

SUSTAINABILITY ISSUES IN WATER MANAGEMENT

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ABSTRACT

In the 1992 Rio World Summit on Environment and Development (UNCED), water resources are indicated to remain at the core of sustainable development and, thus, they are to be managed and developed on a sustainable basis. The problem here is how to evaluate whether water management is sustainable or not and how to ensure sustainability in decision making for management. To be more specific, the question to be resolved is how to measure or quantify economic, social and environmental dimensions of sustainability. The study presented attempts to define sustainability in water resources systems on a quantifiable basis and introduces sustainability indicators. It further demonstrates the assessment of indicators within a DSS system. These issues are considered in the case of the SMART (Sustainable Management of Scarce Resources in the Coastal Zone) and OPTIMA (Optimization for Sustainable Water Resources Management) projects funded respectively by the 5th and 6th Framework Programmes of the European Union. The basic issues discussed will further be demonstrated in the case of the Gediz River Basin in Turkey.

1 INTRODUCTION

In the 1992 Rio World Summit on Environment and Development (UNCED), water resources are indicated to remain at the core of sustainable development and, thus, they are to be managed and developed on a sustainable basis. Agenda 21 of UNCED has officially stated the new outlook towards environmental and water resources management, namely that the environment should be managed by an integrated approach in respect of SUSTAINABILITY. Chapter 8 of Agenda 21 emphasizes that sustainability must be achieved in making decisions for overall development and resource management at regional and national scales. In that regard, decisions must seek for sustainability in 3 dimensions: *economic* (efficiency), *social* (equity) and *environmental* (compatibility). These three dimensions are the pillars of sustainability. If significant, a fourth dimension can be added to cover *institutional* issues. Sometimes, *information* is considered as the fourth dimension (basin information requirements).

The problem here is how to evaluate whether water management is sustainable or not and how to ensure sustainability in decision making for management. To be more specific, the question to be resolved is how to measure or quantify economic, social and environmental dimensions of sustainability. The first step towards quantification of these dimensions requires the identification of “indicators” for sustainability, i.e.

economic indicators, social indicators, and environmental indicators. Chapter 40 of Agenda 21 on 6 “Informed Decision Making” (statements and 7) foresees the identification of sustainability indicators along the above three dimensions and requires that these indicators are updated regularly to be reported in regional or national studies. Accordingly, various international organizations have prescribed lists of indicators to be used in local, regional, national and global development and management plans. These indicators are also classified to represent system (e.g., basin) properties such as: P(stress on the system), S(state of the system) and R(system response). To infer on sustainability in water resources systems, such indicators have to be evaluated by the use of Decision Support Systems (DSS) comprising the integrated tools of databases, models, GIS, and expert systems. DSS allows comparing various water management scenarios where the values of indicators are varied to assess baseline, pessimistic and optimistic management conditions. The success of DSS applications is closely related to the quantity and quality of available information on economic, social and environmental aspects (indicators) of water resources.

The study presented attempts to define sustainability in water resources systems on a quantifiable basis and introduces sustainability indicators. It further demonstrates the assessment of indicators within a DSS system. These issues are considered in the case of the SMART (Sustainable Management of Scarce Resources in the Coastal Zone) and OPTIMA (Optimization for Sustainable Water Resources Management) projects funded respectively by the 5th and 6th Framework Programmes of the European Union. The basic issues discussed will further be demonstrated in the case of the Gediz River Basin in Turkey.

2 SUSTAINABILITY ISSUES AND ENVIRONMENTAL INDICATORS

For the past decade, sustainability has been a highly popular concept in environmental and water resources management. It entails a long-term, instead of a short-term perspective in resource assessment and management and is often attached to the concepts of *renewability*, *resilience* and *recoverability*. Clark and Gardiner (1994) describe these concepts as the following:

- *Renewability* refers to the “rate at which a resource can be replaced, so that sustainability is achieved by restricting the level of use to something at or below the rate of replacement”;
- *Resilience* describes “the ability to withstand stress without long-term or irreversible damage” and “sustainability is achieved by restraining use to a level at or below that which exceeds the system’s resilience”;
- *Recoverability* is “a concept which accepts that detrimental impact may take place, but concentrates on the rate or frequency of impact in relation to the inherent rate of recovery. A sustainable system is one in which impact intensity and frequency are small in relation to recovery rate”.

