WaterStrategyMan

EVK1-CT-2001-00098

DELIVERABLE 16

COHERENT WATER MANAGEMENT SCENARIOS

Prepared by

NTUA

October 2004

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ANNEX – SCENARIO DATA

1. Preface

This document presents the work undertaken in the case study regions in Task 8.3 of the WaterStrategyMan Project, "Generation of Coherent Water Management Scenarios". The purpose of the task, as defined in the contract is "*build water management scenarios to evaluate alternative allocation options of water resources in the Case Studies*". The scenarios should be based on "*specific supply interventions or demand side actions*", and assess "*their effect on the current and future matching of water demand*", in a "*comparison with the base case*" using "*user-defined criteria*" set by "*the water users, regulators and decision makers*".

This task was undertaken separately by all the Case Study Partners of the Project under the coordination of the NTUA. Each Case Study Partner undertook the analysis of their respective Case Study Regions:

- The National Technical University of Athens, Greece,
- ProGeA S.r.l., Italy,
- The Hebrew University of Jerusalem, Israel,
- The Water Development Department of Cyprus,
- INSULA, Canary Islands – Spain,
- AIOLIKI Ltd, Cyprus, and
- The University of Porto, Portugal.

The present document compiles the findings in the six Case Study regions. The outcomes of the scenario analysis will be used for the formulation of appropriate Water Management Strategies for the Case Study Regions in the next stage of the Project.

2. Introduction

The major goal of the WSM Project is the development of appropriate alternative integrated water resources management strategies for each of the paradigms identified in the 1st Phase of the Project. These will take into account the principles of Integrated Water Resources Management:

- economic efficiency,
- environmental sustainability, and
- social equity.

In Water Resources Management, the word "paradigm" describes a school of thought on prioritizing Policy Options for the Management of Water Resources. Each paradigm refers to the:

- geographical entities and their grouping regarding physical and human criteria,
- driving forces like population or economic activity trends,
- physical parameters of the available water resources (state, uses, effects),
- planning and measures regarding the available resources.

The understanding of the existing policy options and actions that have been followed in order to manage water resources, and their theoretical background, lead to identification of some basic and distinct Paradigms of Water Resources Management for each region. Therefore, a dominant Paradigm for each region is the existing, traditional way of "how things have always been done", combined with the conditions that have led to that approach.

The formulation of a Paradigm is a difficult and complicated procedure as it reflects the conflicts between the established scientific and technological approach and the political and social opinions and demands. In order to define the range of and collect concepts that describe structural (dams, pipes) and human (administration, financial management) parameters of a water system, one must understand the technical, social, financial, cultural and environmental issues of the Paradigm.

The DPSIR approach, which is often used for the assessment of water management systems using indicators describing the existing Drivers, Pressures, State, Impacts and Responses, lends itself to a new interpretation in the description of Paradigm formulation (Figure 2-1). The drivers and pressures and their impact of water stress on the system are defined in terms of a Typology (see Table 2-1), whereas the Paradigm corresponds to the dominant responses used to mitigate water stress.

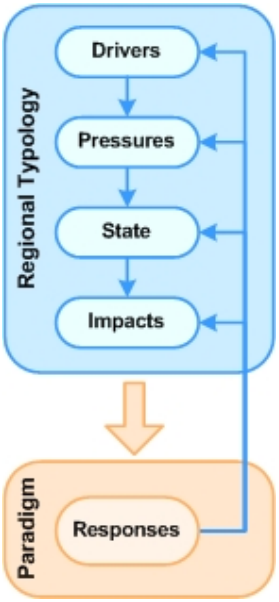


Figure 2-1. Paradigm development in the DPSIR context

The process of eco-adaptation means that the regional Paradigms are not static, as they both influence and are influenced by the regional characteristics in a continuous cycle. The responses employed to modify the water system are subject to the judgment of the local society; the most successful of these will be used again, and combined with any "new" methods that have been shown to be effective under similar circumstances. This new combination of responses constitutes an "Emerging Paradigm" that may in turn become dominant after it has been proven effective.

The integrated water resources management strategies under development fall under the scope of determining the Emerging Paradigm for the six regions of Case Study Analysis, described below.

1) Paros Island in the Cyclades complex, Greece. The main water stress issue is the peak in demand during the summer months, due to the high tourist influx onto the island. The existing infrastructure capacity is stretched during that period and is often insufficient to cover demand at peak times, leading to temporary shortages that in return are damaging to tourism.

- Typology: Predominantly tourist (Type II), insular.
- Dominant Paradigm: Since the water demand started to grow significantly in the 1980s, the residents of Paros have attempted to cover the water deficit through the construction of private and public drills, a small dam, seven interception walls and a small (1,450 m^3/day) desalination plant. However these have not been the subject of a systematic effort, and as such the policies followed have led to a number of problems in terms of both hindering economic development and exerting pressure to the environment. The dominant Paradigm on the island shows a strong tendency towards small-scale structural supply enhancement solutions.

2) The Limassol area, Cyprus. The effects of the competition for water resources between tourism and agriculture, the two major sources of income of the island, are being analysed, and the potential for a compromising water management solution that will be beneficial to both sectors needs to be determined. The region is one of the main tourist destinations in Cyprus, while at the same time its agricultural production accounts for more than 50 % of the fruit trees, 50% of the vegetable and 60% of the table grapes production of the country.

- Typology: Predominantly tourist (Type II), regional.
- Dominant Paradigm: The current strategy used for ensuring adequate water supply for all uses, responding to the current conditions of water deficit, is based on a combination of a number of policy options, which fall short however in achieving the goal of meeting demand. The Dominant Paradigm in the region is the combination of large-scale infrastructure, smaller structural interventions and reuse for supply enhancement.

3) Belice Basin, Italy. The major source of water stress is the peak in demand during the summer, due to irrigation demands in the region, and new interventions are needed in order to satisfy the local irrigation demands.

- Typology: Predominantly agricultural (Type III).
- Dominant Paradigm: The formation of the Arancio Lake on the Carboj River in 1952 served irrigation purposes for the nearby territories, and the increased water availability contributed to a change in agricultural practices from crops requiring little irrigation to more irrigation dependent ones. The subsequent creation of the Garcia dam on the Belice Sinistro River provided further supply for irrigation and domestic demand. The Dominant Paradigm in the region is focused on the construction of large-scale supply enhancement infrastructure.

4) Tel-Aviv region, Israel. There are conflicts arising between the provision of water for urban water supply and for agriculture irrigation in a country where water is a very scarce and valuable resource. The Tel Aviv region is the largest in Israel with two million people, 30% of the total population, and 5% of the total cultivated land in the country. The water economy in Tel-Aviv is characterized by relatively high domestic and industrial consumption, and relatively low agricultural consumption.

- Typology: Predominantly urban (Type I).
- Dominant Paradigm: The water used for the region comes from desalinated sea water, groundwater abstractions and water reuse. About two thirds of it is supplied to Tel-Aviv via the national water system operator, and the remainder is provided by private producers from the coastal aquifer. The Dominant Paradigm relies heavily on large-scale water production technologies.

5) The island of Tenerife in the Canary Islands, Spain. The year-round high water demand in the island is caused by a tourist influx much larger than the local population,

demanding large infrastructure that nevertheless needs to be paid for by the locals. In addition, the combined effect of increased tourist activity and maintenance of high water-demanding crops in the last decades is highly alarming, and the overexploitation of the groundwater resources is obvious.

- Typology: Predominantly tourist (Type II), insular.
- Dominant Paradigm: The water shortages in Tenerife have traditionally been addressed through the increasing drilling of underground water galleries for abstraction. The dominant paradigm for the island relies mostly on supply enhancement through medium to large-scale infrastructure development.

6) Ribeiras do Algarve, Portugal. Despite the relative abundance of water resources, salinity of the underground aquifers is a rapidly intensifying problem due to the over-abstraction of water for use in golf courses and other tourism-related uses. In the last decades the basin has suffered deep changes in its demography mostly due to the development of tourist activities. The pressure on water resources created by seasonal population is very strong, leading to water shortage problems during the summer months, and is compacted by the significant agricultural demand. The increasing abstraction has led to salinisation of the underground aquifers in the area, making finding an alternative means of supply both necessary and urgent.

- Typology: Predominantly tourist (Type II), regional.
- Dominant Paradigm: The water demand of the region has traditionally been covered with abstracted groundwater; this however has changed in recent years, and water demand is now mostly covered through surface water from reservoirs. The current dominant paradigm in Ribeiras do Algarve involves mainly the use of large-scale supply enhancement infrastructure.

Table 2-1. Summary presentation of identified types

Typology	Description of underlying conditions	Regions
I (Predominantly Urban)	• Regions including metropolitan/large urban centres. • Main economic activities largely belong in the tertiary sector, although secondary sector activities are also present. • Water deficiency is either: o permanent, due to insufficiency of resources for the existing population, or o seasonal due to meteorological / hydrological fluctuations. • Some price elasticity in water supply.	Tel-Aviv
II (Predominantly Tourist {insular / regional})	• Regions or islands dependent on tourism, with small to medium sized urban centres and large seasonal population fluctuation. • Dependence on agriculture as well but the main source of income is tourist activities. • Seasonal water deficiency as a result of the population fluctuations due to the tourist industry's peak in the summer months. • Price elasticity is variable, depending on the local conditions.	Paros, Tenerife (insular) / Limassol, Algarve (regional)
III (Predominantly Agricultural)	• Regions dependent on agriculture, with small to medium sized urban centres and limited population fluctuation. • Dependence on secondary and tertiary sector activities is often limited compared to agriculture, which is the main source of income. • Usually seasonal water deficiency as a result of increased crop requirements of water in the summer time. • Price elasticity is variable, depending on the local conditions.	Belice Basin

3. Methodology and objectives of the scenario formulation and evaluation

3.1. Methodological background

The WSM research approach is based on the successive generalization resulting from systematic analysis of specific conditions. Following from that, the ultimate goal of the formulation of scenarios for the Case Studies is to provide a stepping stone in the process of **Strategy Formulation** for the identified paradigms.

The main objectives of scenario analysis were to determine the options that could be effective in meeting the targets of each Case Study analysis, and estimate their potential extent, cost and environmental impact. Under this context, the analysis process is based on the concept of a **"comprehensive scenarios"** is used in the analysis process, which has been defined as combinations of:

1. A hydrological (availability) scenario and a demand scenario, which represent alternative future developments that are not affected by the decision-making process. These are not however sufficient to develop Water Management Scenarios that will satisfy the requirements of the Project, as they do not cover the issue of supply and demand-side interventions. For that purpose the third component that will allow the formulation of Comprehensive WM Scenarios, is
2. A selected water management option to be evaluated, one of a set of alternative supply or demand side management measures available.

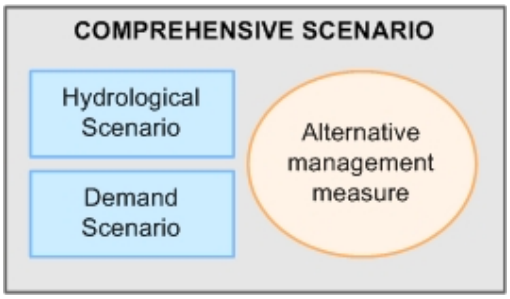


Figure 3-1. Components of Comprehensive Water Management Scenarios

The baseline scenario compared to which the alternative options were evaluated has been defined as the current state of the water system, including scheduled interventions as these are planned, under the assumptions that water availability and water demand will continue following the currently observed and forecasted trends. For the purposes of the WSM Case Studies, the scenarios were evaluated for a long time horizon, from 20 to 30 years, using the GIS-based Decision Support System that has been developed.

For each individual management measure, the behaviour of the water system was assessed and evaluated, in comparison to the baseline scenario.

The parametric analysis focused on the range of cost, effectiveness in demand coverage, and environmental sustainability of the system, expressed in terms of environmental costs. The performance of each of the management options applied was evaluated under different availability and demand conditions, and more specifically:

- a **"worst case scenario"**, combining low water availability and high demand,
- a **"best case scenario"**, combining high water availability and reduced demand, and
- a **"business as usual scenario"**.

In that way, it is possible after analysing the evaluation outcomes of all scenarios to select the options that are efficient in meeting the specific requirements of the case study. The performance of each option under a range of conditions is critical in defining the extent of their applicability.

The DSS models conditions in a given area/region and estimates how much water is needed to meet the existing and projected demand, to determine what interventions are necessary, as well as when and where, and their cost. It provides indicators of performance for the selected actions under each potential availability and demand scenario, and ranks all available scenarios based on these indicators. The DSS user can this way assess the functionality and performance of the water system within the entire region of application as well as at individual points of demand/interest.

The interrelationships between the scenarios and water management measures can also be viewed through the DPSIR approach: the Water Availability scenarios represent the Drivers, the Demand Scenarios represent the Pressures, the State of the system is the Base Case state, and the management measures, which are the Responses, act on the whole system and redefine it.

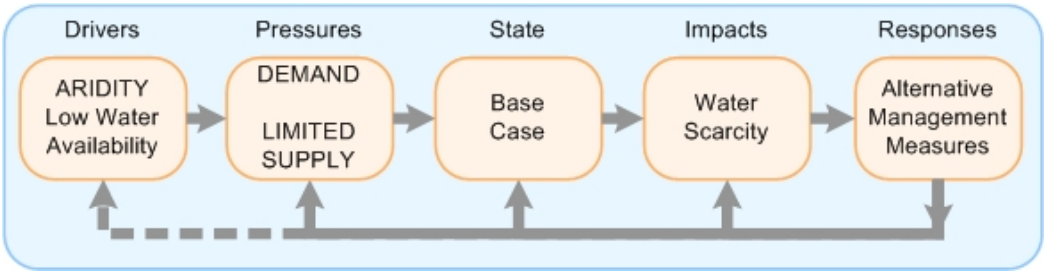


Figure 3-2. The DPSIR system as a parallel to the strategy formulation process

3.2. Formulation of Water Availability scenarios

The *Water Availability Module* of the WSM Decision Support System aims at estimating the amount of water that is available in a water resource system, to be allocated to the existing demand users. The water sources considered in the WSM package comprise of surface water, such as artificial or natural lakes and the river network system, and of groundwater, renewable or not.

The purpose of the water availability modelling is to generate monthly time series of forecast available water for each water source node in the network.

The time series output of the module concern natural recharge for renewable groundwater and surface runoff for reservoirs and river reaches. The results can be obtained in two ways:

1) by defining a set of customized years to be repeated in time, based upon the real observations at existing monitoring stations, and
2) by estimating runoff and natural recharge from a surface water balance performed on a monthly time step.

In the first case, the *Discharge Scenarios* within the DSS, the user has to go through the list of reservoirs, river reaches and renewable groundwater nodes that exist on the case study map, and define a *Normal Year (Average)* of runoff and recharge respectively, which is obtained from existing recorded data. Given the normal year, the user can create and customize new years, by editing monthly positive or negative rates with respect to the normal one. Then the availability scenario is constructed by customizing the sequence of water years for the entire duration of the simulation.

The alternative way for building availability scenarios is through water balance computations performed at the watershed level. Time series of available runoff and infiltration are computed for selected river reach nodes, lakes and aquifers. Computation is based on a set of required maps, among which are those of hydro-geological catchments relevant to aquifers and lakes and the Digital Elevation Model (DEM) of the area under study. As far as meteorological data are concerned, twelve maps of precipitation, reference evapotranspiration and temperature, containing monthly data for the average year are used as input.

There are three ways to build scenarios:

1) repeating the base year as it is for the entire duration of the scenario,
2) defining a total increment over the entire period, either annual or monthly, thus defining a yearly or monthly trend, or
3) building up a sequence of previously created base years, as is done for the Normal year approach.

With respect to the generation of meteorological time series, it is possible to use either reference ETP or temperature maps, depending on data availability. Estimation of ETP in the latter case is based on the Thornthwaite formula, also taking the altitude distribution of the region into account.

A stochastic option is also available; the idea consists in generating a certain number of forecast discharge time series based on a statistical analysis of historical discharge data series: the trend of historical data is kept in the forecast and fluctuations up and down the trend are produced in the generated series trying to maintain to the greatest extent the statistics of the historical fluctuations, such as mean, standard deviation and skewness. The user-defined number of discharge scenarios coming out the stochastic function, have to be all simulated by the water allocation model, and results have to be

compared, thus leading to and permitting the analysis and classification of strategies under uncertain conditions.

3.3. Formulation of Water Demand scenarios

The analysis of water demand in the WSM DSS is strictly functional to the allocation of water resources. The water demand module generates hypothetical demand scenarios, which along with the availability scenarios constitute the basic and discriminating factor in the distribution of water from the sources to the users.

Within the water demand methodology, a specific formulation for scenario building has been adopted for each one of the different kinds of activity and water use, considered to be part of a water resource system. Those are:

- permanent and tourist population, representing the domestic use of water,
- farmers and breeders, needing water for land cultivation and animals, and
- industries of various types.

Besides the activities related to consumptive water demands, as those above, the WSM DSS also addresses non-consumptive uses, such as hydropower-generation, navigation and protection of aquatic life in rivers (environmental demand). Consumptive demands describe the water needs within a particular region the tool is applied to, but not necessarily the water of available resources within it are entirely used to meet home requirements only. In many areas of the world the water transfers between neighbouring zones are common, and sometimes the only way to get water. In order to take this practice into consideration, a further water demand, *Exporting Demand*, describes the amount of water to be allocated externally the region under study.

Scenarios are generated by specifying appropriate growth rates to the key variables (Drivers) that govern the water demand of the nodes, such as population for the domestic use, cultivable area and livestock for agricultural practices, production growth and energy requirements for industries and hydropower plants respectively. The growth rate assigned to a year is implicitly assigned to all the years that follow, which do not have an explicit rate, until another year with a different rate is entered. This specification can be done in two ways:

a) at once for all the uses/requirements belonging to the same demand category, by activating the *Create Scenarios/Demand* option in the Navigation Panel, or

b) use by use going through the list on nodes in the Navigation Panel and editing growth rates from the Data Editor Panel.

Alternatively, growth rates for the demand drivers can be entered for each particular use. Node by node definition of data overwrites the one by sector. Table 3-1 shows the variables to be assigned a growth factor (or another type of customized expression).

Table 3-1. Attributes for building Demand Scenarios

Use/Requirement Type	Variables
Animal Breeding Site	Number of Animals
Industrial Site	Production
	Consumption Rate
	Share of Consumptive Demand
Irrigation Site	Maximum Cultivable Area
	Crop Area Share
Settlement	Residential & Tourist Population
	Population Month Variation (optional)
	Residential & Tourist Consumption Rate
Tourist Site	Tourist Population
	Month Variation (optional)
	Tourist Consumption Rate
Exporting	Demand
	Month Variation (optional)
Hydroelectricity	Energy Requirements
	Month Variation (optional)

The *Month Variation* variable represents the yearly distribution of the increment set by the user to the demand key variable. If not used, the yearly growth is allocated monthly with the same percentage.

Depending on the type of water availability model used, estimation of irrigation water requirements can be performed also in two ways, differing in complexity. A complex model allows for the calculation of crop water requirements according to the scenarios formulated for evapotranspiration (or temperature) using the crop coefficient model developed by FAO. A more simplified approach relies in the average monthly requirement of each kind of cultivated crop, which does not vary over time.

3.4. Management options

In the process of the WSM project, a number of potential policy options and interventions have been identified for use in the management of water resources in arid and semi-arid regions. These were identified in the literature and through field work, and were modelled in the DSS following the development of suitable methodology, and have been summarized in Table 3-2.

Table 3-2. Summary Table of Policy Options and related Actions

Policy Options	Actions
Supply Enhancement	• Unconventional/untapped resources • Surface Waters and precipitation (direct abstraction, dams, reservoirs) • Groundwater (drillings, wells) • Desalination • Importing • Water Reuse
Demand Management	• Quotas, Regulated supply • Irrigation method improvements (drip irrigation, enclosures) • Conservation measures in the home (water saving plumbing systems) • Recycling in industry and domestic use • Improved infrastructure to reduce losses (networks, storage facilities) • Raw material substitution and process changes in industry
Social-Developmental Policy	• Change in agricultural practices (low irrigation crops, genetic improvement) • Change of regional development policy (tourism/agriculture limitation)
Institutional Policies	• Institutional Capacity Building (Education and awareness campaigns, Use of standards, Public participation, Stakeholder involvement, Conflict resolution, Contingency planning) • Economic Policies (Water pricing, Cost recovery, Incentives) • Environmental Policies (Enforcement of environmental standards and legislation, Monitoring, Penalties and fines, Impact and risk assessment)

The options that have been modelled and are available for application and evaluation in the DSS are outlined in Table 3-3. These are grouped under four categories:

1) Measures related with Supply Enhancement, introducing new structural interventions to increase water availability;

2) Measures of Demand Management, aiming to control and limit water demands;

3) Regional Development measures, affecting the socio-economic preferences given to certain types of water use with respect to others and finally,

4) Institutional policies, such as changing water pricing.

Instruments not available in the DSS can also be modelled through changes to the network structure or function (e.g. the introduction of cisterns in a settlement is modelled as a small reservoir with total capacity equal to that of the sum of the individual cisterns, set just outside the settlement).

Table 3-3. Management options identified and used in the DSS

Management option	Description
Change in regional developmental policy	Implementation of changes in the regional developmental policy, such as shifting the local economy towards another sector that is less water-intensive. This is effected either through different priorities for the water sectors or through different growth rates.
Introduction of new crop types	Substitution of existing crops with other crop species or varieties that have either lower irrigation requirements, or require irrigation during the less water-stressed season.
Construction of surface Storage Reservoirs	Construction of water storage facilities that will be able to collect and hold water to be used later.
Desalination unit construction	Construction of desalination units that will process sea or brackish water to produce drinking-quality water.
Groundwater exploitation	Sustainable exploitation of underground aquifers through the drilling of new boreholes, pumping from existing boreholes and wells.
Importing	Importing of water from nearby or remote areas by transporting it through any means or container possible such as pipelines, water barges etc.
Water reuse	Transport of varying quality effluents for use to sectors where that quality is acceptable (e.g. treated wastewater used for irrigation of certain crops).
Conservation measures in household use	Application of water-saving devices and measures in the home, such as fitting flow-restrictors to faucets, insulating water pipes, outfitting garden hoses with shut-off nozzles etc.
Irrigation method improvement	This Action involves changes in irrigation practices in order to improve irrigation efficiency and reduce water losses (e.g. changing from flood to drip irrigation).
Process change in industry	Implementation of changes in industry processes, in order to reduce the amounts of water required during processing and production (e.g. new processes, recycling etc).
Quotas	Restriction of the amounts of water available per user, either directly through the allocation of a set volume to each user, or by limiting the duration of time that the water flow is available to users.
Reduction of network losses	Repair and/or replacement of old networks in order to reduce the water losses that are a direct result of the network aging.
Pricing	Control of the elastic water demand through the application of varying pricing levels.

3.5. Evaluation of alternative options

The formulation and evaluation of a water management option, and consecutively that of a strategy, should evolve around and reflect the principles of Integrated Water Resources Management, economic efficiency, environmental sustainability and social equity. Those principles are expressed through a set of goals that have to be achieved by a water resource system, summarized in Figure 3-3.

Figure 3-3. The goals of an IWRM strategy

No single instrument can address all of the goals mentioned above. However, each option should be evaluated against a set of indicators that at best can address such issues in order to formulate a set of candidate options that can achieve those targets during the next phases of the project.

Under this context and in order to achieve a meaningful overall evaluation for the options examined in the range of Case Studies, it is necessary to ensure comparability. For that purpose, a specific set of indicators has been selected for cross-Case Study comparison, and those are presented for each measure evaluated. These are:

- Total cost, expressed as the Present Value of direct costs, reflecting the economic efficiency of each measure,
- The coverage of domestic demand, reflecting technical efficiency,
- The coverage of irrigation demand, reflecting social efficiency, and
- The total groundwater abstractions, reflecting the environmental efficiency.

Those indicators are not comprehensive for all case studies involved in the Project and the list can be enhanced in order to include other indicators that are meaningful in the analysis of the case study areas.

Indicators for evaluation

Indicators are a tool to describe the economic, environmental, social and/or institutional conditions of a system, i.e. a country, region, community, etc. Indicators are instruments of simplification as they summarise large amounts of measurements to a simple and understandable form in order to highlight the main characteristics of a system. Information is reduced to its elements, maintaining the crucial meaning for the questions under consideration. This aggregation may cause a loss of information, but if the indicator is planned properly, the lost information will not gravely deform the result.

Selecting indicators for the assessment of a water system needs to conform to the following criteria:

- Direct relevance to set objectives,
- Limitation in number,
- Clarity of design,
- Realistic collection or development costs,
- Clear cause and effect links,
- High quality and reliability,
- Appropriate spatial and temporal scales,
- Targets and baselines,
- Little or no interrelation.

A number of indicators are used in the developed Decision Support System. As the general idea of the DSS is to compare the performance of different water management strategies over a sufficiently long period of time, the evaluation approach that is implemented in the Decision Support System (DSS) of the WaterStrategyMan is based on a two step procedure.

Evaluation in the WSM DSS

The first step involves a temporal aggregation of time series of aggregation into single values, the second step is aimed at providing time series of indicators as additional information to the decision maker.

Temporally aggregated values

Based on the primary objectives of a water management strategy (environmental compatibility, cost recovery of water services and coverage of demand for all sectors), a set of indicators is used that "measures" the performance of a strategy compared to those objectives. The selected indicators are outlined in Table 3-4.

Table 3-4. Selected indicators for the evaluation of water management schemes

	Indicator
Environment Resources	Dependence on Inter-basin water transfer
	Desalination and reuse percentage
	Groundwater exploitation index
	Non-sustainable water production index
Efficiency	Demand coverage-Animal breeding
	Demand coverage-Domestic demand
	Demand coverage-Environmental demand
	Demand coverage-Hydropower demand
	Demand coverage-Industrial demand
	Demand coverage-Irrigation demand
Economics	Total Benefit from Water Use
	Rate of cost recovery

Additional indicators that can be incorporated in the analysis concern the present value of direct, environmental, resource costs and benefits from water usage.

Temporal aggregation is done according to a system performance approach suggested by the American Society of Civil Engineers (ASCE) that is aimed at temporally aggregated time series of performance indicators of a system. The procedure provides a classification where the high-ranked schemes are performing better than low-ranked ones.

The score of the schemes is defined as the value of a *Relative Sustainability Index*, which is derived from specific statistical criteria that are calculated for each scheme and based on a predefined list of indicators. More specifically, the procedure to get the final score of one WMS is the following:

a) The desired indicators, on which the evaluation will be based, must be selected (activated). Weights and least and maximum acceptable values must be assigned for each of them according to the specific goals of the case study and the decision maker;

b) Three statistical criteria are calculated for each indicator, over their time series in the simulation horizon: *Reliability*, *Resilience* and *Relative Vulnerability*; those are connected with the concept of *Range of Satisfactory Performance Value* whose extent is fixed by the least and maximum acceptable values;

c) Statistical criteria are normalised where necessary and then aggregated in the sustainability index;

d) Sustainability indices for the respective indicators are weighted to get the *Relative Sustainability Index*, at both the indicator category level and the entire management scheme level.

In order to generate a valid and sensible score of sustainability, the user should pick up and activate those indicators that strictly pertain to the water system simulated and the strategy they want to evaluate. The available indicators for evaluation are grouped under

the three categories of *Environment and Resources*, *Efficiency* and *Economics*. The first one includes: Minimum flow requirement coverage, Desalination and Reuse Supply Share, Dependence on Imported Water, Groundwater Exploitation Index and Non Sustainable Groundwater Production Index. The Efficiency group is characterised by the rate of demand coverage for each kind of water use in the region, from domestic to hydroelectrical. The economic indicators are: Total Benefit from Water Use, Total Environmental Cost and Rate of Cost Recovery.

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 the indicator can assume. The lower and upper limits of the satisfactory field of values are not fixed, although suggested usual ones are proposed; they can be assigned by the user of the DSS properly: they are the least and maximum acceptable values mentioned in point a) above. The first represents the lower, minimum satisfactory value the monthly indicator is expected to assume, whereas the latter is the upper, the maximum. For example, in the case of Domestic coverage, satisfactory values can range from 0.8 to 1, signifying that the user (or decision maker) is satisfied if at least 80% of the domestic demand is met.

Reliability is defined as the probability that any particular indicator value will be within the range of values considered satisfactory.

Resilience is a criterion describing the speed of recovery from an unsatisfactory condition. It is the probability that a satisfactory indicator value will follow an unsatisfactory value.

The *Vulnerability* statistical index measures the extent and the duration of failures (unsatisfactory values) in a time series. The extent of a failure is the deviation when the indicator value exceeds the upper limit, or that falls short the lower limit. It can be based on the extent of failure of individual unsatisfactory values or the cumulative extent of failure of a continuous series of unsatisfactory values. In the latter case, each individual extent of failure is added together for the duration of each continuous failure sequence. Within the evaluation module of the DSS, vulnerability is expressed for each criterion by three indices, namely a Conditional Expected Extent or simply **Extent**, the **Maximum Extent** and the **Expected Duration**.

As can be seen from the formulation of these criteria, all vulnerability criteria are not positive indices as opposed to reliability and resilience (in the sense that higher values have a negative meaning) and their values do not range from 0 to 1. As a consequence, each vulnerability criterion (extent, max extent and duration) is converted by the DSS to be comparable with the other two. First, the largest vulnerability value for each indicator is defined amongst all Water Management Schemes that are compared and each vulnerability measure for each Water Management Scheme is divided by this maximum value. That defines the **Relative Vulnerability** of each the criterion.

Then the **Sustainability Index** for each indicator is computed, where each relative vulnerability measure is subtracted from 1 so that higher values are to be preferred. The

Sustainability index for each indicator ranges from 0, for its lowest and worst possible value, to 1 at its highest and best possible value.

To obtain a combined weighted relative sustainability index that considers all indicators, the relative weights entered by the DSS user are used. Those weights refer to the preferences and the weight imposed by the local society to each indicator examined. The Water Management Scheme having the highest value can be considered the most sustainable with respect to the indicators selected, the values of each criterion that are considered satisfactory and the relative weights.

Following from the outcomes of the Comprehensive Scenario evaluation and ranking, the next stage is the formulation of strategies. This will involve the planning of combinations of management measures in the timeframe set, and re-evaluating the strategies in their entirety using the DSS as previously done for each measure individually. This will enable the ranking of the selected strategies for each Case Study and the selection of the best suited approaches.

Time series of indicators

In addition to the indicators and indices that are directly used for the evaluation of water management strategies, the DSS provides a number of additional time series of indicators and indices based on the primary data that is either modelled by the system or entered as initial data. Their purpose is merely to provide the user with additional information on the evaluation process.

Table 3-5. Additional time series of indicators in the WSM-DSS

Category		Indicator
Environment Resources	Exploitation	Total Water production
		Groundwater exploitation index
		Consumption index
		Non-sustainable groundwater production
	Dependencies	Dependency ratio
		Anthropogenic water produced/total water production
	Water quality	Percentage of treated urban water
		Share of primary treatment
		Share of secondary treatment
		Share of tertiary treatment
Social Indicators	Pressures	Agricultural demand per ha
		Tourist per inhabitant
		Water abstractions per capita
	Deficits	Domestic deficit as percentage of demand
		Industrial deficit as percentage of demand
		Environmental deficit as percentage of demand
		Hydropower deficit as percentage of demand
		Irrigation deficit as percentage of demand
Economics		Direct costs
		Environmental costs

Category		Indicator
		Revenues
		Rate of cost recovery
		Benefit from water use

Evaluation in the Comprehensive Scenario Context

No single instrument, as those examined in the scenario analysis, can address all of the goals mentioned above. However, each option should be evaluated against a set of indicators that at best can address such issues in order to formulate a set of candidate options that can achieve those targets during the next phases of the project.

Under this context and in order to achieve a meaningful overall evaluation for the options examined in the range of Case Studies, it is necessary to ensure comparability. For that purpose, a specific set of indicators has been selected for cross-Case Study comparison, and those are presented for each measure evaluated. The overall aim is to collectively score measures in order to rank those as to their general applicability and efficiency in arid and semi-arid regions.

For this purpose, a series of indicators was selected to be used for all Case Studies, based on the typology of regions outlined in the Introductory Section. Those are:

- **Effectiveness vs time** for irrigation and domestic water 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)abstraction of surface and groundwater, expressed also in present value terms.

Those indicators are not comprehensive for all case studies involved in the Project and the list can be enhanced in order to include other indicators that are meaningful in the analysis of the case study areas.

However, they can be used to derive a **Performance Matrix** which permits to rank the options identified through stakeholder consultation, modeled and simulated in the WSM Decision Support System.

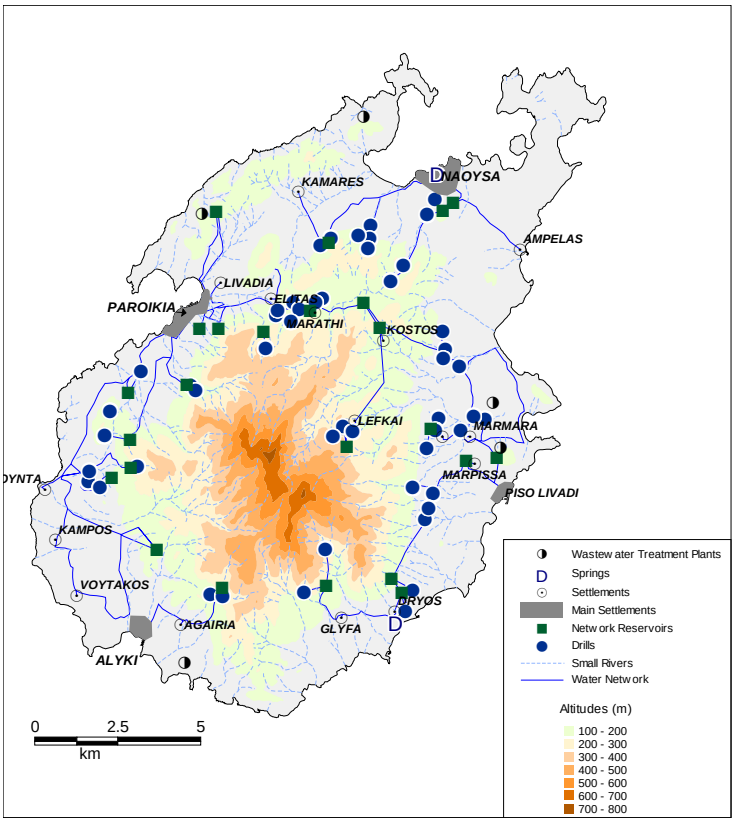
Following from the outcomes of the Comprehensive Scenario evaluation and ranking, the next stage is the formulation of strategies. This will involve the planning of combinations of management measures in the timeframe set, and re-evaluating the strategies in their entirety using the WSM DSS as previously done for each measure individually.

The ultimate goal is the ranking of the selected strategies for each Case Study and the selection of the best suited approaches.

4. Comprehensive Scenarios for Paros Island

The island of Paros, with an area of 196 km^2 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. 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 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 was done 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. At the same time, the agricultural activities that had been abandoned to a large extent were enhanced by the tourist development, and the demand for local traditional products (for example local wines) was boosted, triggering an increase in irrigation demand.



Map 1. Domestic water network in the island of Paros

The water demand growth of the last decades has been addressed mostly with the construction of 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. Paros has the potential to combine multiple activities; both tourism and agriculture can offer a prosperous future for the inhabitants under suitable planning and control. So far however, the existing infrastructure is inadequate for dealing with these issues, and therefore new water management responses are necessary to cover the shortage.

