Estimation of the level of cost recovery of different scenarios of water allocation in arid areas - an easy-to-implement approach

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Contents

I. Abstract

This work aims to present the integration of WFD economic elements in a prototype Decision Support System for the evaluation of water management options and strategies in arid and semi-arid regions. The DSS incorporates water availability, demand, allocation, quality, and economic models, all integrated in a GIS environment. Water allocation between the various uses is simulated for a long time horizon using a deterministic model running on a monthly time step. Evaluation of alternative options and strategies is based on a set of well-defined, comprehensive indicators, expressing the three major principles of Integrated Water Resources Management underlined in the Water Framework Directive: economic efficiency, equitable allocation of resources and costs, and environmental sustainability. The economic evaluation and the development of appropriate cost recovery strategies for alternative water management options and strategic plans is based on the estimation of financial, environmental, and resource costs associated with the different uses. This paper presents results from the case study conducted for the island of Paros, Greece, developed in the framework of the EU-funded WaterStrategyMan project – "Developing Strategies for regulating and managing water resources and demand in water deficient regions" (EVK1-CT-2002-00098).

II. Introduction

In the context of the EU Water Framework Directive, the systematic evaluation of water management interventions should be performed for a long time horizon, simulating long-run accumulative effects and anticipating potential future changes and uncertainties. Indicators selected should assist decision-makers in identifying the appropriate policy and management instruments in relation to regional economic growth and environmental sustainability. Complex integrated modelling can meet those objectives when based on comprehensive information systems. Multidisciplinary information is needed for the analysis of water management strategies and plans, and evaluation of their effects, taking into account economic, hydrologic and environmental interrelationships (McKinney et al. – 1999, Bouwer – 2000, Albert et al. – 2001). A variety of models and systems have been developed for water allocation and quality estimations. The systematic formulation and evaluation of alternative policies and strategies integrating the economic principles of the WFD is however missing.

One of the most ambitious objectives of WFD that directly influences economic sectors and water uses is the adequate recovery of the cost of water services. In the first stage of implementation, Member States have to assess the level in which the cost of water services is recovered in each river basin. In the next stage they are obliged to use appropriate pricing policies towards an appropriate level of recovery of water services cost. The level of recovery of water services cost and the extent to which the *polluter pays principle* is applied is assessed through the following steps:

- Determination of water service providers, users and polluters;
- Assessment of the full water cost;
- Identification of the cost recovery mechanism and cost allocation to the different users;
- Estimation of the level of cost recovery.

Under this context, the following paragraphs briefly present the different components of the total cost of water services and the methodologies proposed for their estimation, as outlined by the WATECO Working Group. It should be noted that in all cases the most crucial step is the determination of the service providers, users and polluters. The spatial analysis, the type of entities involved and the type and extent of environmental impacts from the provided services are the main factors that have to be analysed.

Article 9.1 of the Directive refers to the recovery of the full cost of water services and clarifies the cost components that should be included in the full costs. Figure 1 presents the components of full water cost that include:

- The financial cost, including the costs of investments, operation and maintenance, labour, administrative costs and other direct economic costs.
- The resource cost, representing the loss of profit because of the restriction of available water resources.
- The environmental cost, expressing the cost from the damage to the environment and aquatic ecosystems caused by the water uses and services.

The estimation of financial cost is rather straightforward but requires the choice of suitable values for all the parameters such as investments lifetime, discount rates, value of existing infrastructure and depreciation methods. General taxes and subsidies are not included, while environmental taxes are included in the environmental cost since they constitute part of it.

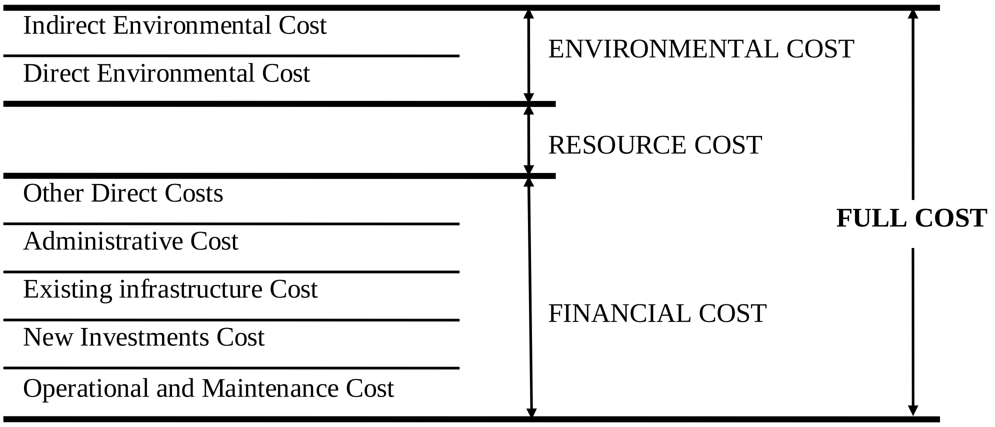


Figure 1. Components of the full cost of water services (WATECO – 2002; Rogers P., Bhatia R., Huber A. – 1998)

An assessment of resource costs can be based on the estimation of the water price before and after the reduction of water resources. Figure 3 outlines the estimation procedure, which requires that the demand curve for both uses and the availability of water resources are available.

When water demand for all competing uses is covered adequately, resource cost is zero. However, the resource cost can increase considerably when water shortages occur for certain water uses. Resource costs for a specific use can also be assessed on the basis of the foregone economic benefits from competitive water uses (Rogers P., Bhatia R., Huber A. – 1998).

