.

A distributed rainfall-runoff model – such as SWAT – divides a catchment into smaller discrete calculation units for which the spatial variation of the major physical properties are limited, and hydrological processes can be treated as being homogeneous. The total catchment behaviour is a net result of manifold small subbasins. The soil map and land cover map within subbasin boundaries are used to generate unique combinations, and each combination will be considered as a homogeneous physical property, i.e. Hydrological Response Unit (HRU). Hence, SWAT will distribute a region into units that have similar characteristics in soil, land cover and that are located in the same subbasin. The water balance for HRU's is computed on a daily time step.

SWAT is becoming one of the more popular physical based models. Singh et al. (2005) evaluated the performance of SWAT against another popular watershed scale simulation model HSPF. Both models were calibrated for a nine-year period and verified using an independent 15-year period by comparing simulated and observed daily, monthly, and annual streamflow. The characteristics of simulated flows from both models were mostly similar to each other and to observed flows, particularly for the calibration results. The final conclusion was SWAT predicts flows slightly better than HSPF for the verification period, with the primary advantage being better simulation of low flows.

SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The SWAT model has been extensively used, is in the public domain and can be considered as becoming the de-facto standard in spatial decision support systems.

SWAT represents all the components of the hydrological cycle including: rainfall, snow, snow-cover and snow-melt, interception storage, surface runoff, up to 10 soil storages, infiltration, evaporation, transpiration, lateral flow, percolation, pond and reservoir water balances, shallow and deep aquifers, channel routing. It also includes irrigation from rivers, shallow and deep groundwater stores, ponds/ reservoirs and rivers, transmission losses and irrigation onto the soil surface. It includes sediment production based on a modified version of the Universal Loss Equation and routing of sediments in river channels. SWAT tracks the movement and transformation of several forms of nitrogen and phosphorus in the watershed. It also tracks the movement and decay of pesticides. All include channel routing components and carrying of pollutants by sediments.

One of the major advances of the SWAT model is the enormous amount of detail and processes that can be dealt with. At the same time, relatively swift analysis of major processes can be assessed. This makes the model suitable to commence stakeholder interest and awareness by making quick and general runs, followed by detailed and more time-consuming water resources assessment and planning incorporating additional data.

Detailed model description of all processes incorporated is given in a 500 pages theoretical document which can elaborates in detail on the following key components of SWAT:

- Climate
- Hydrology (including surface water, soil water and groundwater)
- Nutrients / pesticides
- Erosion
- Land cover / plant
- Management practices
- Main channel processes
- Water bodies

It goes beyond the scope of this report to get into detail on each of these components, but reference is made to the theoretical documentation (Neitsch et al., 2001). Some recent applications of the SWAT model can be found elsewhere (e.g. Immerzeel, 2006; Immerzeel and Droogers, 2006).

In a condensed form a few important characteristics related to the WatManSup project are discussed below:

- Model principles
- Input requirements
- Crop growth
- Irrigation and drainage
- Interaction surface water – groundwater
- Generated output

4.2 Modelling principles

For modelling purposes, a watershed may be partitioned into a number of subwatersheds or subbasins. The use of subbasins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into subbasins, the user is able to reference different areas of the watershed to one another spatially. Input information for each subbasin is grouped or organised into the following categories: climate; hydrologic response units or HRUs; ponds/wetlands; groundwater; and the main channel, or reach, draining the subbasin. Hydrologic response units are lumped land areas within the subbasin that are comprised of a unique land cover and soil.

No matter what type of problem studied with SWAT, the water balance is the driving force behind everything that happens in the watershed. To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed. Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle, depicted in Figure 9. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each subbasin.

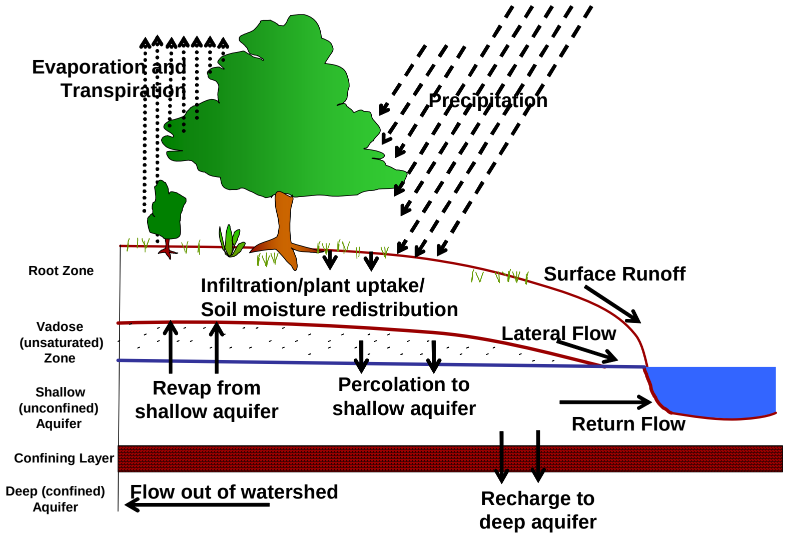


Figure 9. Main land phase processes as implemented within SWAT.