4.1. Demand and Availability Scenario Components

Formulation of Demand Scenarios

Data

Given the growing economic importance of the tertiary sector and especially tourism, the formulation of demand scenarios for Paros was based primarily upon assumptions for permanent and seasonal population growth. For this purpose, a variety of data and estimations have been collected and analysed from associations and the local and governmental authorities, regarding population fluctuations, consumptions, network losses and unaccounted consumptions. Table 4-1 presents the authorities that have been contacted, and the data that have been collected from each one.

Table 4-1. Available information on domestic demand components

Authority	Available Information
Municipal Office of Water Supply and Sewerage (Water Utility)	• Water Supply Provision and Fluctuation • Consumption Fluctuation
National Statistical Service	• Permanent Population • Tourist Arrivals, Departures and Overnight stays
Local Administrative Authorities	• Seasonal Population
National Tourist Organisation	• Number of Hotels, Rooms and Beds • Occupancy • Overnight stays
Room/Hotel Owners Association	• Number of Hotels, Rooms and Beds • Occupancy • Overnight stays

One important conclusion that was drawn from data cross-referencing concerned the real permanent population of the island. The registered population according in the 2001 census was 12,783 inhabitants. However, during the winter months local authorities estimate that actual (permanent) residents are only 35% of the recorded, being mostly permanent employees and farmers or stockbreeders. The rest are either indigents who live permanently in the mainland and have seasonal occupations in Paros or people with a second (country) residence that visit the island for summer vacations. Two types of seasonal population have also been distinguished: the low season visitors, mostly families and pensioners who visit Paros during Easter, May and June, and the peak season tourists (from the mainland and abroad) who visit Paros during August and constitute the massive inflow that creates the summer peak of 54,000 visitors. The yearly population fluctuation is presented in Table 4-2.

Table 4-2 . Monthly variation of permanent and seasonal population in Paros

Month	Permanent Population Fluctuation[1]	Seasonal Population Fluctuation[2]
January	35%	0%
February	35%	0%
March	55%	5%
April	55%	30%
May	70%	35%
June	100%	50%
July	100%	75%
August	100%	100%
September	78%	40%
October	55%	20%
November	35%	0%
December	35%	0%

The uneven spatial distribution of tourist population per municipal department is presented in Figure 4-1. The municipal departments of Paroikia and Naoussa, with their traditional settlements and developed tourist facilities and accommodation, concentrate the largest part (about 70% of the total). The departments of Marpissa and Agairia, currently under tourism development, come second with 15 and 10% respectively. Kostos and Leykes exhibit very small tourism activity, with their total share not exceeding 5% of the total seasonal population.

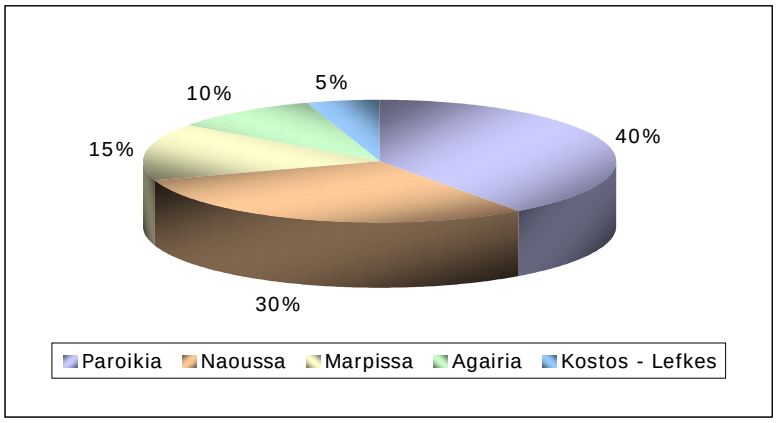


Figure 4-1. Spatial distribution of seasonal population

Estimation of demand parameters, such as consumption rates and loss coefficients, was performed using data obtained from the Water Utility of Paros, using the flowchart presented in Figure 4-2.

[1] Share of registered population (12,783)
[2] Share of the seasonal population during August (54,000)

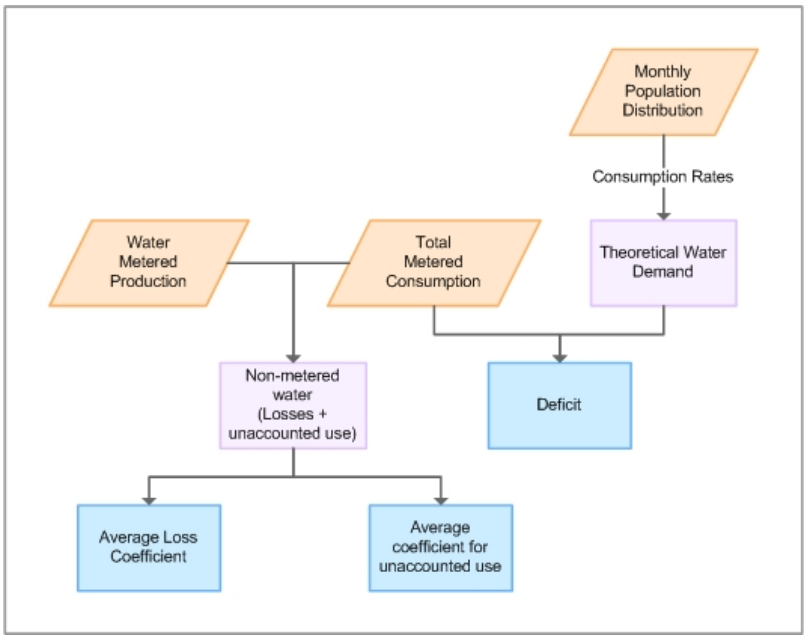


Figure 4-2. Flowchart for the estimation of demand parameters

Domestic consumption rates, estimated on the basis of real consumption and excluding losses, were estimated at approximately 130 and 180 l/capita/day for permanent and seasonal population respectively. The relatively low rates (with respect to the international standards of 200 and 350 l/capita/day) are attributed to the rural character of the majority of residential population and the conservation campaigns that have increased the awareness of both inhabitants and tourists on periodical water stress conditions. Unaccounted for water use was estimated as the difference between the metered (charged volumes) and the delivered supply, on the basis of data and estimates provided by the Water Utility. Average network losses account for about 25% of the delivered supply volumes.

Projections

The economic development, which began in the 1970's, resulted in increasing permanent population growth rates (Table 4-3). For identifying a business as usual scenario, it was assumed that during the period examined (2004 – 2030) the population will continue to increase with a steady yearly rate equal to the average of the previous decades. Seasonal population is assumed to follow a similar trend, as the permanent population increase should be supported by a proportional economic growth, which is nowadays strongly related to tourism development.

Table 4-3. Growth of registered permanent population (National Statistical Service)

Year	Registered permanent population	Yearly Growth Rate (%)
1971	7,314	-
1981	7,881	1%
1991	9,591	2%
2001	12,783	3%

Two other scenarios formulated for the period analysed assume that after a point the island has reached its carrying capacity regarding tourism development. This would be followed by stabilization of population while a more pessimistic scenario assumes a small decrease of tourism that is followed by minor emigration trends towards the mainland.

Under this context, three different potential trends were distinguished, forming the potential scenarios for domestic demand (Table 4-4):

I. A scenario where demand increases at a steady rate, equal to that currently observed, and corresponding to a "business as usual" state (**BAU**),

II. A scenario where demand is stabilized after a point in time, in this case taken to be 15 years after the reference year (**Stabilized**),

III. A scenario where the demand decreases after a point in time, in this case taken to be 25 years after the reference year (**LD**).

Table 4-4. Population trends for the three scenarios

Scenario	Period	Growth Rate (%)	
		Permanent Population	Seasonal Population
BAU	2001 – 2030	1.5	1.5
Stabilized Demand	2001 – 2015	1.5	1.5
	2016 – 2030	0.0	0.0
Low Demand	2001 – 2015	1.5	1.5
	2016 – 2025	0.0	0.0
	2026 – 2030	-0.5	-0.5

The three domestic demand scenarios are depicted in Figure 4-3. It should be noted that due to the continuous decline of agricultural activities, irrigation and animal breeding demands are assumed to be stable over time and equal to 2.51 and 0.04 million m^3 respectively. A very small quantity (7,000 m^3/yr) is exported to the nearby island of Antiparos during the peak months of July and August.

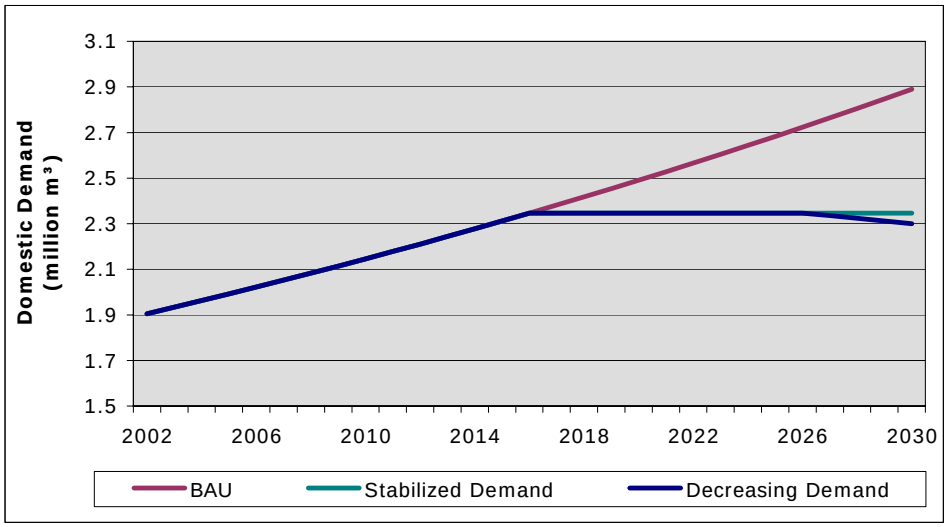


Figure 4-3. Domestic Demand Scenarios

Formulation of Availability Scenarios

Data

The climate in Paros, as in all the islands of the Cycladic complex, is temperate Mediterranean. The average temperature is 16.5 – 19.5 °C. The average annual rain height is 480 mm according to the last 50 year measurements from the meteorological stations of Naxos and Paroikia.

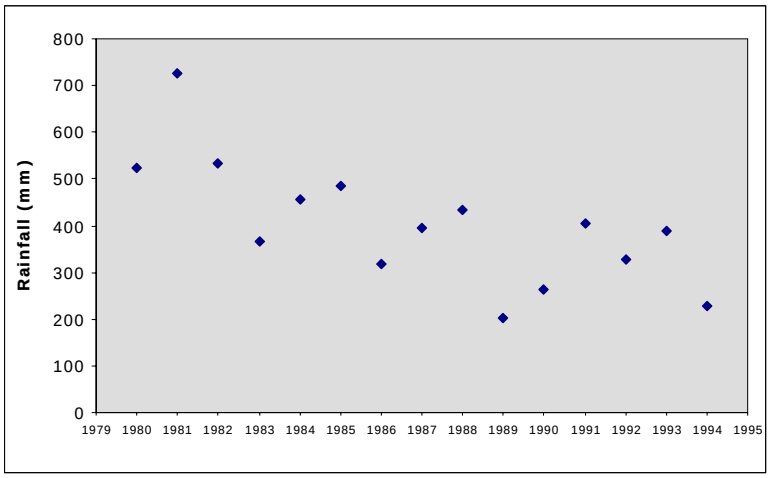


Figure 4-4. Rainfall measurements from the Naxos meteorological station

Rainfall monthly variation is presented in Figure 4-5. Highest rainfall values are observed during the winter, while during the summer season, from May to August, precipitation is very rare, not exceeding 5 mm/month.

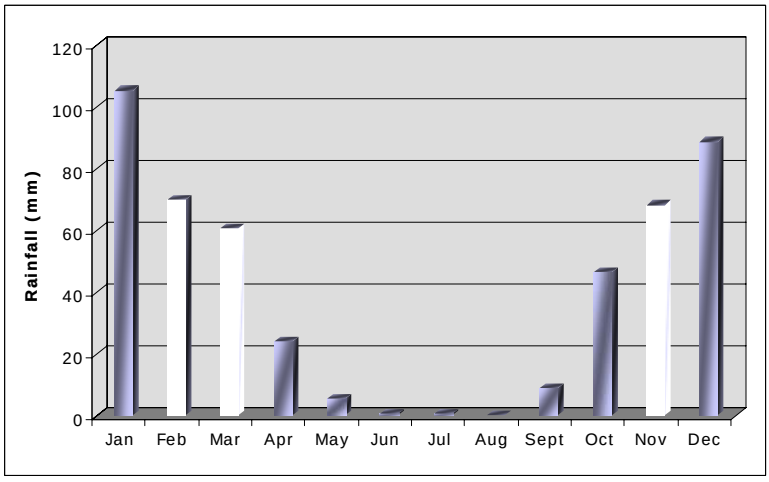


Figure 4-5. Average monthly rainfall in Paros

Scenarios

The main variable in the formulation of availability scenarios was the sequence of years with respect to rainfall. Sequences that were developed and entered in the DSS were composed of average, wet (values in the top 30 percentile of observed) and dry years

(values in the bottom 30 percentile of observed). The hydrological scenarios that were used reflected:

a) a period of 30 years with a high frequency of dry years (**HD**),

b) a period of 30 years with a high frequency of wet years (**HW**),

c) a period of 30 average water availability years, which signifies the assumption of standard water availability, reflecting the baseline scenario (**Normal**).

The three availability scenarios are depicted in Figure 4-6.

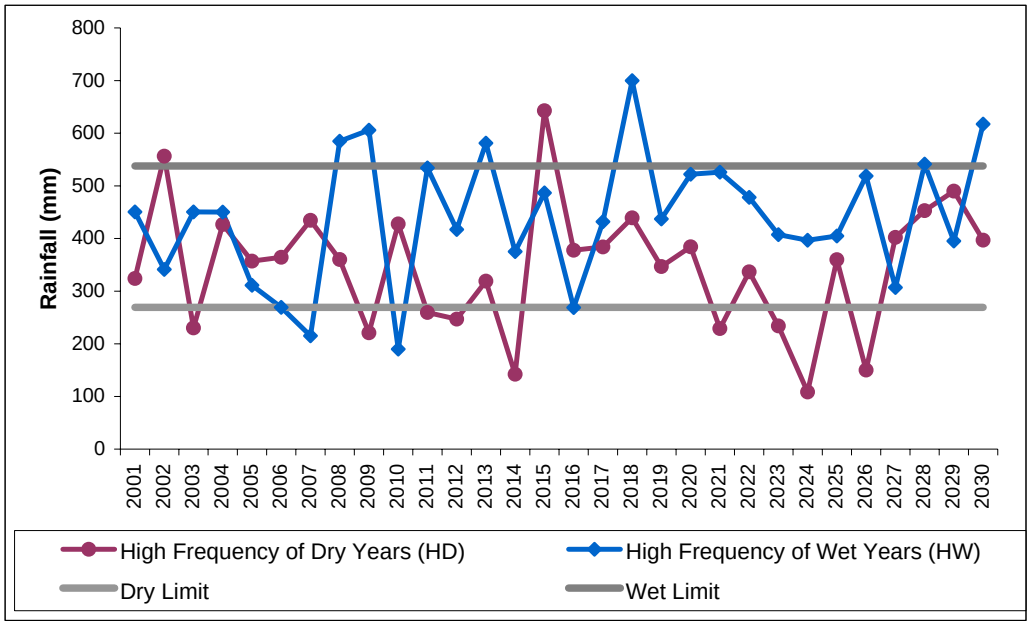


Figure 4-6. Water Availability Scenarios

Combinations of hydrological and demand scenarios

In order to be able to assess the behaviour of the water system under a best case scenario, a worst case scenario and a business as usual scenario as intended, the combinations of availability and demand scenarios under which the different management options have been evaluated were the following:

- 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.

Figure 4-7 presents the overall domestic deficit under the three scenarios. From the temporal and spatial variation of domestic shortages throughout the island, the following are concluded:

- The municipal department of Paroikia and the towns of Marpissa and Piso Livadi face permanent water deficiency. This is due to the large tourist influx in those areas and the limited available groundwater resources. Aquifers supplying those areas are on the verge of overexploitation.
- The current desalination capacity is adequate to meet both residential and tourist water needs of the town Naoussa up to 2023. However, the rest of the municipal department, mainly supplied through boreholes, faces small water shortage problems. Groundwater exploitation is very high mainly due to the irrigation activities of the area, facilitating the advance of the sea intrusion front. During recent years efforts have been made to limit groundwater abstractions to sustainable levels and enhance the Naoussa aquifer through the construction of small interception dams.
- The municipal department of Arhilohos faces small, periodic water shortages, aggravated by seasonal droughts.
- The exploitation of the aquifer of Agairia at the southern part of the island is rather low. The hydrogeological survey of the island has concluded that, due to the impermeable geologic structures, further exploitation is possible without endangering the water balance of the area.
- The municipal departments of Agairia and Leykes do not face deficiency for the entire simulation period.

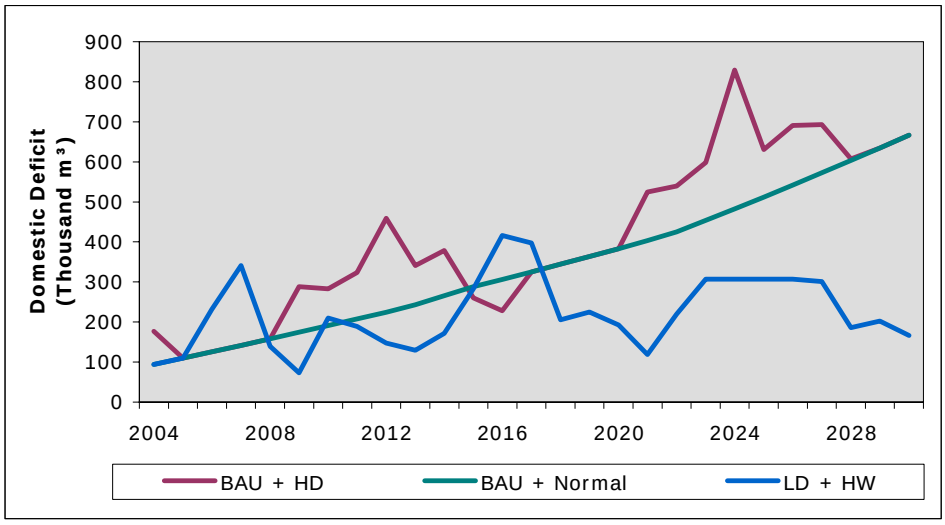


Figure 4-7. Estimated domestic deficit under the selected demand and availability scenario combinations

In all cases peak shortages are observed during the month of August when both domestic and irrigation requirements reach their peak. For domestic use, deficit reaches 174, 288, and 67 thousand m^3 in 2009 in a normal (average), dry, and wet year respectively under the three scenarios (Figure 4-8).

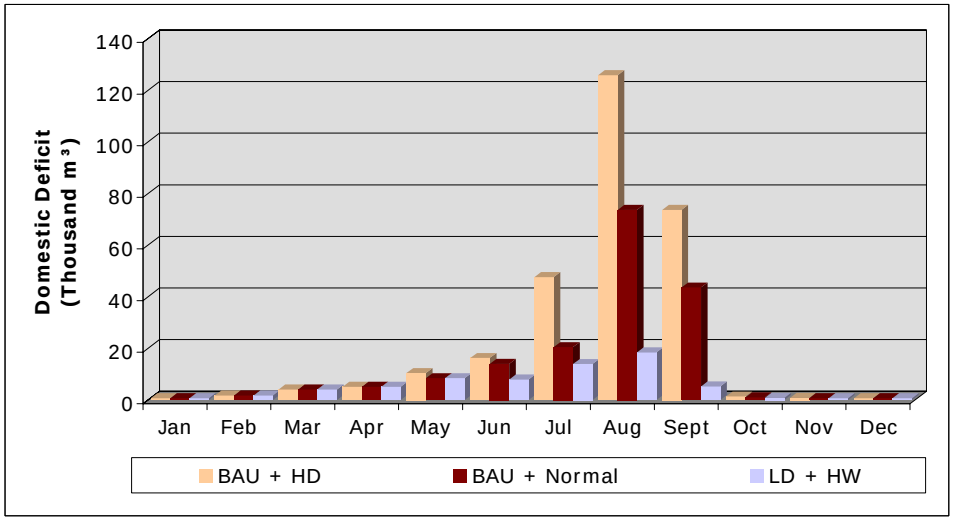


Figure 4-8. Monthly domestic deficit under the three scenarios (year 2009)

Cost Estimation

Direct Costs

The estimation of direct costs for the island of Paros consists of:

- Amortization of capital expenditures associated with new infrastructure;
- Additional operating costs incurred from the use of new infrastructure for both domestic and irrigation purposes;
- Costs associated with the application of demand management options, which are supposed to be in the form of subsidies provided to the pertinent sector.

In addition, and in order to cope with the lack of relevant data, and appropriate information, the following assumptions have been made in order to estimate the total annual costs from the operation of existing infrastructure:

- **For domestic use**, an additional unit cost of 0.6 €/m^3 of supply delivered has been assumed, in order to account for the operating expenses of the Water Utility. This cost was derived assuming that for the year 2001 the cost recovery rate, computed on the basis of annual operating costs and revenues from water billing, was equal to 90%.
- **For irrigation use,** which is performed mainly through private boreholes, the provision of water supply was considered not to entail capital or operational costs. The approximation is due to the fact that no data have been made available for irrigation abstractions, borehole number and depth etc.

Environmental Costs

Environmental costs for the case of Paros are associated with:

- Groundwater abstraction
- Pollution generated from domestic uses.

Groundwater abstractions are associated overabstractions originated from the major aquifers of the island, i.e. the Ksiropotamos-Naoussa aquifer, the Prodromos – Tourlos - Dryos aquifer and the small aquifers of Alyki. 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 that are summarized in Table 4-5.

Table 4-5. Area coefficients used for groundwater abstraction environmental costs

Groundwater Body	Area Coefficient
Ksiropotamos - Naoussa	2.0
Prodromos – Tourlos - Dryos	1.8
Alyki	1.5

With respect to pollution, environmental costs have been estimated as equal to the operating expenses of a secondary wastewater treatment plant. Since no particular environmental problems have been recorded in terms of aquifer, stream or coastline degradation, the relevant coefficients were set equal to 1. It should be noted that pollution environmental costs are related to the activity levels and not on the volumes of

water abstracted and disposed. Therefore, they do not vary for all water management options that have been examined in the current analysis

Present Values

Present values have been estimated for the period of 2004 to 2030, using a discount rate of 4%.

4.2. Selection of management options

The potential policy options identified in the course of the WSM Project were subsequently analysed in their applicability to each region through consultation with the local stakeholders. As expected, for Paros all locals proposed different approaches to water resources management, according to their different targets 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 fundamental target of all strategic approaches is to adequately meet the domestic and irrigation needs, without however incurring additional costs to consumers. For this purpose, large-scale infrastructure should be financed by the government. Ultimately, such a strategy would lead to the promotion of the local tourist industry while at the same time keeping the public satisfied.

Although under the control of the Municipality, 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 as well recognize the necessity for structural interventions; they would like however 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.

A synthesis of the current management policies, the perceptions of the local stakeholders, and of additional, imposed instruments applicable to Paros island is presented in Figure 4-9.

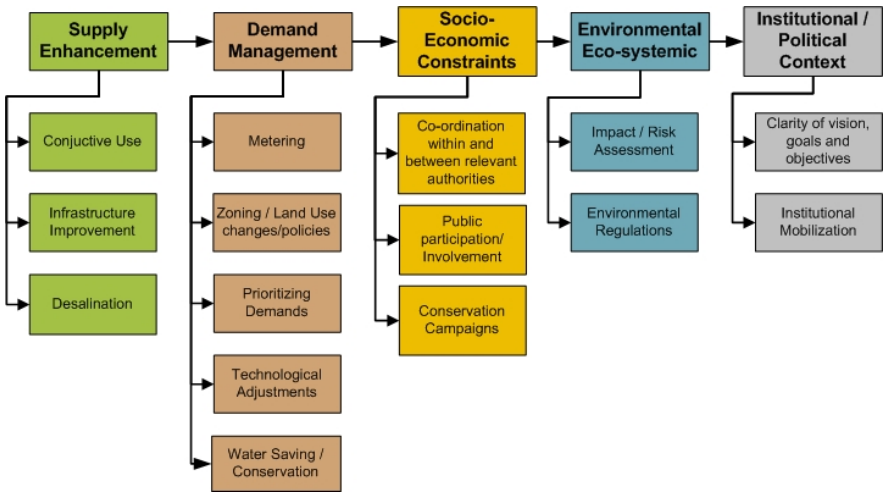


Figure 4-9. Summary of management options

Of these instruments only a number can be modelled through the Decision Support System. The rest, expressing the governance and capacity building mechanisms (e.g. institutional mobilization, clarity of vision), are to be examined at a later stage of the project, during the Protocol Development Stage. Examined options pertain to three major categories:

- **Structural options** for supply enhancement, including:
  - *Network Unifications***,** aiming at the integration of the fragmented water networks of the island;
  - *Desalination unit(s) construction*, to provide additional water supplies particularly during the peak consumption periods;
  - *New Boreholes*, in areas where groundwater exploitation is below the sustainable level;
  - *Storage Reservoirs (and interception dam) construction* to provide a means of storing run-off during low consumption periods to be used later;
  - *Reduction of Network losses*, through replacement of old and damaged piping in the island towns (structural intervention);
- **Demand management options**, including:
  - *Cistern construction* subsidization in the households/hotels, for better regulation of the network flow between peak and low consumption times/periods;
  - *Conservation Methods* in the Domestic Sector and the hotels;
  - *Improvement in Irrigation Methods*, for better irrigation efficiency and savings in water consumption;
- **Socio-economic measures** in the form of adjusted *Pricing* aiming to examine to what extent a difference of pricing structures would influence the targeted indicators of the analysis.

4.3. Analysis of water management instruments

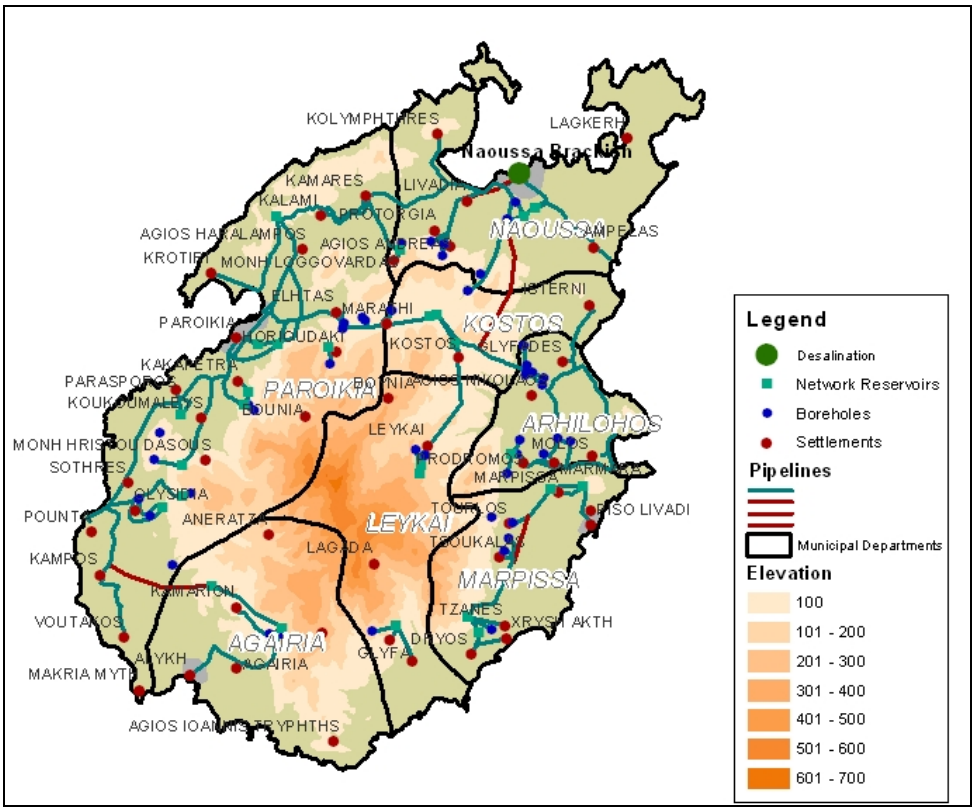
Structural options

Network Unifications

The water supply network of Paros is highly fragmented, due to the past administrational structures governing the water supply. As a result, there are a number of separate water supply networks that are each supplied by local resources, some in the most heavily populated parts of the island facing water shortages during the summer peak. Other regions are more water-rich and could contribute towards alleviating the problems where these are faced through the implementation of network connections and unifications.

A combination of four feasible interventions has been identified, in terms of water availability and existing deficits, and technical feasibility (Map 4-2):

- A connection between the water networks of Alyki and Kampos.
- A connection between the water networks of Dryos and Marpissa.
- A connection between the water networks of the town of Naoussa and its suburbs.
- Finally, a connection between Kostos and Naoussa.



Map 4-2. Proposed network unifications

The first three of the proposed connections are considered necessary, since the areas to be supplied face permanent water shortage problems. Between scenarios it is the appropriate connection years that will vary and that will be assessed. The cost of the new connections, estimated according to their length and pipeline diameter, is presented in Table 4-6, while the implementation year for each connection is presented in the Annex.

Table 4-6. Network unification costs

Connection	Construction Cost (€)
Agairia – Kampos	9,000
Naoussa – Naoussa Suburbs	44,000
Dryos – Marpissa	18,000
Kostos - Naoussa	400,000
Total	*471,000*

Under normal (average) water availability conditions, the first three connections are implemented in 2005. Since the settlement of Naoussa does not face deficiency problems before the year 2021, the connection should be made much later, in 2028. Figure 4-10 presents the total volume of water transferred by each connection under the BAU + Normal scenario.

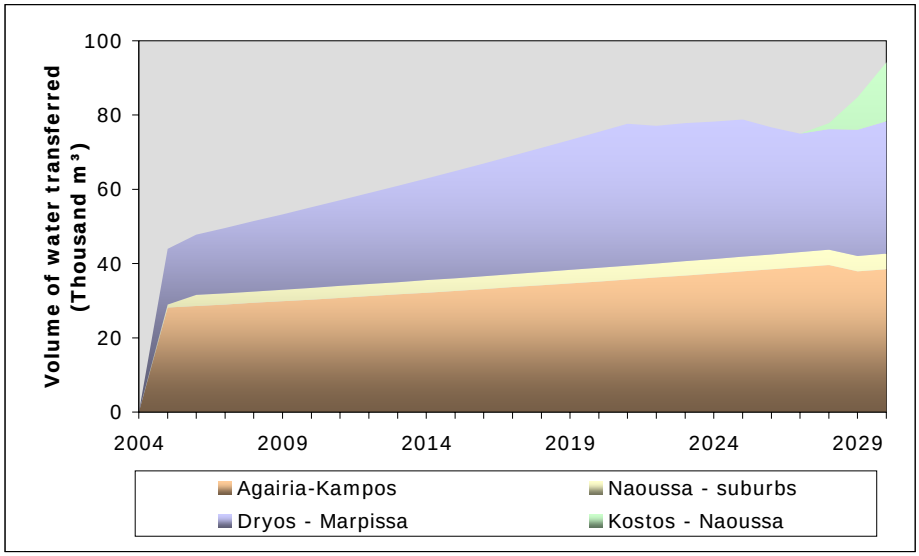


Figure 4-10. Volume of water transferred from each connection (BAU + Normal scenario)

In dry years transferred volumes normally increase during the summer months, with the provision that local water needs are always satisfied before any transfer is made. Monthly distribution differs for average or wet years. In some areas (e.g. Paroikia) already existing infrastructure is adequate to meet water needs up to the peak month of August. After that however, local resources are depleted, and additional water transfers are required for meeting the demand.

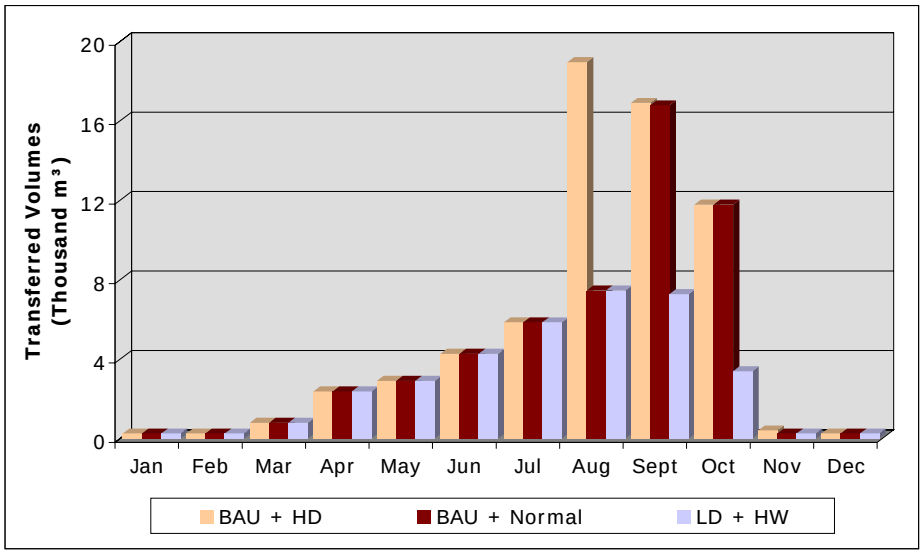


Figure 4-11. Monthly volumes of water transferred for the three scenarios (year 2009)

Under average availability conditions, the unification of the island's fragmented networks can lead to an increase in domestic demand coverage. Overall, when water availability is increased due to increased precipitation, there is a significant effect on the domestic demand coverage, due entirely to a better allocation of the available resources (Figure 4-12 and Figure 4-13). The effect becomes smaller as demand increases, since larger water quantities are required for satisfying local needs before making water transfers through the new connections, and since no additional water supply sources have been introduced in the system.

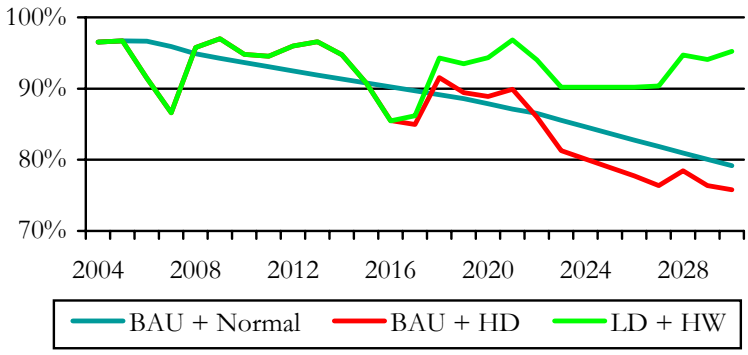


Figure 4-12. Percent demand coverage effectiveness of Network Unifications to Domestic use

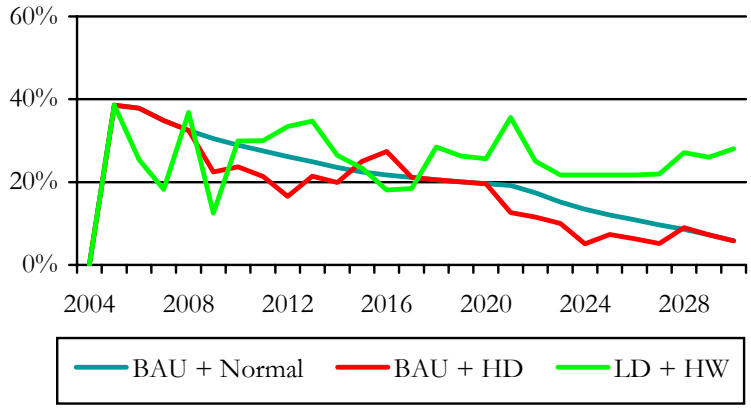


Figure 4-13. Percent Improvement of deficit in Domestic use with respect to the reference scenarios

Network unifications have a positive effect only in domestic demand coverage, which is higher under a high frequency of wet years (LD + HW scenario). Irrigation demand coverage (Figure 4-14 and Figure 4-15) is overall decreased over time due to the increasing demand for domestic use. A similar pattern of effectiveness improvement as with the domestic use is observed where the overall water availability is significantly increased due to increased precipitation.

