WaterStrategyMan
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DELIVERABLE 8

METHODOLOGY FOR EVALUATING WATER RESOURCES SCENARIOS

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1. Introduction

The overall objective of this deliverable is to integrate different methods that have been reviewed to a consistent methodology and to select those indicators and aggregation methods that are most appropriate for the paradigms.

This document is organised in the following way: The first section summarises an appropriate approach for water demand forecasting based on different levels of data availability. Next, a method for evaluating water management strategies will be introduced that concentrates on the assessment of water management strategies by different scenarios. Finally, a set of core indicators is presented that forms the basis for the evaluation of strategies described above.

2. Demand forecasting

2.1 General remarks

Given the wide range of data availability as well as the level of detailed information provided by the case study partners, it is suggested to use a “graded” approach that takes into account the data situation and the required level of detail.

In cases with very limited data a simple activity level is used that estimates water demand for a given sector by multiplying the activity levels with the corresponding units.

If further information such as data demand elasticity etc. exists, this may also be incorporated. The basic approach for the different types of users is briefly described below.

2.2 Domestic Demand

A deterministic forecast of water demand for domestic purposes is generally based on future estimates of population, water use characteristics, the type of commercial use that is involved, the unaccounted for water in the distribution system and so on. Water use characteristics, in turn, depend on the type of households, the social structure and water prices etc. The factors influencing residential water demand are given in Figure 1 whereas factors influencing a commercial demand include costs and type of technology amongst others

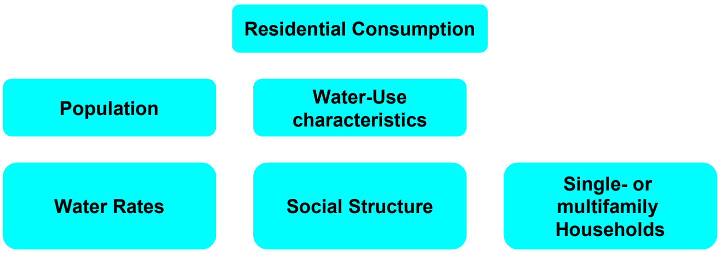

Figure 1: Factors influencing residential water demand

Non-revenue water can be broadly classified into water that is used for the operation of the system, water that is used for public purposes (a loss of revenue), meter inaccuracies and system losses due to leakage etc. The classification of losses (both losses of water and losses of revenue) and the corresponding influencing factors are depicted in Figure 2.

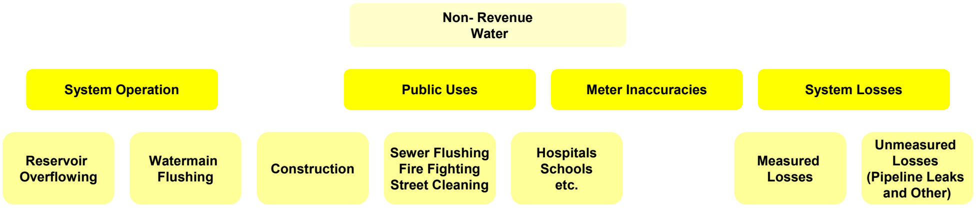

Figure 2: Non-revenue water and some influencing factors

For both the definition of scenarios and the evaluation of strategies in economical terms it is of utmost importance to distinguish between water that is used for residential and non-residential purposes (i.e. tourism).

On top of that it is well known that per-capita demand for residential population differs significantly from per-capita demand for tourists.

The distinction will not always be easy to determine as water demand figures will be provided for an entire settlement.

2.2.1 Assumptions:

1. Residential domestic per-capita demands and per-capita demand for tourists are largely different.
2. Residential domestic demand, residential population, losses and unaccounted for water are constant throughout the year
3. Per-capita demand and population (or tourist arrivals) are subject to a linear trend (to be specified by the user). Other types of trend functions will be implemented later.
4. Unaccounted for water (UFW) and distribution losses are given as a share of the total amount of water delivered.
5. The seasonal pattern of tourist arrivals will remain constant throughout the simulation period.