The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

Once SWAT determines the loadings of water, sediment, nutrients, and pesticides to the main channel, the loadings are routed through the stream network of the watershed using a command structure. In addition to keeping track of mass flow in the channel, SWAT models the transformation of chemicals in the stream and streambed. Figure 10 illustrates the different in-stream processes modelled by SWAT.

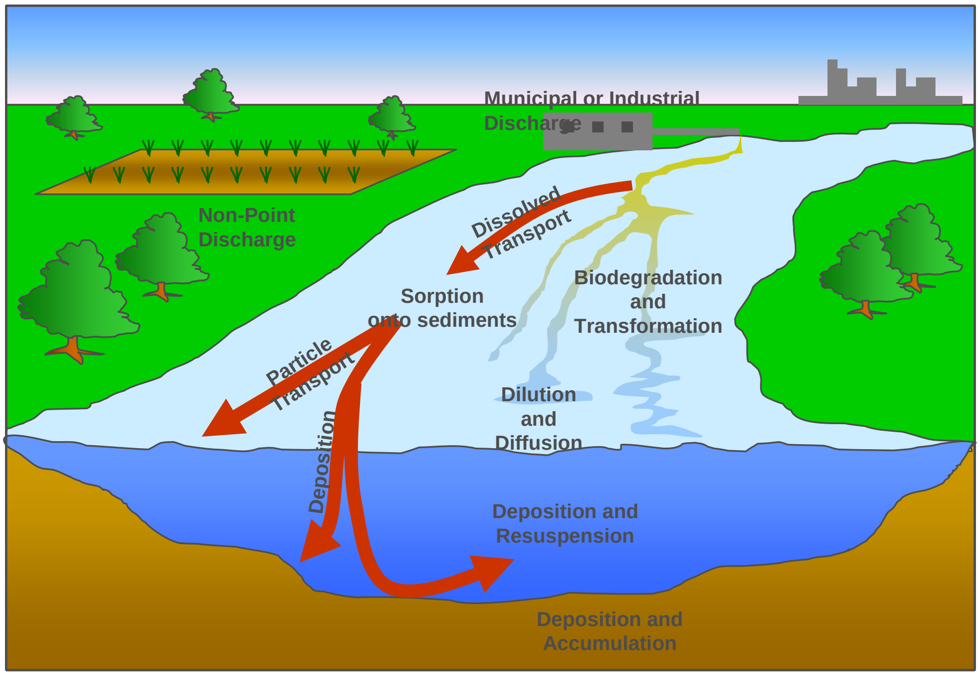


Figure 10: The routing phase of SWAT.

AVSWAT-2000 (Di Luzio et al., 2002) is an ArcView extension and a graphical user interface for the SWAT model. This interface allows a user to build a SWAT model based on readily available GIS data. Important functional components and the analytical capability of ArcView GIS are implemented in several sets of customised and user-friendly tools designed to:

- generate specific parameters from user-specified GIS coverages
- create SWAT input data files
- establish agricultural management scenarios
- control and calibrate SWAT simulations
- extract and organise SWAT model output data for charting and display

The most relevant components of the SWAT system are: a complete and advanced watershed delineator, a tool for the definition of the hydrologic response units, and the latest version of the SWAT model with a helpful interface. AVSWAT software is developed as an extension of ArcView GIS for the PC environment. Within this system (Figure 11) ArcView provides both the GIS computation engine and a common Windows-based user interface. AVSWAT is organised in a sequence of several linked tools grouped in the following eight modules:

- Watershed Delineation;
- HRU Definition;
- Definition of the Weather Stations;
- AVSWAT Databases;
- Input Parameterisation, Editing and Scenario Management;
- Model Execution;
- Read and Map-Chart Results;
- Calibration tool

Once AVSWAT is loaded, the modules get embedded into ArcView, and the tools are accessed through pull-down menus and other controls, which are introduced in various ArcView graphical user interfaces (or GUIs) and custom dialogs. The basic map inputs required for the AVSWAT include digital elevation, soil maps, land use/cover, hydrography (optional), and climate. In addition, the interface requires the designation of land use, soil, weather, groundwater, water use, management, soil chemistry, ponds, and stream water.