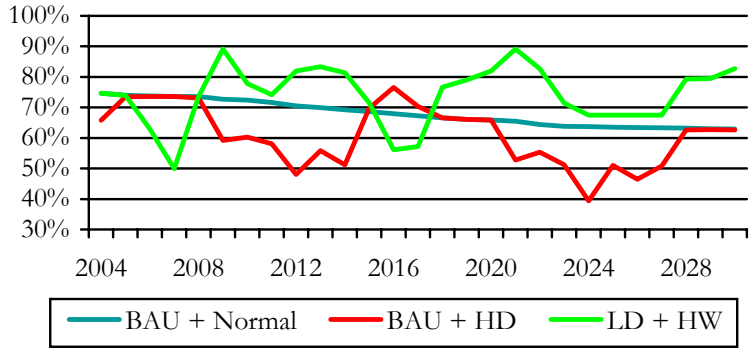


Figure 4-14. Percent demand coverage effectiveness of Network Unifications to Irrigation use

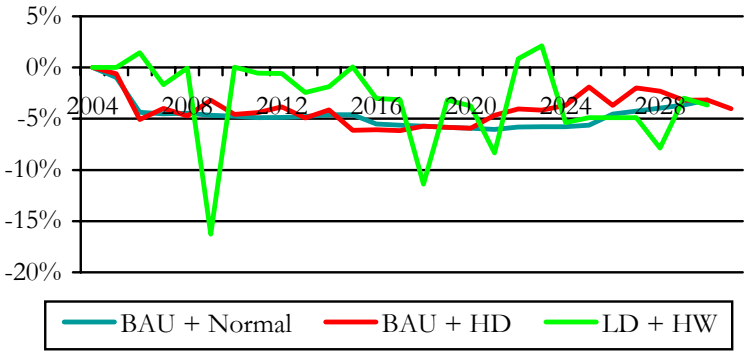


Figure 4-15. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios

Overall the option is not very expensive, since the unifications proposed are between neighbouring municipal departments and construction costs are low (Table 4-6). Additional cost is incurred from the augmentation of water distributed through the network but in any scenario this increase does not exceed 5% of the respective reference scenario direct cost, expressed in present value terms (Figure 4-16). The present value increase of the option under the LD+HW scenario is much lower, since the most expensive connection between Kostos and Naoussa is not required.

An additional remark is related to the most expensive connection between the municipal departments of Kostos and Naoussa. This connection is used only after 2028, when the installed desalination capacity cannot meet the demand, and is required only under normal or dry conditions. Additionally, the unification creates problems in the provision of water supply to the Paroikia municipal department. Therefore, the connection should - if realised - be combined with the construction of new boreholes or other supply enhancement measures in order to stabilise the supply delivered to the other regions from the boreholes of Kostos area.

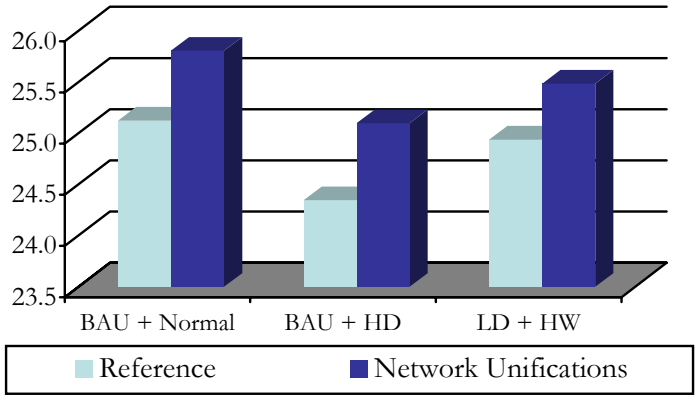


Figure 4-16. Total direct cost difference of the Network Unifications option under the three scenarios (Present Value – Million €)

The total environmental costs for network unifications do not vary significantly between the intervention scenario and the reference conditions for each availability/demand scenario (Figure 4-17); this is due to the fact that the environmental cost is calculated at the level of the resource and on the basis of total abstraction levels. The option does not affect groundwater abstraction levels; all available water resources are considered exploited and the increase of domestic abstractions is followed by a decrease of irrigation abstractions. Therefore, the total volume of water abstracted from each aquifer remains at the same level as with the reference scenario, and total environmental costs are more or less constant.

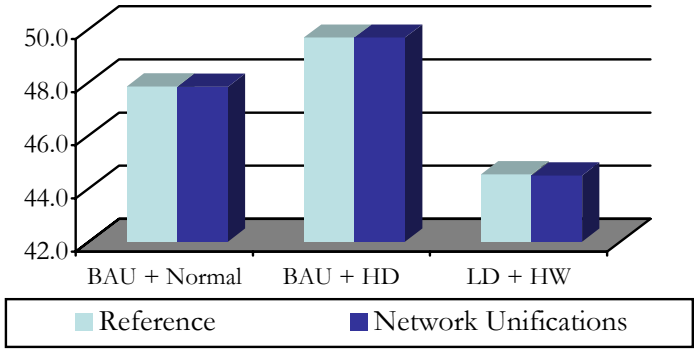


Figure 4-17. Total environmental cost difference of the Network Unifications option under the three scenarios (Present Value – Million €)

Desalination

Desalination is a water supply enhancement option of increasing popularity in the Greek islands and worldwide. A brackish water desalination plant already exists in Paros, with capacity of 1,450 m^3/d, and supplies only the settlement of Naoussa.

Based on the water demand patterns and the seasonal peaks observed on the island, the intervention evaluated involved the construction of four additional desalination units, aimed to supply:

- The town of Marpissa and the tourist settlement of Piso Livadi (Marpissa unit),
- The town of Paroikia (Livadia unit),
- The southern part of the municipal department of Paroikia (Livadia and Parasporos units)
- The suburbs of Naoussa and potentially after 2023 the town of Naoussa as well (Naoussa suburbs unit).

The desalination units were designed to have a lifetime of 15 years, and their capacity was estimated so as to meet approximately 95% of the domestic water needs in the selected regions. Units are replaced with increased capacity in 2021. Initially required capacity (year 2005) ranges from 2,300 m^3/d (LD+HW scenario) to 2,750 m^3/d (BAU+HD scenario). Details on the capacity for the each of the four units under the three scenarios can be found in the Annex.

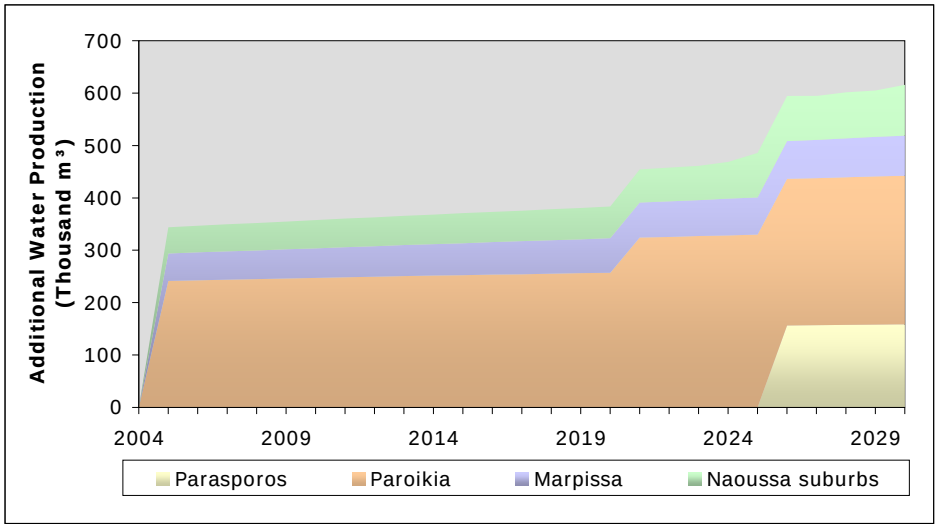


Figure 4-18. Water production from the four new desalination units (BAU + Normal scenario)

In all cases desalination is used as a primary supply source, with the aim to limit groundwater exploitation and indirectly improve coverage of irrigation water requirements. Figure 4-18 presents the water produced from the four units in the BAU + Normal scenario. Although desalination in all four areas is used as a primary resource,

units operate in full capacity only during August. During the winter operation falls to approximately 25 % of the installed capacity (Figure 4-19).

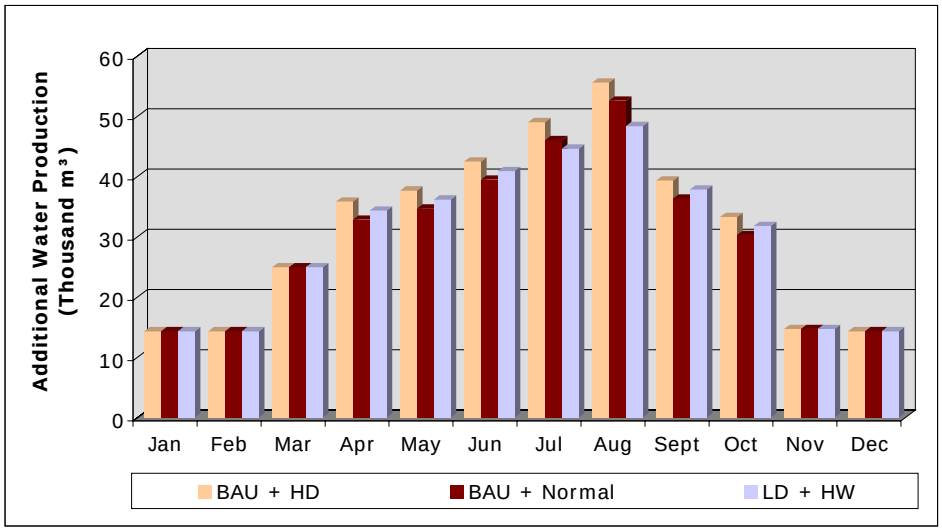


Figure 4-19. Monthly water production from the new desalination plants for the three scenarios (year 2009)

Desalination is the structural solution that performs the best among all examined. Due to the design specification, domestic demand coverage does not fall below 95% with the exception of a dry period in the BAU+HD scenario, where the effectiveness to domestic use is approximately equal to 92% (Figure 4-20). The domestic deficit improvement with respect to each reference scenario is subject to the high hydrological variations; improvements are lower under the LD+HW scenario where due to high water availability and decreasing demand trends, the domestic deficit is lower. Under the two other scenarios domestic deficit improvements can reach even 80% with respect to the reference scenario (Figure 4-21).

The domestic use relies more on desalination, and the smaller dependency to groundwater resources helps in the alleviation of irrigation shortages (Figure 4-22). Desalination units have been designed so as to meet domestic deficits, and not to completely substitute the use of groundwater resources; therefore, irrigation deficit improvements decrease as domestic demand increases and domestic use dependence on groundwater resources becomes higher (Figure 4-23).

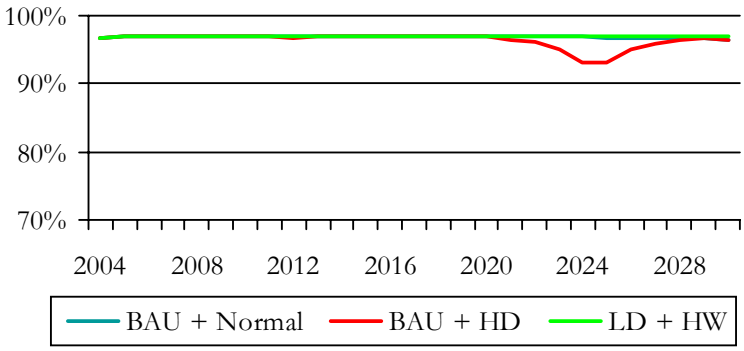


Figure 4-20. Percent demand coverage effectiveness of Desalination to Domestic use

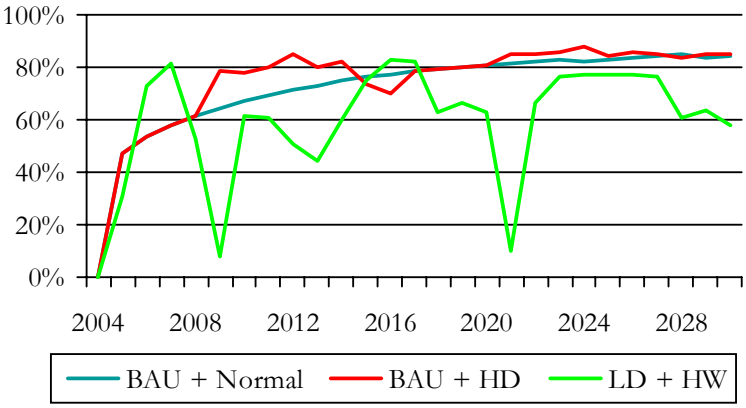


Figure 4-21. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Desalination option)

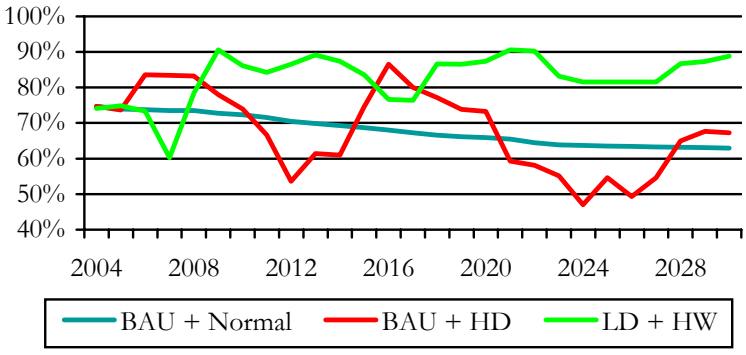


Figure 4-22. Percent demand coverage effectiveness of Desalination to Irrigation use

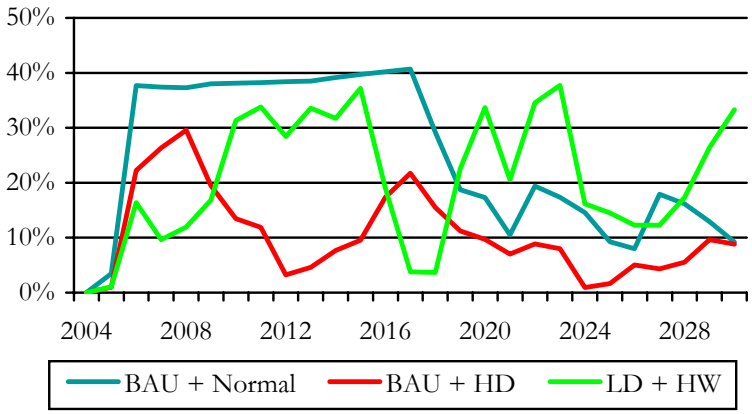


Figure 4-23. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Desalination option)

Despite the observed improvement and the recent technological advances, which lower energy consumption and costs, desalination remains a very expensive solution. Figure 4-25 presents the present value of direct cost between the three scenarios that were examined. In all cases an at least 30% increase of costs is anticipated if a strategy shall predominantly rely on desalination. A combination of the option with other, mostly non-structural solutions should therefore be preferred in an effort to limit the required capacity, and avoid incurring very high additional costs to consumers.

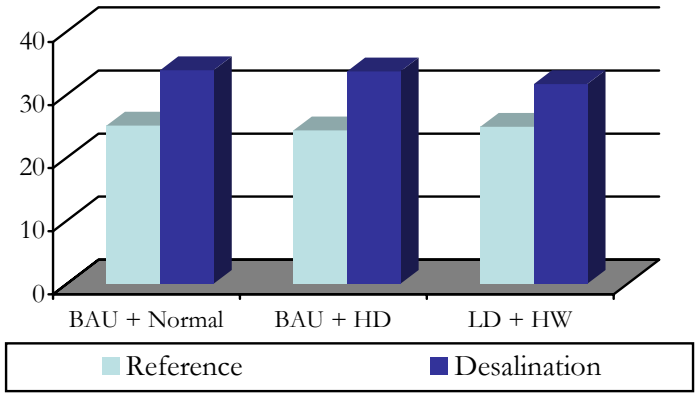


Figure 4-24. Total direct cost difference of the Desalination option under the three scenarios (Present Value – Million €)

The Environmental costs, presented in Figure 4-24, are once again almost constant within the BAU+Normal scenario, and within the BAU+HD scenario, for the reference case and the addition of Desalination. Under the LD+HW scenario however, the environmental cost is significantly reduced where Desalination is introduced, due to the reduction in groundwater abstractions that would be otherwise needed for the provision of drinking water.

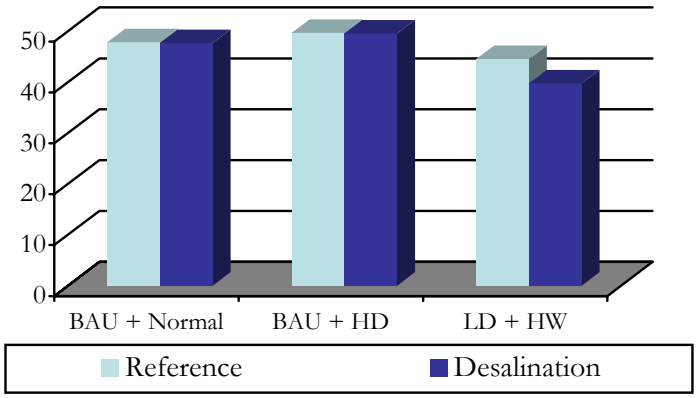


Figure 4-25. Total environmental cost difference of the Desalination option under the three scenarios (Present Value – Million €)

Groundwater Exploitation

The construction of new boreholes to provide additional water supply is the method that has been used most frequently in the case of Paros, as until recently the groundwater reserves were adequate, the costs entailed in the use of boreholes are significantly lower than those of major structural solutions, such as reservoir construction or desalination, and the solution was quick and easy to implement. As a result, the island today is perforated by a large number of boreholes, most being used for irrigation purposes. The size of this potential water management intervention as a component of the comprehensive scenarios for Paros was defined in the basis of the local geological structures and the current exploitation patterns. Since little or no data are available for abstracted water volumes from irrigation, the option is examined for domestic use only. Very low priority is given to the new supply source.

As in the case of Network Unifications, the size of such an intervention cannot be varied on the basis of demand conditions, since it depends more on available quantities for abstraction. Thus it was the schedule of implementation (see Annex) that was defined by the demand – availability conditions in the area, and formed the extent for the application of the option.

The locations that could be selected for the application of this intervention were:

- The Agairia – Alyki area. This area does not face water deficit, and thus can provide water for other parts of the island. However, this can only be effected in conjunction with network unifications, as this water network is currently isolated.
- The Archilohos area. This area faces small, periodic deficits, and exhibits low water exploitation. An additional borehole yielding about 47,000 m^3/yr can be constructed.
- The Kostos area, in order to supply water to the main town of Paroikia and its suburbs. A maximum of two new boreholes can be constructed here, based on current estimates, yielding about 75,000 m^3/yr each.
- The Glysidia area. However, the local aquifer is non-productive and vulnerable to salinisation; to that end, it is estimated that a borehole yielding only 7,000 m^3/yr should be constructed.

Yields and costs are summarized in Table 4-7.

Table 4-7. Yield and construction costs for new boreholes

Borehole	Yield (m^3/yr)[1]	Construction Cost (€)
Arhilohos	47,000	40,000
Glysidia	7,000	20,000
Kostos 1	75,000	40,000
Kostos 2	75,000	40,000
Total	*204,000*	*140,000*

Figure 4-26 presents quantities abstracted from the new drillings for the BAU+Normal scenario. The month variation of water production for a normal, dry and wet year (2009 under the three scenarios) is presented in Figure 4-27.

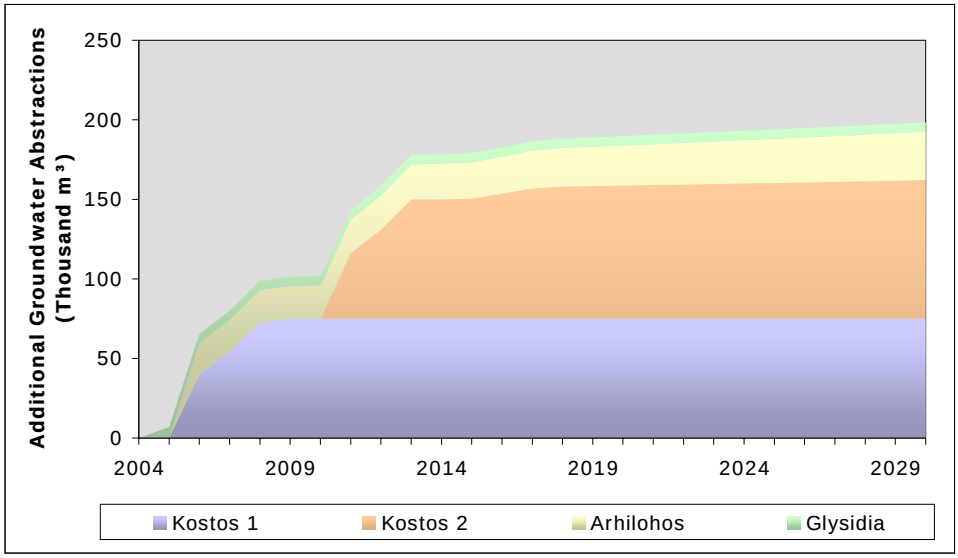


Figure 4-26. Additional Groundwater Abstractions (BAU+Normal scenario)

The new boreholes are assigned a very low supply priority with respect to existing supply sources. For this reason, under all three scenarios the new boreholes operate after the peak summer months, when the traditional supply sources have been depleted. During the peak season, supply normally originates from the existing groundwater drillings.

[1] Yields refer to a normal year.

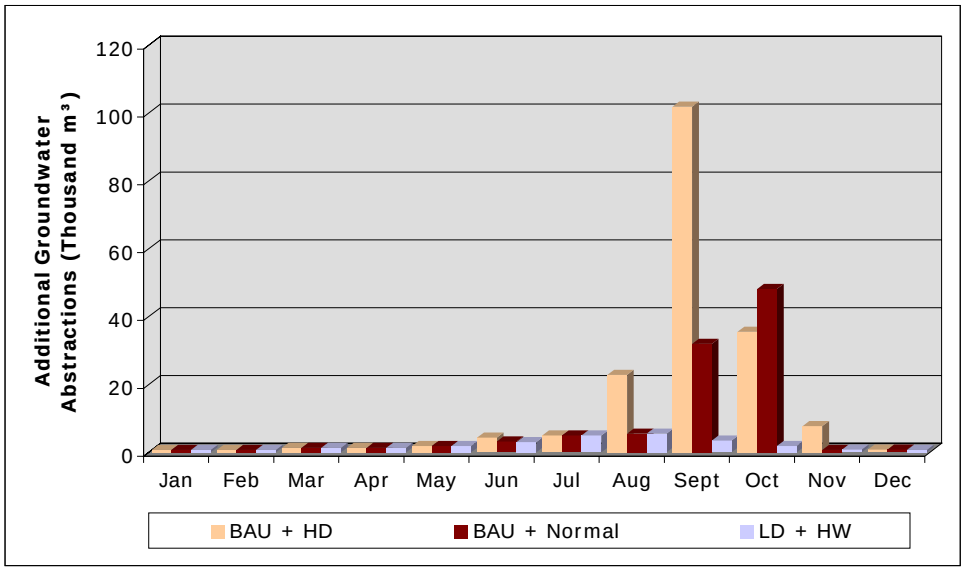


Figure 4-27. Monthly variation of abstractions from the new boreholes (2009)

The coverage of Domestic demand shows some improvement where the option is applied, which is once again diminished as the demand grows over time (Figure 4-28).. Although the traditional practice of groundwater exploitation can assist in meeting some domestic requirements, this effect is almost diminished in cases of drought, as it is depicted from the results of the BAU+HD scenario (Figure 4-29).

The coverage of Domestic demand shows some improvement where the option is applied, which is once again diminished as the demand grows over time (Figure 4-30 and Figure 4-31). Although the traditional practice of groundwater exploitation can assist in meeting some domestic requirements, this effect is almost diminished in cases of drought, as it is depicted from the results of the BAU+HD scenario. In general, irrigation deficits are not significantly affected, with the exception of the high dry scenario.

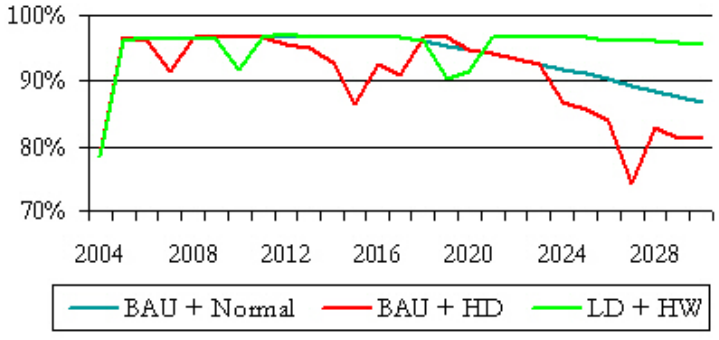


Figure 4-28. Percent demand coverage effectiveness of Groundwater exploitation to Domestic use

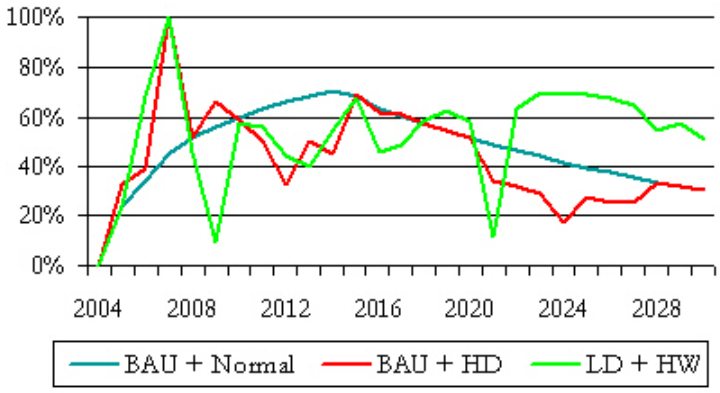


Figure 4-29. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Groundwater Exploitation option)

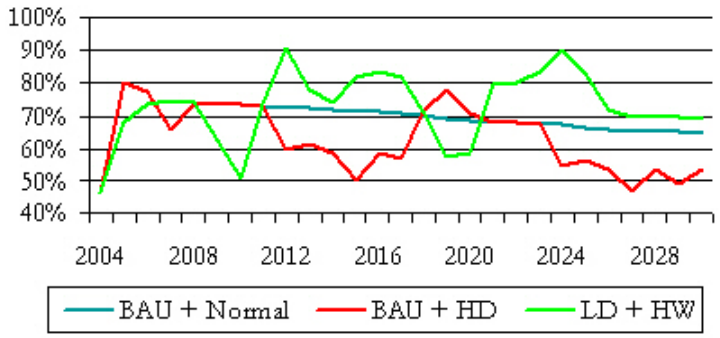


Figure 4-30. Percent demand coverage effectiveness of Groundwater exploitation to Irrigation use

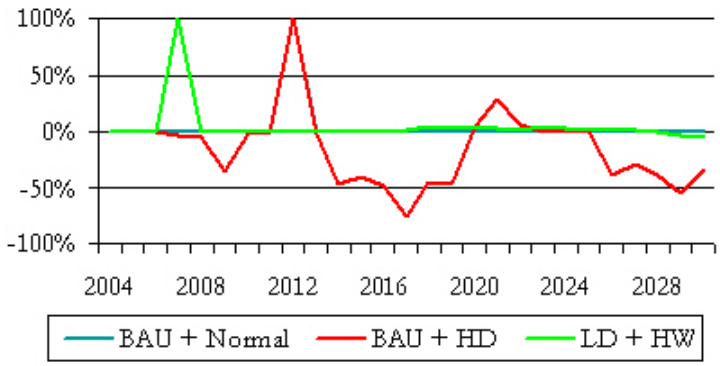


Figure 4-31. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Groundwater Exploitation option)

Direct cost increases are similar to those of the network unification option. A small average increase of about 3.5-5% is common among all three scenarios. Infrastructure

construction costs are low; the increase is due to the augmentation of water abstracted and delivered to domestic use, which incurs a proportional increase in annual operating costs.

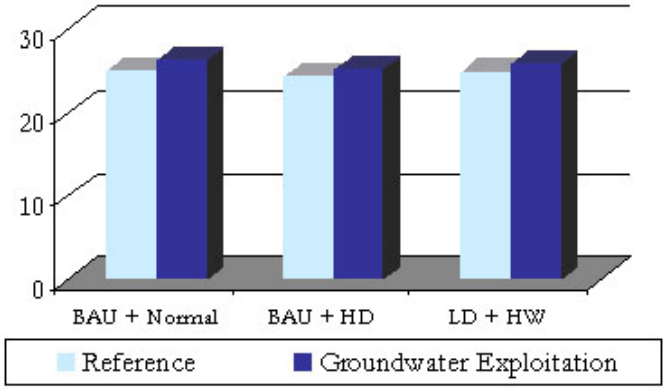


Figure 4-32. Total direct cost difference of the Groundwater exploitation option under the three scenarios (Present Value – Million €)

The total environmental cost records a substantial increase due to the increase of groundwater abstractions. In all cases, it is considerably higher than the respective reference case, with the highest values recorded for the high dry scenario.

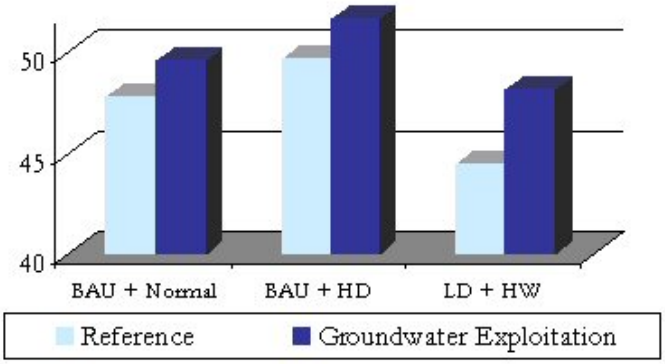


Figure 4-33. Total environmental cost difference of the Groundwater exploitation option under the three scenarios (Present Value – Million €)

Storage Reservoirs

In recent studies undertaken, two separate proposals have been made for the construction of storage reservoirs; the first was for the construction of a dam at Kavouropotamos river (Markantonatos, 2000), and the second the construction of an interception dam at Vrontas river (SPEED, 2003).

The Kavouropotamos river is located in the southern part of the island. The water of the proposed dam, with a capacity of 450,000 m^3 (dead volume equal to 30,000 m^3), would be intended for domestic supply only, and a drinking water treatment plant of capacity 7,500 m^3/d would be necessary. Extensive distribution networks to supply the entire island have been proposed by the study. The cost specifications of the dam and related waterworks are presented in Table 4-8.

Table 4-8. Cost components for Kavouropotamos dam (Markantonatos 2000)

Cost Component	Cost (million €)
Dam	4.70
Drinking water treatment plant	0.01
Connections	
From DWTP to Syrigos (Agairia)	1.42
From Syrigos to Paroikia	1.18
From Paroikia to Naoussa	0.72
From Naoussa to Marpissa	1.11
From Marpissa to Dam	0.96
Total	*9.13*

The construction of an interception dam at Vrontas river, which is located in the eastern part of the island, would contribute to the enhancement of local aquifers and therefore enhance domestic and irrigation supplies while inhibiting sea water intrusion. The specifications of the dam were:

- Capacity: 98,000 m^3.
- Dead volume: 30,000 m^3.
- Construction cost: 1.1 million €.

Construction for both dams starts in 2005 and it is estimated that they will be fully operational in 2009. In the scenario that was examined, Kavouropotamos dam was connected to the areas of Agairia, Marpissa and Paroikia, since the perimetric connection that was proposed is considered too costly and high energy heads are required to transfer water up to the northern settlement of Naoussa. Estimated runoff for both dams is presented in the Annex.

Figure 4-34 presents the abstraction from Kavouropotamos dam and the groundwater recharge from Vrontas dam under the BAU + Normal scenario.

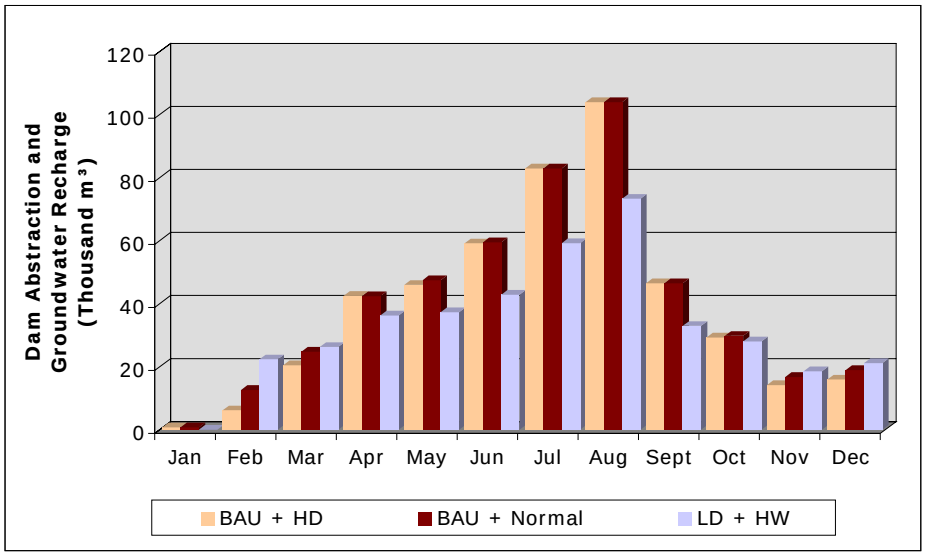


Figure 4-34. Monthly abstractions from Kavouropotamos and Vrontas dams for the three scenarios (year 2009)

The construction of storage reservoirs can be an effective solution in meeting domestic needs while at the same time increasing irrigation demand coverage, as can be seen in Figure 4-35 to Figure 4-38. Under normal (average) availability (BAU+Normal scenario), the effect of the option is similar to the one of desalination. However, the option performs much worse in the case of dry years, when inflows to both dams drop to 30% of normal (average) ones.