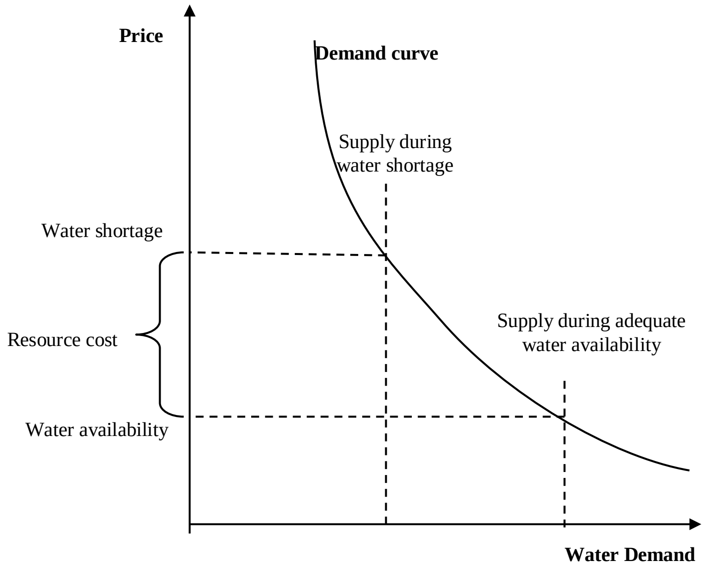


Figure 2. Estimation of resource costs (WATECO – 2002)

Environmental costs can be assessed using several methods such as (WATECO, 2002):

- *Market methods* (valuation of environmental costs and benefits): These methods use values from prevailing prices for goods and services traded in markets;
- *Cost-based* valuation methods (used as a technique for the valuation of environmental costs and benefits): This method is based on the assumption that the cost of maintaining an environmental benefit is a reasonable estimation of preventive and / or mitigation measures;

- *Revealed preference methods* (used as a technique for the valuation of environmental costs and benefits): The underlying assumption is that the value of goods in a market reflects a set of environmental costs and benefits, and that it is possible to isolate the value of the relevant environmental values. These methods include recreational demand methods, hedonic pricing models and averting behaviour models;
- *Stated preference methods* (used as a technique for the valuation of environmental costs and benefits): These methods are based on measures of willingness to pay through directly eliciting consumer preference on either a hypothetical or an experimental market;
- *Contingent Valuation*: Contingent Valuation is based on survey results. A scenario including the good that would be delivered and how it would be paid for (e.g. through an increase of the water bill) is presented to the respondent.
- *Use of Value Transfer* (an alternative option to the direct valuation of environmental costs or benefits - more commonly known as *Benefit Transfer* in the case of benefits): This method uses information on environmental costs or benefits from existing studies and uses this information for the analysis in the area under consideration.

Article 9.1 of the directive determines that an "*adequate contribution of the different water uses*" should be achieved through the water pricing policies. This requirement suggests that grants, subsidies and general taxes should not be taken into account in the estimation of water services costs and the design of the cost recovery mechanism. Moreover, it suggests that efforts should be made to expand the level of user contribution on the recovery of water services costs.

The next paragraphs briefly describe a prototype DSS for assisting decision making under a GIS environment for strategic planning in the context of the economic principles outlined in the WFD and environmental sustainability objectives. The DSS emphasizes on the water stress problems and social conflicts arising in arid and semi-arid regions. The system is currently being applied to river basins and administrative regions in Greece, Italy, Cyprus, Portugal, Israel and Spain; however it can easily be extended to work with other regions (WaterStrategyMan project, 2003). In this work, the approach is demonstrated through an exemplary application in a typical Greek island.

III) Decision Support System Overview

The developed (prototype) DSS uses the concept of a **water management scheme** (WMS), defined as a set of scenarios for variables that cannot be directly influenced by the decision maker (i.e. rainfall patterns constituting a water availability scenario and population growth formulating a demand scenario) and the application of one or more water management interventions or instruments. An overview of the interface (presentation of detailed results) is depicted in Figure 4.

The concept of the prototype DSS is the simulation of water management strategies or single interventions under different scenarios. Then those can be compared, and the decision maker or the analyst can formulate responses to mitigate water stress impacts with respect to their objectives, economic or environmental. For this purpose, different models have been incorporated for estimating:

- Water availability;
- Demand;
- Water allocation;
- Water quality;
- Cost estimations, that include financial, environmental and resource costs and allocation of these to particular uses.

Water resource systems are modelled on the basis of geometric networks. A geometric network is described as a set of junctions (points) and edges (polylines) that are topologically connected to each other. In the Object Model junction elements are conceptualized as water nodes while the connections between them are the water links. Water nodes are classified into three categories, (a) supply nodes standing for alternative water supply sources and characterized by the monthly available supply,

(b) demand nodes modelling water uses and flow requirements and, (c) transhipment nodes standing for treatment plants and generic network junctions. Water link objects are classified in four categories according to the connectivity rules of the system and the particular modelling requirements of the DSS, (a) supply links (pipelines and canals) conveying water from supply sources to demand nodes, (b) groundwater interaction links (recharge and discharge), representing the natural interaction between surface and groundwater bodies, (c) return flow links, conveying return flows from consumptive demand uses to receptor bodies (surface or groundwater) or wastewater treatment plants, and (d) river links, representing the natural course of a river water body. An overview of the water nodes incorporated in the system is presented in Figure 5.