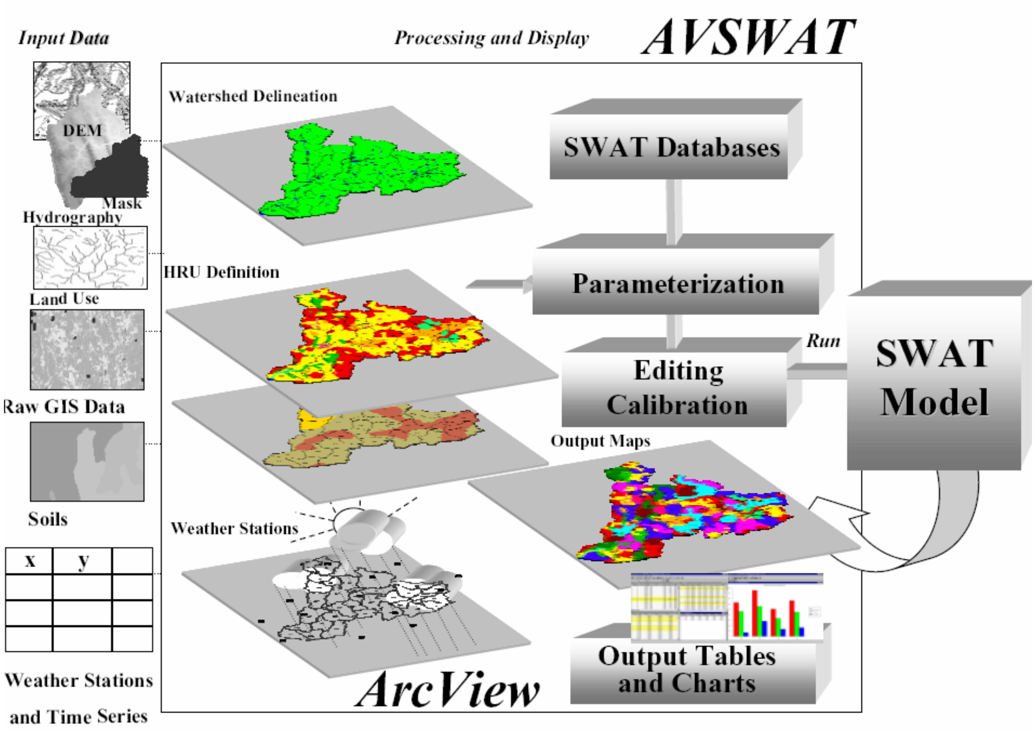


Figure 11: An overview of AVSWAT.

For detailed information on SWAT input files and different parameters reference is made to Neitsch et al. (2002). Reference is made to the AVSWAT user manual (Di Luzio et al., 2002) for more information on how to operate the GIS toolbox and model.

4.3 Input requirements

The main driving forces of the model are the following input requirements:

- Digital Elevation Model
- Canal and stream flow network (generated automatically from the DEM or added manually, or a combination)
- Soils information
- Land cover and land use (including cropping patterns)
- Climate data
- Operational rules for dams, weirs, groundwater extractions.

The accuracy and detail required to run the model depends completely on the accuracy of the desired output. It might be clear that higher quality input will generate more reliable results. However, it has been demonstrated that even with lower quality data, a first rough assessment of the state of the water resources can be done and the results generated can be used for inducing discussions and interest.

4.4 Crop growth

For each day of simulation, potential plant growth, i.e. plant growth under ideal growing conditions, is calculated. Ideal growing conditions consist of adequate water and nutrient supply, and a favourable climate. First, the Absorbed Photosynthetically Active Radiation (APAR) is computed from intercepted solar radiation, followed by a Light Use Efficiency (LUE) that in SWAT is essentially a function of carbon dioxide concentrations and vapour pressure deficits. The crop yield is computed as the harvestable fraction of the accumulated biomass production across the growing season (Figure 12).

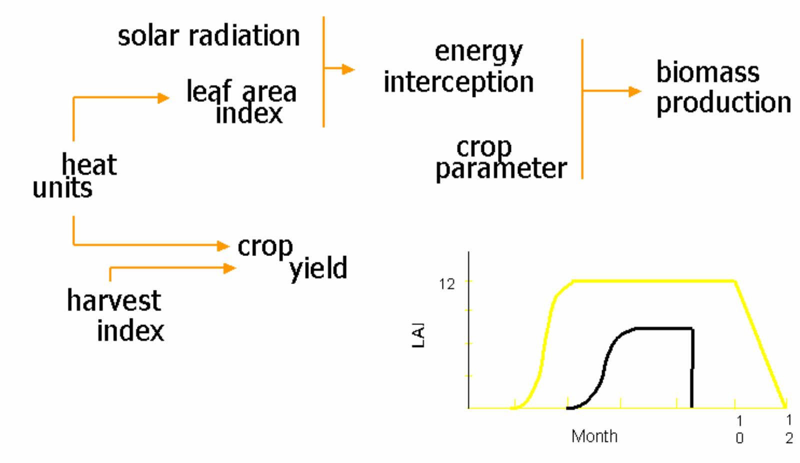


Figure 12. Parameterisation of crop production in SWAT.

4.5 Irrigation and Drainage

Irrigation in SWAT can be scheduled by the user or automatically determined by the model depending on a set of criteria. In addition to specifying the timing and application amount, the source of irrigation water must be specified, which can be: canal water, reservoir, shallow aquifer, deep aquifer, or a source outside the basin.

SWAT is able to deal with tile drainage systems. To simulate this, the following information must be specified: the depth from the soil surface to the drains, the amount of time required to drain the soil to field capacity, and the amount of lag between the time water enters the tile till it exits the tile and enters the main channel. Tile drainage occurs when the soil water content exceeds field capacity. In addition to this tile drainage natural drainage is taken into account such as percolation, surface runoff, subsurface runoff, and even bypass flow through cracks.

4.6 Interaction surface water – groundwater

SWAT can deal with standard groundwater processes (Figure 13). Water enters groundwater storage primarily by infiltration/percolation, although recharge by seepage from surface water bodies is also included. Water leaves groundwater storage primarily by discharge into rivers or lakes, but it is also possible for water to move upward from the water table into the capillary fringe, i.e. capillary rise. As mentioned before, water can also be extracted by mankind for irrigation purposes. SWAT distinguishes recharge and discharge zones.

Recharge to unconfined aquifers occurs via percolation of excessively wet root zones. Recharge to confined aquifers by percolation from the surface occurs only at the upstream end of the confined aquifer, where the geologic formation containing the aquifer is exposed at the earth's surface, flow is not confined, and a water table is present. Irrigation and link canals can be connected to the groundwater system; this can be an effluent as well as an influent stream.