All of the above concepts are significant in catchment planning. Furthermore, a holistic approach is emphasized in assessing the catchment system so that the system is considered to be interconnected, and short-term decisions are viewed to have long-term direct and indirect consequences (Clark and Gardiner, 1994).

Chapter 8 of Agenda 21 emphasizes that sustainability must be achieved in making decisions for overall development and resource management at regional and national scales. In that regard, decisions must seek for sustainability in 3 dimensions: economic (efficiency), social (equity) and environmental (compatibility) (Fig.1). If significant, a fourth dimension can be added to cover institutional issues as in Fig.2.

Furthermore, Chapter 40 of Agenda 21 on “Informed Decision Making” (statements 6 and 7) foresees the identification of sustainability indicators along the above three dimensions and requires that these indicators are updated regularly to be reported in regional or national studies. Accordingly, various international organizations have prescribed lists of indicators to be used in local, regional, national and global development and management plans. For example, the indicators developed by the World Bank for various projects cover the following:

- *Population related indicators*: demographic indicators, rate of population increase, life standards, health aspects, and the similar;
- *Land use*: rate of urbanization, properties of vegetation cover, land use types, etc.;
- *Economic activities*: economic indicators, indicators on agriculture, energy, fisheries, mining, industry;
- *Environmental indicators*: water use, water demand, water quality and quantity, water supply, wastewater discharges, air quality, hazardous wastes and the similar;
- *Actors and policies*: number of actors involved in water management, number of NGOs, presence of regulations on environment, etc.

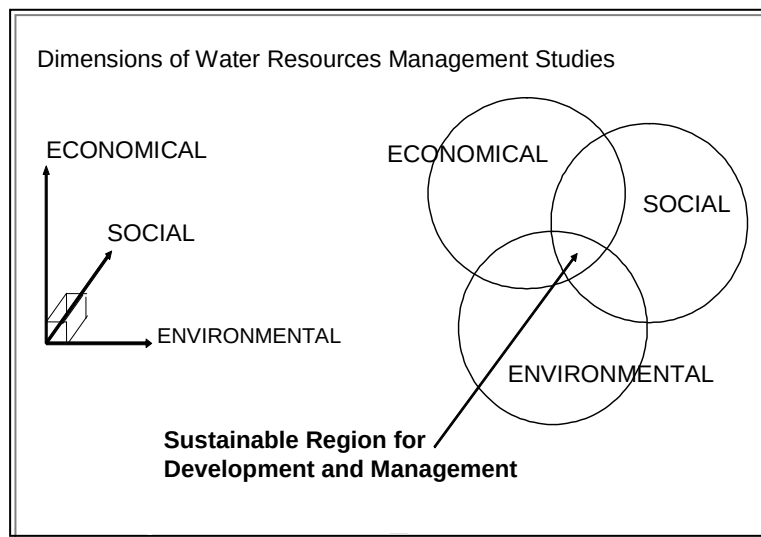


Figure 4. Dimensions of water resources management studies.

The above indicators are also classified to represent system (e.g., basin) properties such as P(stress on the system), S(state of the system) and R(system response). Similar indicators are identified by the European Environment Agency (EEA) and by the Mediterranean Action Plan (MAP) for Mediterranean countries. There are 130 MAP

indicators, 45 of which are P type; 45, S type; and 40, R type (UNEP, 2000). In essence, the system properties of P, S and R are major components of the DPSIR approach proposed by EEA in resource development and management studies as shown in Fig.3 (Harmancioglu, 2004).

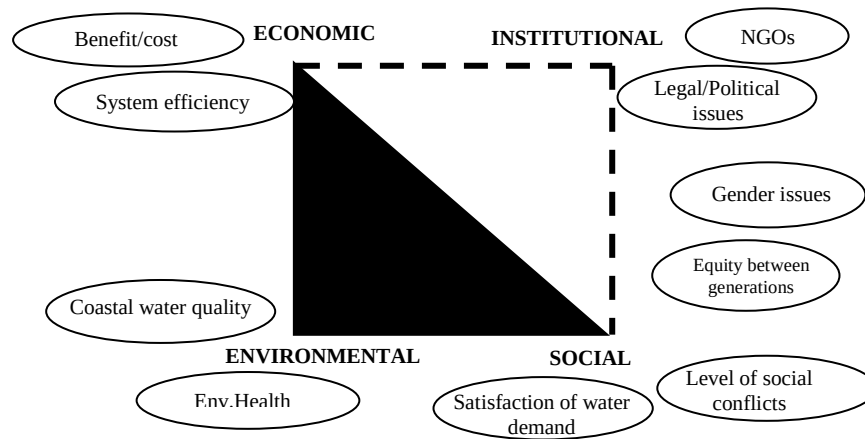


Figure 2. Pillars of sustainability and examples of indicators.