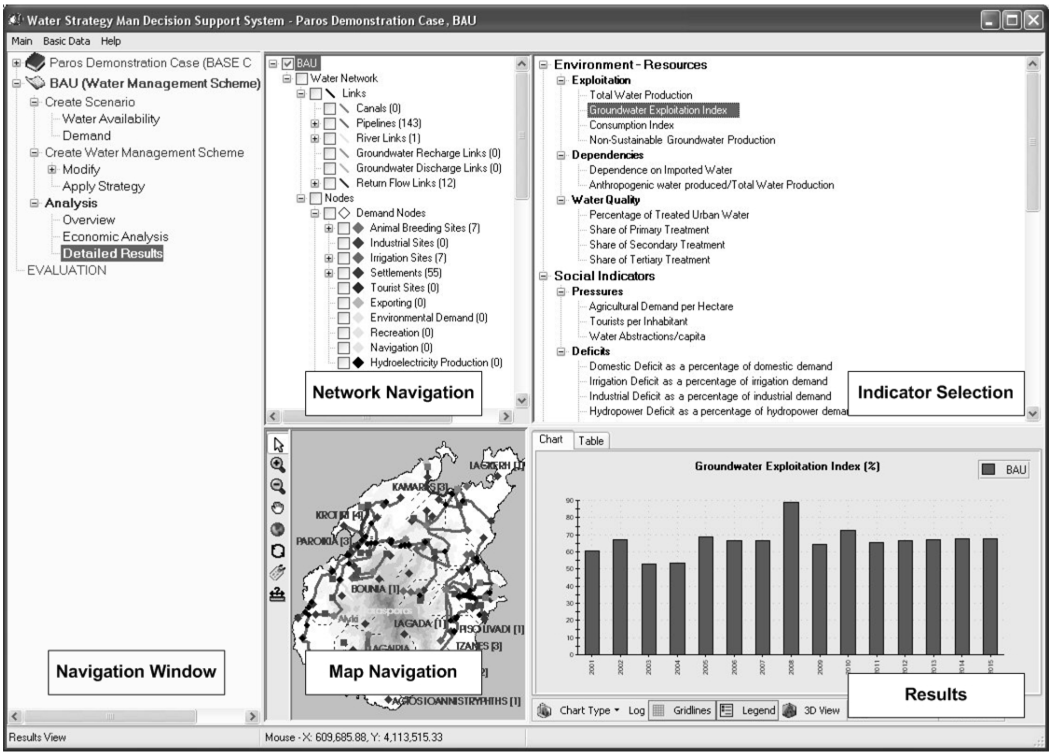


Figure 3. The Detailed Results interface of the DSS

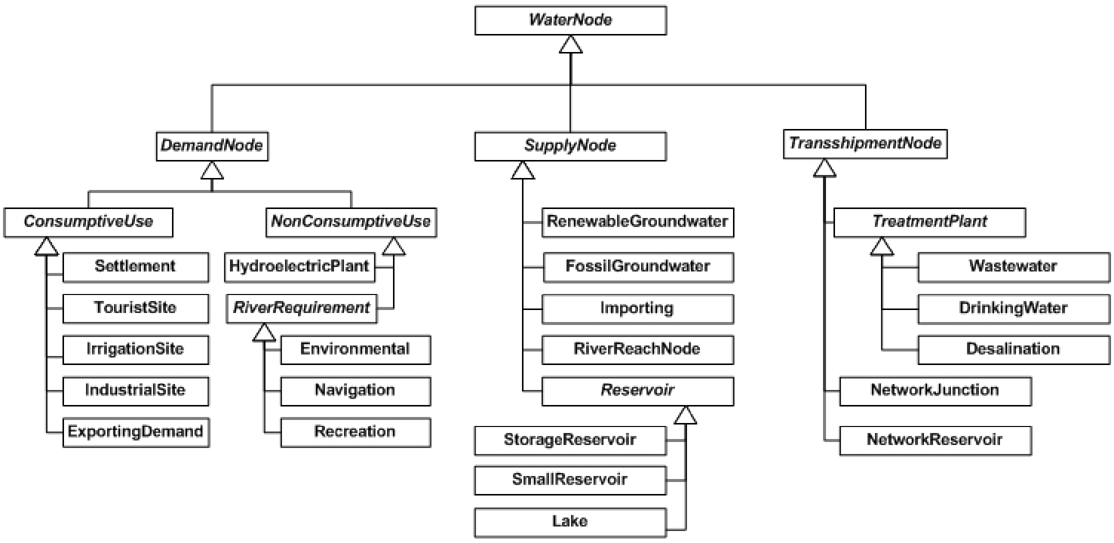


Figure 4. Overview of the modelled nodes of the water resource system

A) Water allocation and modelling of water management options

Economic optimization models, aiming to maximize the social water surplus require the monetary valuation of environmental impacts, societal objectives, developmental priorities and property rights, which in most cases is subject to many constraints and limits the applicability of a tool. The DSS **water allocation** model minimizes water shortage under limited water supplies (Manoli et al., 2001). In situations of water shortage, distributing the water available from the various supply sources to the connected uses creates conflicts. The allocation model can solve this problem using two user-defined priority rules. First, competing demand sites are treated according to specified priorities. Those can express social preference or constraints, economic preference (prioritization to activities with highest economic values), or a system of water rights. In case that a particular use can be supplied by more than one resource, supply priorities are used to rank the choices for obtaining water. Supply priorities in this case express:

- cost preference;
- quality preference of uses (e.g. domestic or industrial use) for supply sources with high water quality;
- need for the protection of resources and the formation of strategic reserves.

A characteristic of the DSS is that it predefines a number of “abstract” water management measures and instruments (actions) and incorporates them as methods into the system. Those actions modify accordingly the properties of the water system objects or introduce new ones, related to water infrastructure development. An “abstract” action becomes “application specific” by the user-definition of its magnitude, time horizon and geographic domain. An initial set of actions that can be taken into consideration is presented in Table 1. Actions incorporated are mainly focused on instruments to deal with the frequent water shortages occurring in arid regions. The main aim is to either enhance supply, promoting the protection of vulnerable resources through structural interventions, or to regulate demand through the promotion of conservation measures, technological adjustments for promoting efficiency of water use, and pricing incentives.

Table 1. Summary Table of Policy Options and related Actions

Policy Options	Actions
Supply Enhancement	o Unconventional/untapped resources o Surface Waters and precipitation (direct abstraction, dams, reservoirs) o Groundwater o Desalination o Importing o Water Reuse
Demand Management	o Quotas, Regulated supply o Irrigation method improvements o Conservation measures in the home o Recycling in industry and domestic use o Improved infrastructure to reduce losses (networks, storage facilities) o Raw material substitution and process changes in industry
Social-Developmental Policy	o Change in agricultural practices o Change of regional development policy
Institutional Policies	o Economic Policies (Water pricing, Cost recovery, Incentives)

B) Evaluation and Economic Analysis

Evaluation of alternative schemes takes into account the entire simulation horizon. As a first step, time series of indicators are computed, describing the behaviour of the water system in terms of environmental, efficiency, and economic objectives (Table 2).