After water is infiltrated into the soil, it can basically leave again the ground as lateral flow from the upper soil layer – which mimics a 2D flow domain in the unsaturated zone – or from return flow that leaves the shallow aquifer and drains into a nearby river. The remaining part of the soil moisture can feed into the deep aquifer, from which it can be pumped back. The total return flow thus consists of surface runoff, lateral outflow from root zone and aquifer drainage to the river.

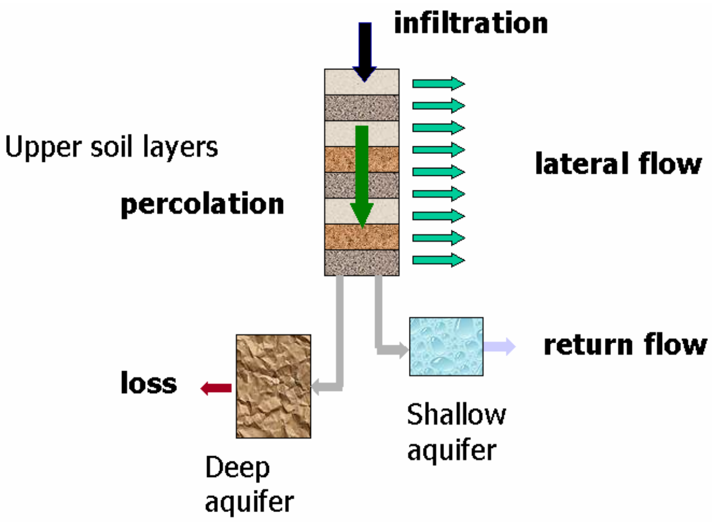


Figure 13. Schematic diagram of the sub-surface water fluxes.

4.7 Outputs

Outputs from the SWAT model exceed 500 variables. It is important to make a distinction between the different output groups, which are related to the main processes in SWAT:

- land based processes:
    - evapotranspiration
    - runoff
    - groundwater flows

- channel based processes:
    - streamflow
    - sediment transport
    - chemicals
- agronomic processes:
    - yields
    - nutrient balance
    - salinisation

Outputs are provided spatially as well as temporal distributed. In two separate WatManSup reports detailed input and output analysis will be given for the case studies in Kenya and Turkey (WatManSup Research Report No.3 and 6).

5 Multi Criteria Tools[1]

5.1 *Introduction*

Everybody makes decisions, many times a day. Most decisions come naturally, a well trained reaction to familiar stimuli to which people apply habitual responses. Some decisions are a little harder, because they are not a routine business and gave more important consequences. Buying a new car, changing job or leaving for an expensive holiday are decisions which are worth some attention. For these decisions, it seems obvious that we should gather information and ask people for advice before "making-up" our minds. This requires time, effort and perhaps money. The resources allocated for the analysis of the decision depend on the magnitude of its consequences: choosing where to go on holiday is likely to be far less demanding than deciding in which country to settle for the next ten years.

Few decisions have a single objective. The very idea of making decisions suggests the need for considering multiple aspects and achieving a successful blend of performances. Management of water resources is no exception to this general rule. Multiple stakeholders participate in management of water resources. This leads to multiple objectives to be considered by any decision maker involved in water management. Examples are:

- Selection of a management strategy for a freshwater lake. Objectives are water quality, water quantity, biodiversity, recreational quality, residential quality, cost etc.
- Selection of a flood management strategy. Objectives are risk of flooding, biodiversity, visual quality, land use and cost.
- Selecting a strategy for river basin management. Objectives are water quality, flood risks and navigation, but also visual quality of the landscape and biodiversity.

5.2 *Software for multi-criteria analysis*

Multi-criteria methods combine factual information with policy priorities. Therefore, they not only support decision-making with multiple objectives but also discussions and negotiations between stakeholders involved in the decision process. Belton and Stewart (2002, p.281) state that for the effective conduct of MCA good supporting software is essential. In this way the facilitator, analyst and decision maker are free from the technical implementation details, and are able to focus on the fundamental value judgments and choices. Although it is possible to set up macros in a spreadsheet to achieve this, it is more convenient to make use of specially designed software. This software should be visual and interactive to facilitate communication about the problem and the evaluation of the results. Interactive software permits information on evaluations, impact scores, priorities and other parameters to be easily entered and changed. Effective visual tools can be used to display the results back to the decision makers, for example by using a graphical presentation of a value function or of an aggregated evaluation result. These visual tools can help to create a better understanding of the issues.

[1] Authored by: Marjan van Herwijnen, Ron Janssen and Ralph Lasage (IVM)

MCA software tools can be subdivided into four groups:

1. problem structuring for discrete choice problems,
2. discrete choice problems,
3. discrete group choice problems, and
4. discrete spatial choice problems.