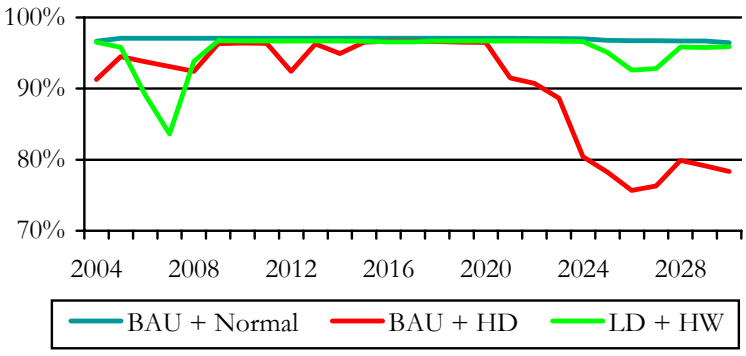


Figure 4-35. Percent demand coverage effectiveness of Storage Reservoirs to Domestic use

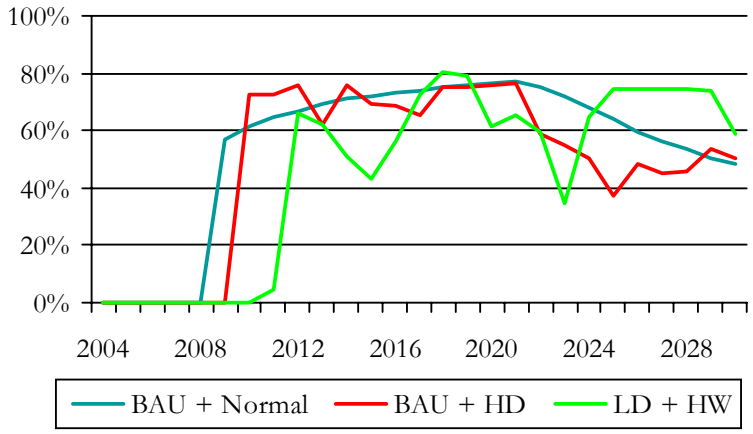


Figure 4-36. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Storage Reservoirs option)

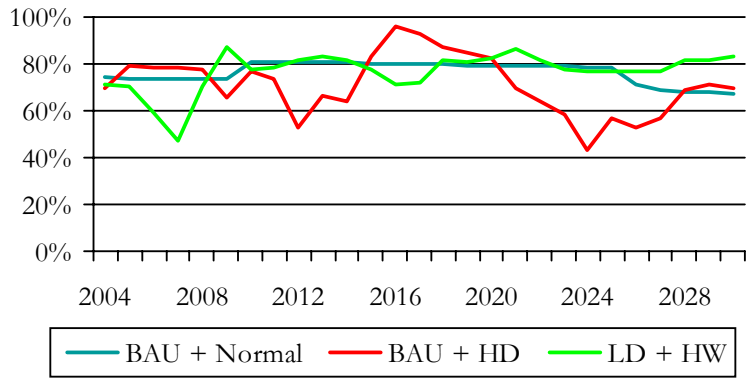


Figure 4-37. Percent demand coverage effectiveness of Storage Reservoirs to Irrigation use

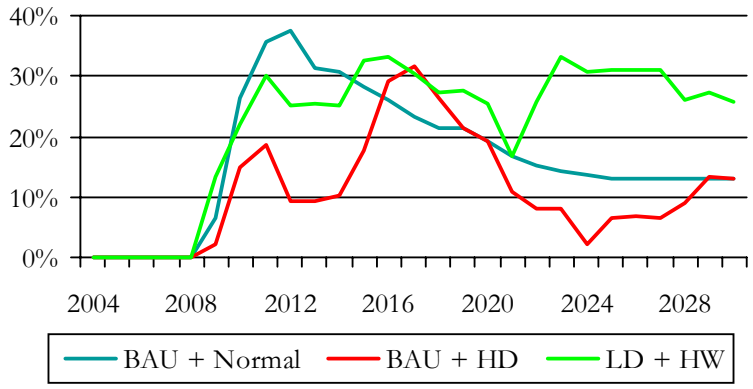


Figure 4-38. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Storage Reservoirs option)

Since alternative financing schemes are not examined at this stage, the Kavouropotamos dam is considered to be too expensive (even without including the operational costs of the system, such as pumping requirements). Another disadvantage concerns the operation of such an extensive network rather vulnerable to failures, which also renders the construction of a remote monitoring system for leakage control, and the facilities to support this, necessary. At the same time, the interception dam at Vrontas can with significantly lower costs help in the mitigation of the overexploitation of the aquifer and assist in sustaining the irrigation of the traditional vineyards in the municipal department of Naoussa.

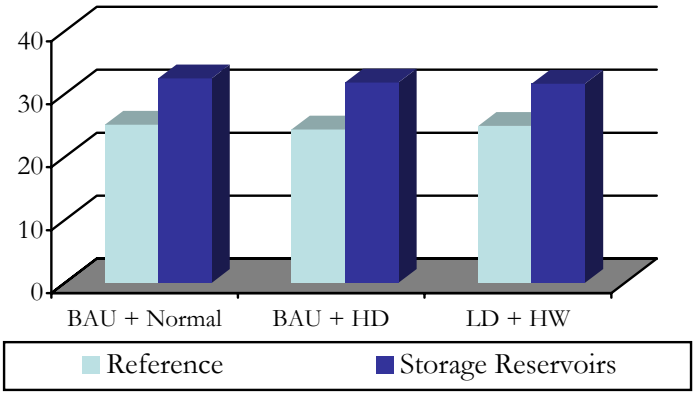


Figure 4-39. Total direct cost difference of the Storage Reservoirs option under the three scenarios (Present Value – Million €)

Given that the levels of abstraction are reduced and the recharge is increased due to the introduction of the interception dam, the environmental costs show a perceptible reduction, which becomes significant under the LD+HW conditions, which are optimal for both storage and groundwater recharge (Figure 4-40).

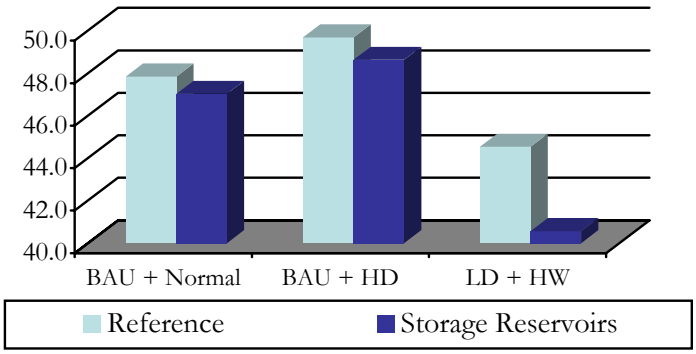


Figure 4-40. Total environmental cost difference of the Storage Reservoirs option under the three scenarios (Present Value – Million €)

Reduction of Network Losses

The current estimated level of network losses in Paros is in the range of 25% of the total supply. The option that was explored was a gradual reduction of losses from 25% to 15%, through successive network replacements. The application of this intervention was made on the assumption that internal network replacement will be gradually implemented in the different municipalities. First priority was given to the larger municipalities, Paroikia, Naoussa and Marpissa and secondary to the minor ones, Agairia, Arhilohos, Kostos and Leykes. The assigned scheduling of network replacements was made on the basis of demand size, current network status and observed deficits.

The process of network replacement has been estimated to last approximately 3 years, with an even distribution of costs throughout this time. The total cost of the option is presented in Table 4-9. In the case of the traditional settlements of Paroikia and Naoussa, where the internal distribution network is particularly old, extended and in some cases even undocumented, replacement may last up to 4 years.

Table 4-9. Network Replacement Costs (Markantonatos, 2000)

Municipal Department	Total Network Replacement Cost (€)
Paroikia	450,000
Naoussa	202,000
Marpissa	94,500
Arhilohos	51,000
Agairia	61,500
Leykes	133,500
Kostos	50,100
Total	*1,042,600*

Figure 4-41 presents the new demand for each municipal department under the BAU – Normal Scenario. Network replacements for Paroikia and Naoussa occur during the period 2005-2008, for Marpissa from 2005 to 2007 and for the other municipal departments in 2006, 2009 and 2012.

Scheduling of replacements does not differ much for the other two examined scenarios. The implementation of the option can be delayed in the smaller municipal departments with the exception of Kostos, whose boreholes are used to supply the department of Paroikia. More details on the implementation of the option are presented in the Annex.

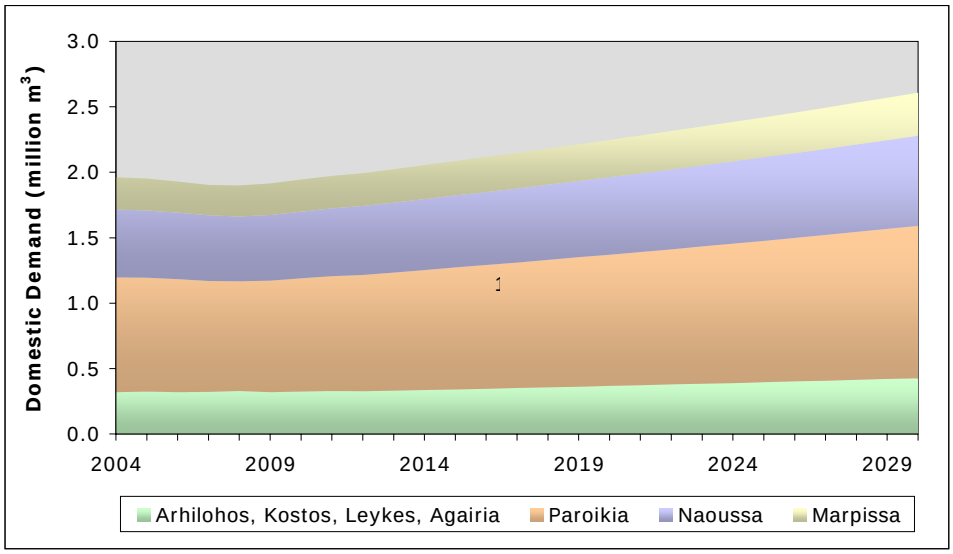


Figure 4-41. Domestic demand per municipal department under the network loss reduction option (BAU + Normal scenario)

Reduction of losses through distribution network replacements shows a significant improvement in terms of both domestic and irrigation demand coverage. The reduction of losses results in improved efficiency in the supply of water towards the domestic use (Figure 4-42 and Figure 4-43). As with all measures targeted to promote conservation, some improvement in irrigation demand coverage is observed; this is due to the decline in domestic groundwater abstractions resulting in higher water availability for agricultural purposes (Figure 4-44 and Figure 4-45). Since no additional supply sources are introduced in the system, the effect of the option for both domestic and irrigation water use, decreases as domestic demand becomes higher due to population growth. This is not of course the case for the LD+HW scenario where, after 2015 demand stabilises.

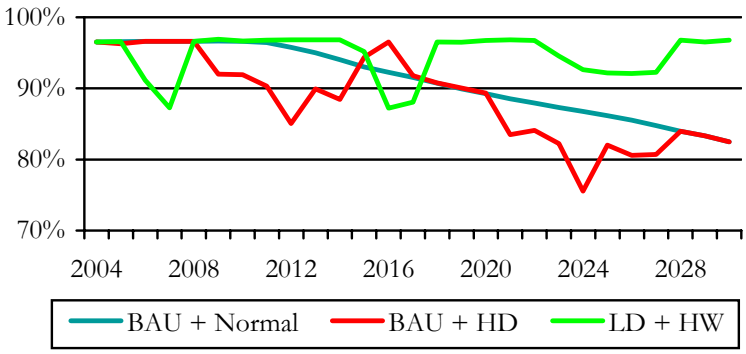


Figure 4-42. Percent demand coverage effectiveness of Reduction of Network Losses to Domestic use

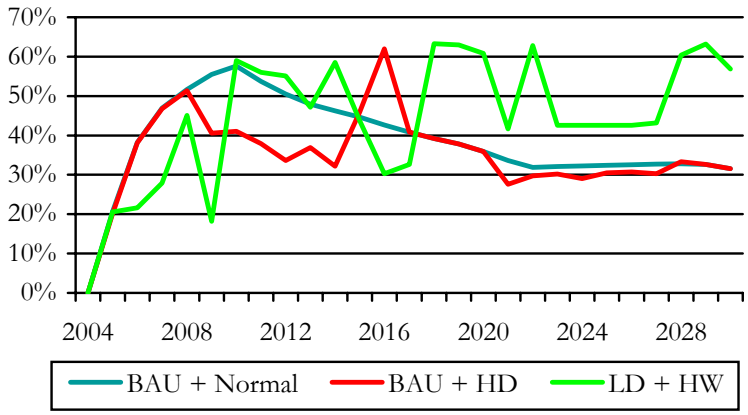


Figure 4-43. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Reduction of network losses option)

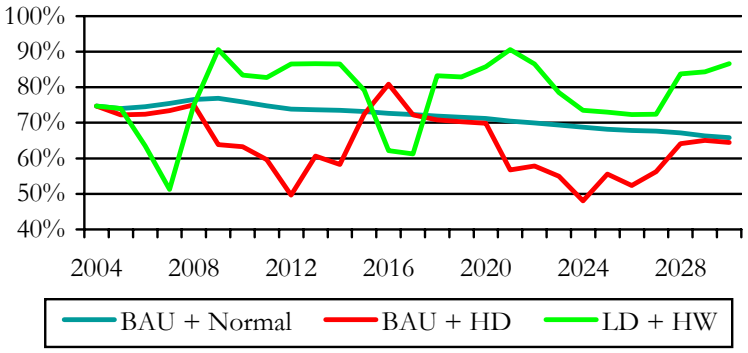


Figure 4-44. Percent demand coverage effectiveness of Reduction of Network Losses to Irrigation use

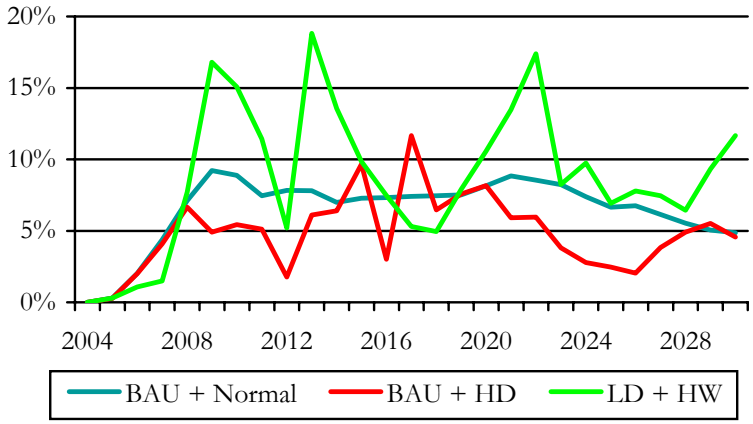


Figure 4-45. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Reduction of network losses option)

Figure 4-46 presents the direct cost (expressed as the present value over the period 2004-2030) between the three scenarios after the implementation of the scheduled network replacements. An average reduction of direct costs of about 4% is common between all three scenarios. Additionally, in all three cases direct costs are smaller than those of the respective reference scenario, since the volume of water delivered to domestic uses is significantly lower. This reduction of annual operational costs adequately covers the expenses of the network replacements. The effect of the option is less significant under a high dry frequency; however the relatively low cost makes the measure a candidate for further examination during the strategy development phase.

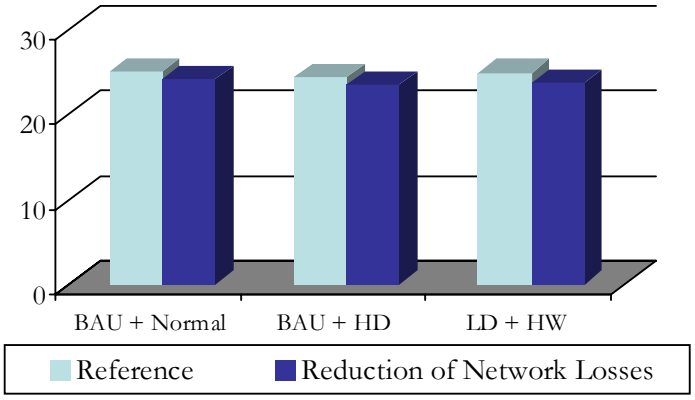


Figure 4-46. Total direct cost difference of the Reduction of Network Losses option under the three scenarios (Present Value – Million €)

As the introduction of network improvements does not directly affect the level of abstraction, the environmental costs within each scenario show no significant variation, with the exception of the LD+HW scenario, where the preferential abstraction from less vulnerable aquifers (possible only under high availability conditions) means an improvement in overall environmental performance (Figure 4-47).

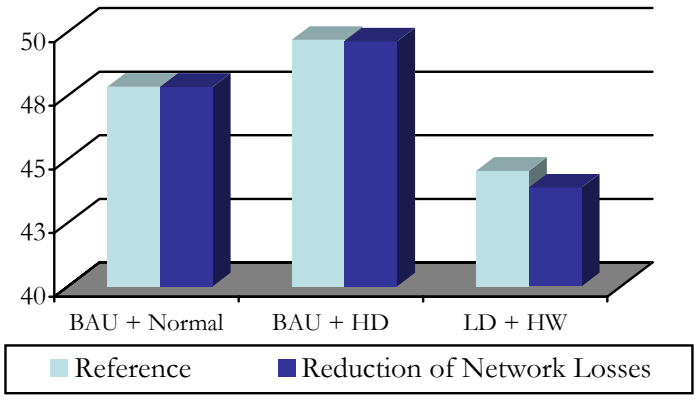


Figure 4-47. Total environmental cost difference of the Reduction of Network Losses option under the three scenarios (Present Value – Million €)

Demand management options

Cisterns

A traditional method for household water management is the use of cisterns that collected rainwater to be used later for various domestic uses. Today this method can be adapted to promote rational use of water resources in each household, by providing a means of storing water during the low-consumption times and alleviating pressure on the water network during peak times. The use of a cistern functioning as a water tank in each building to provide a buffering effect in the spatial and temporal distribution of the water supply could make a significant difference in the coverage of demand in areas facing problems of seasonal deficits and reduced flow at peak consumption times.

The proposed scenario assumed the existence of a state subsidy for the construction of household cisterns in areas with seasonal deficits. In order to enable modelling of this option in the DSS, it was assumed that the construction of cisterns was represented by the construction of a small storage reservoir set on the water network of each area selected for application. Each of these reservoirs was set with a capacity reflecting the total of the proposed cisterns, and the corresponding cost. The capacity of the reservoirs was estimated according to the permanent population of each area, assuming an initial penetration of the intervention at the range of 50% of households. A possibility for expanding this capacity by 20% after 5 years or more was also considered. Initial capacity and associated capital cost for each municipal department are presented in Table 4-10.

Table 4-10. Estimated capacity and cost for cisterns

Municipal Department	Permanent Population (2001)	Number of cisterns	Initial Capacity (m^3)	Capital Cost (thousand €)[1]
Paroikia	5812	937	20,150	2,063
Marpissa	984	159	4,000	350
Arhilohos	910	147	3,150	323
Naoussa	3027	488	10,500	1,075
Kostos	374	60	1,300	133
Total	*11107*	*1791*	*39,100*	*3944*

The total volume of water stored and used during the summer is presented in Figure 4-48.

[1] Assuming an average cost of approximately 2,200 €/cistern

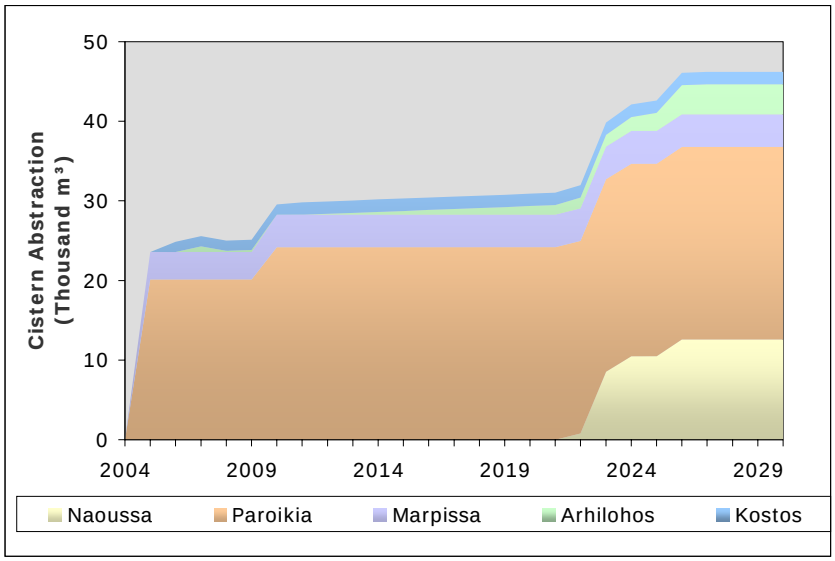


Figure 4-48. Cistern Abstractions under the BAU + Normal scenario

This abstraction may vary according to the water availability for each year. Figure 4-49 presents abstractions from the cisterns in the Paroikia municipal department for the three scenarios in year 2009. For an average year, cisterns are used during September and October, since available supply is adequate to meet the August peak. In cases of drought and limited available resources, abstraction takes place in August, while for wet years cisterns are not needed at all.

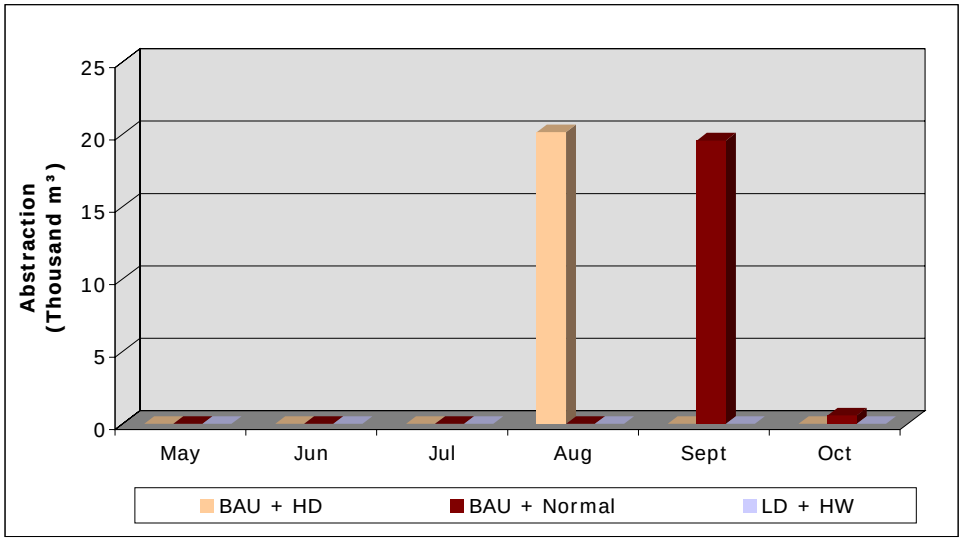


Figure 4-49. Abstractions from Paroikia cisterns under the three scenarios (2009)

Domestic deficit does not present any significant improvement; as demand escalates, the initial improvement of 10% falls to approximately 3% in 2030 (Figure 4-50 and Figure 4-51). The small increase in groundwater abstractions, used to fill up the cisterns, results in a similar deterioration of irrigation deficit and decreases in effectiveness (Figure 4-52 and Figure 4-53).

Overall, the option can help to alleviate some pressure on available resources during the high demanding summer months while improving the reliability of domestic supply. Of course the small capacity cannot adequately meet the structural deficit appearing in some municipal departments, and an expansion of the application of the option in the hotel sector is considered unrealistic. Additionally, the measure is not effective in cases of drought and escalating demand.

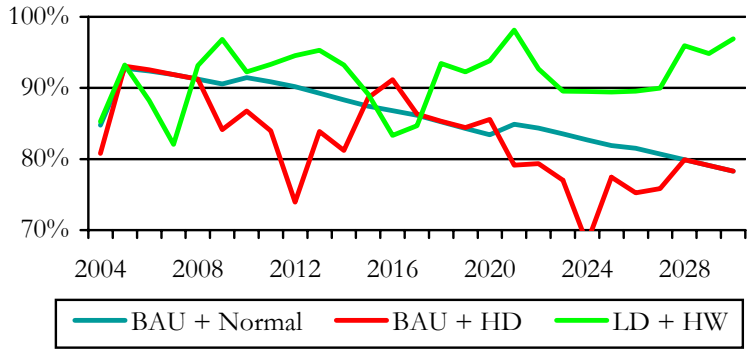


Figure 4-50. Percent demand coverage effectiveness of Cisterns to Domestic use

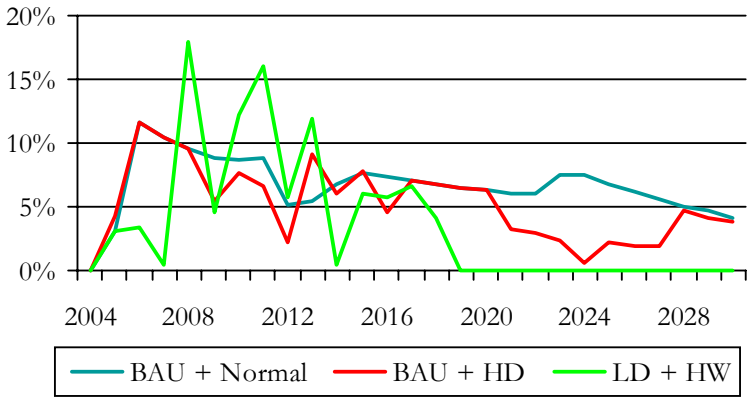


Figure 4-51. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Cisterns option)

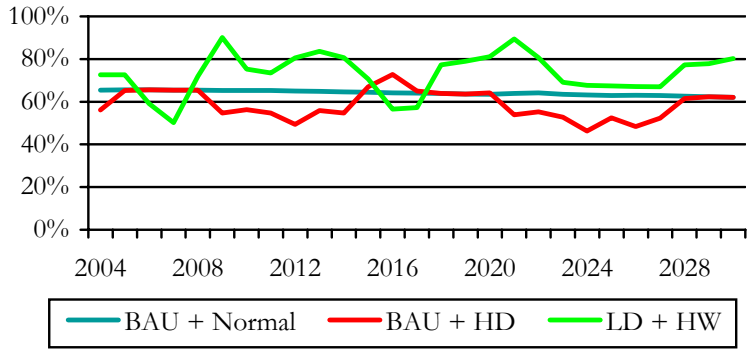


Figure 4-52. Percent demand coverage effectiveness of Cisterns to Irrigation use

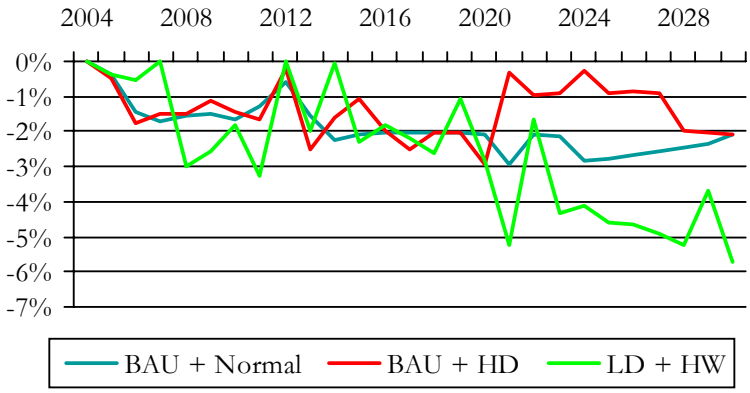


Figure 4-53. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Cisterns option)

Figure 4-54 presents the direct cost (expressed as the present value over the period 2004-2030) between the three scenarios after cistern construction. In all three cases, direct costs increase about 15-16% due to the high subsidies for allowing the penetration of cisterns into the supply system.

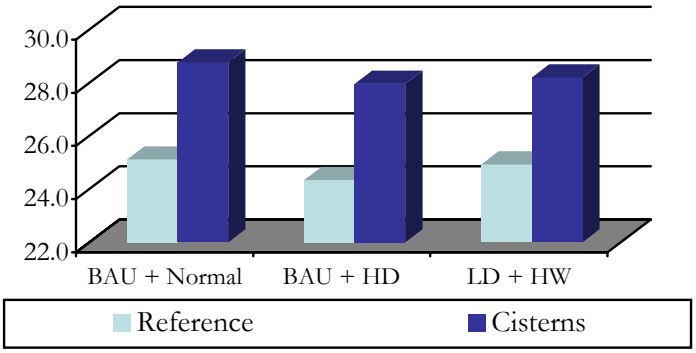


Figure 4-54. Total direct cost difference of the Cisterns option under the three scenarios (Present Value – Million €)

Environmental costs present a marginal increase, due to the augmentation of groundwater abstractions, that are used for filling up the cisterns during the low peak months (Figure 4-55).

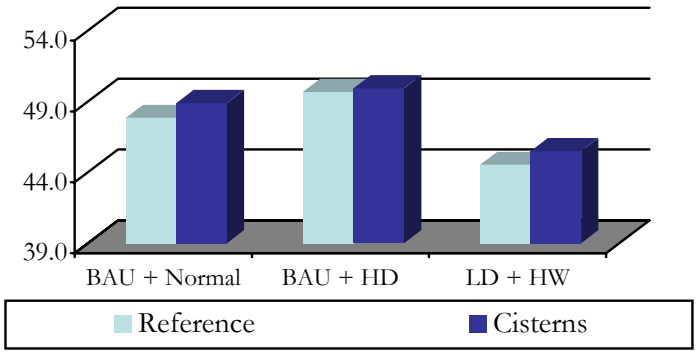


Figure 4-55. Total environmental cost difference of the Cisterns option under the three scenarios (Present Value – Million €)

Improvement in Irrigation Methods

Although agriculture in Paros Island is not the major economic activity, it is vital to the local economy and social structure. The climatic conditions on the island demand that any crops need to be irrigated, for at least part of the year; the season of highest irrigation demand coincides with the peak tourist season, creating strong conflicts. At the same time, farmers have neither been educated on how to improve irrigation efficiency, nor are they offered any significant incentives to reduce their water usage. Current irrigation efficiency is estimated to be in the range of 50%.

The scenario that has been evaluated for improvement of irrigation methods assumes a transition from the currently used irrigation methods, which mostly involve furrow irrigation, with drip irrigation that is most efficient, for all crop types with the exception of cereals (in the case of garden vegetables or pulses it is assumed that cultivation takes place in greenhouses).

The improvement was scheduled to be implemented gradually in 4 time steps, with time intervals of at least two years between each. Initial implementation was set to begin in 2005, with cost estimated at 0.45 €/m^2. The maximum feasible penetration was defined by the crop cultivation patterns in each area. Figure 4-56 presents the scheduling for the application of drip irrigation in the municipal department of Agairia under the three scenarios.

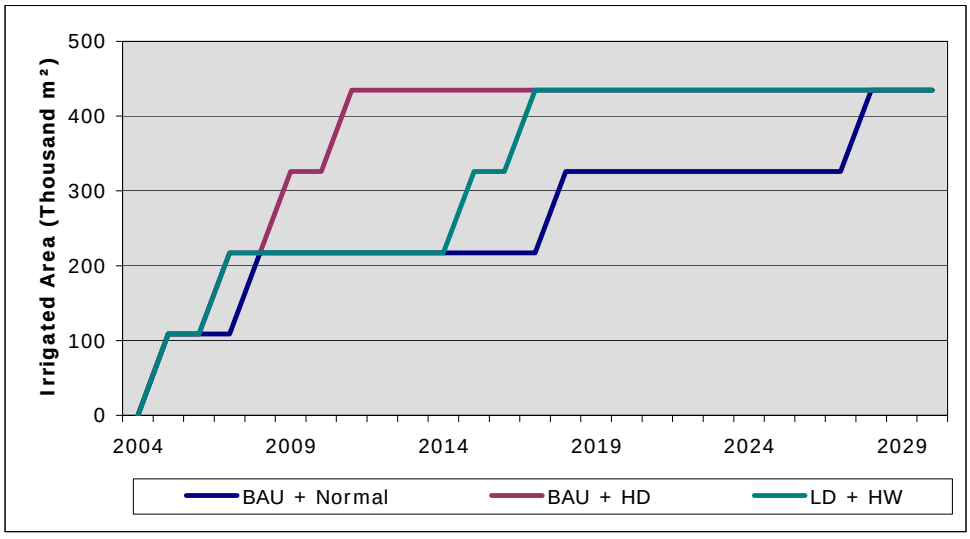


Figure 4-56. Application of drip irrigation in Agairia under the three scenarios

Effectiveness to domestic demand coverage presents minor increases under all three scenarios and exhibits a decreasing trend as the demand escalates (Figure 4-57). The improvement of domestic deficit with respect to each reference scenario is minor, with maximum values ranging from 12% (BAU+Normal) to 35% for the wet periods of the LD+HW scenario (Figure 4-58). This is due to the reduction of irrigation demand and therefore groundwater abstractions during the low peak months, which results in higher groundwater availability for the prioritised domestic use during the peak summer period.

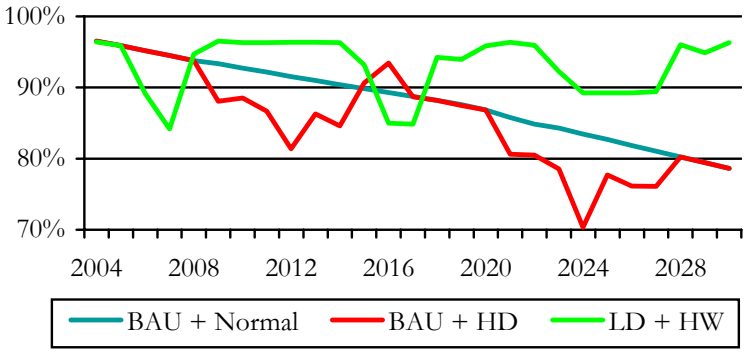


Figure 4-57. Percent demand coverage effectiveness of Improvement of Irrigation Methods to Domestic use

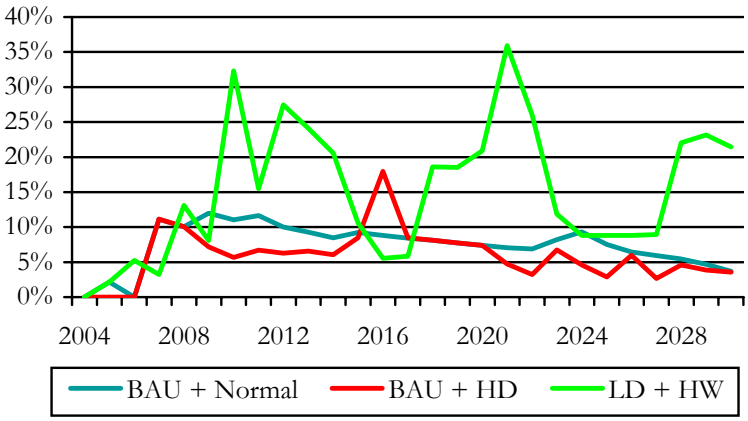


Figure 4-58. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Irrigation Method Improvement option)

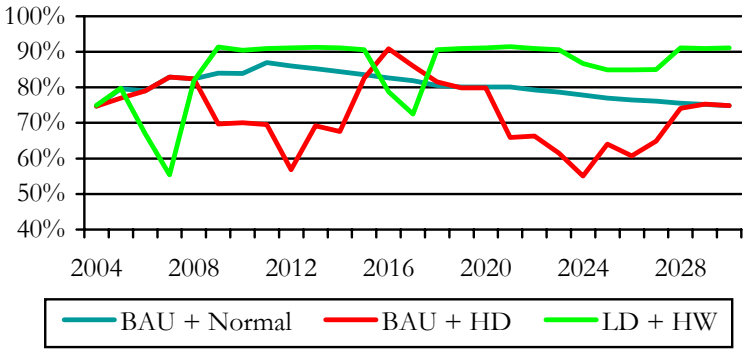


Figure 4-59. Percent demand coverage effectiveness of Improvement of Irrigation Methods to Irrigation use

Improvement in irrigation demand coverage is of course very important, reaching a maximum of 90% in terms of effectiveness and of approximately 65% in terms of relative deficit improvement (Figure 4-59 and Figure 4-60). However, it should be emphasised that even after irrigation method improvements, irrigation demand is not fully met. Additionally, irrigation deficit improvement is much lower in cases of drought, when available supply is low and a higher priority is given to domestic uses.