It follows from the above that sustainability has to be defined on the basis of indicators which, in turn, require large numbers and types of data to be realistically specified. It is also clear that we need data not only in the environmental dimension but also in social and economic dimensions. These two issues are illustrated in the case of two EU projects, SMART and OPTIMA, which were carried out on five case studies respectively in Turkey, Lebanon, Cyprus, Morocco, and Jordan. Figure 4 summarizes the basic approach applied in the projects where the final stage comprised a comparative analysis across the five case studies. The following section displays only the Turkish case to summarize assessment of indicators.

3 SMART AND OPTIMA PROJECTS: GEDIZ CASE STUDY

Gediz River Basin along the Aegean coast of Turkey (Fig.7) demonstrates the entire range of prototypical water management problems in the Mediterranean region and reflects the importance of the institutional and regulatory framework, and the need for direct participation of major actors and stakeholders in the decision making process for sustainability (Harmancioglu, 2001). The case is studied within the scope of two EU INCO projects: SMART (Sustainable Management of Scarce Resources in the Coastal Zone-Contract Number ICA3-CT-2002-10006) and OPTIMA (Optimization for Sustainable Water Management-Contract Number INCO-CT-2004-509091), sponsored by EU FP5 and FP6 Programmes, respectively (<http://www.ess.co.at/SMART>; <http://www.ess.co.at/OPTIMA>). The SMART project was completed in 2005 and OPTIMA in 2007.

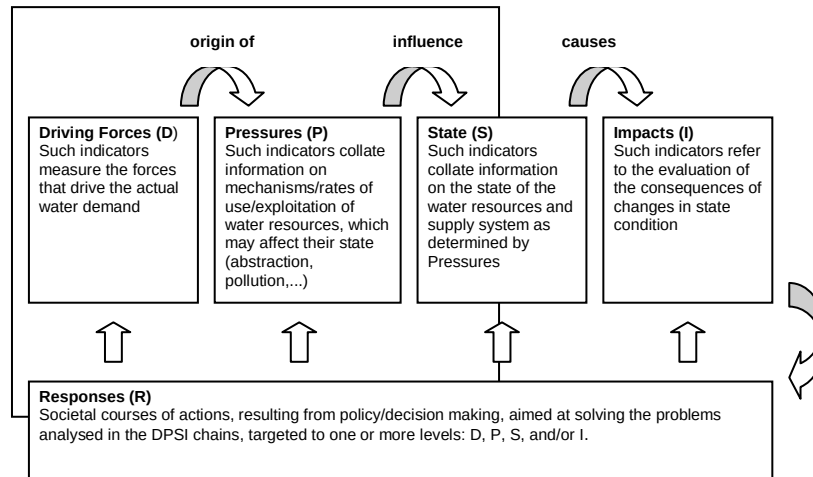


Figure 3. Basics of DPSIR approach and relevant indicators in resource management studies.

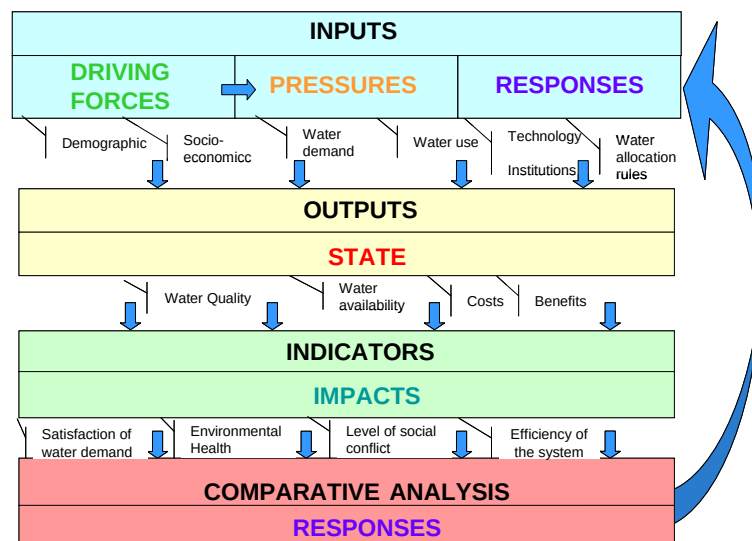


Figure 4. Basic approach employed in SMART and OPTIMA projects for basin management studies.