Table 2. Summary of indicators in the DSS evaluation procedure

Category	Indicator
Environment Resources	Dependence on Inter-basin water transfer
	Desalination and reuse percentage
	Groundwater exploitation index
	Non-sustainable water production index
	Share of treated urban water
Efficiency	Coverage of Animal breeding, Domestic, Environmental, Hydropower, Industrial and Irrigation demands
Economics	Direct Costs
	Benefits
	Environmental Cost
	Cost recovery rate

The comparison is performed through a multi-criteria analysis based on the computation of statistical criteria for reliability, resilience and vulnerability (Bogardi and Verhoef- 1995; ASCE- 1998). The statistical criteria express the behaviour of the monthly or yearly time series of each indicator with respect to the predefined range of satisfactory values that the indicator can assume. *Reliability* is defined as the probability that any particular indicator value will be within the range of values considered satisfactory. *Resilience* describes the speed of recovery from an unsatisfactory condition. *Vulnerability* statistical criteria measure the extent and the duration of unsatisfactory values. Performance for each indicator is computed as the product of the above criteria, and the relative sustainability index of each WMS is the weighted sum of the performance of the selected indicators, and can be used to rank alternative strategies or modelled actions according to the objectives of the undertaken analysis.

Alternatively, the evaluation of alternative schemes can be performed through the economic analysis. The primary aim of the **economic analysis of water management schemes** is the estimation, according to the results of the allocation algorithm, of financial, environmental and resource costs. A water services cost recovery strategy can be used as an indication of pricing structures that could meet the desired cost recovery levels. Detailed reference on the models used for implementing the economic analysis of water management schemes can be found in the Annex of this document.

Estimation of financial costs associated with the provision of water supply is rather straightforward and depends on data entered for the amortization of capital investments, specific energy consumption and cost, and other operation and maintenance costs associated with each part of the infrastructure.

For the estimation of environmental costs, a practical model based on the concept of cost valuation has been adopted. The aim of the model is to approximate environmental costs as the cost of preventive or mitigation measures that are required in order to prevent environmental damage or to achieve good status, using localised coefficients according to the vulnerability of each water body. Currently, two types of environmental costs have been incorporated, one for the abstraction and consumptive use of freshwater resources (surface and groundwater) and one for the discharge of polluting effluents from the various economic activities.

Resource costs in the current assessment are approximated by the **scarcity rent**. The scarcity rent of water, (i.e. the rent per unit of a scarce resource - water in this case) is a surplus, the difference between the opportunity cost of water (equal to the market equilibrium price P) and the per unit (marginal) direct costs (such as abstraction, treatment and conveyance) of turning that natural resource into relevant products (e.g. agricultural crops for farmers and water services for the residence of the urban centre).

IV) Application of the prototype Decision Support System-The Case Study of the island of Paros, Greece

A) Case Study Overview

The island of Paros, with an area of 196 km² is one of the most popular tourist destinations in the Cycladic Complex in Greece, and has a registered permanent population of 12,800 that is increased by as much as 300% during the summer months. The rapid development of the tourist industry in the last 30 years made the creation of new infrastructure necessary to cover the ever-increasing needs of the visitors and the lodging owners. The little-by-little infrastructure development took place without proper planning and control, leading to the problems that the island is facing today, both economic - offer of accommodation being greater than demand of accommodation - and environmental - great seasonal pressures applied on water resources. The water demand growth of the last decades has been addressed mostly with extensive water drillings, both public and private, to supply the domestic and agricultural sectors. Paros is a typical case where the water shortage occurs on a seasonal basis. Tourism and irrigation demand reach their peak during the same time, in the summer, creating conflicts between uses and problems with water supply adequacy during peak consumption.

Under this context, the goal of the formulation of scenarios and strategies for Paros Island is to reconcile the supply and demand of water, resulting in the coverage of the domestic demand, while at the same time attempting to ensure the sustainability of supply and the achievement of environmental goals for the island, through protection of the vulnerable groundwater resources. The target set for the analysis that follows was to:

- Meet at least 80% of the domestic and irrigation needs in the peak summer period, and
- Meet 100% of the domestic and irrigation needs during the rest of the year.

Domestic needs in the year 2004 are estimated at approximately 1.96 hm^3. Irrigation demand is estimated at approximately 2.5 hm^3. In a “business as usual” scenario domestic demand is estimated at 2.5 hm^3 in 2020 and 2.9 hm^3 in 2030, resulting in a total deficit (under normal hydrology conditions) of 1.36 hm^3.

B) Identification of options, and evaluation under different scenarios

Potential policy options that could address those problems have been identified through consultation with the local stakeholders. As expected, locals proposed a number of different approaches to water resources management for Paros, according to their different goals and economic interests. For the **Municipality of Paros**, water management should concentrate mainly on supply enhancement through structural interventions, such as boreholes, interception dams and desalination. The perception of the **Municipal Office of Water Supply and Sewerage** (the local Water Utility) is quite different. They hold the opinion that new measures should concentrate on the more efficient use of water resources, through technological adjustments, conservation campaigns and regulation of groundwater abstractions. They too recognize the necessity for structural interventions; however they would like to promote more technical solutions, such as desalination, without abandoning the traditional practices of groundwater exploitation. The **Union of Agricultural Associations** and the **Union of Hotel Room Owners** have similar points of view. Both consider that an expansion of desalination capacity would be an efficient solution for dealing with the water scarcity problems. They are increasingly aware of the limited available supply and recognize the benefits of technological adjustments and rationalization of water usage.

As a result of the consultation process, a series of options were identified and selected for evaluation in order to formulate alternative responses. Those are outlined in Figure 5.