Most decision support systems assume that a problem is already structured (cause-effect relationships are known, evaluation criteria are specified, alternatives under evaluation are well described etc.). But in practice this assumption is the exception rather than the norm. Therefore, a number of software tools are available to support the structuring of discrete choice problems (group 1). If a discrete choice problem is structured, many software tools are available to support the evaluation of the problem. Most of these tools were originally designed for individual support, or group support in which the group shares one single set of information (group 2). Lately, a number of developments have taken place in the field of real group systems. A group system allows more than one user to independently input their own evaluations and provides facilities for synthesising and displaying this information. Group systems can therefore be used to support discussions in stakeholder sessions (group 3). Another development taking place in the field of multi-criteria decision support is the integration of spatial data. Systems that allow space-dependent input data, incorporate spatial multi-criteria evaluation tools and can display the information and results spatially, are called spatial decision support systems (see also Herwijnen, 1999 and Uran, 2002). Most of these systems are tailor-made for one specific problem. But tools to support general discrete spatial choice problems can sometimes be found in specific procedures incorporated in a GIS (group 4). Listings of MCA software can be found in Belton and Stewart (2002, p.345-350) and at www.lionhrtpub.com/orms/surveys/das/das.html.

For practical reasons this section focuses on software for discrete choice problems. Most software tools to support discrete choice problems from this list are designed around one multi-criteria technique. Because the objective of this report is to illustrate a range of methods, the software package DEFINITE is used to demonstrate the use of decision support software.

5.3 *From problem definition to report:*

The four steps of an evaluation:

Step 1. Problem definition,
Step 2. Multi-criteria analysis,
Step 3. Sensitivity analysis,
Step 4. Reporting.

Figure 14 shows part of the main menu of DEFINITE including the first three steps.

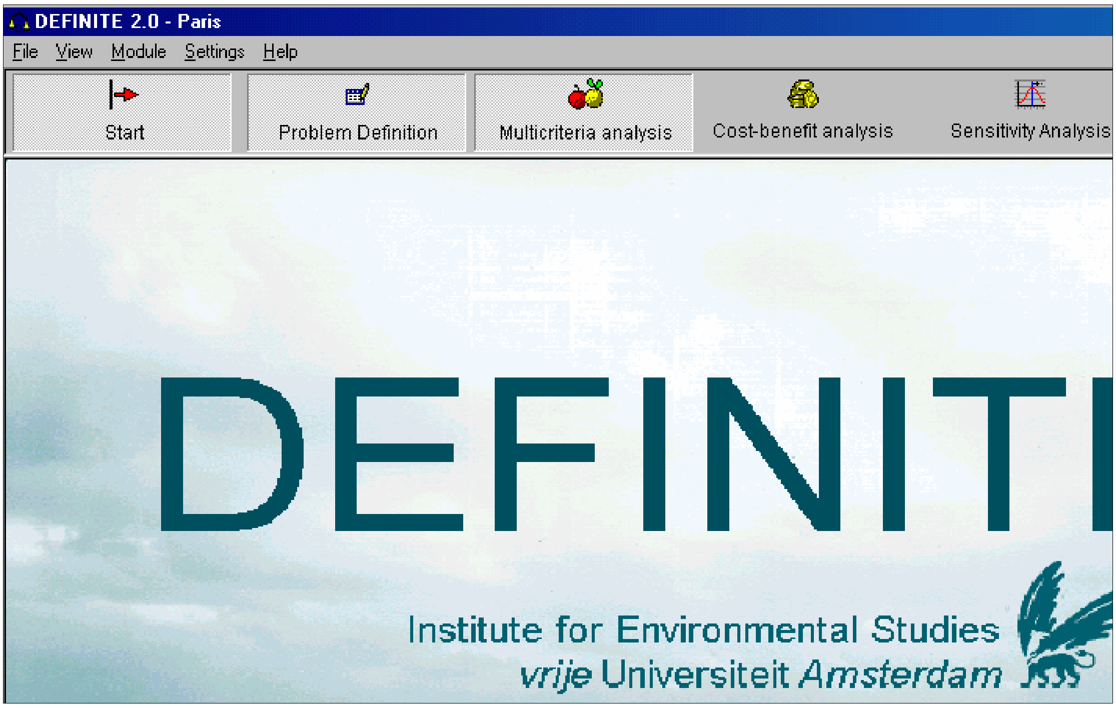


Figure 14. Main menu: Steps of an evaluation procedure.

5.3.1 Step 1. Problem definition

Step 1 involves:

1. Definition of alternatives: identify the policy alternatives which are to be compared with each other,
2. Selection and definition of criteria: identify the effects or indicators relevant for the decision, and
3. Assessment of scores for each alternative: assign values to each effect or indicator for all alternatives.

Definition of alternatives

Generating a complete set of relevant alternatives is a complex task. Political reasons, bad practice or the pressures of time may lead to an incomplete set. This can cause substantial delay because external pressure may force the decision maker to include additional alternatives at a later stage of the process.