3.1 Data requirements

Data availability and quality are considered prerequisites for achieving the objectives of both SMART and OPTIMA in solving water supply/demand issues through testing of strategies that can reconcile conflicting demands on scarce water.

resources. The database for the Turkish case study comprises data required by the three primary components of project, namely, the socioeconomic framework and two quantitative analysis tools (models): WaterWare and TELEMAC. Initial investigations on data availability and quality are accomplished through a “Requirements and Constraints Analysis”. This analysis disclosed:

1. Description of the case study area;
2. Information on data: availability, sources, coverage, formats, quality and cost;
3. Key water issues;
4. Key issues of changes;
5. Policy relevant information;

which were then summarized as a profile of the basin as in Table 1 to present the basic initial information

Table 1. Compilation of basic information on Gediz Basin in the form of a basin profile

Description	Data	Area	Reliability	Source
The geographic Location of the case study in longitude and latitude	North: 38°04' - 39°13' East: 26°42' - 29°45'	Turkey	M	USGS
The Drainage Area in km ²	18.000 km ²	The Gediz river basin	M	State Hydraulic Works (DSI)
The resident Population	1.700.000	The Gediz river basin	M	State Institution of Statistics (DIE)
The average annual Rainfall	700 mm	The Gediz river basin	M	State Institution of Meteorology (DMI) and State Hydraulic Works (DSI)
The Cost of water per litre in Euros	Bottled: 0.87€	National		Market prices

Current Annual Water Supply: 1100 MCM		Per Capita: 647 M³		
Ground Water The volume of water pumped to the surface for use each year	160MCM (9 mm)	The Gediz river basin	M	State Hydraulic Works (DSI)
Surface Water The volume of annual mean discharge from the drainage area	940MCM (52 mm)	The Gediz river basin	M	State Hydraulic Works (DSI)
Treated Water The volume of water treated annually	There is no use of treated water			

Current Annual Water Demand: 886 MCM		Per Capita: 521 M³		
Annual volume of water required for Domestic purposes.	133MCM (7.4 mm)	The Gediz river basin	M	Municipalities and DSI
Annual volume of water required for Agricultural purposes.	695MCM (39 mm)	The Gediz river basin	M	DSI
Annual volume of water required for Industrial purposes.	54MCM (3 mm)	The Gediz river basin	M	Municipalities
Annual volume of water required for Touristic purposes.	There is no tourism activity			
Annual volume of water required for Environmental purposes.	3.6MCM (0.2 mm)	The Gediz river basin	M	DSI

Table 1. (Continued)

Key Issues: Problems for discussion regarding the sustainable management of scarce water resources	
Water Issues: Problems for supplying sufficient water to meet current and future demands	Urban and industrial wastewater and agricultural return flows deteriorate water quality. At Middle Gediz the quality classification has declined from class III to class IV. Over the entire basin, daily BOD loads from domestic and industrial discharge amount to 210.000 kg that flow into surface waters. (DSI) According to Turkish water quality classification, 60% of surface water and 30% of groundwater are in class IV (DSI). Water shortage is a significant problem due to frequent droughts and competition for water among various uses, mainly irrigation and domestic (DSI and municipalities). Supply (61mm) $\cong$ Demand (49.6mm): There is no water left for allocation whereas domestic demand increases at a rate of 2% (0.15 mm) each year and industrial demand increases at a rate of 10% (0.3 mm) each year.
Trends in Demographic Change and how they affect water supply and demand	Basin population is growing at a rate of 1.5%. There is considerable internal migration and rapid urbanisation. Total basin population increased from 1.100.000 in 1970 to 1.700.000 in 1997 (DIE)
Trends in Land Use Change and how they affect water supply and demand	Urban areas are increasing at a rate of 2%, and industrial areas are growing at a rate of 10% resulting in an increase in water demand. Urban population is increasing at a rate of 2%, while rural population is decreasing at a rate of 0.7% (DIE).
Trends in Technological Change and how they affect water supply and demand	New irrigation technologies are encouraged to improve irrigation efficiency through the reduction of water loss, and changes in irrigation methods. This may reduce irrigation demand or may cause an increase in irrigated areas, using the same amount of water (DSI).
Trends in Institutional Change and how they affect water supply and demand	There are serious institutional, legal, social and economic drawbacks, which enhance water allocation and environmental pollution problems. There are constraints to achieving basin management objectives. Institutional evolution is slow in comparison to rapid evolution in water management problems. Legislation used in current management practices is too old and can not meet current demands.