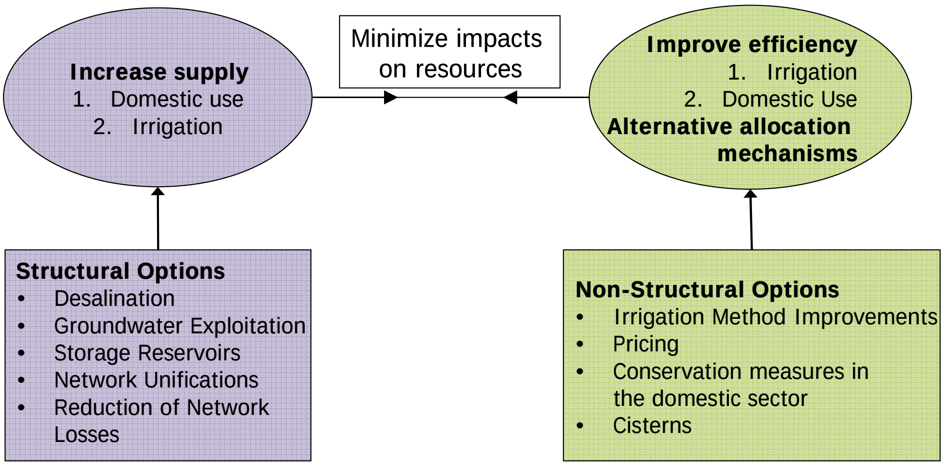


Figure 5. Summary of identified feasible and available options for the island of Paros

The behaviour of the water system under each management option was assessed under three alternative baseline scenarios, a best case scenario, a worst case scenario and a business as usual scenario. Those scenarios have been derived from the combinations of availability and demand scenarios, including scheduled interventions as these are planned, and constitute the reference scenarios under which the different management options have been evaluated. In brief, all examined management options were evaluated under the following conditions:

- A combination of high demand with a high frequency of dry years (**BAU+HD**), reflecting the worst case scenario of water shortage,
- A combination of reduced demand with a high frequency of wet years (**LD+HW**), reflecting the best case scenario, and
- A combination of high demand with a series of average years (**BAU+Normal**), in an effort to reflect the current trends of the system in a "business as usual" context.

A specific set of indicators has been selected, considered as representative of the water management issues experienced in the island of Paros. Those were:

- **Effectiveness vs. time** for irrigation and domestic use, expressed as:
    - Coverage of water demand;
    - % improvement of deficit with respect to each reference scenario;
- **Total direct cost** for the provision of water services and the application of the different options, expressed in present value terms,
- **Total environmental cost**, incurred from pollution and (over)exploitation of groundwater resources, expressed also in present value terms.

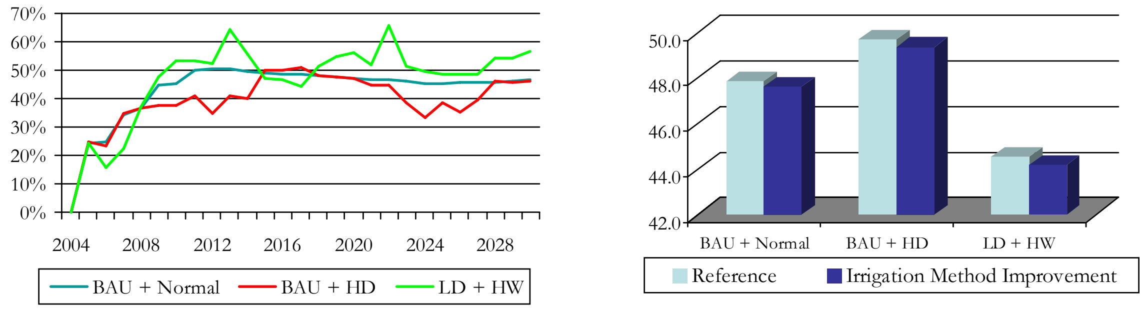
Figure 6 presents an example of the results obtained from irrigation method improvements, in terms of improvement in effectiveness to irrigation demand coverage and environmental cost.

Environmental costs for the case of Paros are associated with:

- Groundwater abstraction
- Pollution generated from domestic uses.

In the first case, environmental costs are associated with overabstractions from the major aquifers. The selected reference period runs from May to September and the average costs incurred from abstraction were set equal to 0.5 €/m^3.The vulnerability of each aquifer to overabstraction was effected through the use of area coefficients, ranging from 0.5 (less vulnerable) to 1.8 (highly vulnerable).

With respect to pollution, environmental costs have been estimated as equal to the operating expenses of a secondary treatment plant for wastewater. Since no particular environmental problems have been recorded in terms of aquifer, stream or coastline degradation, the relevant coefficients were set equal to 1.



(a) (b)

Figure 6. Example of results obtained from the simulation of irrigation method improvements (a) % improvement of irrigation demand coverage with respect to reference scenarios (b) environmental costs for reference scenarios before and after the implementation of the option (present value – million Euros)

In order to rank the options identified, modelled and simulated in the Decision Support System, and select the most effective combination of measures with respect to the targets of the analysis, a **Performance Matrix** was derived. Results for the three baseline scenarios were combined and normalized in order to obtain a preliminary ranking of the management options to be used for the formulation of alternative strategies. The obtained normalized matrix is presented in Table 3.

Table 3. Normalised option performance matrix[1]

Option	Relative Sustainability Index for Demand Coverage	Financial Cost	Environmental Cost
Base Case	-	*	**
Network Unifications	*	*	**
Storage Reservoirs	*	*	-
Loss Reduction	**	***	**
Irrigation Method Improvements	**	**	**
Irrigation Pricing	****	*****	****
Domestic Pricing	***	*****	**
Desalination	*****	*	**
Conservation	**	***	**
Cisterns	-	-	-
GW Exploitation	-	*	**

C) Formulation of strategies and estimation of total cost

Following the option ranking, two alternative Strategies, as combinations of water management options, were formulated to be evaluated against each other and against the reference case.

Strategy 1 focuses on the current mostly supply-oriented management practices, incorporating the newest techniques and methods applied and proposed, while Strategy 2 implements mostly demand management measures and small-scale structural interventions where such are required. In brief, the measures incorporated in each Strategy are presented in Table 4.