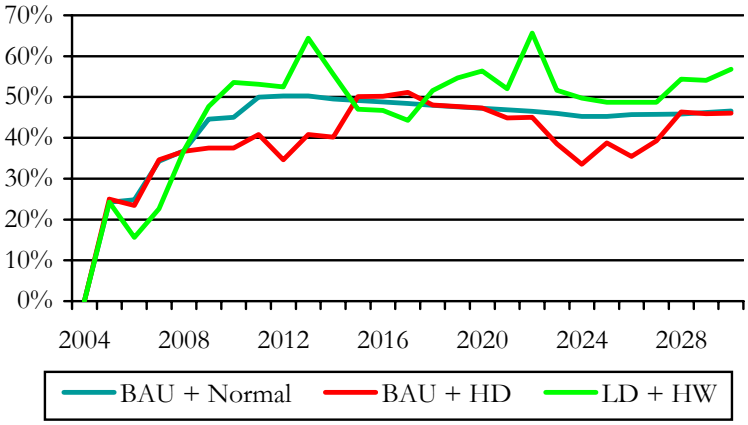


Figure 4-60. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Irrigation Method Improvement option)

Direct cost increases are relatively low, ranging from 5% under normal (average) conditions to 5.6 % under a high wet frequency (Figure 4-61). The small increase is due to the increase of two cost components:

- Capital costs, which are associated with the provision of subsidies to farmers for the implementation of the option;
- Increase of operating costs, due to the marginal increase of domestic water consumption during the peak summer months.

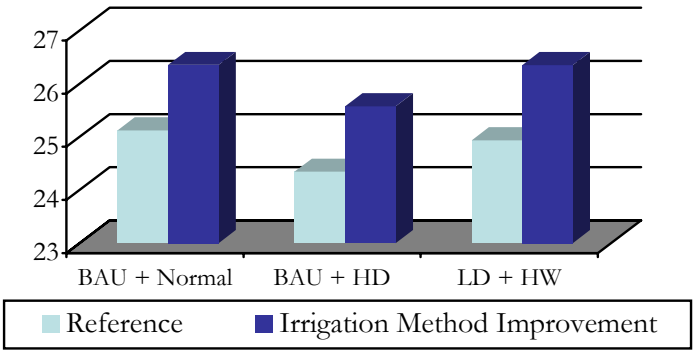


Figure 4-61. Total direct cost difference of the Improvement of Irrigation Methods option under the three scenarios (Present Value – Million €)

The total environmental cost does not differ much after the implementation of the option, presenting only a marginal decrease. As previously stated, since both domestic and irrigation demands are not fully met, all available resources are exploited; thus environmental costs associated with groundwater abstraction remain constant (Figure 4-62).

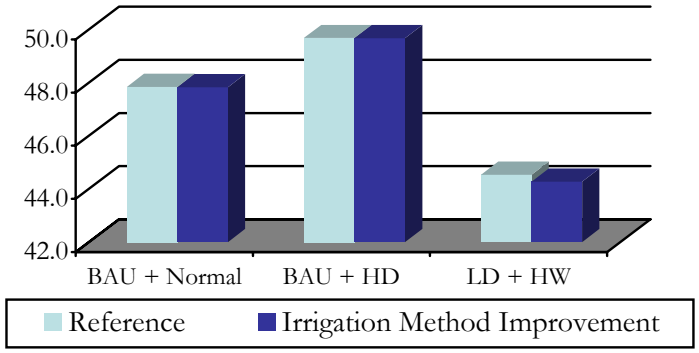


Figure 4-62. Total environmental cost difference of the Improvement of Irrigation Methods option under the three scenarios (Present Value – Million €)

Conservation measures in domestic use

A large proportion of the water consumed by the domestic sector is never actually used and eventually wasted, particularly so in the case of tourist services. Some of this is due to lack of awareness, while a large amount is due to inappropriate or faulty equipment - high pressure showerheads, large volume flushes, leaky or dripping faucets to name a few. In addition to increasing awareness about water issues, there are also several technical methods for effecting a decrease of water consumption in the domestic sector, such as dual/reduced flow flushes, low-flow taps, and water meters.

The scenario evaluated for the application of conservation methods in the domestic sector, including in this case the tourist industry, assumed a state subsidy for the installation of low flow taps in households and in hotels. The initial penetration of the measure was assumed to be 40% of all households, a figure doubled and reaching 80% at the point in time where a large water deficit was estimated to appear. Detailed scheduling for the application of the measure under the three scenarios is presented in the Annex. Figure 4-63 presents domestic demand after the implementation of successive applications of conservation measures.

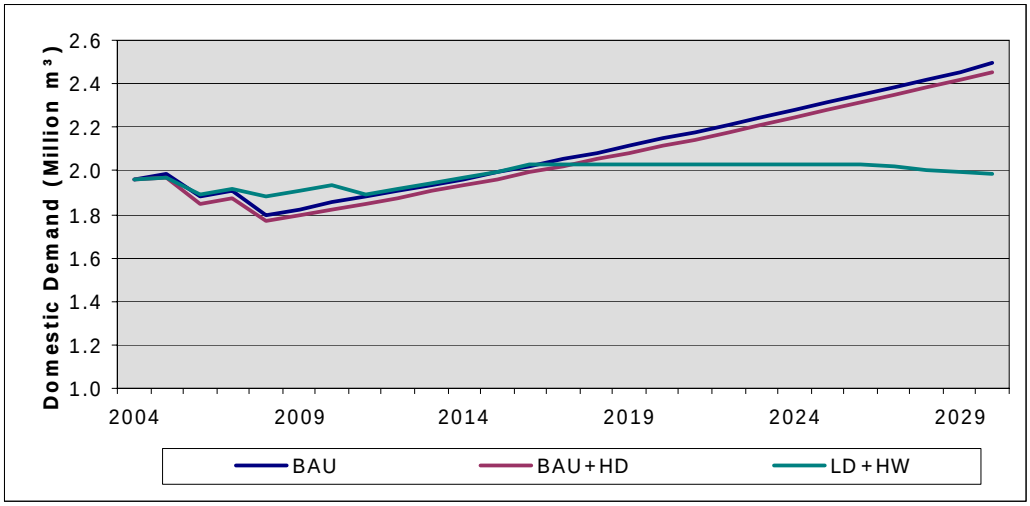


Figure 4-63. Domestic demand after the application of conservation measures for the three scenarios

Domestic conservation can be an effective response in terms of domestic demand coverage, since it can stabilise the effect of domestic demand increase for a period of approximately 10 years (Figure 4-64). The maximum improvement in domestic use deficit is reached under high wet conditions, while under a normal (average) water availability sequence, this reaches a maximum of 47% in year 2015 (Figure 4-65). After that, the effect of the application of the option gradually reduces as demand escalates. The same improvements, although more decreased, stand for the effectiveness to irrigation demand coverage and the improvement of irrigation deficits, with a more pronounced effect under the LD+HW scenario (Figure 4-66 and Figure 4-67).

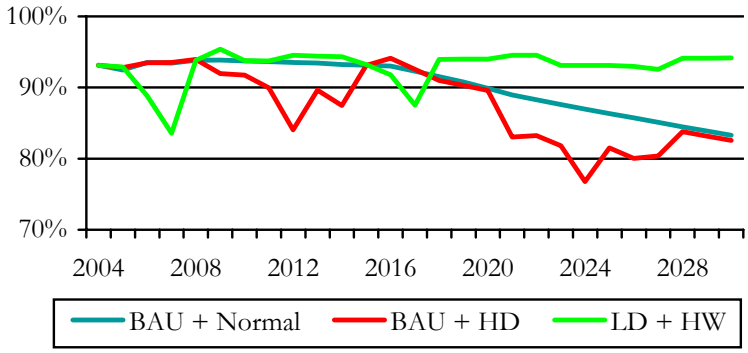


Figure 4-64. Percent demand coverage effectiveness of Domestic use Conservation measures to Domestic use

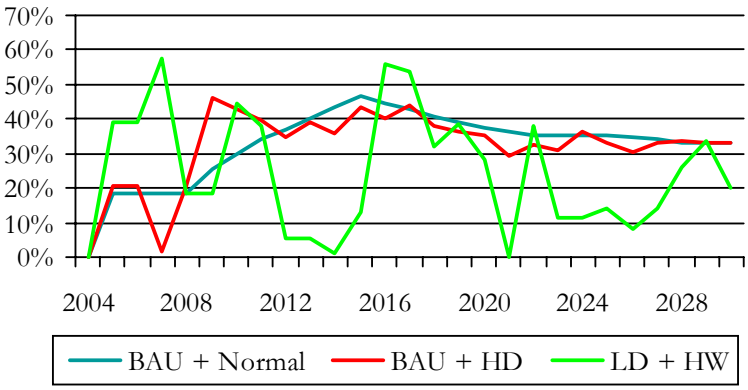


Figure 4-65. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Domestic conservation option)

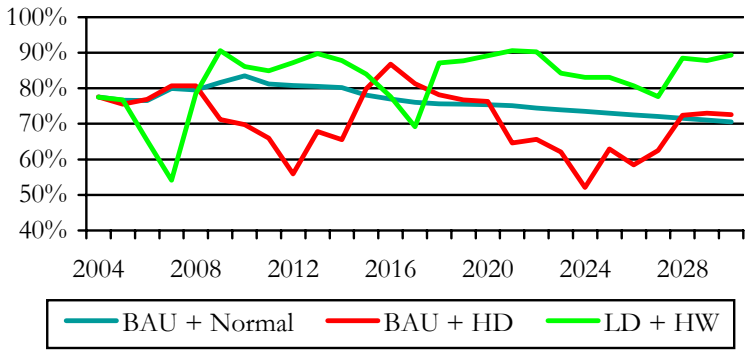


Figure 4-66. Percent demand coverage effectiveness of Domestic use Conservation measures to Irrigation use

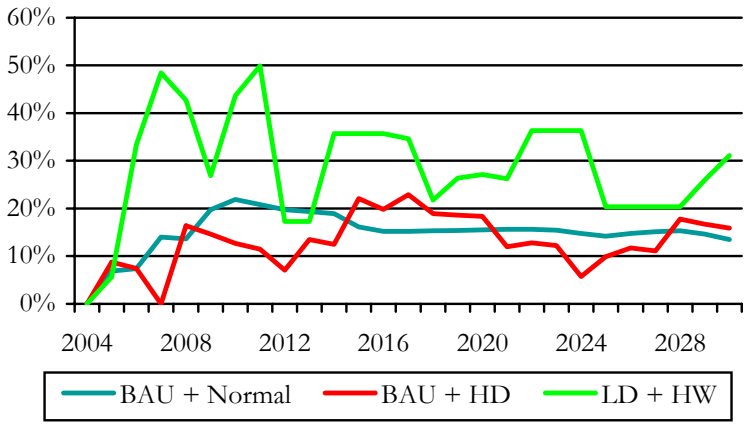


Figure 4-67. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Domestic conservation option)

As with all measures aiming to enhance the efficiency of domestic usage, conservation results in a decrease of the total direct cost of the system, of about 8-10%, due to the reduction of operating costs associated with domestic water supply (Figure 4-68). The effect is more intense than the one associated with network loss reduction, since the cost of conservation is much lower than the one associated with network replacements.

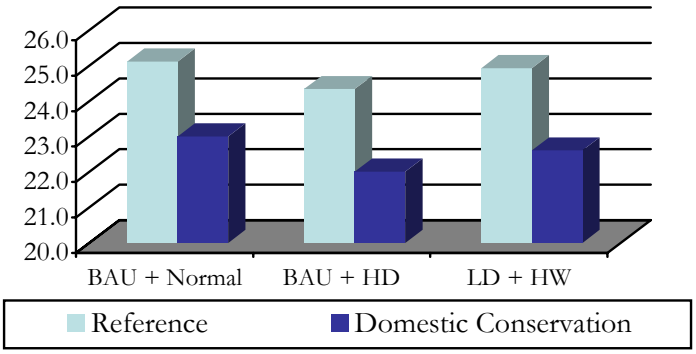


Figure 4-68. Total direct cost difference of the Domestic use Conservation measures option under the three scenarios (Present Value – Million €)

Similarly to the reduction of network losses, domestic conservation does not directly affect groundwater abstraction volumes. Therefore, with the exception of the LD+HW scenario, environmental costs do not show significant variation (Figure 4-69).

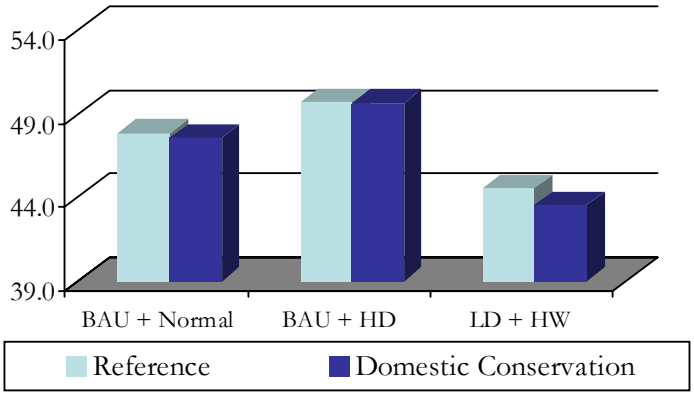


Figure 4-69. Total environmental cost difference of the Domestic use Conservation measures option under the three scenarios (Present Value – Million €)

Pricing

Domestic Use Pricing

Although the management of domestic water supplies is the responsibility of one single authority, prices throughout the island are not uniform. The current weighted average selling price is at approximately 1.45 €/m^3 with the highest prices being charged during the summer period. Water is most expensive in the municipal department of Naoussa (1.57 €/m^3), Paroikia (1.54 €/m^3) and Marpissa (1.52 €/m^3), while the lowest prices are charged in the water-rich departments of Arhilohos (0.73 €/m^3) and Leykes (0.42 €/m^3). No data exist on the conservation incentives of the existing tariff system, making it hard to estimate an elasticity of the demand on price. In the scenario examined for domestic pricing, the goal was not of course to lower consumption in order to achieve a better coverage of domestic needs, but to estimate the effect that a price increase would have on demand. For this purpose, and since consumption rates are relatively low, a small elasticity of -0.21 was assumed for residential consumption and an elasticity of -0.42 for tourist consumption. The pricing scheme that was examined was a gradual increase (every two years) of average prices from 1.6 €/m^3 to 2.5 €/m^3. Figure 4-70 presents the new domestic demand under the examined pricing scheme for the BAU scenario.

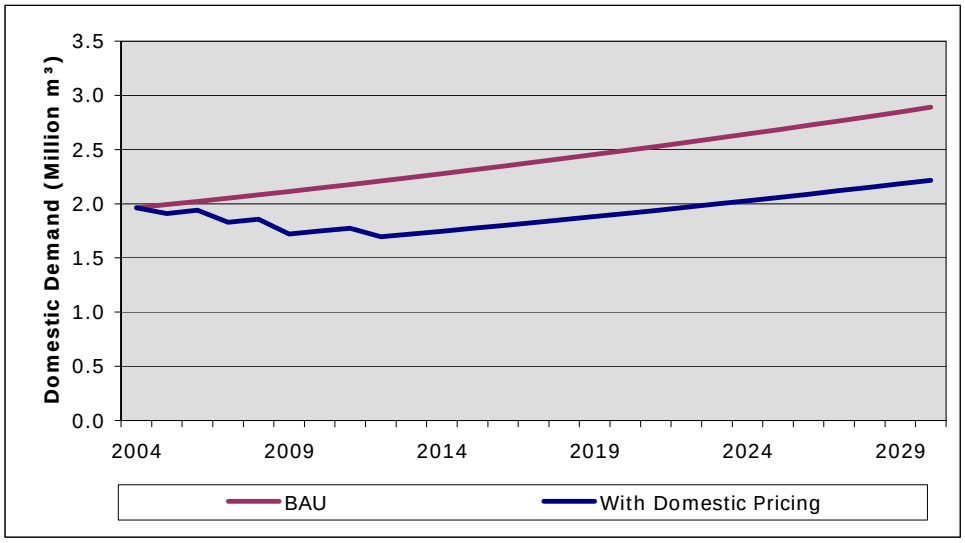


Figure 4-70. Domestic demand before and after pricing application (BAU demand scenario)

The significant domestic demand decrease, due to the rather large augmentation of prices and the high assumed elasticities, directly affects domestic demand coverage effectiveness (Figure 4-71). Especially under the LD+HW scenario, domestic pricing after 2007 stabilises effectiveness to 97%. Similarly, domestic deficits present a significant improvement, reaching almost 80% under the BAU+Normal and LD+HW scenario (Figure 4-72). Similar trends are observed for irrigation water use. For example, under the BAU+Normal scenario, effectiveness to irrigation demand coverage gradually increases up to the year 2015, when almost 80% of irrigation needs are covered,

following the application of the pricing scheme. After this point, the gradual increase of domestic demand, due to population growth results to the gradual decrease of irrigation effectiveness (Figure 4-73). The same observation stands for the relative improvement of irrigation deficits. However, the effect under the BAU+HD scenario is much more pronounced, in some cases exceeding even 50% with respect to the reference case (Figure 4-74).

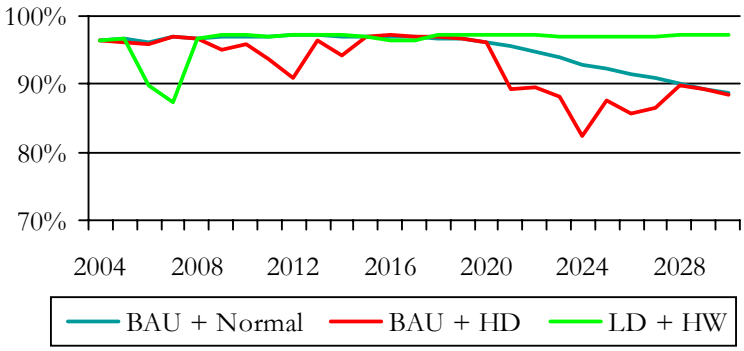


Figure 4-71. Percent demand coverage effectiveness of Domestic Use Pricing to Domestic use

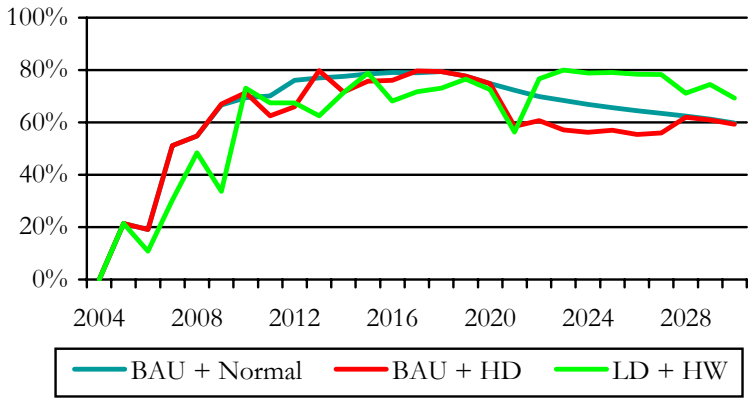


Figure 4-72. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Domestic use pricing option)

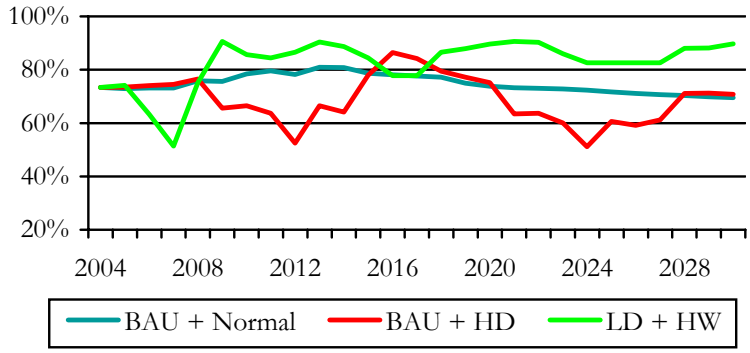


Figure 4-73. Percent demand coverage effectiveness of Domestic Use Pricing to Irrigation use

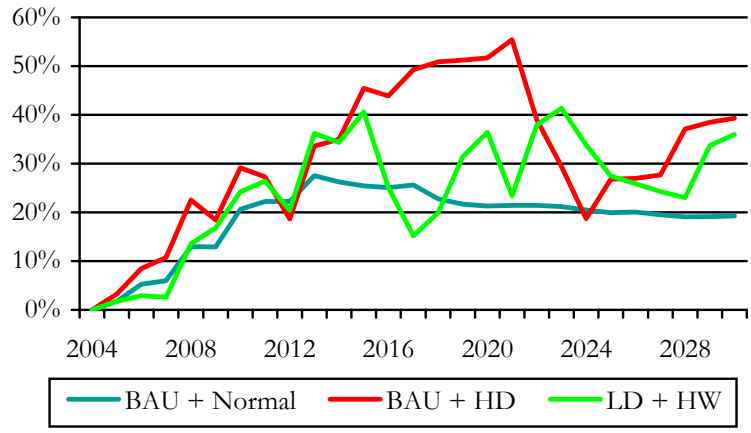


Figure 4-74. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Domestic use pricing option)

In all cases the option results in a significant decrease of direct costs (Figure 4-75). This is due to the fact that operational costs are only associated with domestic use. Consequently, the reduction of supply delivered to domestic use incurs a direct cost decrease, which under the LD+HW scenario can reach even the 13% of the present value of the respective reference case.

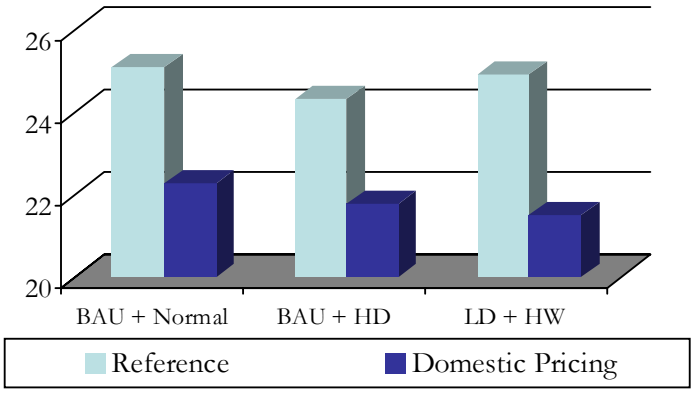


Figure 4-75. Total direct cost difference of the Domestic Use Pricing option under the three scenarios (Present Value – Million €)

Total environmental costs present a marginal decrease, since in some aquifers unsustainable groundwater abstractions are reduced. However, the total volume of groundwater abstractions more or less remains constant, and therefore, the decrease of the total environmental cost is very low (Figure 4-76).

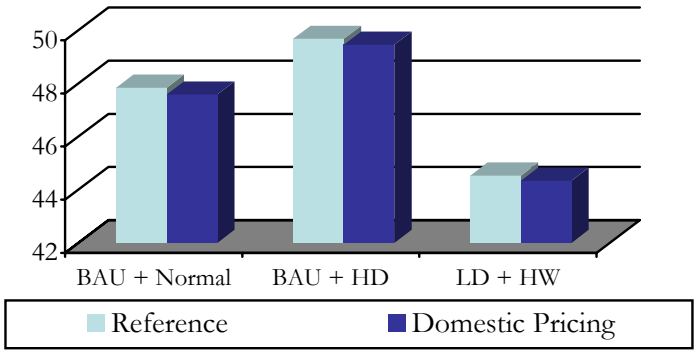


Figure 4-76. Total environmental cost difference of the Domestic Use Pricing option under the three scenarios (Present Value – Million €)

Irrigation Pricing

As in most places in Greece, irrigation water is not charged or an area charging system is used. In the case of Paros, with the exception of the municipal department of Naoussa, there is no central irrigation system and normally irrigation activities are supported through private boreholes operated by the farmers themselves or by farmer associations. Although no data exist either for prices or for demand elasticities, an assumption is made for estimating the impact that a small pricing system would have on irrigation demand. For this purpose it is assumed that initially (2004) prices for irrigation are set at 0.07 €/m^3 and they are gradually increased by 0.02 €/m^3 every two years during the period 2005-2009. The elasticity of demand on price is assumed to be equal to -0.8 (almost double to the one assumed for tourism demand). Irrigation demand under the selected pricing scheme is presented in Figure 4-77.

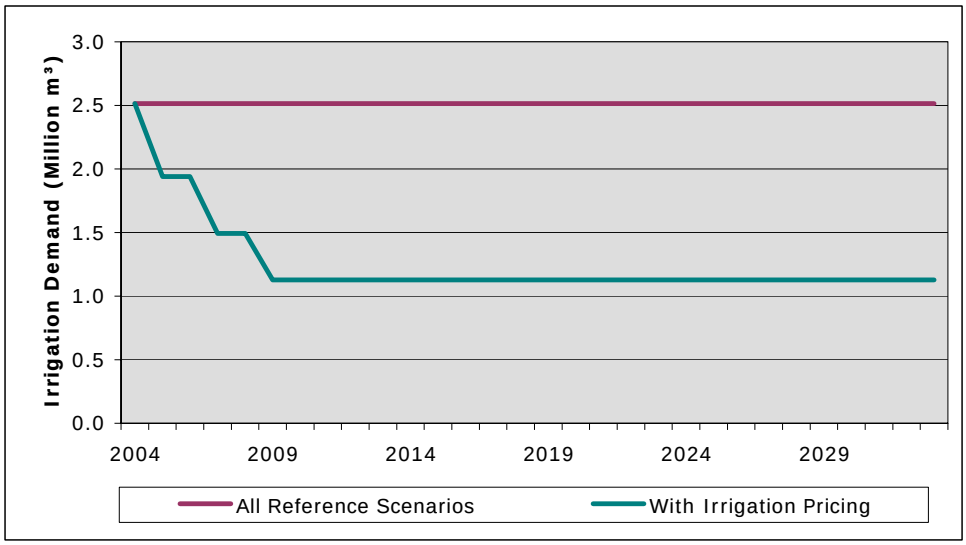


Figure 4-77. Irrigation demand before and after the implementation of a pricing scheme

As with domestic pricing, irrigation pricing has a significant impact on agricultural demand. The high price increase and the relatively high tentative elasticity assumed lead to a considerable improvement of domestic and irrigation deficits. This improvement is adequate to stabilise the effectiveness to domestic demand coverage up to the year 2010, provided of course that water availability is constant (Figure 4-78). Similarly, the improvement of domestic deficits reaches a maximum of 62% during the same period (Figure 4-79). It should be noted that during wet years the option has particularly no effect, since it is during these periods that domestic deficit is at a minimum and no further improvements can be achieved.

The impact on the effectiveness to irrigation demand coverage is higher (Figure 4-80). It reaches approximately 90% under the LD+HW scenario, while under the BAU+Normal scenario it drops at 87% due to the increase of domestic demand. The improvement with respect to each reference case shows a stabilising trend, around 80%.

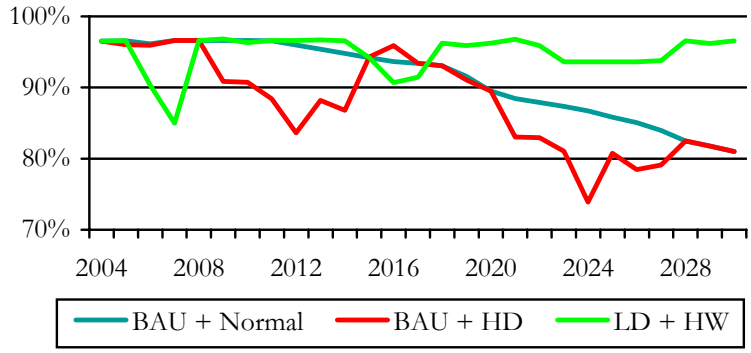


Figure 4-78. Percent demand coverage effectiveness of Irrigation Pricing to Domestic use

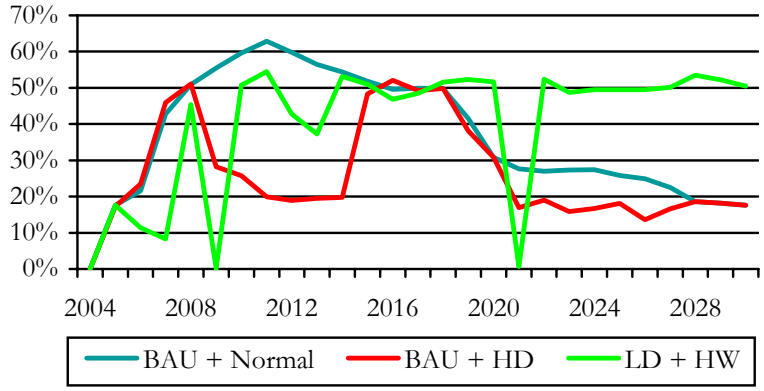


Figure 4-79. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Irrigation pricing option)

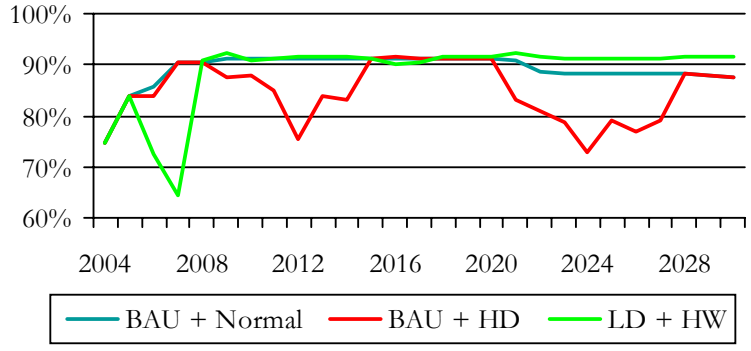


Figure 4-80. Percent demand coverage effectiveness of Irrigation Pricing to Irrigation use

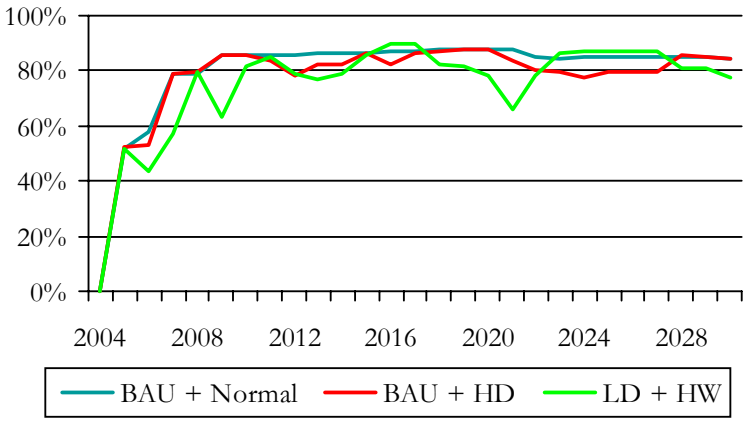


Figure 4-81. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Irrigation pricing option)

Reduction of irrigation demand results in the augmentation of supply delivered to domestic uses. This in turn, increases the operating costs of the system and leads to an average increase of about 4-8% on direct costs. (Figure 4-82).

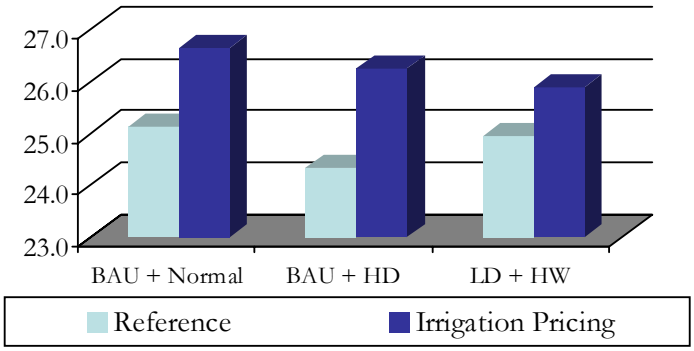


Figure 4-82. Total direct cost difference of the Irrigation Pricing option under the three scenarios (Present Value – Million €)

The decrease of environmental costs is marginal for the application of irrigation pricing on the BAU+Normal and on the BAU+HD scenaria (Figure 4-83). However, under the LD+HW, this decrease reaches 4%; the large reduction of irrigation demand leads to a more sustainable exploitation of groundwater resources, limiting groundwater abstractions.

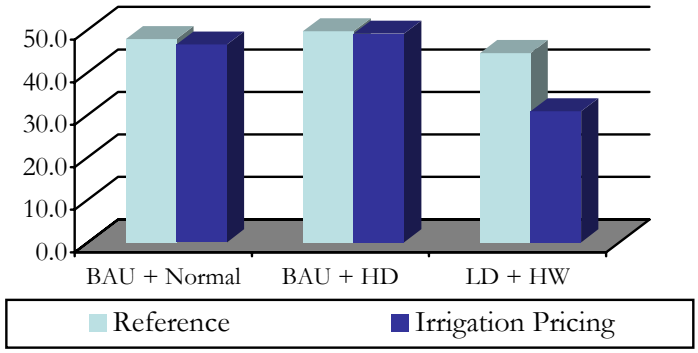


Figure 4-83. Total environmental cost difference of the Irrigation Pricing option under the three scenarios (Present Value – Million €)

4.4. Final Selection

The final selection of instruments to be further analysed during the strategy formulation phase depends on the performance of the options examined regarding the indicators that were presented throughout the analysis.

Results are summarized in Table 4-11. The effectiveness of each option is approached through the evaluation score obtained by the WSM DSS, from the performance with respect to domestic and irrigation demand coverage, assuming a weight of 0.5 for each indicator, and a satisfactory range of values from 80 to 100%.

Environmental sustainability is expressed through the total environmental cost for each option, associated with pollution generation and unsustainable groundwater abstractions. It should be noted that the major environmental problem faced by water management authorities in Paros lies in the overexploitation and salinisation of aquifers. Economic efficiency, the ability to produce more with less, is expressed through the total direct cost, expressed in present value terms.

Table 4-11. Final evaluation of instruments

Option	Effectiveness (Relative Performance Index for Demand Coverage)	Economic Efficiency (Direct Cost – PV – million €)	Environmental Sustainability (Total environmental cost – PV in million €)
Reference Case	0.0001	25.1	47.8
Network Unifications	0.0003	25.8	47.8
Desalination	0.5003	33.9	47.7
GW Exploitation	0.0001	26.3	49.0
Storage Reservoirs	0.0005	32.5	48.8
Loss Reduction	0.0007	24.1	47.8
Cisterns	0.0000	28.8	45.9
Conservation	0.0018	23.0	47.8
Irrigation Improvement	0.0033	26.4	47.8
Domestic Pricing	0.0041	22.3	47.8
Irrigation Pricing	0.0655	26.3	46.5

The normalisation of the results obtained in Table 4-11 under a scale ranging from 0 to 5 yields the results presented in Table 4-12.