The socio-economic data required by the projects were defined in the form of another analysis on “Socio-economic Framework and Guidelines”. These data provided inputs to the following four tasks:

1. Population, demographic and migration policy analysis
2. Political and economic options adopted for the study areas
3. Competing water uses
4. Economic analysis of water resources

The socio-economic data were analyzed and processed through a “Data Compilation and Analysis” into a consistent database. The use of these data led to various management scenarios.

3.2 Further data

The data requirements of the study extended to compilation of geospatial data in the form of base maps, covering also hydrometeorological observations. Within the SMART project, a number of digital maps in the form of several GIS layers are prepared for the Gediz River Basin, by following a series of digital data capturing methods. The most fundamental among all these methods is the Digital Elevation Model (DEM), representing the topography throughout the whole basin area. The river network within the basin is first obtained from the Digital Chart of the World (DCW), which is then transferred to the same projection system with the DEM and modified for some parts by spatial editing on the basis of the hydrographic information available on hard copy maps. Landcover information was directly transferred from the geospatial database of an already completed project (IWMI, 1998) and examined for compatibility with the previously produced data layers. Soil information was obtained in the same

way from the external database of the above mentioned project and was included in the geospatial database of SMART with the same coordinate information used for the other layers.

The geospatial database for Gediz also includes three layers of geospatial information, each representing geographic locations of observation points within the basin. Meteorological stations are placed inside and around the basin area, using the coordinate information given on the website of the General Directorate of State Meteorological Works (DMI). Stream gauging stations are included in two different digital layers, again based on the coordinate information on the Internet, as some of these stations are operated by the General Directorate of State Hydraulic Works (DSI), while the rest are run by the General Directorate of Electrical Works Authority (EIE).

Further data are also compiled for purposes of modeling studies via WaterWare. WaterWare (WRM) is an annual water budget model which simulates the river system on a daily basis; hence daily hydro-meteorological data within a certain year are compiled for the Gediz River Basin on the basis of its topological features. The data needs of WRM depend on identified “nodes” and connecting “reaches” to be identified in the model. In the Gediz case, data on inflows, precipitation, temperature and dynamic demand series are compiled to satisfy the data needs of WaterWare. In addition, some physical features and characteristics of reservoirs, reaches and aquifers are considered in the data compilation process.

OPTIMA project builds upon the results of SMART and intends to identify the best management plan for the basin. To realize the optimization procedure involved, OPTIMA requires further data and couples the WaterWare modeling system with an optimization component.

In OPTIMA, the performance of the basin system is expressed in terms of criteria and indicators (any one of which can be used in the optimization) such as the

- **Overall water budget**, balancing all inputs, losses, uses, outflows including export and inter-basin transfer, and change in storage including reservoirs and the groundwater system; additional information relates to the storage/extraction relationships and, thus, the sustainability of the overall system in a long-term perspective;
- **Technical efficiency** of the system: this describes the ratio of useful demand satisfied to the losses through evaporation from reservoirs and seepage losses through the various conveyance systems;
- **Supply/demand ratio**, globally, for any and all individual demand nodes in the basin, or any functional/sectoral grouping; this also includes any environmental water demands, low flow constraints, wetland nourishing, etc.
- **Reliability of supply**, measured at any or all demand nodes and control nodes that compare the water available with user-defined needs/expectations as constraints;
- **Development potential**, which relates the unallocated water summed over all demand points to the total input: this, in principle, defines the amount of water that is available for further exploitation;
- **Costs and benefits**, derived from useful demand satisfied and the added value derived, versus the costs of shortfalls (again at any or all nodes), as well as the costs of supplying the water in terms of investment (annualized) and operating and maintenance costs of structures and institutions;

• **Groundwater sustainability**, which describes the ratio of content to the net withdrawal (balance of recharge, summed over natural and artificial) and evaporative and deep percolation losses, measured in years of reserves at current exploitation levels.