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[1] The reference case presented in the matrix refers to the combined results from the three reference scenarios, without incorporating any measures

Table 4. Specifications for the alternative water management strategies

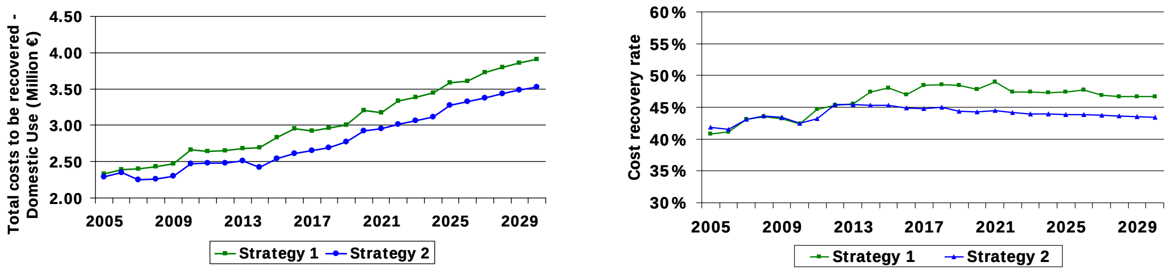
Strategy 1	Strategy 2
Groundwater Exploitation A total of 4 additional boreholes, yielding 204,000 m^3/yr **Surface water exploitation** Interception dam for aquifer enhancement Capacity of 98,000 m^3 **Reduction of Network Losses** From 25 to 20 % **Desalination** Additional capacity of: 1300 m^3/d in 2010 2000 m^3/d in 2020 2700 m^3/d in 2030	**Network Unifications** **Groundwater Exploitation** 1 additional borehole, yielding 75,000 m^3/yr **Surface water exploitation** Interception dam for aquifer enhancement Capacity of 98,000 m^3 **Reduction of Network Losses** From 25 to 20 % **Conservation measures in the hotel sector** 10% reduction of consumption **Irrigation Method Improvement** Substitution of current methods with drip irrigation **Desalination** Additional Capacity of 600 m^3/d

The temporal planning of option application was based on the technical aspects of the selected options (e.g. lifetime, construction time etc), as well as the performance of each option as presented in Table 3.The results of the evaluation of the two strategies are presented in Table 5.

Table 5. Strategy evaluation results

	Relative Sustainability Index for Demand	Financial Cost (PV – million €)	Environmental Cost (PV – million €)	Resource Cost (PV – million €)
Reference case	0.000	25.2	49.2	5.40
Strategy 1	0.503	30.9	50.1	1.90
Strategy 2	0.504	26.8	49.8	1.60

Total costs (financial, resource and environmental) allocated to domestic use for the period 2005-2030 and the initially estimated cost recovery rate are presented in Figure 7. Under the proposed strategies, cost recovery rate for domestic use is estimated at approximately 40%. Although Strategy 1 entails additional capital investments, cost recovery is higher due to the augmented volume of water production.



(a) (b)

Figure 7. (a) Total costs allocated to domestic use and (b) cost recovery rate for the two evaluated strategies (period 2005-2030).

On a preliminary basis, the cost recovery scheme adopted was not tiered; flat-rate average volumetric prices were estimated instead, to be readjusted after 5-year periods. The set cost recovery targets, to be achieved through a gradual increase of prices, were:

- A 100% recovery of financial costs for the total duration of the examined period (2005-2030),
- An initial (in the year 2005) recovery of 50% of the associated environmental and resource costs, and
- A targeted (in the year 2030) recovery of 70% of the associated environmental and resource costs.

For Strategy 1 this defined an average price ranging from 1.47 €/m^3 in 2004 to 2.5 €/m^3 in 2005 and 2.8 €/m^3 in 2025. Price increases for Strategy 2 were higher ranging from 2.9 €/m^3 in 2005 to 3.05 €/m^3 in 2015, 3.26 €/m^3 in 2020 and 3.44 €/m^3 in 2025.

The proper formulation of a cost-recovery scheme is performed in two steps. The first requires the setting of a cost recovery target for each of the three major cost categories, financial, environmental and resource costs. The current pricing scheme can then be analysed with respect to the recovery of these costs, thus providing an estimate of the increases in price required in order to reach the set targets. These estimated increases will be then incorporated in the current pricing system, and yield a set of initial prices for meeting cost-recovery targets. As the elevated water prices will in most cases influence the water demand, each strategy was re-evaluated, incorporating the new pricing system. Given the demand elasticity for the domestic use in Paros, estimated at -0.2, the introduction of pricing is expected to affect the demand significantly. Therefore an iterative process was used in order to redefine the extent for the application of options, their costs, and the prices required for the targeted cost recovery. By this process, the final prices for domestic supply in the year 2030 were determined at:

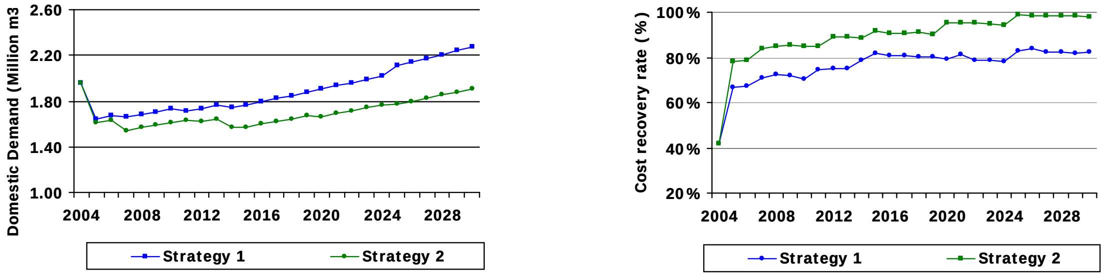
- 2.7 €/m^3 for Strategy 1, and
- 2.9 €/m^3 for Strategy 2.

Following the re-adjustment of the two Strategies to reflect the effects of pricing, their performance was re-evaluated; the re-evaluation results are shown in Table 6 below.

Table 6. Adjusted strategy evaluation table under a cost recovery scheme (values before re-adjustment are in brackets)

	Relative Sustainability Index for Demand	Financial Cost (PV – million €)	Environmental Cost (PV – million €)	Resource Cost (PV – million €)
Reference case	0.000	25.2	49.2	5.40
Strategy 1	0.503 (0.503)	26.8 (30.9)	47.60 (50.1)	1.90
Strategy 2	0.508 (0.504)	23.2 (26.8)	46.8 (49.8)	1.60

The final cost recovery achieved, as a result of the new tariffs is presented in Figure 8.