2.2.2 Data required

Parameter	Description	Dimension	Default
$DCTOUR_t$	Per capita water demand for tourists in year t	l/d	300
$DCRES_t$	Per capita water demand for residential population in year t	l/d	150
POP_t	Residential Population in year t	-	-
$TOUR_{t,i}$	Tourist arrivals in month i; i=1,,12	-	-
$LOSS_t$	Network losses in year t, share of water delivered	-	0.35
UFW_t	Unaccounted for water in year n, share of water delivered	-	0.15

Table 1: Required data for a simple domestic water demand model

It may not always be easy to distinguish between unaccounted for water (public use, public gardening etc) and water that is lost due to leakages in the network. Such a distinction is, however important as it has to be distinguished between losses of water and losses of revenue.

If data for tourist arrivals is only available on a yearly basis, an indication of the seasonal pattern of tourist arrivals has to be provided.

2.2.3 Water demand in month i and year t [m³]

Water demand for a given month i in year t in m³ can be easily computed using

$$D_{i,t} = \left(TOUR_{i,t} \cdot DCTOUR_t + POP_t \cdot CDRES_t\right)\left(1 + UFW_t + LOSS_t\right) \cdot \frac{3}{100}$$

where all variables with index t are subject to t linear trend (see below).

2.2.4 Trend functions

Initially, only a linear trend will be considered. The trend function is given by

$$f(t) = \beta_0 + \beta_1 \cdot t$$

or

$$f(t) = y_0 + \frac{y_t - y_0}{t} \cdot t,$$

y_0	Baseline value today,
y_n	value in t years

2.2.5 Demand estimation with uncertainties

A random component will be considered in the final version. The water demand for tourists is probably difficult to determine. In case of uncertain data, a per-capita demand should be estimated that is typically higher than for residential demand. The seasonal pattern may be estimated by comparing water demand in less-touristic settlements.

2.2.6 Return flow:

The amount of return flow from a settlement is generally considered to be equal to the water delivered (billed volume + UFW+losses). If the share of consumptively used water is considerably high, their value has to be specified.

2.2.7 Water quality[1]

The concentrations of pollutants for waste water (return flow) should be specified by the user. If those values are not available, the following per capita values of pollutant quantities (!) can be used

Table 2: Default values for per capita pollutant generation [g/cap*day]

BSB	60
CSB	120
Total dissolved solids (SS)	70
Total Organic Carbon (TOC)	50
Total Phosphorus (P)	2.5
TKN (Kjeldahl-Nitrogen)[2]	11

2.3 Agricultural node

2.3.1 Assumptions:

1. No surface runoff from the field
2. Constant irrigation efficiency over all crop development stages
3. Return flow fraction is independent of crop stages

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[1] For thresholds and target values, the relevant EU legislation applies (Urban Waste Water Directive etc)

[2] TKN=orgN+NH4-N

2.3.2 Input required

Parameter	Description	Dim.	Default
$EffA_t$	Field application efficiency of the irrigation site in year t	-	Surface methods 0.55-0.80 Subsurface up to 0.8 Sprinkler 0.6 –0.8 Rice 0.32
$EffB_t$	Field canal efficiency of the irrigation site in year t	-	0.7-0.9
$A_{t,i,k}$	Area planted with crop k in month i and year t	ha	-
$LR_{t,i,k}$	Leaching requirement for crop k in month i and year t	-	-
$Peff_{i,t}$	Effective precipitation in year t and month i (taken from USGS maps)	mm	-
$ETO_{i,t}$	Reference ETP in month i and year t (taken from USGS)	mm	-
$RETURN_{i,t}$	Return flow in month i and year t	-	0,2