Selection and definition of criteria

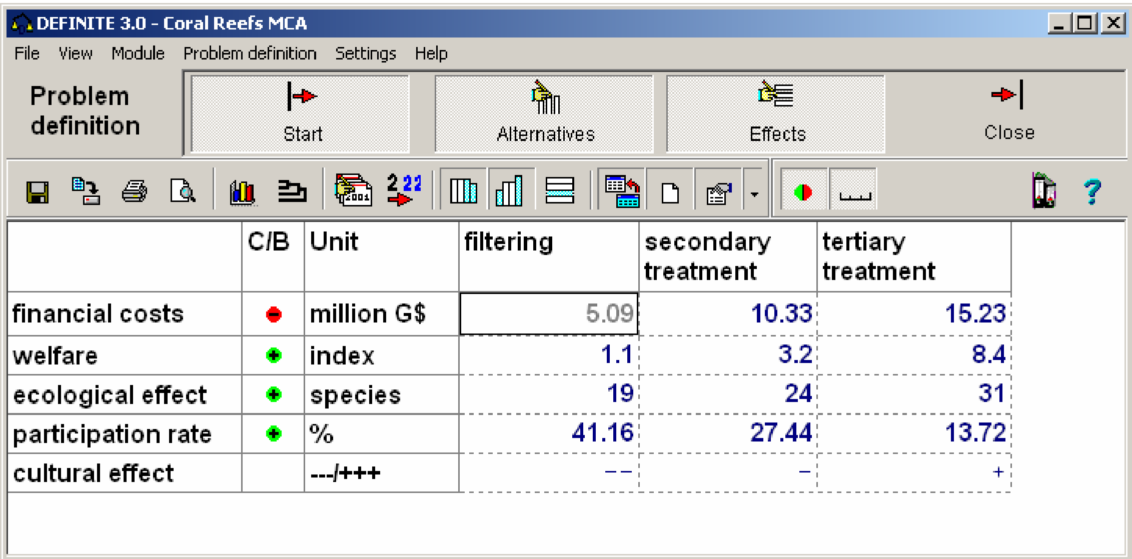
The choice of decision criteria is a very important step in the MCA process. The criteria are specifications of the impacts that will be taken into account in the decision. The criteria must be unambiguous, and it must be possible to measure their performance with reasonable accuracy. Typical examples are:

1. Financial costs. These costs cover investment costs and maintenance costs;
2. Welfare. An index measuring the welfare of the people;
3. Ecological effects. The ecological quality of the sea and its marine life, measured in number of fish species;

4. Participation rate. Willingness of people to obey the new rules, measured as a percentage;
5. Cultural effects. Possibility to preserve cultural practices.

Assessment of scores for each alternative

Scores can be assessed in many ways. Examples are simulation models, laboratory tests, direct measurement, and expert judgment. Impact scores can be measured on a quantitative scale such as ratio, interval or monetary scale, or on a qualitative scale such as an ordinal, +++/--- , or binary scale. A +++/--- scale is useful to score expert judgment. An example of this is shown in Figure 15 in the third column. The second column indicates whether a criterion is a benefit criterion (green plus; the higher the better) or a cost criterion (red minus; the lower the better).



	C/B	Unit	filtering	secondary treatment	tertiary treatment
financial costs	−	million G$	5.09	10.33	15.23
welfare	+	index	1.1	3.2	8.4
ecological effect	+	species	19	24	31
participation rate	+	%	41.16	27.44	13.72
cultural effect		---/+++	--	-	+

Figure 15. Example of a problem definition in DEFINITE.

5.3.2 Step 2. Multi-criteria analysis

Multi-criteria analysis is the second step in this evaluation procedure. The purpose of Step 2 is to derive a ranking of the alternatives. To do this the scores must be standardised to make them comparable, and weighted to determine the relative importance. The three elements of multi-criteria analysis are:

1. Standardisation,
2. Weighting, and
3. Ranking.

Standardisation

If the performances of the criteria are measured on different measurement scales (e.g. costs in million $ and ecological effects in number of species), they must be standardised to a common dimension or dimensionless unit before the criteria can be combined. There are several ways to standardise the criteria. The simplest procedure involves scaling the performance according to the relative distance between zero and the maximum performance, called maximum standardisation. This means that for each criterion the alternative with the best effect receives a value of one and all other alternatives receive a value between one and zero according to the following formula:

Benefit effect: $$\frac{score}{highest\ score}$$

Cost effect: $$1-\frac{score}{highest\ score}$$

Alternatively, the performance can be scaled according to the relative position on the interval between the lowest and highest performance. This can be done using the following formula:

Benefit effect: $$\frac{score-lowest\ score}{highest\ score-lowest\ score}$$

Cost effect: $$1-\frac{score-lowest\ score}{highest\ score-lowest\ score}$$

It is also possible to specify for every effect an ideal or goal value and a worst value, and then scale the scores between these two values. This is called goal standardisation. A meaningful worst value can, for example, be the score in a reference year in the past. Goal values can sometimes be deducted from policy documents or environmental standards. In this case study all criteria are standardised using maximum standardisation. The linear value function linked to this standardisation is shown in Figure 16.