It follows from the above that data requirements of OPTIMA are more exhaustive to include information on sectoral water use, irrigation districts, areas and crop patterns, basin institutions, stakeholders, and economic benefits and costs. Economic valuation (expressed as net present values or annualized costs considering investments, operating costs, and project or technology life times) includes estimates of the cost of various alternative water technologies (from non-conventional supply options like desalination, water harvesting, recycling and re-use to new reservoirs, lining irrigation canals and more efficient irrigation technologies to water saving showers) versus the benefits generated by supplying water for useful demands (Fedra & Harmancioglu, 2005).

Different allocation scenarios and also the use of different water technologies lead to different cost-benefit ratios for the system. From the set of results generated, any number of constraints can be derived for the optimization, both global criteria aggregated over all nodes and a yearly simulation run such as overall reliability of water supply, as well as node and location specific constraints defined as minimum or maximal flow (or supply) expectations, again with different temporal resolution and aggregation (Cetinkaya & Harmancioglu, 2008; Cetinkaya et al., 2008). Table 2 presents an example of the constraints used in optimization, which constitute another set of indicators. These indicators were defined by basin stakeholders for optimization purposes of OPTIMA.

Table 2: The range of “rigid constraints” for optimization (in the form of indicators), identified by basin stakeholders

Indicator	Min & Max Value	State Hydraulic Works
Overall Supply / Demand ratio	> 70-95 %	> 90 %
Reliability of supply	> 70-95 %	> 90 %
Benefit / Cost ratio	> 0.8-2.0	> 1.5
Economic efficiency (direct)	0.10-0.70 €/ m3	0.5 €/ m3
Economic efficiency (indirect)	0.08-0.9 €/ m3	0.35 €/ m3
Net benefit (direct or indirect)	960-1200 €/ ca	1000 €/ ca
Cost of water (direct)	0.10-0.7 €/ m3	0.4 €/ m3
Cost of water (indirect)	0.08-0.7 €/ m3	0.25 €/ m3

4 DEFINITION OF INDICATORS AND MANAGEMENT SCENARIOS

Management scenarios are developed for the Gediz Basin on the basis of the approaches described in Figs.3 and 4. First, the baseline scenario is developed to identify the current status of the basin. Next, three types of future scenarios are assessed: *Business-as-Usual Scenario*, where all practices and characteristics of the basin are considered to remain the same in the future; *Optimistic Scenario*, where practices are improved so that indicators are also improved; and a *Pessimistic Scenario*,

where things change for the worse. For each scenario, economic, social and environmental indicators are computed and then the scenarios are compared as in Fig. 5.

Both SMART and OPTIMA projects involve socio-economic analysis and basin simulation through the WaterWare model (Harmancioglu et al., 2008). SMART also uses the TELEMAC model for modeling of the Izmir Bay to assess the pollutants discharged by Gediz River into the Bay, which is not discussed herein. Table 3 presents the results of the 3 scenarios developed for the basin.