2.3.3 Crop evapotranspiration ETC

Crop evapotranspiration is computed using the FAO method:

$$ETC_{i,j} = Kc_{i,j} \cdot ET0_i \quad [mm]$$

$\mathrm{ETC_{i,j}}$ Net crop ETP for Area j in month i [mm]

KC Crop coefficient [–]

$\mathrm{ETO_i}$ Reference evapotranspiration in month i [mm]

ET0 values from FAO data (compiled by ProGeA)

KC values from FAO paper 56 (tabled; available in digital format from RUB)

Crop coefficients are given for the initial, mid and end period. Values for the length of the vegetation period are given in FAO tables. The development of the crop coefficient is exemplarily depicted in Figure 3

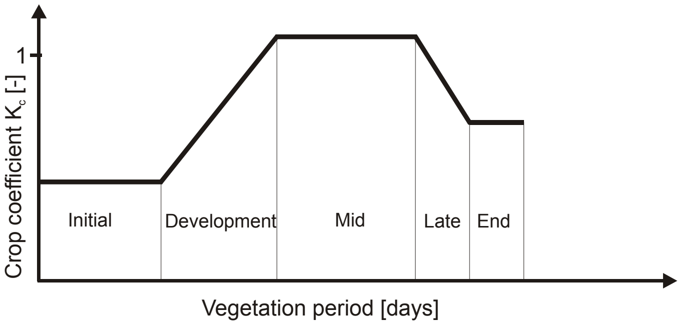

Figure 3: Crop coefficient over the vegetation periods

2.3.4 Net irrigation water requirement I_{net}

The net irrigation water requirement is calculated using the (highly simplified) field water balance (Groundwater contribution and stored soil water at the beginning of the calculation period are not considered)

$$I_{net} = ETC - (P_{eff} + GW) \qquad [mm]$$

Effective rainfall P_{eff} is usually considered as the amount of rainfall that can be expected in 4 out of 5 years (80% probability of occurrence). Since not all rainfall is effective and part of it may be lost by surface runoff or evaporation, a factor alpha has to be provided that describes that amount of effective rainfall as a fraction of the observed rainfall. GW denotes the contribution of groundwater. This may be important where groundwater levels are high but is hard to determine since detailed experiments under field conditions are required. If the contribution plays a major role, the crop coefficients may be adjusted by the user accordingly.

2.3.5 Irrigation water supply requirements per month

The volume of water needed by an irrigation plot in a month is given by

$$V_i = \frac{10}{Eff} \sum_i \left[\frac{A \cdot I_{net}}{1 - LR} \right]_i \quad [m^3 / month]$$

All variables are subject to a (linear) trend as described above.

2.3.6 Leaching requirement LR

Leaching requirement is the amount of water that is needed for leaching of accumulated salts from the root zone, and to control the soil salinity at the given specific level and is given as a fraction of the water supplied.

If detailed data is available, the LR may be determined depending as follows:

For surface irrigation methods (including sprinklers)

$$LR = \frac{EC_w}{5EC_e - EC_W} \qquad [-]$$

for drip and high frequency sprinkler (near daily):

$$LR = \frac{EC_w}{2MAXEC_e} \qquad [-]$$

Where:

ECW	electrical conductivity of the irrigation water
Ece	Electrical conductivity of the soil saturation for a given crop appropriate to the tolerable degree of yield reduction
MaxECe	Maximum tolerable EC of the soil saturation

2.3.7 Water-yield function

There exist a number of empirical functions that relate the actual crop yield to the amount of available water and to the salinity of the soil respectively (as a fraction of the maximum yield). In general, these methods are widely used but do not seem to be applicable in the WSM project. If the amount of water available to an irrigation site and hence the yield drops significantly the farmer will most probably abandon his plot or change the cropping pattern.

2.4 Industrial Demand

The water demand for industry varies considerably depending on type of industry, units produced, type of process etc. A general model for industrial demand does not seem to be reasonable, so that water demand, consumptive use and quality of return flow has to be specified individually.