Table 4-12. Normalised option performance matrix

Option	Effectiveness (Relative Performance Index for Demand Coverage)	Economic Efficiency (Direct Cost – PV – million €)	Environmental Sustainability (Total environmental cost – PV (million €)
Reference Case	-	****	**
Network Unifications	*	***	**
Desalination	*****	-	**
GW Exploitation	-	***	-
Storage Reservoirs	*	*	*
Loss Reduction	**	****	**
Cisterns	-	**	*
Conservation	**	*****	**
Irrigation Improvement	**	***	**
Domestic Pricing	***	*****	**
Irrigation Pricing	****	***	****

From the normalised matrix presented in Table 4-12 it is obvious that a new strategy for Paros cannot rely on the application of a few instruments only. Desalination seems to occupy an advantageous position in terms of technical, economic and environmental sustainability. However, the very high cost associated with the option and technical limitations which do not allow for the installation of a capacity exceeding 5,000 m^3/d, renders the "massive" application of the option impossible. If a strategy that is developed relies predominantly on desalination, it should also incorporate measures to improve efficiency of domestic and irrigation uses and to promote conservation of the island's vulnerable resources. Required installed capacity can also be decreased if the option is combined with small-scale structural interventions that can improve the use of existing resources. Those are network unifications, the storage reservoir that is proposed at Vrontas, and a reduction of network losses.

It therefore becomes apparent that in the scope of integrated water resources management, in addition to the common practice of supply enhancement-based approaches, we need to examine strategies incorporating "softer" measures. In doing so, we can maximise efficiency improvements in the water network with minimal cost, effected through demand management, public participation and awareness, and incorporate complementary supply enhancement methods to ensure adequacy of supply where necessary.

5. Comprehensive Scenarios for Belice Basin

The area of *Garcia-Arancio Irrigated Districts* under study is located in the Western part of the Italian Sicily region and is comprised of the hydrological basin of the Belice River, which extends almost from the Southern to the Northern coast of the Island in the territories of Palermo, Trapani and Agrigento, and of the four irrigation districts Castelvetrano, Menfi, Sambuca di Sicilia and Sciacca that lie along the Southern coast, between the provinces of Trapani and Agrigento. It also includes the catchment of the artificial Arancio Lake, a valuable resource for the agricultural use of water.

The water resources of the Belice Basin are mostly represented by the artificial Garcia Lake, built during the years 1977-1985 on the left branch of Belice and having a present useful capacity of 63 million m³. Water from the Garcia is used both for irrigation purposes and for providing the urban settlements, inside and outside the basin, with drinkable water.

As regards the urban use of water, the Belice resources just integrate the main two networks of the Montescuro acqueduct and the Favara di Burgio aqueduct, which constitute the water source with the first priority for the settlements of the area.

Montescuro originates from the springs of the Sicani Mountains, outside and East of the examined area, and goes across the Belice Basin from East to West. It covers 65% of its urban demand. Within the case study area, it supplies the settlements of Castelvetrano, Gibellina, Montevago, Partanna, Poggioreale, S. Margherita Belice, Salaparuta and Sambuca di Sicilia. Outside, its carries water to some territories of Palermo, Trapani and Agrigento. Favara di Burgio is fed by the water springs in the town of Caltabellotta and supplies water for 67% of the demand. It supplies Menfi and Sciacca within the area and other territories of Agrigento outside.

In terms of irrigation, the Garcia Lake serves the cultivated lands under the competence of the Co-operative no.2 – Palermo, Co-operative no.1 – Trapani and Co-operative no.3 – Agrigento, this latter being responsible for the four *Garcia –Arancio districts* of the case study.

These districts can rely on their own water source, the Arancio Lake, which has a useful capacity of 30 million m³, and is entirely used for irrigation. This lake, however, is not sufficient to cover the crop requirements during the summer period, and the withdrawals from the Garcia are fundamental to the survival of the cultivations. The role of Garcia is not limited to the water supply during summer: it also has the task to recharge the Arancio during the winter months. But although in the winter water is available for all the users and uses, both irrigation and urban consumes, it is in the summer that the water resources of Belice Basin have to be shared and deficits may arise. Although the construction of the Garcia Reservoir was promoted in 1969 with the scope of irrigating the nearby lands, and only in 1986 it started being used for urban needs, the latter have the higher priority and the shares for the exploitation of the reservoir waters, established as percentages of the existing volume, are bound by that.

The goal of the formulation of scenarios and strategies for the Garcia-Arancio districts area is to verify the policy measures that are under implementation by the local authorities, which concern improvement of distribution efficiency, both for domestic and agricultural use, and further exploitation of existing surface water. This analysis addresses the potential solutions for a complete satisfaction of the agricultural demand under a negative trend of the climatic conditions, precipitation decrements and temperature increments, and under a forecast rise of the urban rate of consumption.

The dominant philosophy of the past concerned the constructions of new reservoirs, the interconnection of existing ones and the mutual integration between different water sources such as lakes, springs and local boreholes. At the time being, some projects for waste water re-use are under study and others are being carried out. On the side of irrigation practice, several steps have been made towards an efficient distribution of water since 1957, when the first cultivated lands of the area were provided with water through a network of open surface canals. They have been progressively replaced by pipelines, and the use of irrigation methods such as drip is even more growing. Demand management options, such as reduction of network losses or application of quotas, are also to be implemented to balance the growing consumption rates for the urban water use, which are forecast to double in 30 years.

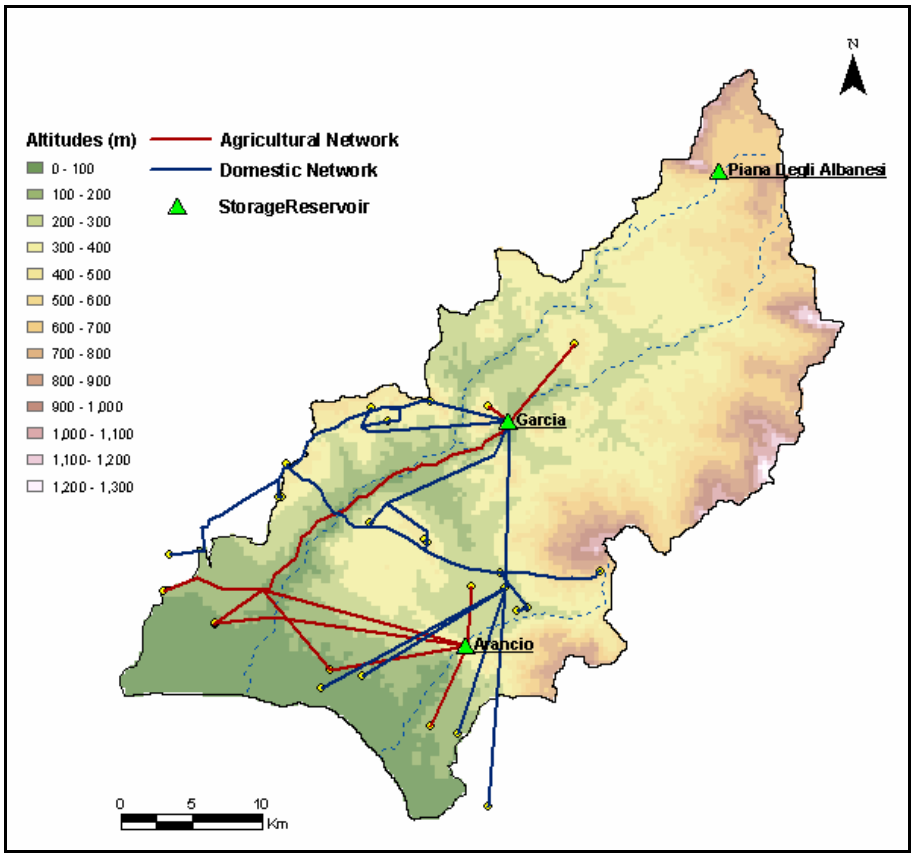


Figure 5-1. Domestic and agricultural networks in the Garcia-Arancio Districts and Belice Basin

5.1. Demand and Availability Scenario Components

Formulation of Demand Scenarios

Data

The formulation of demand scenarios for the Garcia-Arancio districts involved the four types of node Settlement, Irrigation Site, Exporting and Tourist Site. Except for the agricultural scenarios, which were based on assumptions of a growing cultivated land, the others involved forecasts of the consumption rates, rather than growth rates of population. The necessary data was provided by the agencies, shown in Table 5-1.

Table 5-1. Available information on demand components

Agency	Available Information
Land Reclamation Consortium 3 - Agrigento	• Water Supply Provision for irrigation, development of new areas equipped for irrigation, constructions of tourist sites and number of beds
National Statistical Service	• Permanent Population
University of Palermo + AMAP local agencies for water services (AMAP and SOGESID)	• Permanent and Seasonal Population, growth rates
INEA (National Institute of Agricultural Economics)	• Land reclamation of areas included into agricultural exporting nodes

According to official analyses made for the preparation of the local water resource management plans, both permanent and seasonal population of the area are not expected to increase in the next three to four decades, while the consumption rates are estimated to double during the same time. The monthly fluctuation of permanent population is not significant with seasonal variations while seasonal population is significant only during the summer period, from June to August, with almost the same monthly distribution. The total population for each settlement is presented in Table 5-2.

Castelvetrano, Menfi and Sciacca have the highest populations among the settlements considered in the case study area, but their water supply sources are different. While the two latter obtain water from the Garcia Lake, the Castelvetrano relies on valuable local boreholes that cover 80% of its monthly demand, obtaining the remaining 20% from the Montescuro aqueduct. In general, the more populated sites are those having water available locally, such as Sambuca di Sicilia, S. Margherita Belice, Castelvetrano and Partanna.

The domestic consumption rates are estimated at about 170 and 200 l/capita/day for permanent and seasonal population respectively. Average network losses are rather high, varying from 33% to 44% of the delivered supply volumes.

As regards the irrigated districts, the available information about the land reclamation process, and the related equipment of new cultivable areas for irrigation with internal and

external distribution networks, refers only to short time forecasts. Agricultural expansion involves the two irrigated districts of Menfi and Sciacca, and the operational start of a brand new district in the territory near the settlements of Montevago and S. Margherita Belice that will be served by the Garcia Lake. In the simulation of the case study, the other districts of Castelvetrano and Sambuca di Sicilia are assumed not to increase their cultivated land.

Table 5-2. Permanent and seasonal population in settlements and use of local resources

Settlements	Permanent Population	Permanent (% over the total)	Seasonal Population	Seasonal (% over the total)	Use of local resources
Sciacca	40,220	34.81%	21,173	27.08%	no
Castelvetrano	27,243	23.58%	41,000	52.44%	yes
Menfi	12,760	11.04%	9,429	12.06%	no
Partanna	11,376	9.85%	2,616	3.35%	yes
Santa Margherita Belice	6,474	5.60%	500	0.64%	yes
Sambuca di Sicilia	6,159	5.33%	2,000	2.56%	yes
Gibellina	4,675	4.05%	500	0.64%	no
Montevago	3,096	2.68%	700	0.90%	no
Salaparuta	1,835	1.59%	200	0.26%	no
Poggioreale	1,711	1.48%	60	0.08%	no
TOTAL	**115,549**	**-**	**78,178**	**-**	**-**

With reference to the water demand outside the Garcia-Arancio districts, the exporting nodes being taken into account in the area symbolize urban and agricultural needs. Water transferred outside the area for urban use is asked by the exporting nodes *Urban_Agrigento*, *Urban_Trapani* and *Urban_Favara di Burgio*. Node *Urban_Agrigento* stands for the settlements of Agrigento served by the Montescuro aqueduct, such as Giuliana, Chiusa Sclafani and Palazzo Adriano. They have an overall population of 8,729 inhabitants, who consume a monthly volume of 44,517 m³. Exporting node *Urban_Trapani* stands for some settlements in the territories of Palermo and Trapani served by the Montescuro after it exits Belice basin at the west. They include Calatafimi, Vita, Salemi, S. Ninfa and Campobello di Mazara. The full amount of permanent and seasonal population is 59,571 inhabitants and the monthly water volume delivered is 303,812 m³. The scenarios for these two external demands are driven by the consumption rates that tend to double in the next twenty-thirty years in the same way as the ones of internal settlements do. The third urban exporting node of *Urban_Favara di Burgio* represents the water from Garcia that is treated in the drinking plant of Sambuca di Sicilia and integrates the resources of the Favara di Burgio aqueduct, namely the water

springs of Caltabellotta, in the territory of Agrigento. The annual water volume required from the treatment plant is about 2.8 million m^3.

Projections

The available information about the agricultural development are only short-term and limited. For that reason, the corresponding projections have been taken in every simulated scenario to have the same weight. Projections for cultivated areas under the competence of Consortium no.3 Agrigento are shown in Table 5-3. The district of Menfi will increase by 2000 ha in the next years. The growth has been assumed to take place in four years, from 2004 to 2007, with a 500 ha of increment per year. The increment for the district of Sciacca is lower: its total additional area will be 300 ha in the three years 2004-2006. The new district of Montevago-S.Margherita Belice will develop by 2500 ha in four years from 2005 to 2009, with a growth of 500 ha per year.

Table 5-3. Growth of cultivated areas (Land Reclamation Consortium 3 –Agrigento)

District	Period of development	Actual Cultivated Land (ha)	Total Additional Land (ha)
Menfi	2004-2007	6,490	2,000
Sciacca	2004-2006	3,925	300
Montevago-SMB	2005-2009	0	2,500

According to data from INEA, National Institute of Agricultural Economics, the two Consortiums for Land Reclamation of Trapani and Palermo are planning an expansion of their areas equipped for irrigation from 2004. The areas of Trapani would constitute a brand new irrigated zone of 16,051 ha, in the areas 1/D West and 1/C that are west to the Castelvetrano irrigated district. Palermo would develop two areas for a total 2,712 ha in three years from 2005 to 2007. The forecast annual demands are shown in Table 5-4. Although the expansion of cultivated area is planned by the two Consortia, it was not considered in the latest simulation of the case study water network, because they are not realistic in the actual context of water scarcity and unmet domestic demands. The irrigation demands for exporting of these users were kept constant, and were also reduced upon the present simulated inflows to the Garcia Lake. They are 7.9 million m^3 per year for Trapani and 5 million m^3 per year for Palermo respectively.

Table 5-4. Growth of cultivated areas outside the case study (not incorporated in the analysis)

Exporting	Period of development	Actual Annual Demand (million m^3)	Annual demand after expansion (million m^3)
Irrigation_Trapani	2005-2020	0	9.4
Consortium 2_Palermo	2005-2007	8.9	10.4

The construction of two minor tourist facilities has been planned. A site is under construction in Menfi, with a total capacity of 3,000 beds, which is assumed to grow progressively by 1,000 beds per year from 2004, to be operational at 100% in 2006. The other tourist site relates to the territory of Sciacca and a total capacity in 2007 of 20,000 beds to be operational in four years. In terms of overnight stays, which is the variable driving the demand scenarios for this kind of water user, the relevant values refer to the three summer months of June-August and are presented in Table 5-5. These forecasts of tourist presence are considered in every demand scenario as it is for the agricultural growth.

Table 5-5. Growth of overnight stays for Tourist sites

District	Period of development	Total overnight stays
Menfi	2004-2006	270,000
Sciacca	2004-2007	1,800,000

The trends of urban consumption rates are the core of the demand scenarios for the Garcia-Arancio case study. The projections made by the Sogesid agency from 2005 to 2032 estimate an average growth rate from 170 l/capita/day to 280-300 l/capita/day, which means an average annual increase of 2.31% for the case study settlements. The trends affect the residential population only, the consumption rate of the seasonal and tourist being assumed to remain constant at 200 l/capita/day. The annual increase rates and the final consumption rates in 2020 for the settlements are presented in Table 5-6. Similarly for the exporting nodes, representing urban demand; the assigned rate is the average over the single settlements aggregated into the exporting: 2.39% is applied to *Urban_Trapani* and 1.89% to *Urban_Agrigento* and *Urban_Favara di Burgio*.

Table 5-6. Increase of consumption rates for settlements

Settlements	Annual Increase Rate (%)	Consumption Rate in 2020 (l/cap/d)
Sciacca	2.73%	235
Santa Margherita Belice	2.31%	225
Sambuca di Sicilia	2.31%	225
Salaparuta	1.89%	215
Poggioreale	1.89%	215
Partanna	2.73%	235
Montevago	1.89%	215
Menfi	2.73%	235
Gibellina	1.89%	215
Castelvetrano	2.73%	235
Average	**2.31%**	**225**

Three different scenarios were distinguished upon the domestic demand of settlements and exporting nodes (Table 5-7):

I. A "growing demand" (**GD**) scenario where urban demand increases from 2005 to 2020 at a steady average rate of 2.31**%** for settlements and 2.39% and 1.89% for the exporting nodes;

II. A "stabilized demand" (**SD**) scenario where demand is stabilized after a point in time, in this case 14 years after the reference year;

III. A constant, "permanent demand" (**PD**) scenarios, which assumes that not only will the population stay the same, as is confirmed by recent studies, but also that the rates of consumption and agricultural expansion will be fixed in time.

Table 5-7. Consumption rate trends for the two scenarios

Scenario	Period	Annual Growth Rate (%) (Average over the settlements)	Annual Growth Rate (%) (export urban)
Growing Demand	2001 – 2004	0.0	0.0
	2005 – 2020	2.31	2.39% and 1.89%
Stabilized Demand	2001 – 2004	0.0	0.0
	2005 – 2014	2.31	2.39% and 1.89%
	2014 – 2020	0.0	0.0

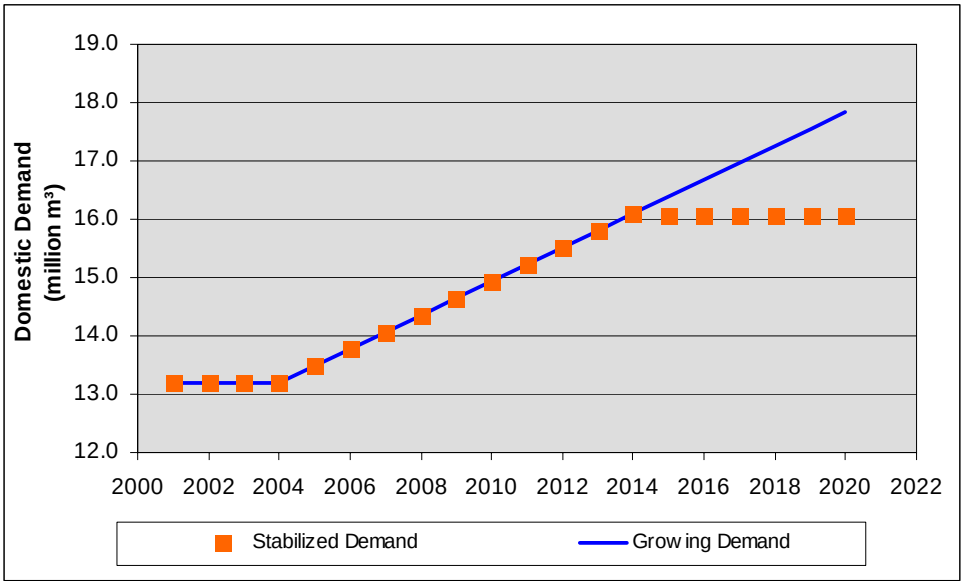


Figure 5-2. Domestic Demand Scenarios in Belice Basin

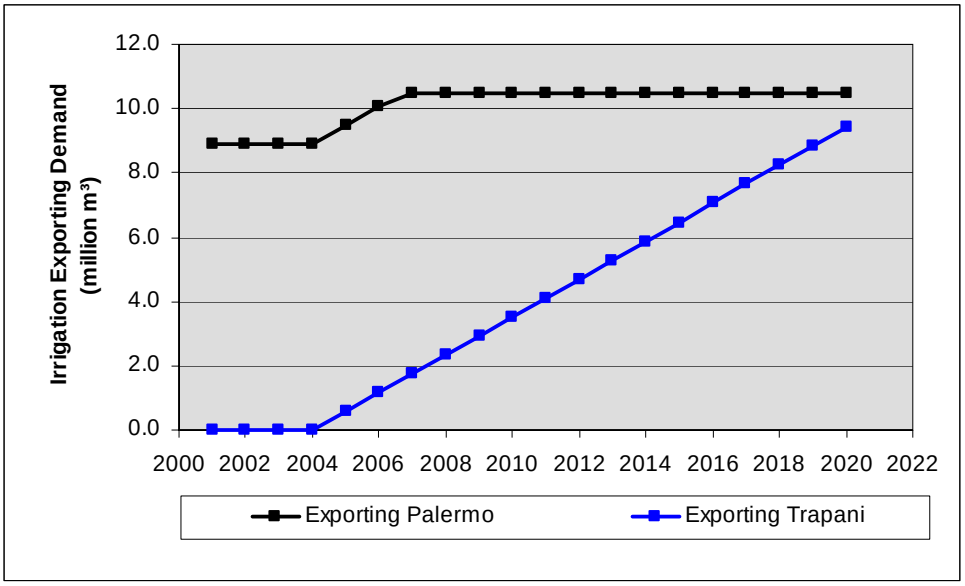


Figure 5-3. Irrigation Demand Scenarios for areas supplied by Belice Basin sources, outside Belice Basin (not incorporated in the analysis)

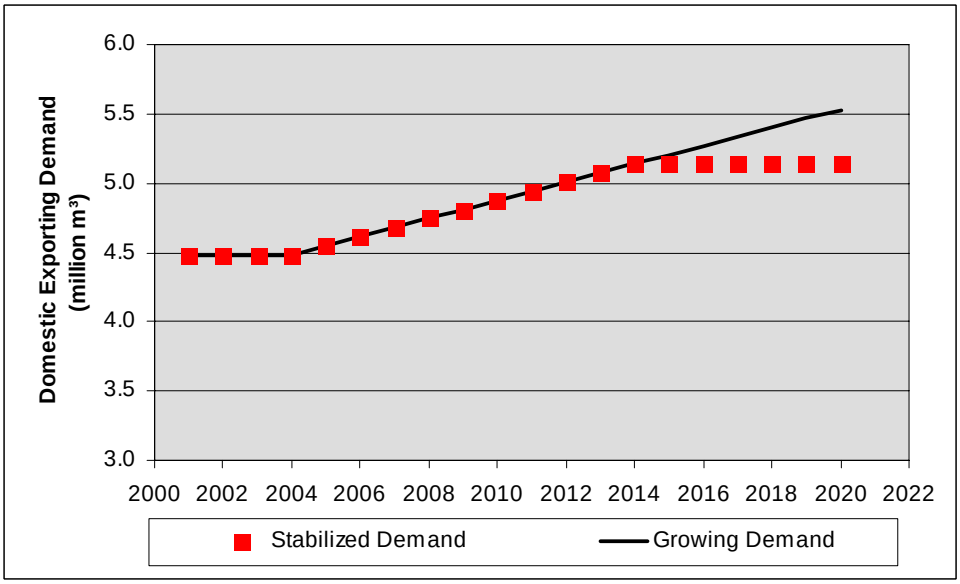


Figure 5-4. Domestic Demand Scenarios for areas supplied by Belice Basin sources, outside Belice Basin

Formulation of Availability Scenarios

Data

Daily recorded time series of rainfall, temperature and runoff are available for the Belice basin. The data have been analyzed and aggregated both in time, i.e. at monthly and yearly time step, and spatially, over the area of the basin.

According to the humidity index of Thornthwaite, 54% of the case study area is defined as semi-arid, whereas 44% is dry-sub-humid and 2% is sub-humid-humid. The annual precipitation is about 500-600 mm and is unevenly distributed during the year with the 85% concentrated between October and March. The average annual evapotranspiration ranges from 800-900 mm to 1000 mm along the coast. The average annual temperature falls between 10-11 °C in the inland areas and between 17-19 °C in the coasts. The maximum values appear in summer and are about 30-31 °C.

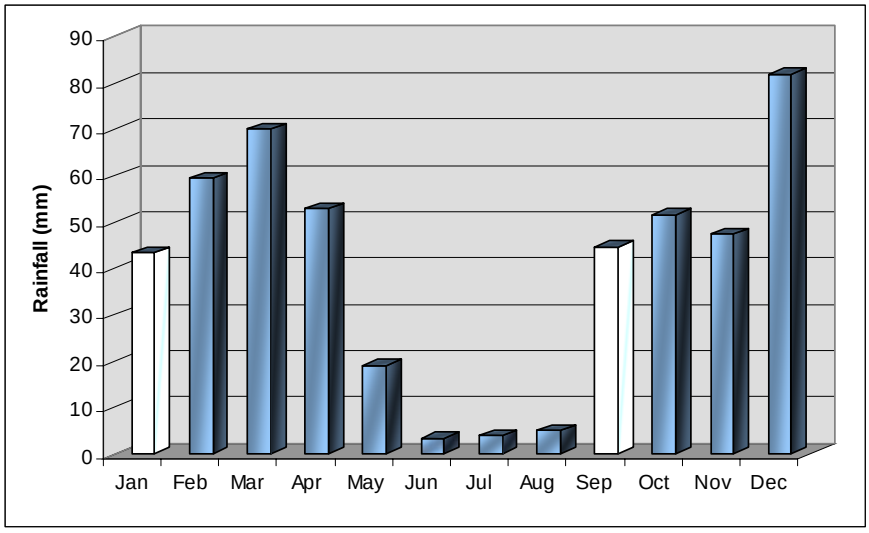


Figure 5-5. Average monthly rainfall in the Garcia-Arancio districts

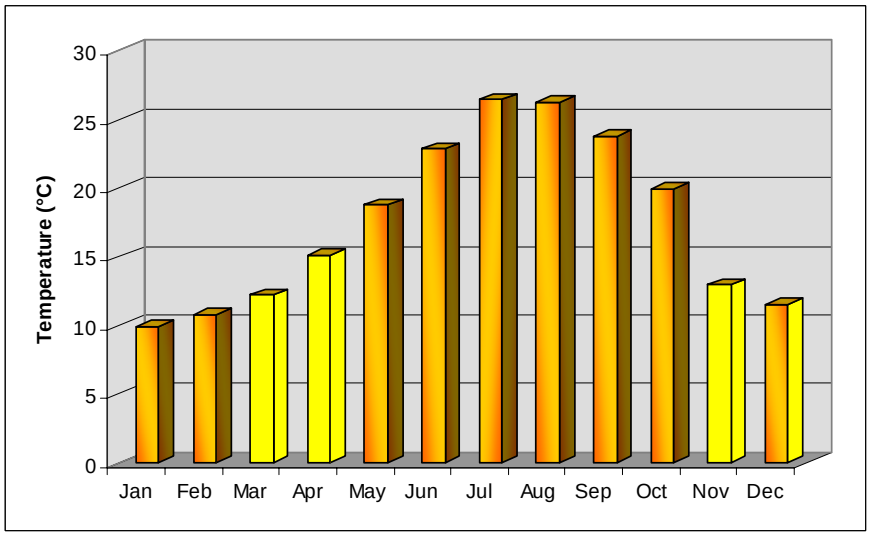


Figure 5-6. Average monthly temperature in the Garcia-Arancio districts

Scenarios

The availability scenarios of runoff and aquifer recharge have been built with the Rainfall scenario module of the WSM DSS. First of all, three scenarios of rainfall and three of temperature have been defined, namely Normal, Wet and Dry for the former, and Normal, Hot and Cold for the latter. Then they have been combined together in order to perform the soil water balance at the watershed level and obtain availability scenarios of runoff and recharge. The generated availability scenarios express:

a) a period of 20 years with a high frequency of wet years and low temperatures (**WET scenario**),

b) a period of 20 years with a high frequency of dry years and high temperatures (**DRY scenario**),

c) a period of 20 years comprised of Normal Rainfall and Normal Temperature (**NORMAL scenario**),

In order to be consistent with past historical events, the forecast availability scenarios have been built by following the negative rainfall trends of the past forty years, from 1951 to 1990. The time frames of continuous data with the higher frequency of dry and wet years have been identified in the past events. Then the deviations from the general trend of those time frames have been applied to the forecast trend. The dry period for rainfall is from 1966 to 1985, and the wet from 1953 to 1972 as depicted in the figures that follow. The three availability scenarios are reported in the Annex of the present document.

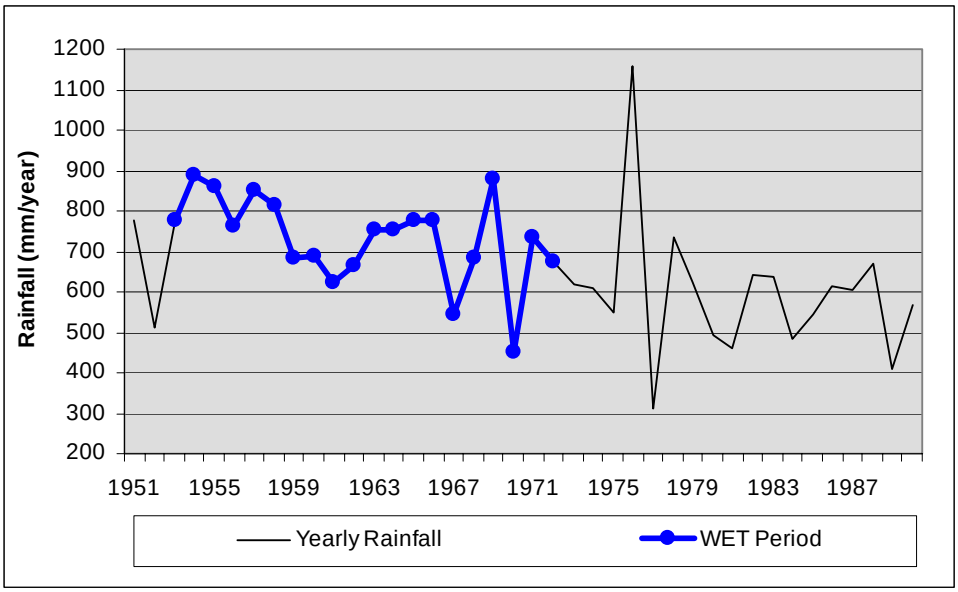


Figure 5-7. Historical wet period

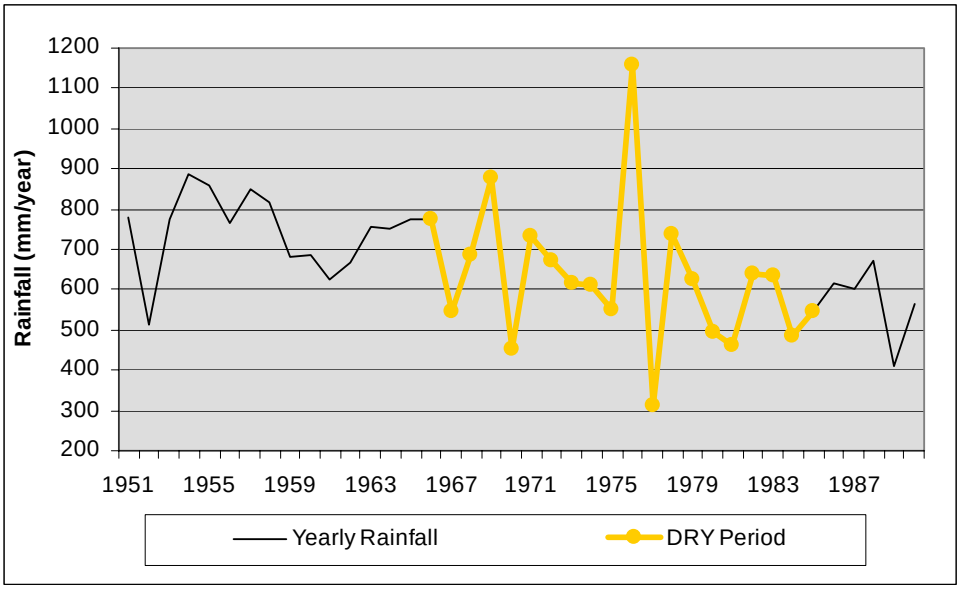


Figure 5-8. Average Historical dry period

In the generation of the time series of rainfall and temperatures the trends of each single month have also been accounted for, that is, the tendency of the months of January, the months of February etc., in order to maintain a variation within the year while considering the specific historic behavior of each month and its tendency in the future.

Combinations of hydrological and demand scenarios

In order to be able to assess the behaviour of the water system as intended under a best case scenario, a worst case scenario, and a business as usual scenario, the combinations of availability and demand scenarios under which the different management options have been evaluated were the following:

- A combination of the *Growing* Demand Scenario with the *Dry* Availability Scenario (**GD+DRY**), reflecting the worst case scenario of water shortage,
- A combination of the *Stabilized* Demand Scenario with the *Normal* Availability Scenario (**SD+NORMAL**), reflecting the current trends of the system in a "business as usual" context, and
- A combination of the *Permanent* Demand Scenario with the *Wet* Availability Scenario (**PD+WET**), reflecting the best case scenario.

As regards the water resource system that has been simulated and evaluated, there is a overall and generalized condition of water scarcity in the Garcia-Arancio districts, which depends on the very limited amount of water that is considered to enter the system in terms of runoff. In addition to that, the system has been simulated by taking into account the real forecasts on the rates of consumption for the urban use and the projects of land expansion as related to the agricultural practice. After the first simulations it was immediately clear from the collection of the relevant data that the system is to be considered non sustainable, at least according to the information that is available at the time of writing this paper. In particular:

- The Arancio lake should be the primary water source for the districts but it is always at its minimum storage because of the low inflows that do not assure a sufficient recharge;
- All the irrigated districts are facing a permanent deficit every year from May to October, during the season of irrigation. Their demands are satisfied just for the three-four years of the simulation, until the Garcia reservoir can provide the Arancio and some of the districts with water;
- From the introduction of the urban demand of settlements within the simulated water resource system, the overexploitation of the Garcia appeared to be the first cause of the overall condition of deficit, because too much water is expected to be abstracted yearly to integrate the Montescuro aqueduct, coming from outside the region;
- The settlements facing the higher unmet demands are Castelvetrano and Partanna, which are located West of the area and are the latest to be supplied by the urban distribution network. Second highest are Menfi and Sciacca that are in the territories administrated by the agency for land reclamation but receive water only by the Garcia reservoir: as a consequence of the critical drought conditions

of the reservoir they are subject to a basic deficit of 120,000 cubic metres, exacerbated to 160,000 from June to August;

- From some institutional constraints the two land reclamation agencies of Trapani and Palermo are legitimated to take a fixed yearly amount of water from the Garcia reservoir, but it seems to be incongruent with the real allocation of water. Their role in the resource system will be further investigated during the next strategy formulation phase.