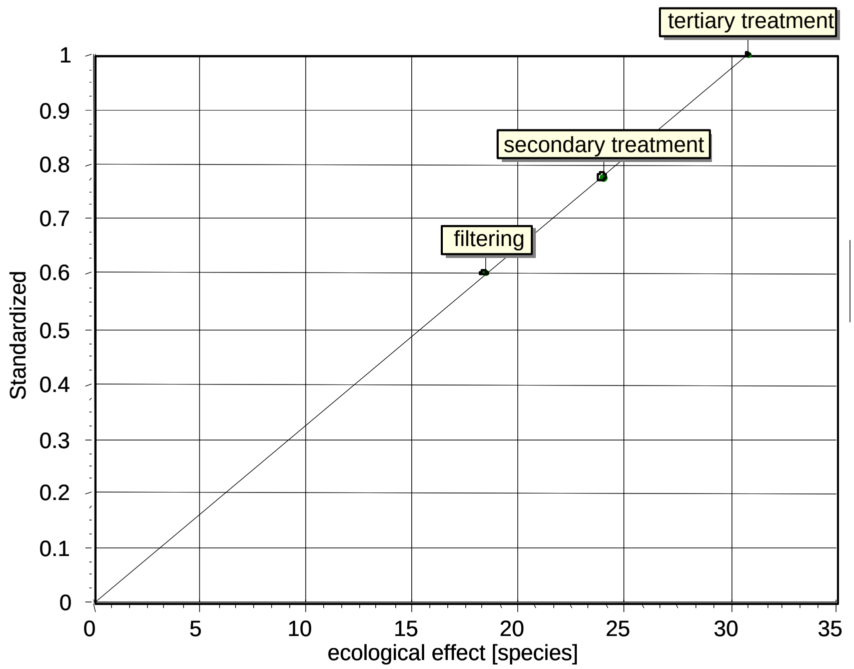


Figure 16. Linear standardisation of the ecological effects (number of species).

Although in practice the relationship between a criterion score and its value (utility) is usually more complex, a linear standardisation is often an acceptable approximation if the range of the scores is not too large. In those cases where a linear approximation is not acceptable, other, non-linear, standardisation or value functions should be used. An example of an S-shaped value function is presented in Figure 17.

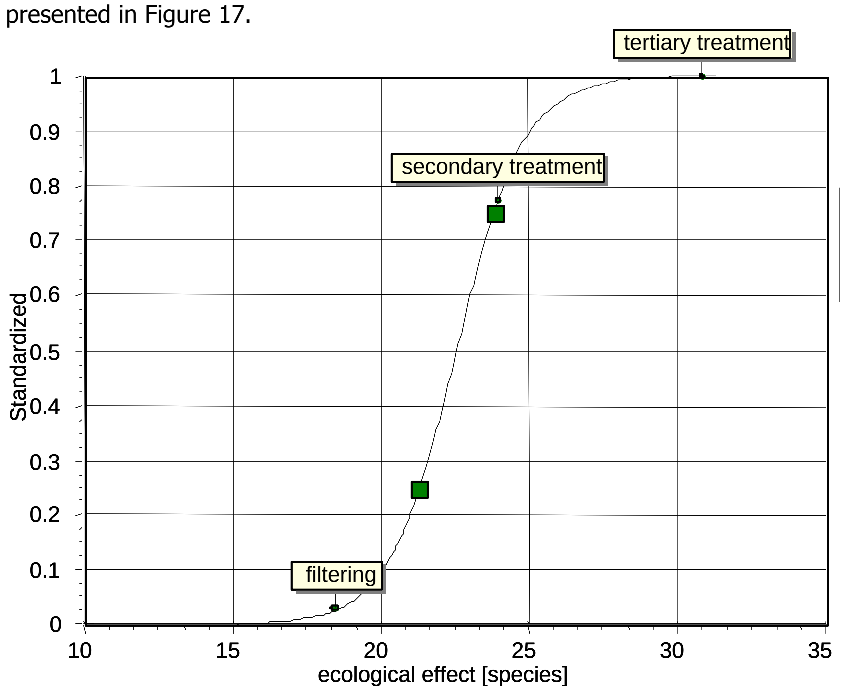


Figure 17. Standardisation of the ecological effects (# species) using an S-shape value function.

In Figure 17 the range of standardisation is between ten and 35 species. The shape of the value function is in this case based on interviews with experts (Beinat, 1997). The value of filtering is low for criterion 'ecological effects'. Secondary treatment shows a substantial improvement. Tertiary treatment achieves the maximum value. The shape of the curve is dependent on the type of criterion to be standardised. Value functions can be linear or S-shaped, and also convex, concave or free form. Assessment of value functions and corresponding weights is a difficult task. DEFINITE includes the EValue procedure. This interactive procedure can be used to assess these functions by conducting interviews with experts (Beinat, 1997).

Weighting

The allocation of weights is often criticised because it introduces subjectivity. This subjectivity is inherent to all methods that include making choices. Criticism is justified when such choices are not made explicit. It is important for decision makers to know who determined the weights and on what basis. The weights can be attributed by experts on the basis of generally accepted knowledge or by politicians on the basis of policy priorities. The distribution of the weights is shown in the pie chart in the upper right corner of Figure 18.

Ranking

All multi-criteria methods transform the performance scores and weights to a ranking using a decision rule. The MCA method 'weighted summation' is a good candidate for use in water management. Weighted summation is theoretically well established, can be easily explained, and is easy to use. Therefore, there is little chance that the user will view the method as a 'black box'. The principle of weighted summation is simple:

1. Standardise the scores per criterion ($\hat{s}_{ij}$).

2. Allocate the weights (w_i).
3. Multiply the weights by the standardised scores.
4. Add up the resulting scores to obtain total scores for each option.
5. Determine the ranking of the total scores.

The formula used for weighted summation is:

$$\text{score}\left(a_j\right)=\sum_{i=1}^{N} w_i \times \hat{s}_{ij}$$

Where:

A	is the set of alternatives with a_j (j=1..M),
C	is the set of effects with c_i (i=1..N),
s_{ij}	is the score of alternative a_j for effect c_i,
$\hat{s}_{ij}$	is the standardised score of alternative a_j for effect c_i,
w_i	is the weight of effect c_i.