2.5 Environmental Demand

Environmental water demand is the flow in a river stretch that is needed to sustain a given level of aquatic biosphere. It is obviously a non-consumptive demand for which values can only be specified individually.

2.6 Hydropower

Water demand for hydropower is also non-consumptive and may be important to if a given amount of energy is to be produced. The amount of energy produced by hydropower is given by an integration or flow-duration curves over time:

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

where Q is the flow, H is the energy head, g is the acceleration due to gravity and e is the overall efficiency of the hydropower station.

2.7 Other Demands

Such demand nodes include demand for recreation purposes, navigation and others. Demand, return flow, required quality and water quality of the return flow can only be defined individually.

3. Evaluation of Strategies

3.1 Introduction and Terminology

The evaluation of strategies (a set of water management actions) is based on the performance of these strategies for a one or more different scenarios. Scenarios are understood here as a set of circumstances that cannot be influenced directly by the decision maker.

In addition, the following basic definitions will be used here:

- 1st level indicators

  Basic data (model output); time series at nodes

  Example: Effluent WQ of a WWTP

- 2nd level indicators

  Spatially aggregated basic data: Time series at regional level

  Derived statistical characteristics: Frequencies of failures

- 3rd level indicators (index)

  Spatially and temporally aggregated indicators

  (single number, if applicable)

  Example: Overall score for strategy A: 0.975

All strategies will be compared with respect to the baseline (i.e. the non-intervention) strategy.

The framework for assessing strategies is depicted in the Figure 4 and can be summarised as follows: A strategy is composed of a number of different water management interventions (actions). The simulation will be done taking into account a number of scenarios such as different climate conditions, increased market prices for agricultural products etc. The results of the simulation are values at node level for all scenarios and all time steps. From this basic values, matrices of temporally integrated indicators at node level will be derived.

The indicators will be further aggregated in space so that a matrix for all strategies is obtained.

A matrix of utilities is computed using utility functions for the spatially aggregated values.

The indicators are grouped according to the overall objectives of an integrated water resources management and the strategies are finally ranked using an Mulit-Criteria-Decision-Making (MCDM) approach that is described later in this document. Weights for both the grouped values and the single indicators will be assigned representing the preference structure of the decision maker.