(a) (b)

Figure 8. (a) Domestic Demand (Million m^3) under the applied cost recovery scheme and (b) Final cost recovery rate for domestic use (period 2004-2030).

Following the final evaluation of the two Strategies against each other and the reference case, it can be inferred that pricing will not influence the size of the infrastructure needed for the coverage of demand. The total water consumption (including both domestic use and irrigation) remains the same as the demand decrease in the domestic sector only means that the water volumes available to irrigation are increased. Due to the current institutional frameworks in Greece, pricing of irrigation water is an instrument that cannot for the time being be implemented in Paros, as it would require a major governance reform; a subsidy is therefore always present between the domestic and agricultural use of water. The evaluation results for Strategy 2 compared to the reference case and Strategy 1 emphasise that the high temporal water imbalance in the island of Paros can best be solved through a combination of small-scale structural interventions and soft interventions aiming to increase the efficiency and productivity of water use.

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VI) Annex: Summary of economic formulas used in the prototype Decision Support System

A) Estimation of the total financial cost

Total financial costs are estimated as:

$$TFC = \sum_{i=1}^{n} AEC_i + OMCost_i + ECCost_i$$

where:
TFC is the total financial cost
AEC_i is the annual equivalent capital cost for infrastructure i
$OMCost_i$ are the annual operational costs (excluding energy consumption) for infrastructure i.
$ECCost_i$ are the annual energy costs for infrastructure i

Annual equivalent capital costs for a part of the infrastructure are determined as:

$$AEC_i = \frac{CapitalCost_i \cdot DiscountRate}{1-(1+DiscountRate)^{-DepreciationPeriod_i}}$$

Operation and Maintenance Costs are calculated through the following equation:

$$OMCost_{i,t} = SpecificOMCost_i \cdot \sum_{Months} WaterInflow_{i,Month}$$

Finally, energy costs are determined through the energy consumption for a part of the infrastructure:

$$ECCost_{i,t} = \sum_{Months} EnergyPrice \cdot EnergyConsumption_{i,Month}$$

where $EnergyPrice$ is the tariff corresponding to the actual level of energy consumption.

Allocation of financial cost to particular uses

Financial costs are allocated to particular water uses proportionally to the water distributed to each one of them on an annual basis, based on the principle that each user should pay for the part of the infrastructure that he is using. For each node, the additional financial cost for allocating water is estimated, summing the direct costs coming from all incoming supply links (pipelines and canals). Therefore, the total financial cost at the inflow point of each node is computed as:

$$TFC_{outflow_{j,t}} = \sum_{i=1}^{n} TFC_{i,t}$$

Then, the total financial cost at the outflow point estimated as the sum of the total financial cost at the inflow point and the financial cost related to the operation of the node. For nodes modelling domestic uses (settlements and tourist sites), an additional operation is performed in order to adding the direct cost related to wastewater treatment.

In case of joint infrastructure (i.e. infrastructure supplying more than one uses), the total financial cost is distributed according to the supply allocated to each. The operation is different according to the financial cost component:

- **Annual equivalent capital costs** are distributed according to the yearly share of the inflow of the link over the total outflow from the node. This determines in the long run the part of the infrastructure that is used by each demand node.
- **Running costs** (operation and energy) are distributed according to the monthly share.

B) Total value to users

The calculation of total social welfare surplus and total value to users is a prerequisite for the estimation of resource costs. Total values are calculated for each user i.e. domestic users, irrigation users, animal breeding activities, industries and electricity productions. Estimations are performed on an annual basis. This section focuses on the two major water consuming sectors, i.e. domestic use and irrigation.

Domestic use

Total value to domestic use (from settlements and tourist sites) is estimated according to the domestic use water value (marginal value).

$$Benefits_{DomesticUse} = \sum_{DomSites} YearlySupplyDelivered_{DomSite} * DomesticValue_{DomSite}$$

Computation can be performed in two ways:

- ⇨ Through data entered by the user. Those data can be derived either through the urban demand curve or through the aggregated willingness of the city residents to pay for water.
- ⇨ Through the approximation that the domestic use value is equal to the cost per m^3 of the most expensive supply source **under use**. In this case it is assumed that the marginal value of water is identical to its average value and equal to the marginal cost of supplying water. When this type of computation is selected, the domestic use value is set equal to the highest cost carried by the incoming supply links.

Irrigation

Field crops

The value of water per ha of irrigated area for a field crop is estimated by:

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where:

V_{FC} = value of irrigated area for a field crop (€/ha);

MC_{FC} = the expected sale price of the crop, net of non-water variable costs (€/ha);

C_{FC} = costs per hectare, independent of the level of yield;

k = the alternative value of land. Commonly it is measured by the net profits, in €/ha, of the best alternative non-irrigated crop, like rain-fed wheat).

Orchards

For orchards, besides the net average annual profit, the value of water has to take also into account the monetary losses associated with the replacement of the crop when the latter is “dried out” due to shortage conditions.

In this case, the net average annual profit per square meter, not including water costs and alternative costs of land, denoted as π is estimated by:

$$\pi = MC_{orch} - C_{orch}$$

where MC_{FC} is the sale price of the crop net of non-water variable costs and C_{orch} are costs per hectare, independent of the level of yield (fertilizers, insecticides, pruning, capital, etc).