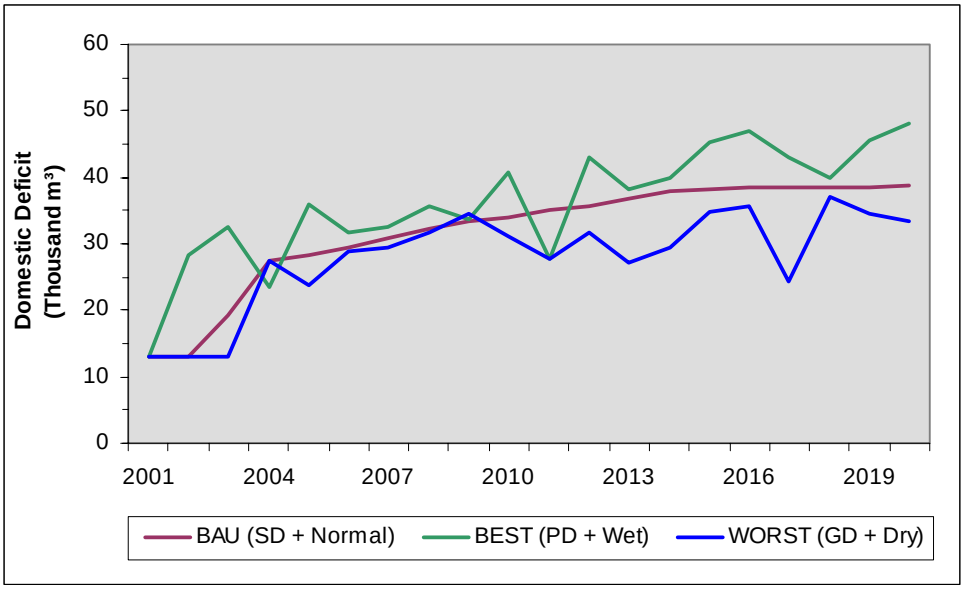


Figure 5-9. Estimated domestic deficit under the selected demand and availability scenario combinations

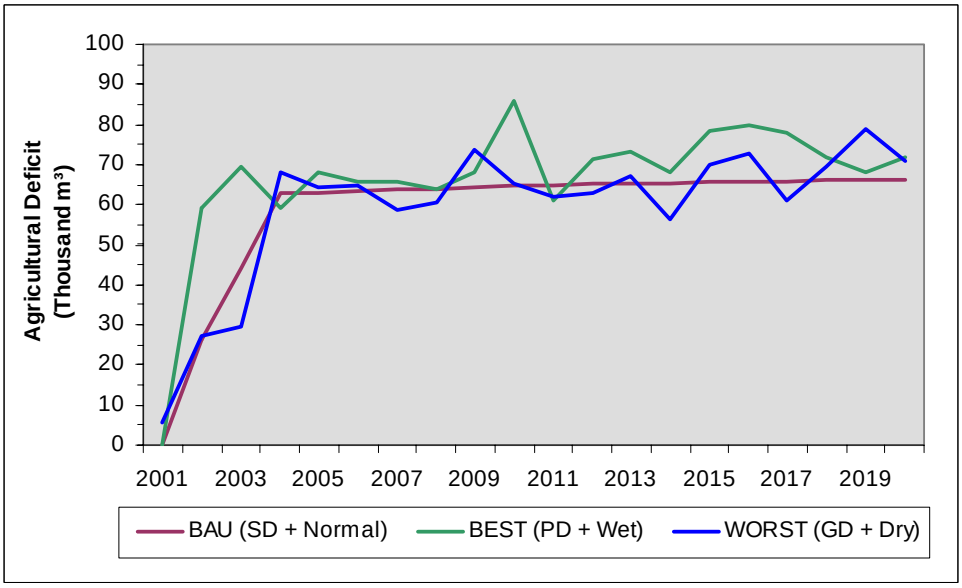


Figure 5-10. Estimated Agricultural deficit under the selected demand and availability scenario combinations

Cost Estimation

Direct Costs

The estimation of direct costs for the Garcia-Arancio Districts consists mostly of depreciation of capital expenditures and running costs associated with both existing and new infrastructure.

Since the appropriate information was not available for some infrastructure, an additional direct cost was considered per m^3 of water distributed, 2 €/m^3 for domestic use, and 0.5 €/m^3 for irrigation use respectively.

Environmental Costs

Environmental costs for the case of Garcia-Arancio Districts are associated with surface water abstraction and consumption. The surface water bodies involved are the two storage reservoirs of Garcia and Arancio and the Belice river reaches that supply them seasonally.

The selected reference period runs from May to September and the average costs incurred from abstraction and consumptions were set equal to 0.7 €/m^3. The vulnerability of the examined surface water bodies to overabstraction is quite high and was expressed by appropriate area coefficients that are summarized in Table 5-8.

Table 5-8. Area coefficients used for surface abstraction environmental costs

Surface Water Body	Area Coefficient
Garcia	2.0
Arancio	2.0
Belice River Reach 18	1.5

Present Values

Present values have been estimated for the period of 2001 to 2020, using a discount rate of 4.5%.

5.2. Selection of management options and indicators

The potential policy options identified in the course of the WSM Project were subsequently analysed in their applicability to the Garcia-Arancio region through consultation with the local stakeholders.

The Corsortium 3 – Agrigento for Land Reclamation is in charge for the water resource management and water service for irrigation purposes of the case study area. For this agency the critical circumstances for irrigation that can appear during dry climatic conditions are being faced with the enlargement of the pumping station on Belice. At present this plant supplies water to the nearby lands, but it has the major task of recharging the Arancio Lake during the year. Its development would increase the amount of exclusive water the irrigated sites can rely on, given that the volumes transferred by Garcia are constrained to the first priority of use of the settlements. The required energy to pump more water would be provided by wind power plants that are being designed. Another structural option they are working on is the construction of facilities which allow using the treated urban waste water for supplying cultivated lands. They are planning to deliver the treated effluents to the irrigated districts directly during summer, and to recharge the Arancio during winter. From the demand management side, the replacement of high water demand crops with others with smaller requirements is to be excluded, because it would be against the development policy of the past forty years. Instead of that, the measures of the agency relate the improvement of the irrigation efficiency through an overall increased use of the drip method in place of the sprinkler until covering the entire cultivated land with that.

The EAS, Ente Acquedotti Siciliani, is the regional authority in charge of the aqueducts in Sicily, but all their competences pass to the new founded *Sicilia Acque* (summer 2004). The EAS manages the Garcia reservoir, in collaboration with the Corsortium 2 – Palermo for Land Reclamation, and the network of Montescuro Ovest that gives water to many settlements inside and outside the Belice basin. The infrastructure of this aqueduct is currently under replacement, an activity whose scope is to assure lower distribution losses so as to cover, with the same output of the springs, a higher percentage of the total domestic consumes. On the other side, the agency is also going to boost the Garcia reservoir, a water source that presently integrates the Montescuro supplies: a water plug will be constructed on the right branch of the Belice and connected through pipelines to the storage reservoir, on the left branch. The next project will then regard the development of the Drinking Water Treatment Plant of Sambuca di Sicilia, in order to make available an effluent of 1,200 l/s to supplied to the Montescuro and outside the cases study area to the Favara di Burgio aqueduct. From the socio-economic and institutional side, the regional agencies for domestic water supply have to satisfy the urban demand with first priority while at the same time try to recover the cost of service, the direct cost for the new infrastructure mostly. Education and conservation campaigns always appear on the agenda and the water prices are set

according to the tiered pricing method, thus discouraging the waste of water. In spite of that, the first objective is still the augmentation of the available water resources.

A synthesis of the current management policies and of additional, imposed instruments applicable to the area of Garcia-Arancio districts is presented in Figure 5-11.

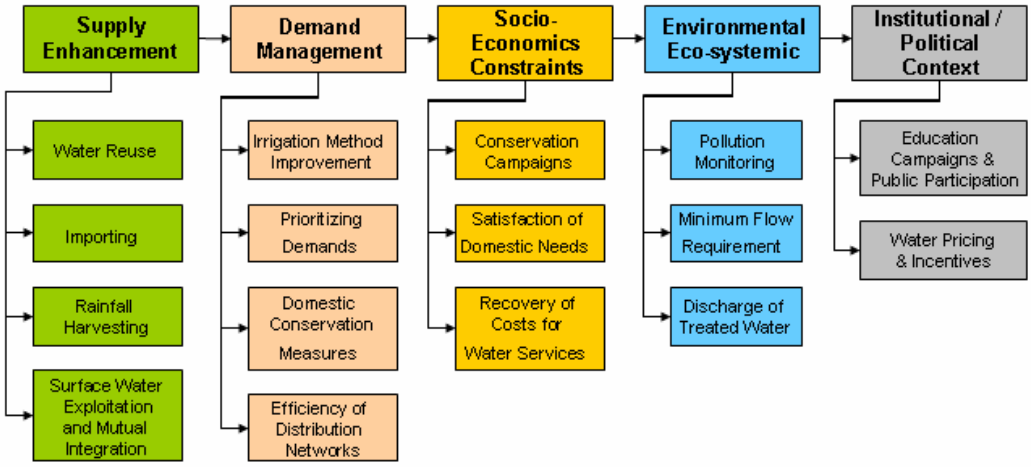


Figure 5-11. Summary of management options

The instruments that were examined for the cases study simulations pertain to three major categories:

- **Structural options** for supply enhancement, including:
  - *Construction and expansion of pumping stations*, aiming at the augmentation of water available at the Garcia reservoir;
  - *Connection to irrigation sites of existing treatment plants*, to provide additional water supplies particularly during the peak consumption periods;
- **Demand management options**, including:
  - *Reduction of Network losses*, through replacement of the fifty year old Montescuro distribution network (structural intervention);
  - *Improvement in Irrigation Methods*, for considering the ever growing use in the districts of the drip method over the sprinkler;
- **Socio-economic measures** in the form of an increasing water selling price for the domestic sector, under assumptions on the demand elasticity, in order to see how it would influence the water allocation in the system.

The selection of appropriate indicators for ranking the above options reflects the duty of the water agencies to assure the coverage of the domestic demand, and the objectives of the Consortium no.3 Agrigento to have at their disposal a sufficient yearly amount of water to satisfy the crop requirements during the irrigation season. These water uses are also in conflict during the summer because they share the surface water of Garcia, but

settlements are to be served first. As a consequence the analysis of options is to be formulated around the **coverage of domestic and irrigation demands**. This information is presented graphically for each option in terms of "effectiveness", together with the % improvement (reduction of the deficit) obtained with each option with respect to the reference simulation without any intervention. The satisfactory range of values and the weights assigned to the two coverage indicators are presented in Table 5-9.

The analysis of options is completed by the graphs of the **direct (financial) cost** and of the **environmental cost**, which are important to quantify the price to be paid for water management measures, and for the over-exploitation of the surface water resources of the Garcia-Arancio region.

All the graphs presented show the effect of each option under the three coherent management scenarios representing worst conditions, i.e. **GD+DRY** scenario, "business as usual" context, i.e. **SD+NORMAL** scenario, and best conditions, **PD+WET** scenario.

Table 5-9. Satisfactory range of values and weights for the indicators of the Belice Basin case study

Indicator	Satisfactory range of values	Weight
Domestic demand coverage	70-100%	0.50
Irrigation demand coverage	70-100%	0.50

5.3. Analysis of water management instruments

Structural options

At the time being, the irrigated districts receive water from two surface sources, which are for the exclusive use of irrigation: the Arancio Lake and a weir on the Belice river. Additional water comes from the Garcia Lake that has the double task of directly providing with water the district of Castevetrano and partly of Menfi, and of recharging the Arancio Lake during the winter months. However, the consortium 3 has to share the available water at Garcia with the urban requirements inside and outside the Belice Basin. Since in case of water scarcity the urban use has a higher priority to be served by Garcia than the agricultural, the plans of the agency aim mostly at expanding their own water sources and at maximizing the irrigation efficiency. The first goal can be attained by means of structural options.

Wastewater Reuse for irrigation

First of all there is the project to use the effluents of some treatment plants to feed the irrigation sites directly, or to recharge the Arancio Lake. This second alternative would be operative during the winter, whereas during the summer the critical crop requirements would use treated water with straight connections. The plants involved are those that currently serve the settlements of Castelvetrano, Menfi and Sambuca di Sicilia, and will be linked to the corresponding irrigated districts. The total additional volume the three districts can count on is about 12,497 m^3/day and will be used with first priority. This measure partially frees the Consortium Agrigento for Land Reclamation from the domestic constraint on the Garcia supplies. The total financial cost of the water reuse project is about 118.8 Million €, including the construction of the canals and/or pipelines carrying the effluents to the internal irrigation networks of the districts. The water selling price of treated water will be 0.092 €/m^3, which constitutes an incentive to use it, as this price is lower than the price of 1.4 €/m^3 that farmers pay at the time being for fresh surface water.

As far as the simulation is concerned, the option was originally assumed to become active after 2006, but in the latest simulations it started from the beginning of the scenario horizon, i.e. 2001, in order to see the effect from the first years, where water from Garcia is still available for the agricultural use (it decreases during the years due to first priority of domestic abstractions).

From the chart depicting the percent improvement of deficit with respect to the reference scenarios, the effect of the waste water reuse on the irrigation deficit is clear: the three districts can rely on more, and exclusive, water and the unmet demand is reduced by 10%. The irrigation demand coverage remains inside the satisfactory range of 80-100%, except for the worst circumstances. The domestic coverage and deficit are not remarkably influenced since this option is tailored exclusively for meeting the crop requirements.

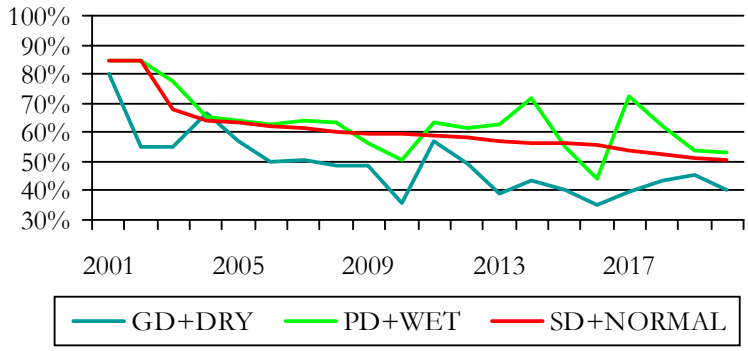


Figure 5-12. Percent demand coverage effectiveness of Wastewater Reuse to Domestic use

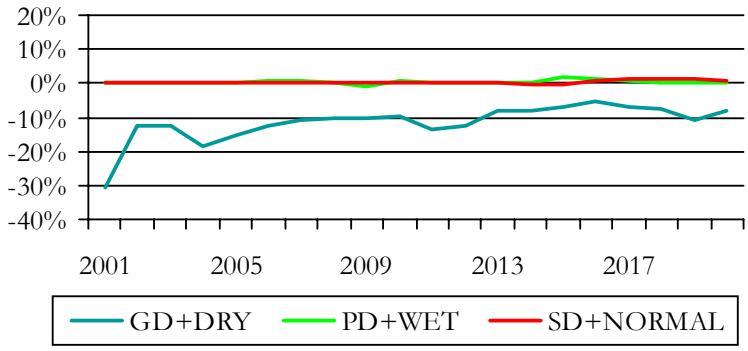


Figure 5-13. Percent Improvement of deficit in Domestic use with respect to the reference scenarios

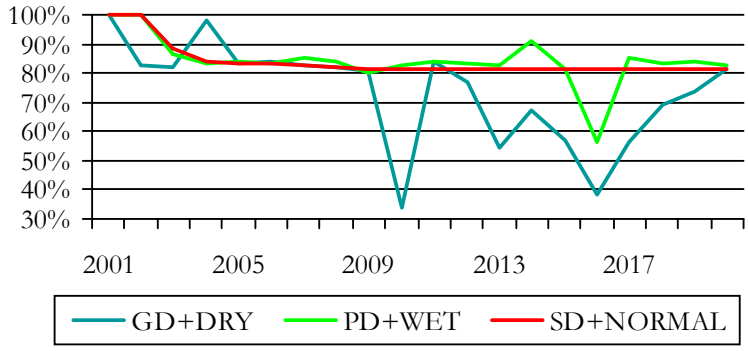


Figure 5-14. Percent demand coverage effectiveness of Wastewater Reuse to Irrigation use

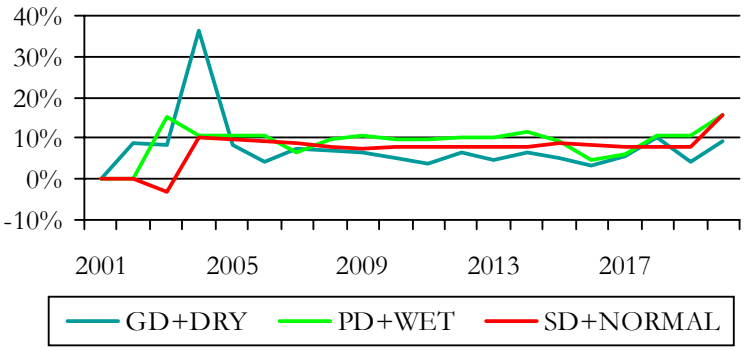


Figure 5-15. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios

The direct costs increase by about 2.3 - 2.4 % both in the Best and the Bau scenarios, while the environmental cost increases by 0.5 and less in the Bau scenario.

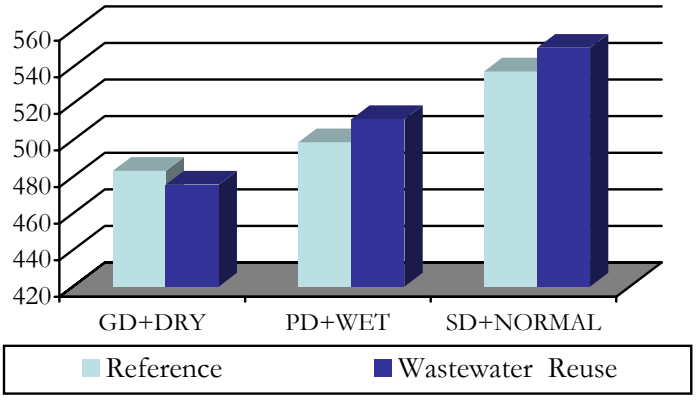


Figure 5-16. Total direct cost difference of the Wastewater Reuse option under the three scenarios (Present Value – Million €)

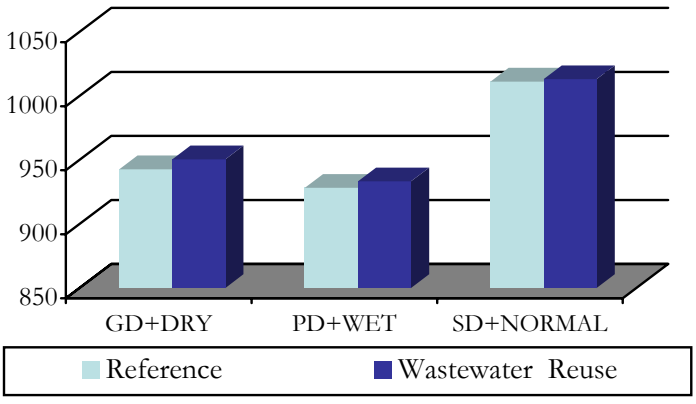


Figure 5-17. Total environmental cost difference of the Wastewater Reuse option under the three scenarios (Present Value – Million €)

Exploitation of Belice River

Another method the local stakeholders in charge of agricultural water services intend to follow in order to become more independent from the domestic constraint on Garcia is the expansion of the existing pumping station on the Belice river, in the district of Castelvetrano, namely the "Basso Belice". They are working to equip the station with new pumps, which will boost the river exploitation up to 15 million m^3 of water withdrawn per month from the present 8 million. This additional volume of water is allocated to the Arancio and will contribute to the coverage of the deficit for all the irrigated relevant districts such as Menfi, Sambuca di Sicilia and Sciacca. recharge. This action is to be coupled with the strategy of the agencies responsible for the exploitation of the Garcia Reservoir for domestic use, as integration of the Montescuro Acqueduct. They are implementing the connection of Garcia with the right branch of Belice, in order to take advantage of the corresponding sub-basin. The annual volume that will be transferred is 6 million m^3 and will represent an additional water volume to be shared between the three Land reclamation agencies of Agrigento, Trapani and Palermo, and the settlements served by the Montescuro, both inside and outside the Belice basin. The construction cost of the connection river-reservoir and of the pumping plant expansion reach a total of 47.9 million €. The implementation year for this combined option is 2004 for the BAU and the BEST management schemes, while it starts in reference year 2001 for the WORST.

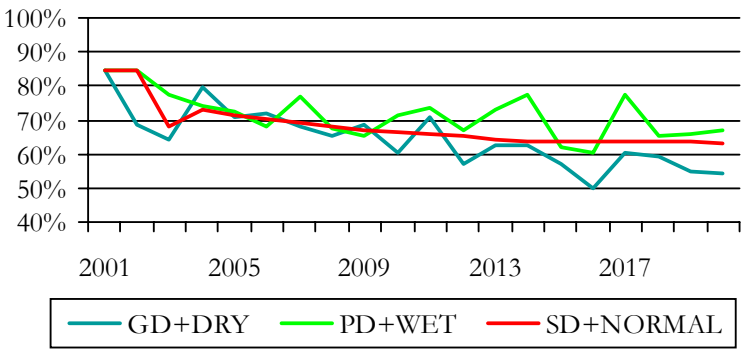


Figure 5-18. Percent demand coverage effectiveness of Belice Exploitation to Domestic use

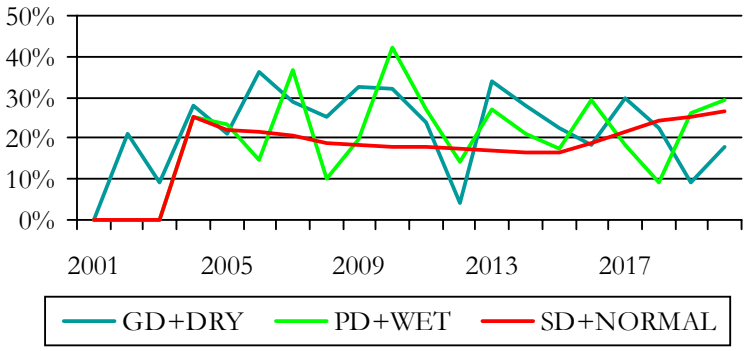


Figure 5-19. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Belice exploitation option)

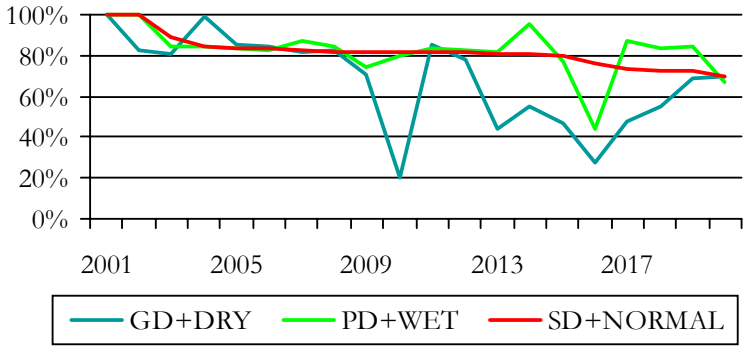


Figure 5-20. Percent demand coverage effectiveness of Belice Exploitation to Irrigation use

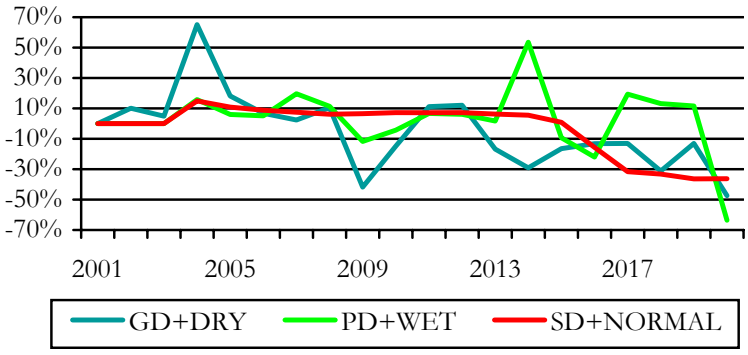


Figure 5-21. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Belice exploitation option)

According to the simulation results, from the implementation year 2004 the situation improves: domestic unmet demand decreases at approximately 20% after the transfer of

water to Garcia but there is a negative trend for the scenario duration, which is due to the declining runoff available at the river reach where water is abstracted. Besides, from the analysis of the water flows in the river reach and in the new Belice-Garcia pipeline appears that only an average yearly value of 3.8 million m^3 recharge the Garcia, compared to the 6 million m^3 of the designed structural intervention. Therefore, water is not sufficient and this availability diminishes in time also. The effect of the runoff scenario is analogous for the river reach related to the expansion of the existing pumping station: the water abstracted yearly is about 6 million m^3 against the 15 million m^3 that the new plant can manage. But in this case there is another limiting factor. In fact the supply enhancement option should permit carrying more water from the Belice to the Arancio, which means more water for all the irrigated districts. As regards the irrigation deficit, its percentage improvement is lower with a mean value of 8% and even slightly exacerbated by the strategic option in the long run, with a mean value of -20% in the last 5 years of the scenario. The reason for that is evident if we look at the geographical location of the river reach whose water is pumped to recharge the Arancio: as it is downstream the connection of Belice to the Garcia, its water flow is reduced by the abstraction towards Garcia itself.

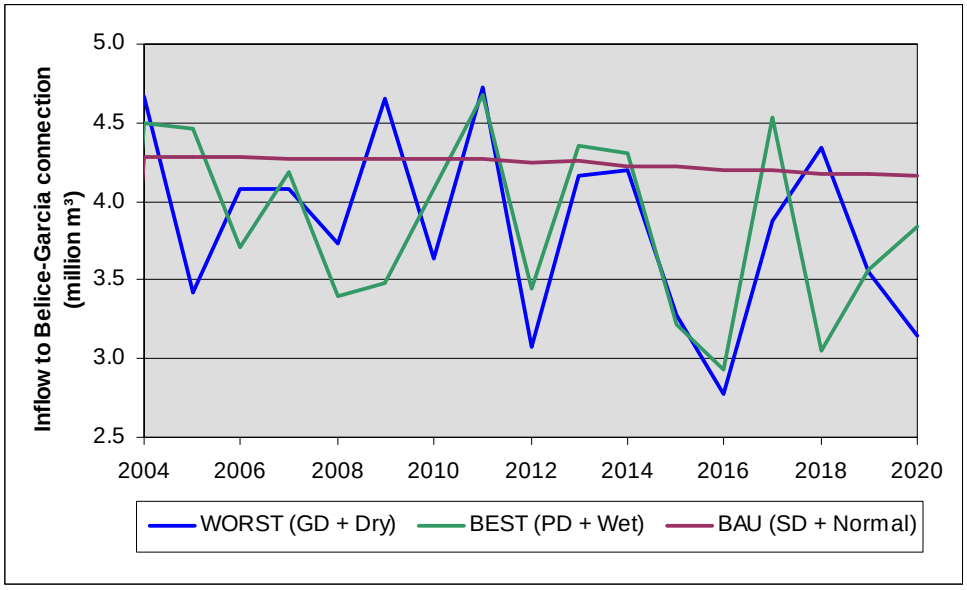


Figure 5-22. Inflows to the pipeline connecting the Garcia to the right branch of Belice River

The increment of the direct costs with respect to the reference scenarios is quite high, about 10%, and it is due to the capital and running cost of the two pumping stations constructed and enhanced. The environmental cost increases by 5% because of the additional amount of water abstracted from the vulnerable resources of the river reach on the Belice recharging the Arancio Lake and the Garcia lake, that is refilled by the new pumping station on the Right Belice Branch.

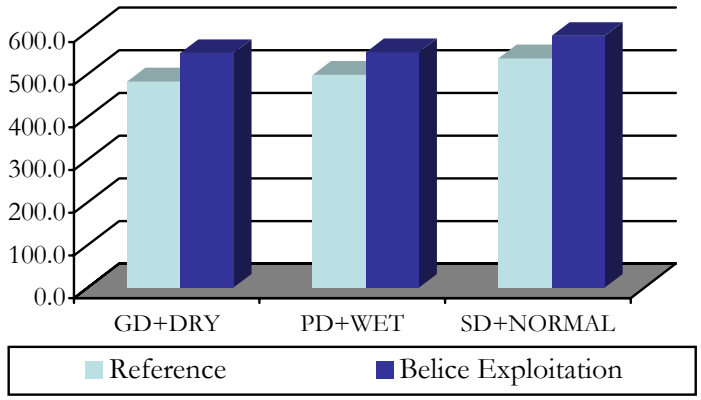


Figure 5-23. Total direct cost difference of the Belice Exploitation option under the three scenarios (Present Value – Million €)

The conclusion is that the combination of the two structural options together is not convenient because the potential advantages for the agricultural users are cancelled by the new structure built for providing additional water to the settlements. Besides, the exploitation of the right branch of the Belice river do not positively influence the irrigated districts because the Garcia reservoir does not have enough water to cover both urban and agricultural requirements and the additional water goes entirely to the settlements. The high direct cost introduced in the BAU management scheme from 2004 by the two options cannot be justified.

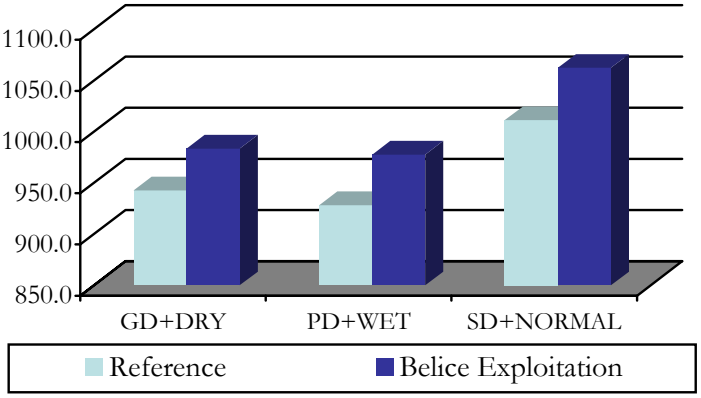


Figure 5-24. Total environmental cost difference of the Belice Exploitation option under the three scenarios (Present Value – Million €)

Demand Management options

Improvement in irrigation methods

The distribution of water to the local irrigation networks of the four irrigated districts Castelvetrano, Menfi, Sciacca and Sambuca di Sicilia is very efficient: the Consortium no.3 Agrigento for Land Reclamation confirmed a factor of 0.98 that is the result of fifty years of progress of agricultural practice in the case study area. However, further water can be saved by using the drip irrigation method in place of the sprinkler. At the time being, a forty percent of the cultivated areas are irrigated by drip irrigation, but the majority is still by sprinkler. The consortium revealed that a gradual shift to a complete use of the drip method is on the agenda, and as a consequence this option has been simulated with the WSM DSS to get an idea of its weight within a demand management approach to water scarcity. The replacement of one method with the other has been assumed to happen progressively with a tendency of +2% per year. Applied from 2005 to 2020, this means a growth of drip irrigation from 40% to 72% in sixteen years, and the correlated reduction of the sprinkler from 60% to 28%. The direct cost for this operation was not available and was not accounted for. The goal is to verify the positive effect this option should have on the coverage of irrigation demand for the three agricultural areas that take water from the Arancio lake directly, Menfi, Sciacca and Sambuca di Sicilia.

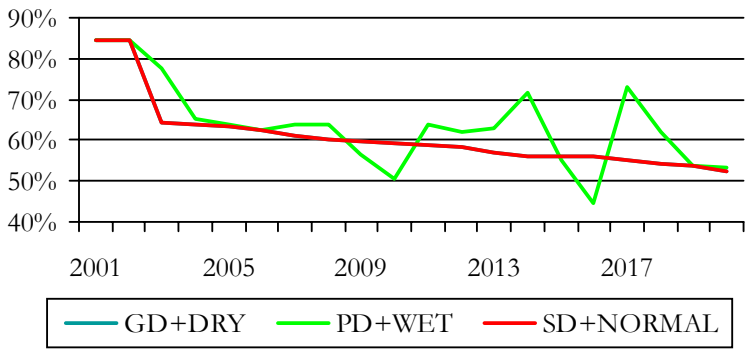


Figure 5-25. Percent demand coverage effectiveness of Irrigation Method Improvement to Domestic use

From the analysis of results it emerges that this kind of action does not remarkably influence the water availability for agricultural use of the cases study. There is a slightly positive effect on the irrigation demand coverage, +2%, but it appears in the long run after 2009, and only for the worst scenario. Under this option the irrigation effectiveness lies in the satisfactory range of 80 – 100 % but on the other side the domestic needs drop to 55% at the end of the scenario horizon. The environmental cost is reduced by -2% because less water is transferred from the vulnerable resources of the Garcia Lake and of the Belice River, since water from the Arancio Lake is supplied to the irrigation sites more efficiently. However, the additional direct cost incurred from the option implementation, about +20%, is very high and not acceptable compared to the minor

advantages the option generates. This is a minor strategic measure for the Garcia-Arancio districts and it should be included into a group of more effective policy options.

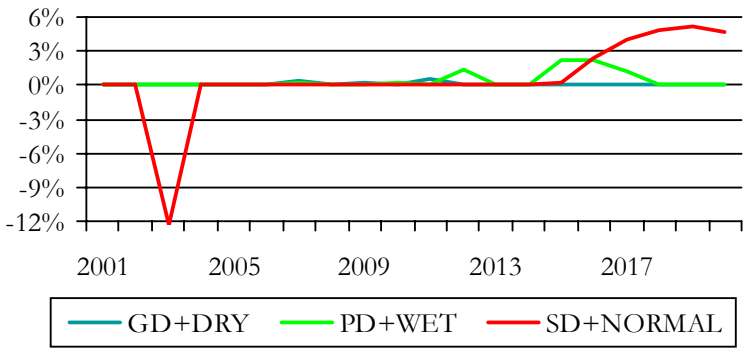


Figure 5-26. Percent Improvement of deficit in Domestic use with respect to the reference scenarios

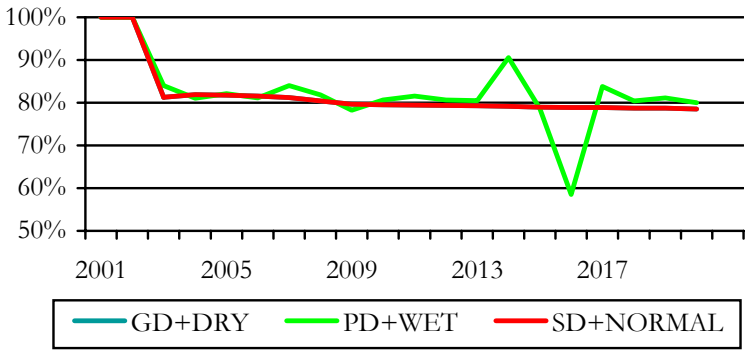


Figure 5-27. Percent demand coverage effectiveness of Irrigation Method Improvement to Irrigation use

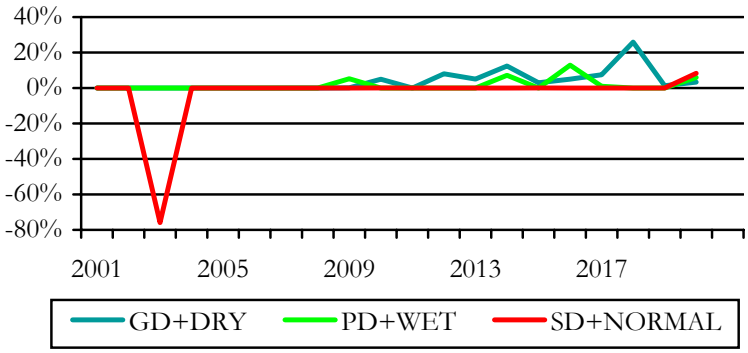


Figure 5-28. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios

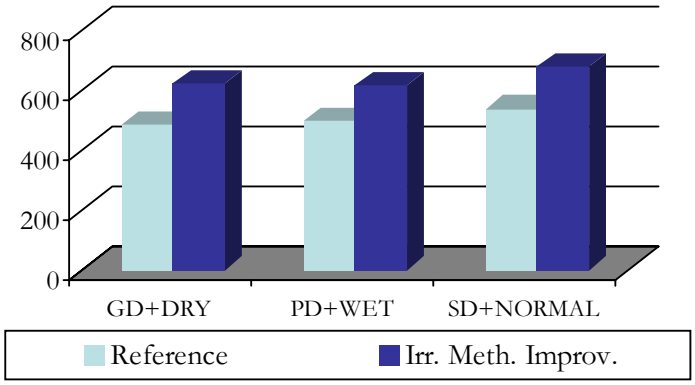


Figure 5-29. Total direct cost difference of the Irrigation Method Improvement option under the three scenarios (Present Value – Million €)

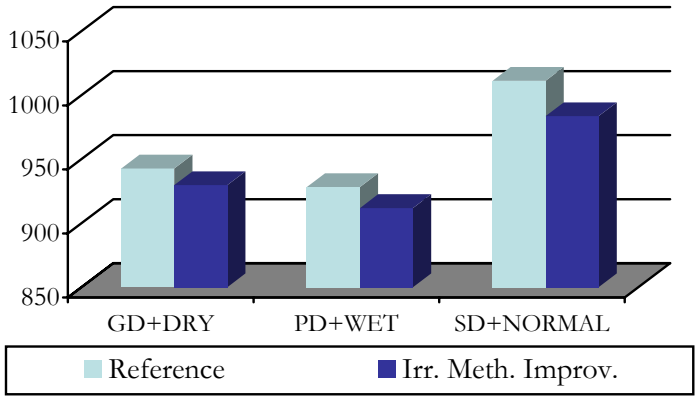


Figure 5-30. Total environmental cost difference of the Irrigation Method Improvement option under the three scenarios (Present Value – Million €)

Reduction of distribution losses

The major selected option from the demand management side, to be applied to the Belice basin, is the reduction of network losses. The internal networks of the settlements considered in the cases study have a pretty high conveyance loss factor, being the average value about 40 %, and respectively it is for the pipelines of the Montescuro aqueduct that carry water for 100 km crossing the Belice basin from East to West. The replacement of the fifty year old Montescuro will save a precious amount of water, which will be used to cover the increasing rate of consumption of the next twenty years. As the replacement project is planned for years 2004-2006, this option has been assumed to appear in the simulation from 2007. The target efficiency to be reached is in the range of 79 – 90 % with the direct (financial cost) being equal to about 61.4 million €. Together with this project an expansion of the Drinking water treatment plant of Sambuca di Sicilia has been also designed by the water authorities for urban use management. Currently, this plant treats the volumes coming from the Garcia and supplying the settlements of Menfi and Sciacca within the cases study area, and the Favara di Burgio aqueduct. The capacity of the plant is going to almost double, from 300 l/s to 600 l/s. This expansion has been simulated within the DSS by setting the maximum monthly volume treated by the plant to a higher consistent value. In reality this project refers to years 2002-2004 but for the simulation it has been assumed to be operational from the beginning of the scenario in 2001.