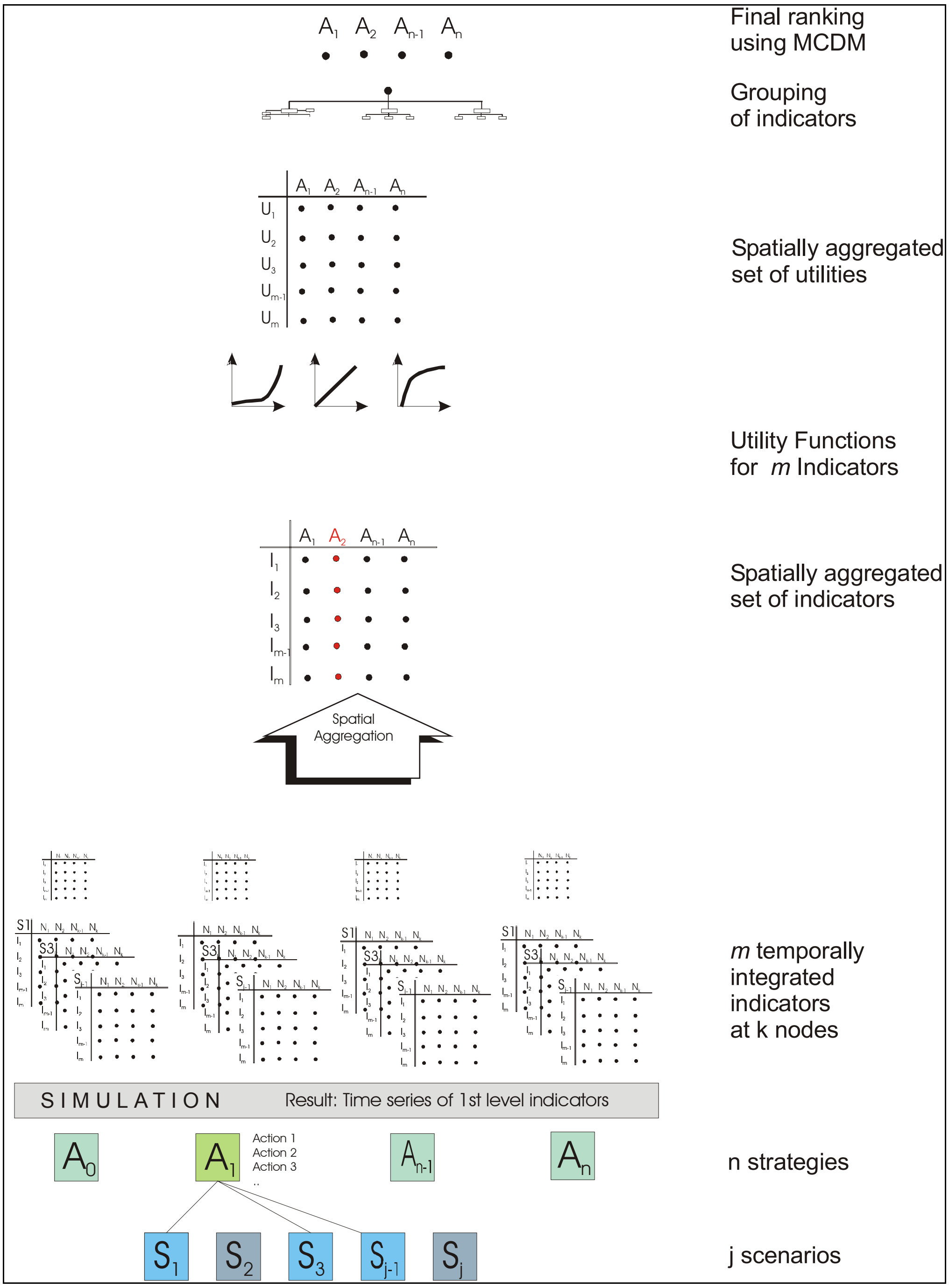

Figure 4: Framework for strategy evaluation

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4. MCDM Approach

The main criteria for selecting appropriate MCDM approaches to be used in integrated water resources management can be summarised as follows:

- Comparability of alternatives
- Methodological Transparency
- Mathematical Sophistication
- Interactivity for preference structure
- Not stakeholder specific
- Involvement of the DM in the decision making process

Out or the many approaches that have been used for an evaluation of water management alternatives, Compromise Programming (CP) has been selected because it represents a good compromise between mathematical sophistication and methodological transparency.

Compromise programming is an interactive method that identifies non-dominated solutions which are closest to the ideal solution by some distance measure.

The underlying idea of compromise programming can be easily explained for a simple case where only two objectives are to be achieved. The degree of achievement of objective Z_1 is displayed on the y-axis and the degree of achievement of objective Z_2 is displayed on the x-axis. The indicators are transformed using the convenient definition that zero denotes the least acceptable value (no achievement) and one represents full achievement of the objective.