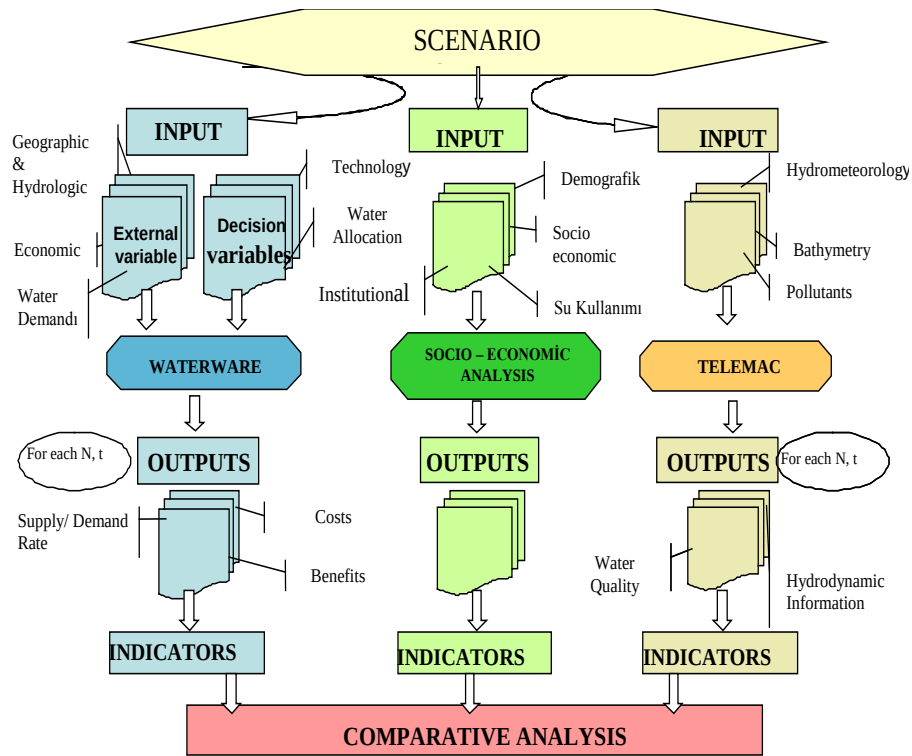


Figure 5. The structure of SMART and OPTIMA projects where indicators are identified for each scenario

At the final stage, WaterWare Model simulations resulted in various management scenarios which were derived by using all the diverse types of data described in Section 3. It is apparent on this case study that development of basin management plans requires exhaustive amounts of data to be collected. The important issue here is that these data should be accurate and reliable to lead to sound decisions on management of a basin. For the Gediz case, water quality management responses could not be assessed due to lack of sufficient data. Consequently, no possible actions can be foreseen for the future. This is an unfortunate situation, resulting from data limitations, since one of the two key problems in Gediz is water pollution. Likewise, the economic efficiency of the Gediz

system for water use/water supply issues cannot be evaluated, again due to lack of sufficient and reliable data. It is fairly difficult to state the economic value per unit of water used in the basin. This again is an unfortunate situation resulting from data limitations and indicates lack of awareness, responsibility, and authority among the decision makers.

Table 3. Scenarios developed for the Gediz Basin.

Variables/driving forces	Baseline	BAU	Optimistic	Pessimistic
Birth control	existing	Existing (partially successful)	Existing (successful)	Existing (unsuccessful)
Urban growth rate	1.5 %/y	1.5 %/y	1 %/y	3 %/y
Rural growth rate	- 1 % /y	- 1 % /y	-1 % /y	-2 % /y
Precipitation rate	700 mm/y	0 %	0%	-10%
Groundwater supply	9 mm/y	0 %	0 %	-10%
Surface water supply	59 mm/y	0 %	0 %	-10%
Groundwater pollution	Class IV	Class IV	Class III	Class IV
Basin-out water supply (surface & groundwater)	0.2 mm/y	0.2 mm/y	0.4 mm/y	0.5 mm/y
Domestic water use (surface & groundwater)	7.4 mm/y	0%	0.5 %/y	2.5 %/y
Industrial water use (groundwater)	3 mm/y	0%	4%/y	8%/y
Irrigation water use	39 mm/y	0%/y	- 40%	15%
Domestic water supply investments	sufficient	sufficient	sufficient	insufficient
Change in crop pattern	Cotton, grape, maize	Cotton, grape, maize	Grape, vegetable, maize	Cotton, grape
Irrigation m/o investments	insufficient	insufficient	Sufficient	insufficient
Loss rate in irrigation system	30 %	30 %	10%	30%
Irrigated area	1070 km ²	0%	0%	0%
Industrial water use (surface water)	0 mm	0 mm	4 mm	4 mm
Surface water quality	Class IV	Class IV	Class III	Class IV
Water exploitation awareness	Insufficient awareness	Insufficient awareness	Comprehensive awareness	Insufficient awareness

5 CONCLUSIONS

To infer on sustainability in water resources systems, social, economic and environmental indicators have to be evaluated by the use of Decision Support Systems (DSS) comprising the integrated tools of databases, models, GIS, and expert systems. DSS allows comparing various water management scenarios where the values of indicators are varied to assess baseline, pessimistic and optimistic management conditions. The success of DSS applications is closely related to the quantity and quality of available information on economic, social and environmental aspects (indicators) of water resources.

The study presented has defined sustainability in water resources systems on a quantifiable basis and introduced sustainability indicators. It further demonstrates the assessment of indicators within a DSS system. These issues are considered in the case of the SMART and OPTIMA projects funded respectively by the 5th and 6th Framework Programmes of the European Union.

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