Figure 18 shows an example of the results of weighted summation. It is clear from this example that the filtering option ranks first, followed by tertiary and secondary treatment. The stacked bars represent the total scores of the three alternatives and also show weighted contribution of each criterion to these totals.

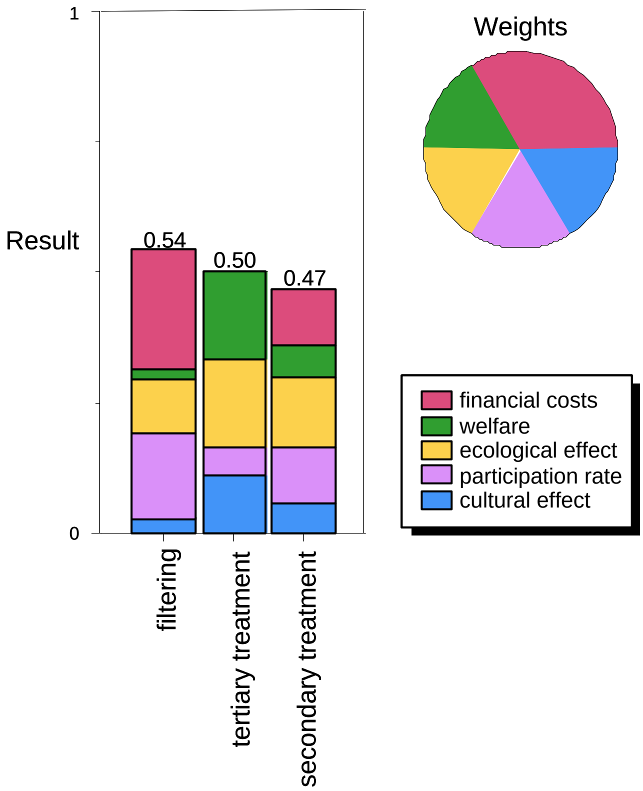


Figure 18. Multi-criteria analysis: ranking, evaluation scores and weights.

The difficulty with weighted summation does not lie in the calculation but in choosing a good standardisation method (the way in which the scores are converted to a common denominator) and in the setting of the weights. A disadvantage of the method is that it is less suitable for processing qualitative data. However, in practice the pluses and minuses used for qualitative assessments are often derived from underlying classes of quantitative data and can therefore be treated as quantitative information. Weighted summation is the simplest and most used form in multi-attribute utility theory. Other non-linear, multiplicative or multi linear utility functions are proposed in the extensive literature on utility analysis (Keeney and Raiffa, 1976; Keeney, 1992 and French, 1988). In addition to weighted summation, other multi-criteria methods are available in DEFINITE: the Electre 2 method (Roy, 1973), the Regime method (Hinloopen and Nijkamp, 1990) and the Evamix method (Voogd, 1983). See Janssen (1992) and Janssen and Munda (1999) for a description of these methods.

5.3.3 Step 3. Sensitivity analysis

Next, the sensitivity of the ranking to uncertainties in scores and weights is analysed. This is a vital step in MCA. Varying weights and scores can check the sensitivity of the results individually or through the use of Monte Carlo Analysis. This provides insight into the significance of the results (see also Herwijnen et al., 1995). The ranking of alternatives is dependent on the scores and weights. Changes in scores or weights may therefore change the ranking.

5.3.4 Step 4. Report

Finally, the results have to be gathered in a report to inform all relevant stakeholders of the impact of an activity. The group of stakeholders include, for example, the initiator of an activity, people involved in public participation rounds or authorities that grant necessary licenses. These stakeholders have different expertise and different interests. To achieve its task of providing information, the MCA must be well documented, easy to repeat, and as objective and transparent as possible. Well-conducted and presented MCAs play an important role in the debate around the activity and are usually appreciated by all participants (Janssen, 2001).

6 Conclusion

The objective of this report was to describe a new approach to integrated water management support emphasising the use of tools to implement this. It is evident that there is a clear need for changes in the way integrated water management is practiced: an increase in water related disasters, a growing population living in more sensitive areas, developing societies expecting better water services, climate change will results in more extremes, etc. In this report it has been advocated that a paradigm shift is required from a re-active approach to a pro-active approach. Although this pro-active approach has been discussed frequently over last years, it has hardly been adopted due to a lack of appropriate methodologies.

The approach introduced here, Integrated Water Management Support Methodologies, is a combination of three different components: (i) physical based, (ii) allocation based, and (iii) multi-criteria based. For the physical based component the SWAT (Soil and Water Assessment Tool) model has been introduced, as this is the de-facto standard in physical based modelling. WEAP (Water Evaluation And Planning system) was selected to be used as allocation component given its excellent capabilities to support scenario analysis. Finally, DEFINITE has been described as the multi-criteria tool, given its intuitive interface and its flexibility.

The Integrated Water Management Support Methodologies as introduced here will be applied and tested for two case studies: Kitui area in Kenya and Gediz Basin in Turkey. Based on these demonstration studies a detailed analysis of the strengths and weaknesses of the entire suite of tools as well as on the power of the integrated approach will be evaluated.

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