The ideal point of optimal achievement is obviously the upper right corner with the coordinates (1,1) (Figure 5). The degree of meeting both objectives d can be calculated by the distance between the ideal point and the points of achievement for a given alternative. :

$$d_i = \left[\sum_{j=1}^{2} \left(1 - n_{ij}\right)^2 \right]^{\frac{1}{2}}$$

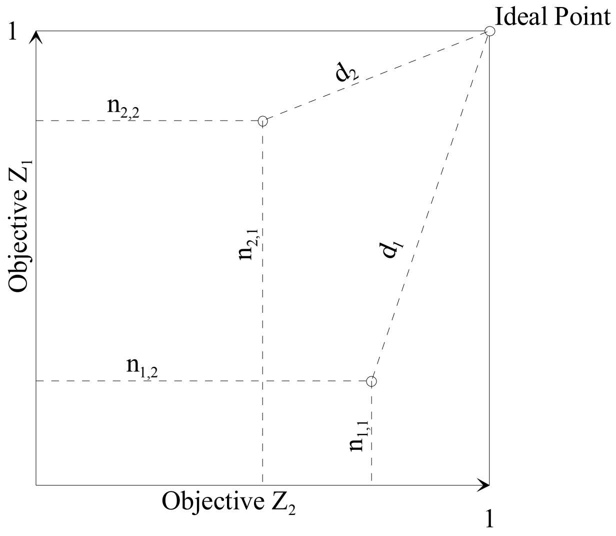

Figure 5: 2-D geometrical interpretation of distance-based methods

For a two-dimensional case, the procedure is illustrated in Figure 5. By introducing a compensation factor p and the weights α for each alternative, the distance from the ideal point in an i-dimensional space is computed using

$$d_i = \left[\sum \alpha_i \left(1 - n_{ij}\right)^p \right]^{\frac{1}{p}}$$

The parameter p reflects the DM's concern with respect to the maximum deviation and determines how a poor achievement of one objective can be compensated with a good performance in another. For p=1, the Hamming distance is calculated and all deviations are weighted equally (i.e. a perfect compensation). For p=2, the Euclidean distance penalises large deviations from the ideal point. The larger p, the larger is the weight for the largest deviation. For the Chebychev distance (p=∞), there is no compensation between criteria. The assessment depends on the largest deviation from the ideal point. The sensitivity of the power factor is depicted in Figure 6.

The weight α_i reflects the DM preference or relative importance of the *ith* objective. Usually, only three points of the comparison set are computed, p=1,2 and ∞. The alternative with the minimum distance to the ideal point with respect to p is selected as the compromise solution.

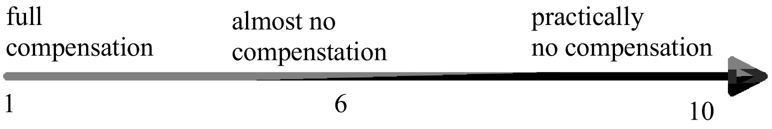

Figure 6: Sensitivity of the power factor p

5. Indicators

5.1 Introduction

Given the wide range of circumstances that exist in the regions in terms of water demand pattern, institutional conditions, development priorities etc. it is very difficult to define one unique set of indicators that is applicable for all regions and is capable of describing all objectives. It is therefore suggested to use a set of core indicators that is supplemented individually if necessary.

The core indicators proposed for an evaluation of strategies in terms of water quantity and quality are depicted in Figure 7.