The net present value of the loss associated with the replacement of a mature, x years old, grove by a new orchard, denoted by LOSS, is given by

$$LOSS = \pi \cdot \left[\frac{(1+r)^{CropLifetime-x} - 1}{(1+r)^{CropLifetime-x} \cdot r} \right] - \{-I - \sum_{t=1}^{MaturityPeriod} \frac{h_t}{(1+r)^t} +$$

$$\pi \cdot \left[\frac{(1+r)^{CropLifetime-MaturityPeriod+1} - 1}{(1+r)^{CropLifetime-MaturityPeriod+1} \cdot r} \right] / (1+r)^{MaturityPeriod} \}$$

where I represents the investment costs, measured in €/ha (plants, cultivation, new irrigation system, etc) in the new grove and $h_t,\ t = 1,\ldots, MaturityPeriod$ represents the costs (excluding water costs), in €/ha, associated with the operation of the pre mature grove at year t. Multiplying the $LOSS$ by capital recovery factor for Lifetime years yields the annual equivalent loss denoted by $AnnLOSS$. Namely,

$$AnnLOSS = LOSS \cdot \left[\frac{(1+r)^{Lifetime} \cdot r}{(1+r)^{Lifetime} - 1} \right].$$

The value of (fresh) irrigation water applied to a 5 year-old mature grove is composed of two components: [contribution of π €/ha to the annual net benefits in the fifth year] + [prevention of the loss associated with the replacement of the mature grove by a new one].
Thus the average value applied to mature grove can be approximated by:

$$V_{Orch} = \pi + AnnLOSS$$

For a particular irrigation site, the total benefits from water use are estimated by:

$$Benefits_{IrrSite} = \sum_{IrrCrops} IrrigatedArea_{Crop} \cdot V_{Crop}$$

C) Environmental Costs

Two types of environmental cost have been incorporated in the DSS:

- Environmental costs related to water abstraction and consumption. A distinction is made between renewable groundwater abstractions and surface water abstractions from rivers, lakes and storage reservoirs.
- Environmental costs related to effluent discharge after treatment.

For each of these categories an effort has been made to provide different methods of computation, according to data availability and the desired level of detail.

For the selection of the appropriate parameters, one should consider that the environmental cost should be equal to the cost (capital + operation and maintenance) of mitigation measures. Those can be, for example, use of desalinated or recycled (for irrigation) water to avoid groundwater overexploitation, interception dams for enhancing aquifer replenishment, new or upgrade of existing wastewater treatment plants etc.

Abstraction Environmental Costs

The estimation of abstraction environmental costs can be performed through two different alternatives:

- By assigning a charge for abstractions that result in exceeding the sustainable yield of an aquifer, in case of groundwater abstractions.
- By assigning different charges for water abstraction and consumption and adapting coefficients to account for the vulnerability of the water body (for both surface and groundwater bodies).

This section presents the second model incorporated in the Decision Support System, where environmental cost for abstraction and consumption is estimated through the following equation:

$$EC = \left[Abstraction_{RefPeriod} \cdot ChargeBase_{Abs} \cdot \left(AreaCoef + ImpactCoef \right) \right]$$
$$+ \left[Consumption_{RefPeriod} \cdot ChargeBase_{cons} \cdot \left(AreaCoef + ImpactCoef \right) \right]$$

where:

Error! Objects cannot be created from editing field codes. = abstraction from the groundwater resource the reference period (m^3);

Error! Objects cannot be created from editing field codes. = consumption of the consumptive demand node during the reference period (m^3);

Error! Objects cannot be created from editing field codes. = specific abstraction charge (€/m^3);

Error! Objects cannot be created from editing field codes. = specific consumption charge (€/m^3);

$AreaCoef$ = area coefficient;

$ImpactCoef$ = impact coefficient.

Abstraction and consumption are summed for the reference period. The reference period depends on the type of the water body and its vulnerability to overexploitation or sea-intrusion (for groundwater).

The volume consumed during the reference period is estimated on the basis of the abstraction during the same period, multiplied by a *"net consumption coefficient"* which takes according to the type of water use. The area coefficient varies according to the abstraction point and is used to express the vulnerability of the resource. Impact coefficients are used to relate abstraction to natural conditions and overexploitation. Their application depends upon two conditions that can be applied:

1. $Abstraction_{RefPeriod} > X$ m^3 during the reference period
2. $\dfrac{Average\ monthly\ flow\ at\ the\ abstraction\ point}{Storage\ of\ the\ driest\ month\ within\ five\text{-}yearly\ frequency\ at\ the\ abstraction\ point} > Y\%$

Values for the constants X and Y are chosen according to local conditions.

Pollution environmental costs

Pollution costs are used to take into account the degradation of resources due to the disposal of polluting effluents. Two different models are available:

- Estimation according to charges for the discharge of untreated effluents and addition of bonuses according to the level of wastewater treatment;
- Estimation according to specific charges for loads generated by the different activities, taking also into account the sensitivity of the receptor body.

In the second case, which is the model analysed here, environmental cost estimation depends on:

- The load generated by each consumptive use;
- The pollution charge;
- The vulnerability of the ecosystem where effluents are discharged;
- Pollution abatement by wastewater treatment.

For each use the pollution cost is estimated using the following equation, taking also into account the possible environmental benefits from wastewater treatment:

$$PolCost_{USE} = \sum_{X} Load_X \cdot Coef_{WB-X} \cdot R_X \cdot (1 - BonusAnnualCoef_{WWTP-USE-X})$$

where:

$PolCost_{USE}$ = Pollution costs allocated to the use (€);
X = Quality parameter;
$Load_X$ = Load of X generated by the node in load units of X;
$Coef_{WB-X}$ = Coefficient of the receptor water body for X (dimensionless);
R_X = Charge for X in €/Load Unit/yr;
$BonusAnnualCoef_{WWTP-USE-X}$ = Bonus annual coefficient of the wastewater treatment plant for X, if such exists (dimensionless).

The following quality parameters are currently included in the model:

- Total Phosphorus;
- Suspended Matter;
- Inhibiting Matter;
- Adsorbable Organic Halogens (AOX);
- Total nitrogen load;
- Coliform Bacteria;
- Heavy Metals.

Practically, bonus annual coefficients for each quality parameter are set equal to the respective pollution abatement coefficients. Pollution abatement coefficients are estimated according to an overall appreciation of the effectiveness of the wastewater treatment process. Other factors, such as sewage collection can also be taken into account for the calculation of the bonus annual coefficient.

D) Private and Social Water Surpluses

The private water surplus (net benefit from use of Q_j quantity of water) accrued to node j, denoted by PWS_j, is estimated as:

$$PWS_j = Benefit_j - P_j \cdot Q_j$$

where P_j is the average water selling price.

The social welfare surplus SWS is presented separately. It is computed as the total benefit - total cost (financial and environmental costs):

$$SWS = TotalBenefit - TotalDirectCost - TotalEnvironmentalCost$$