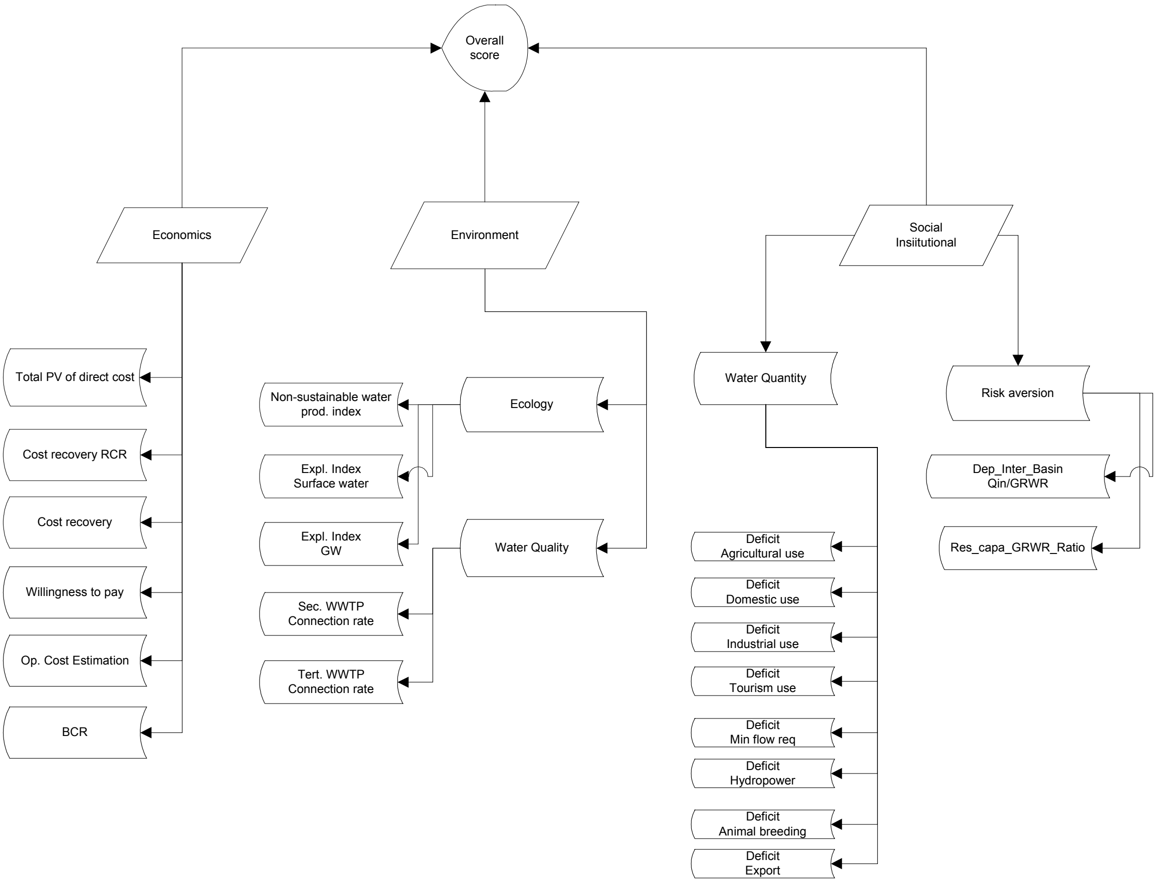

Figure 7: Grouping system for core indicators

5.2 Economic indicators

The indicators for assessing water resources systems in terms of economic costs and environmental impacts that are presented in the following section are taken from deliverable 7.2 that has jointly been prepared by OIEau, NTUA and the Hebrew University of Jerusalem. It must be noted that all indicators are spatially aggregated indicators that are computed for the entire entity under consideration.

5.2.1 Total present value of the direct costs

$$TVPC = \sum_{t=0}^{T} \frac{P.Q_t}{(1+r)^t}$$

where:

the planning period begins in the current year, t = 0, and extends to some future planning horizon T (in year) ;

P = the price per unit of supplied water charged by the water company (in Euros) ;

Q_t = annual quantity of supplied water (in m^3) ;

r = the annual **real** interest rate relevant for the investor.

5.2.2 Cost recovery from water billing to reach sustainability of technical systems (RCR):

$$RCR = \left(\frac{\text{Revenues from water billing}}{\text{Cost of sustainability of technical systems}} \right) \cdot 100$$

Where:

$$\text{Revenues from water billing} = \sum_{j} \left(\text{Billed Volume}_j \cdot \text{Price}_j \right)$$

Cost of sustainability of technical systems = C_{STS}

$$C_{sts} = \sum_{ij} \left\{ C_{i,j} \cdot \left[\frac{(CostPV_i)}{t_i} \right] + CostAO_i + CostAM_i \right\} + \sum_{kj} \left\{ TL_{k,j} \cdot \left[\frac{(CostPV_k)}{t_k} \right] + CostAO_k + CostAM_k \right\}$$

Where *i*, *k*, *j* the parameters that are presented in Table 3.

Table 3: Parts of infrastructure and different water users

Plant *i*	**Total network length *k***	**Users *j***
Dams	Water distribution net	Permanent population
Water catchment	Sewer network	Seasonal population
Water treatment plant	Irrigation network	Irrigation
Distribution systems for freshwater treatment		Industry
Waste water treatment plant		Power generation
Distribution systems for waste water treatment		

and:

C_i: Capacity of i (in m^3)

$CostPV_i$: Present value of i (in Euros)

$CostAO_i$: Average Operating Costs of i (in Euros)

$CostAM_i$: Average Maintenance Costs of i (in Euros)

t_i: Depreciation period (useful life) of i (in year)

TL_k: Total length of network k (in m)

$CostPV_k$: Present value of network k (m^3)

$CostAO_k$: Average Operating Costs of network k (in Euros)

$CostAM_k$: Average Maintenance Costs network k (in Euros)

t_k: Depreciation period (useful life) of network k (in year)

5.2.3 Cost recovery rate for water service

$$CRR = \left(\frac{\mathrm{TR} - Subsidy}{TC} \right) \cdot 100$$

Where:

TR: total revenues from water billing (depending on the cost recovery mechanism - this figure could be based on either fixed or variable charges in € / years)

Subsidy: the total amount of subsidies paid to the water service

TC: the economic costs (in € / year) of water service provided

5.2.4 Willingness to pay for the Conservation of the resource

The comparison between the Total cost of the decision and the willingness to pay for the conservation of the resource can give an indication of the acceptability of the proposed solution.

If there is no local data providing by a scientific survey, willingness to pay for the conservation of the resource should be estimated by the end used of the DSS. Some examples should be provided by the DSS for this estimation (see Table 4).

Table 4 Willingness to pay for the Conservation of the resource (case of ground water) (Source : Point Patrick and alii – 1999)

Localisation	Source	Willingness to pay in euro (translation from Francs1995)	
		Scenario A : 25% of the resource is contaminated	Scenario B : 100% of the resource is contaminated
Alsace	Stenger – 1993	99,85	118,9
Wisconcin	Poe and Bishop – 1993	135,8	550,65
Georgia (USA)	Jordan Elnagheeb – 1993	70,7	96,35
Georgia (USA)	Sun and al. – 1992	**530,2**	
Sweden	Silvander – 1991	36,4	71,35
Massachusetts, pennsylvania, New York	Powell and Allee – 1990	38	73
Dover, new hampshire	Shultz and Lindsay – 1989	**117,2**	
Anglia	Hanley – 1989	**21**	
Cape Cod – Sample A	Edwards – 1988	**357,2**	
Cape Cod – Sample B	Edwards – 1988	**1428,6**	

The book of Richard Carson from University of California, San Diego, entitled: " Contingent Valuation: A Comprehensive Bibliography and History (March 2002)" which includes more than 5000 contingent valuation papers and studies from over 100 countries will give us lot of other examples.

5.2.5 Opportunity cost estimation

The opportunity costs (*P*) of water is equal to the sum of the marginal direct cost and the scarcity rent, i.e., $P = MC_1 + \lambda$.

5.2.6 Benefit-cost ratio = BCR

$$BCR = \frac{\left(\sum_{t=0}^{T} \frac{B_t}{(1+d)^t}\right)}{\left(\sum_{t=0}^{T} \frac{C_t}{(1+d)^t}\right)}$$

Where:

the planning period begins in the current year, t = 0, and extends to some future planning horizon T (in year) ;

B = total benefit in the subcripted year (in Euros) ;

C = total cost in the subcripted year (in Euros) ;

d = discount rate expressed in decimal form