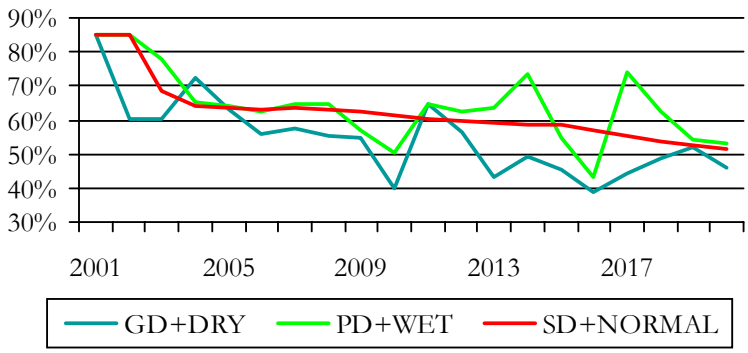


Figure 5-31. Percent demand coverage effectiveness of Losses Reduction to Domestic use

From the analysis of the selected indicators, the average 12% improvement of the domestic demand deficit reached after the replacement of the aqueduct network is evident, occurring in 2006. The positive increment at the beginning of the scenario and till 2004 depends on the augmented capacity of the drinking plant with respect to the reference management scheme: it is visible an immediate effect based on increased water volumes coming from the Garcia.

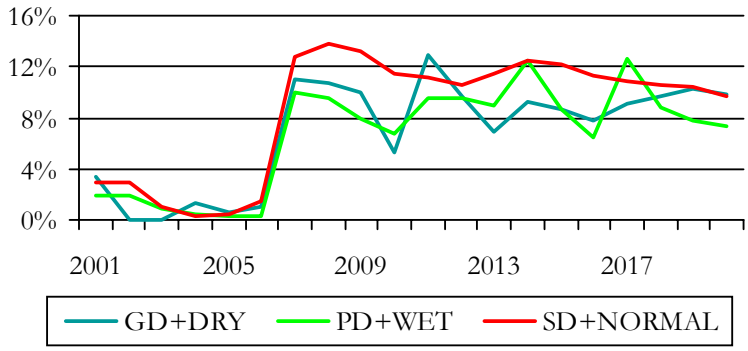


Figure 5-32. Percent Improvement of deficit in Domestic use with respect to the reference scenarios (Loss Reduction)

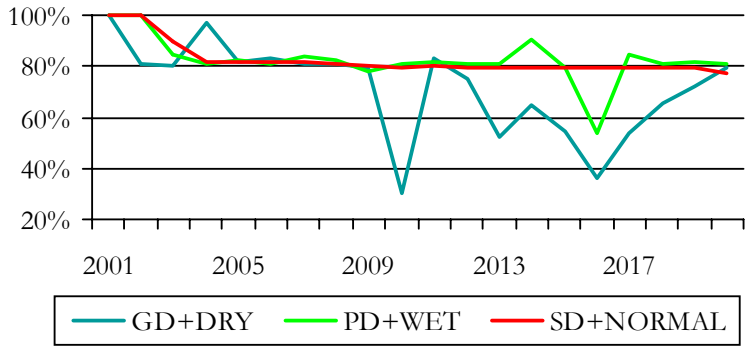


Figure 5-33. Percent demand coverage effectiveness of Losses Reduction to Irrigation use

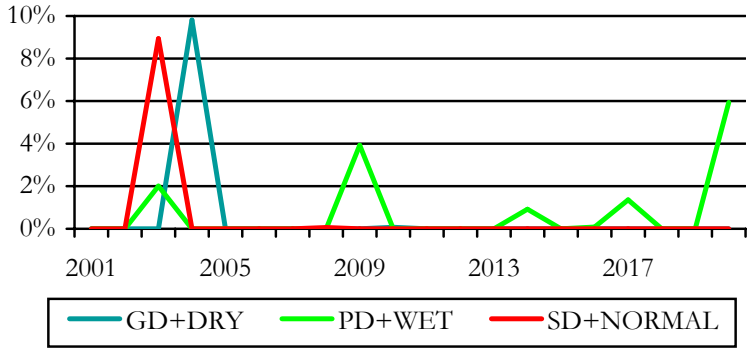


Figure 5-34. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios (Loss Reduction)

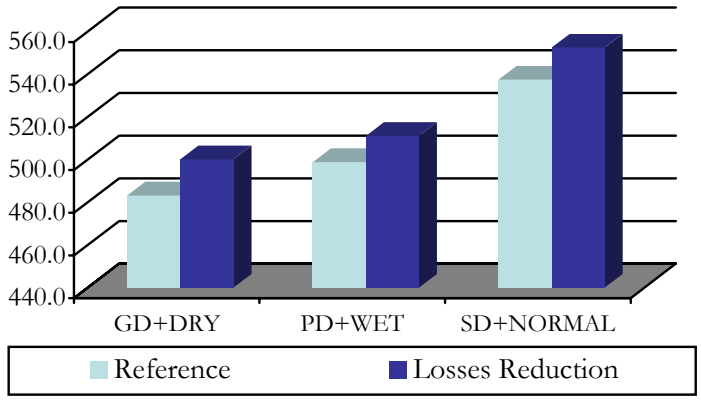


Figure 5-35. Total direct cost difference of the Losses Reduction option under the three scenarios (Present Value – Million €)

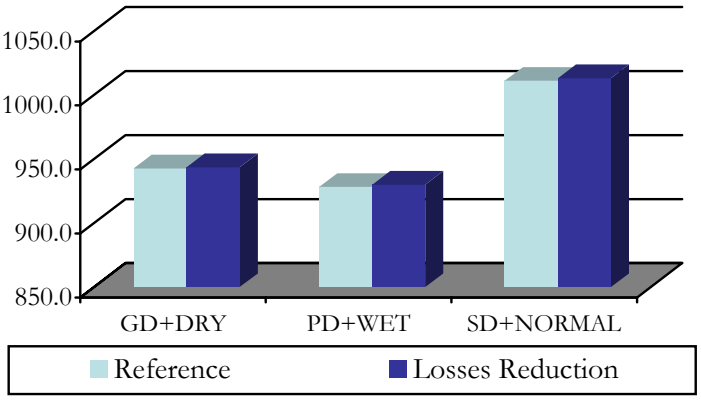


Figure 5-36. Total environmental cost difference of the Losses Reduction option under the three scenarios (Present Value – Million €)

The augmentation of direct and environmental costs are limited under the three scenarios making this option a candidate for strategy development as one that improves domestic demand coverage effectiveness. Environmental cost in particular changes slightly: the system relies more on the water of the Montescuro aqueduct that is distributed more efficiently, using less water from the already overexploited water resources of Garcia and Belice. On the other hand, this option brings no positive effect to the irrigation demand coverage, except for isolated and non-significant improvements under the best scenario. Moreover, the investigation of the water flows in the pipeline connecting the Garcia to the drinking plant pointed out that, although the new treatment capacity is about 18 million m^3, it is not exploited at its maximum due to the limited available surface water. The maximum volume of water treated is 9 million m^3, just half of the new capacity. The situation is similar to the enhancement option of the Belice exploitation, where an unhelpful availability scenario, i.e. the forecast available runoff, makes this structural option insufficient and not completely successful. It is suggested to combine it with another option affecting the irrigation effectiveness directly, such as waste water reuse.

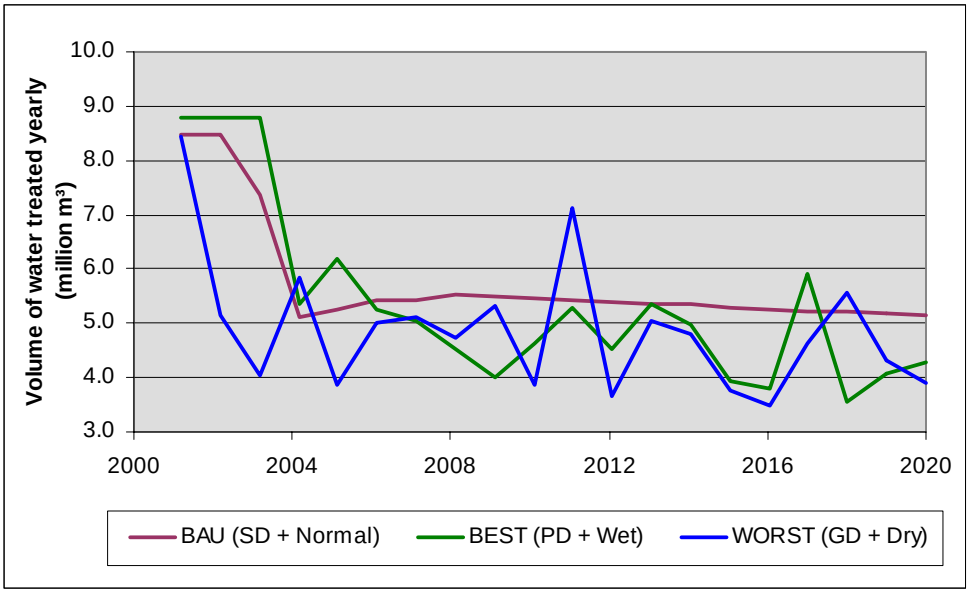


Figure 5-37. The volume of water treated by the drinking plant of Sambuca di Sicilia is always far from the designed capacity of 18 million m^3, and it evolves according to the negative trend of the inflows to the Garcia reservoir.

Pricing

Domestic Use Pricing

An option forecasting the growth of the water selling price for domestic users have been simulated within the case study of the Garcia-Arancio. Standard values of demand elasticity have been used, such as 0.2 for the permanent population of settlements, and 0.35 for the seasonal component and the tourists. The price is assumed to grow 1.87 % each year in the scenario duration, from an initial value of 0.8 €/m^3 to a final 1.1 €/m^3 after twenty years. This kind of analysis is useful to understand to what extent a rising selling price would influence the allocation of water among the conflicting uses and the exploitation of alternate resources. This information will be used by the local agencies for water services to establish the proper price which assures recovery of the costs they have to pay to face the forecast increasing rates of consumption.

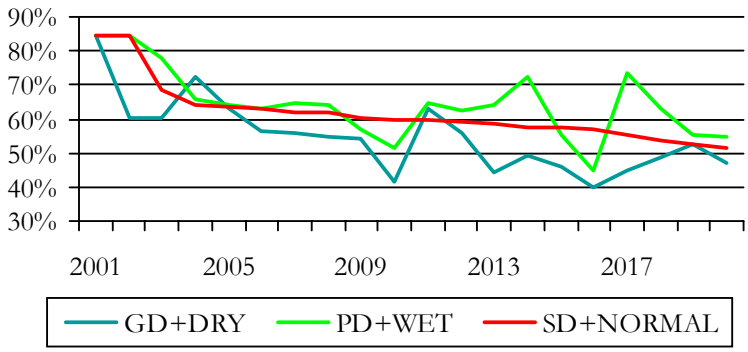


Figure 5-38. Percent demand coverage effectiveness of Water Pricing to Domestic use

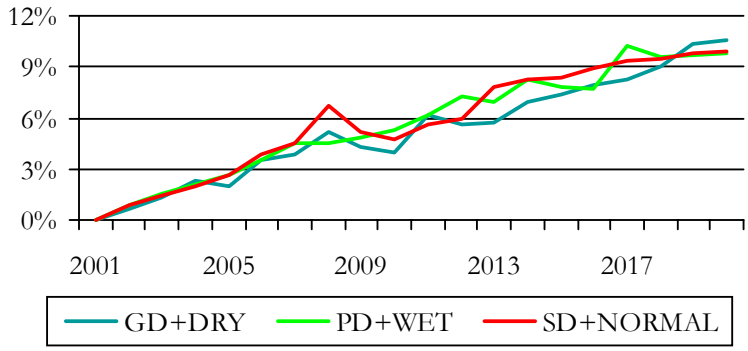


Figure 5-39. Percent Improvement of deficit in Domestic use with respect to the reference scenarios

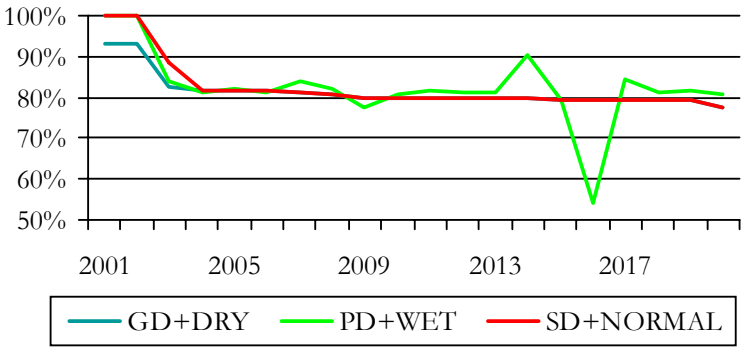


Figure 5-40. Percent demand coverage effectiveness of Water Pricing to Irrigation use

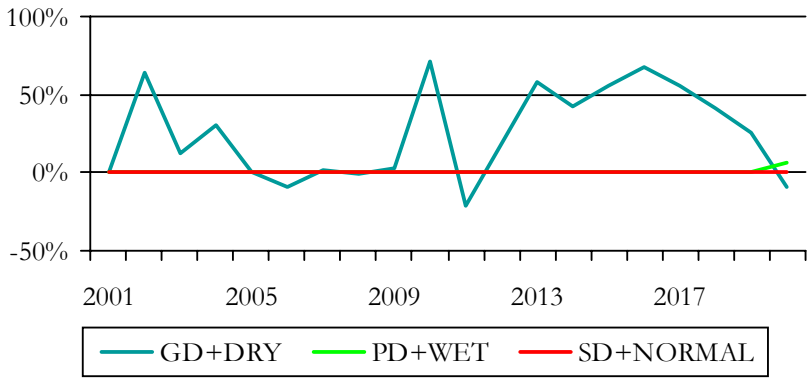


Figure 5-41. Percent Improvement of deficit in Irrigation use with respect to the reference scenarios

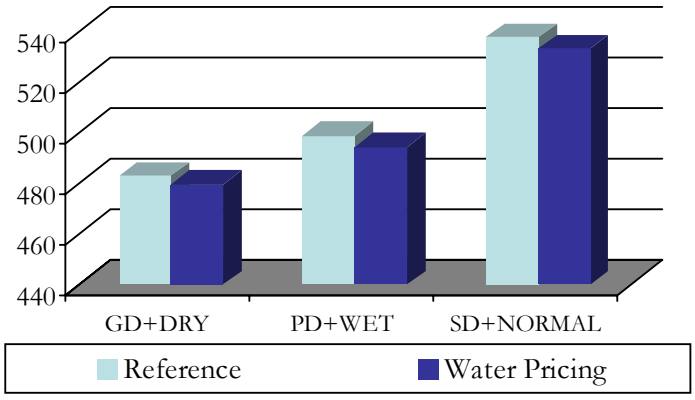


Figure 5-42. Total direct cost difference of the Water Pricing option under the three scenarios (Present Value – Million €)

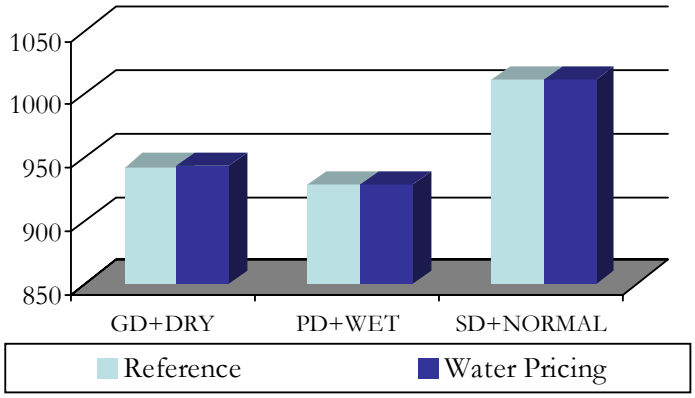


Figure 5-43. Total environmental cost difference of the Water Pricing option under the three scenarios (Present Value – Million €)

The simulation results show the evident impact of the rising price over the domestic deficit. The demand is reduced according to the elasticity demand parameter specified for the permanent and seasonal population, and as a consequence the deficit solves heavily. However this effect was expected, together with the trend of the improvement, which follows the specified growth of the selling price. Of course the unmet demand for irrigation is not touched by this option, given that no elasticity was assigned to irrigation sites. The only exception is under the worst scenario, which is characterized by a growing demand scenario and the worse conditions of rainfall and temperature: in this case the significant reduction of the domestic demand leaves more water available for the irrigation sites and an improvement of deficit appears.

From the side of the costs, the reduction of direct costs of 0.8 % completes a positive effect coming out the application of this option. However, it has to be combined with others that also influence the irrigation effectiveness.

5.4. Final Selection

The final selection of instruments to be further analysed during the strategy formulation phase depends on the performance of the options examined regarding the indicators that were presented throughout the analysis.

The performance of each strategic option is evaluated under the three criteria of effectiveness, economic efficiency and environmental sustainability. The effectiveness of an option relates the level of domestic and irrigation demand coverage that was reached; it is approached by a relative index obtained by the evaluation module of WSM DSS, assuming a weight of 0.5 for each coverage indicator, and a satisfactory range of values from 70 to 100%. Environmental sustainability is expressed through the total environmental cost for each option, which is associated in the Garcia Arancio case study with surface water abstractions from reservoirs and river reaches of interest. This criterion takes into account the costs that the local authorities should have to pay in order to replenish the overexploited surface water resources with treated waste water. Economic efficiency, the ability to produce more with less, is expressed through the total direct (financial) cost. Both the environmental and the direct cost are expressed in present value terms.

Table 5-10. Final evaluation of instruments

Option	Effectiveness (Relative Performance Index for Demand Coverage)	Economic Efficiency (Direct Cost – PV – million €)	Environmental Sustainability (Total environmental cost – PV (million €)
Base Case	0.0308	506.5	960.7
Waste Water Reuse	0.0306	512.6	965.6
Exploitation of Belice	0.0006	550.9	980.5
Irrigation Methods Improvement	0.0137	619.6	941.6
Water Pricing	0.0206	505.6	936.8
Reduction of losses	0.0205	487.0	935.8

Results of the performance evaluation are summarized in Table 5-10 as values, and in Table 5-11 as normalised under a scale ranging from 0 to 5 yields.

Table 5-11. Normalised option performance matrix

Option	Effectiveness	Economic Efficiency	Environmental Sustainability
Wastewater Reuse	*****	****	**
Exploitation of Belice	*	***	*
Irrigation Methods Improvement	***	*	*****
Water Pricing	****	****	*****
Reduction of losses	****	*****	*****

From the point of view of the effectiveness, Table 5-10 shows that the options simulated as freestanding do not help in meeting the global needs of the domestic users and of the irrigation sites. In fact the demands are not 100% covered under the Reference situation and the value of effectiveness stays more or less close to the reference or slightly below it even with the strategic options. All the options analysed in the case study aim at improving the agricultural effectiveness, which is the primary goal of the water strategy in the case study of Garcia-Arancio. These options include interventions that act directly in favour of the irrigation requirements, such as the waste water reuse, the Belice exploitation and the irrigation methods improvements, but also measures that act in favour of the domestic water needs and should have an additional positive effect on the irrigation demand coverage, e.g. reduction of distribution losses and water pricing. Unfortunately, both the irrigation sites and the settlements need water to cover their demands, but the urban use has a higher priority and as a consequence all the policy measures which seem to indirectly bring an advantage to the agricultural requirements are all nullified. In conclusion, although the analysis of the single graphs of domestic and irrigation improvements show that the options help solving the deficit impact occurring in the region, it seems clear from Table 5-10 that only a combination of them into a strategy can lead to a more significant result.

Among the best options examined there is the waste water reuse, which reaches a good score from the point of view of effectiveness and economic efficiency. This is the option that more than others involves and influences the districts directly, and its positive effects do not depend on the competing domestic user or on the reduced availability scenarios. The low performance score of the Belice exploitation option (see Table 5-11) underlines that in general structural interventions must account for the forecasts of water inflows at river reaches and reservoirs, because an expansion of a structure that will never work at its maximum is not worth it. Besides, if a few structural interventions are to be combined together, the possibility that increased allocated supply to a category of users could decrease amounts allocated to others should be investigated and preferably avoided.

This first approach to the demand and availability scenarios and to the evaluation of proposed feasible water solutions for the Garcia-Arancio case study has pointed out that institutional policy, such as water pricing, and demand management options, like the replacement of old aqueducts and pipelines to lower the losses, are the best strategic options, as they reach the highest score for the three criteria of effectiveness, economic

efficiency and environmental sustainability. They will constitute the soft measures of the upcoming water strategy development, to be applied first to the water network as first solution, and to be integrated with the hard structural ones.

6. Comprehensive Scenarios for Limassol region

Cyprus is an arid to semi arid island state situated in the northeastern Mediterranean. The renewable freshwater resources are highly constrained. These are characterized by a strong spatial and temporal scarcity caused by the seasonal distribution of precipitation, and the topography.

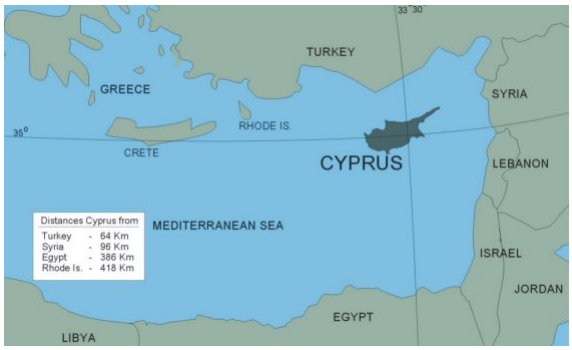


Figure 6-1. Cyprus in the Mediterranean

Although a large number of various water supply investments and interventions have been made such as surface water dams, groundwater exploitation, inter-basin water transfers, desalination and reuse of tertiary treated effluent, Cyprus is still a long way from reconciling the demand to the availability of water. Competing demand and the dynamic competitive tension between agriculture, urban growth including tourism, and the environment are challenging the existing water management practices in the island. With this in mind, the objective in the formulation of the scenarios and strategies for the Limassol Region is to meet the growing demand for water exerted by the permanent and seasonal population without affecting detrimentally the traditional agricultural demand which appears to have stabilized. At the same time, the scenarios attempt to ensure stability of supply and maintain the groundwater exploitation to sustainable levels achieving thus environmental protection of the local aquifers.

The Limassol region (Figure 6-2) is a typical representative study region for the formulation of scenarios and strategies to address the competing and conflicting water uses in the island, since

- the region is one of the main tourist destinations in Cyprus,
- the agricultural production in the area accounts for more than 25 % of the fruit trees, 6% of the vegetable and 20% of the table grapes production of the country
- the water system of the region is very complicated (Figure 6-3 a and b)

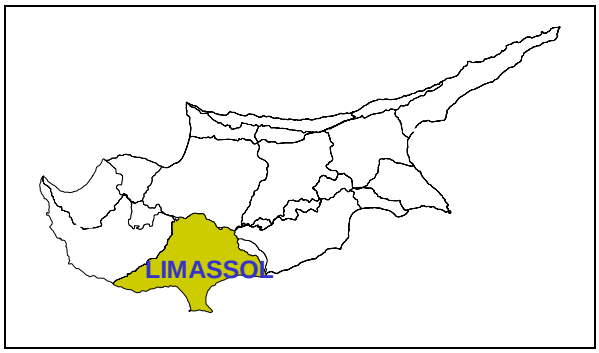


Figure 6-2. The selected Limassol region

The domestic consumption of the region accounts for almost 12.8 hm^3, whilst the domestic water consumption for the tourism (seasonal population) accounts for 3.6 hm^3 in 2000 which is almost 26 % of the island's total seasonal consumption. The domestic consumption is supplied from surface waters after treatment in the Limassol Water Treatment Plant (almost 7.8 hm^3), and from groundwater -boreholes and springs (almost 8.2 hm^3). Irrigation water demand in the region accounts for almost 31 hm^3 from which 24 hm^3 were supplied from the major government irrigation schemes (Figure 6-1).. In addition the annual water demand for animal husbandry in the region accounts for 820,000 m^3 and the industrial demand for 1.5 hm^3 or 43% of the total industrial demand of the island. Environmental demand in the region accounts for 4 hm^3.

The sources of water supply in the region include:

- Surface water stored in the three dams of the region, namely the Kouris Dam (of a total capacity of 115 hm^3), the Polemidhia Dam (of a total capacity of 3.4 hm^3) and Germasogeia Dam (of a total capacity of 13.5 hm^3) which is used for domestic and irrigation purposes.
- Certain quantity of the stored surface water resources is treated and used for domestic purposes in the Limassol Water Treatment Plant which has a capacity of 40000 m^3/day with a potential capacity of 80,000 m^3/day. The plant receives raw water from the Kouris Dam and supplies water to the Limassol city, some villages west of Limassol and to the British Bases of Akrotiri.
- Ground water extraction from a number of boreholes to be used for domestic and irrigation purposes.
- Treated effluent from the Limassol Sewage Board Treatment Plant used for agricultural and landscape irrigation.

The irrigated areas in the region fall in two categories: Areas within the Major Government Irrigation Schemes of the region (Akrotiri West and Germasogheia-Polemidhia) and areas outside the Government Irrigation Schemes.

Water from the Kouris Dam (the biggest dam in Cyprus) is transferred to the eastern part of Cyprus (Kokkinochoria region) through the pipeline of the Southern Conveyor Project (Figure 6-3 a and b).

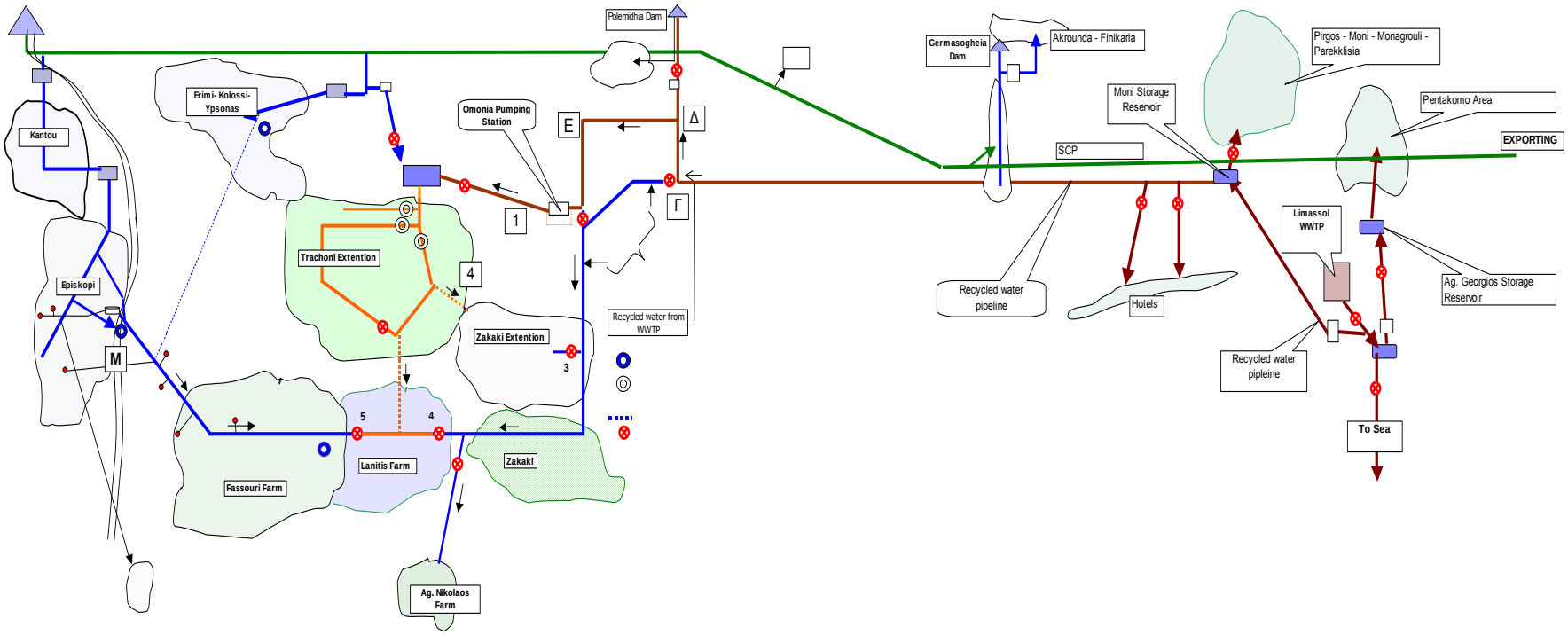


Figure 6-3 a. The irrigation system of the region

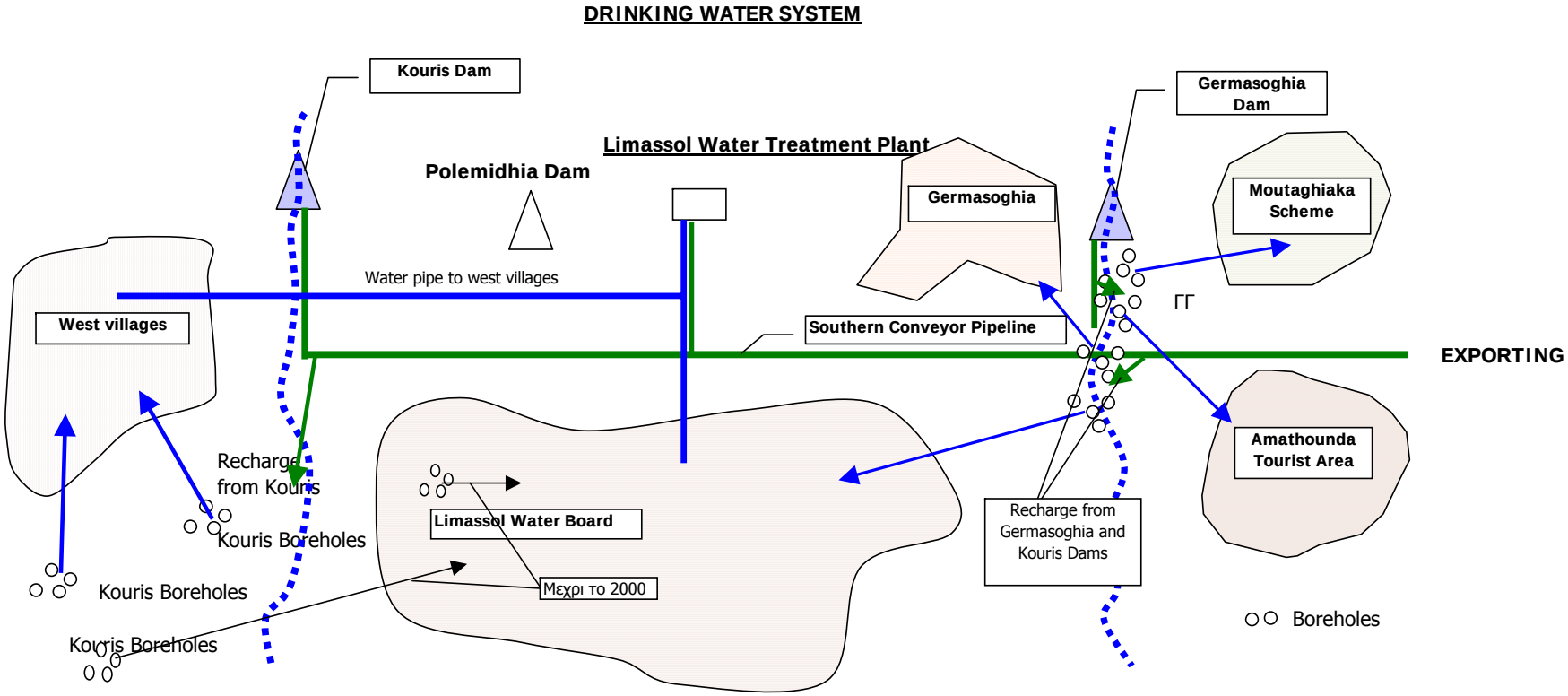


Figure 6-3 b. The irrigation system of the region

6.1. Demand and Availability Scenario Components

Formulation of Demand Scenarios

Cisterns

Since the water management practices in the region reflect the competing demand and the dynamic competitive tension between agriculture, urban growth including tourism, and the environment, the formulation of the demand scenarios will be based upon assumptions for:

- Permanent and seasonal population growth
- Domestic consumption rates
- Agricultural demand growth

Data were gathered from the FAO Study, as well as from other sources including the Water Development Department, the Limassol Water Board, local administrative authorities, hotel owners association, and the Cyprus Tourism Organisation.

Three different demand scenarios were formulated, responding to:

- the Normal conditions (NORMAL);
- the High Demand conditions (HD);
- the Low Demand conditions (LD).

For the population projection the census of 1992 and demographic reports (Ministry of Finance, 1994) were considered. The rate of growth of population (in %) is 0.8 for 2000 – 2005 dropping to 0.7 for the period 2005 to 2010 and to 0.6 afterwards. The assumed growth rates for the local population under the various scenarios appear in Table 6-1.

The seasonal population growth (tourism) is based on the Cyprus Tourism Organization strategic plan. According to this Strategic Plan 2000-2010, the annual increase of Tourism will be in the order of 3.4%. The assumed rate of 3.5% was maintained throughout the study period. An annual increase of 1.5% per capita water demand was assumed.

Table 6-1. Details of Demand Scenarios

SCENARIO	Population Growth		Irrigation	Consumption rate growth	
	Domestic	Seasonal		Domestic	Seasonal
NORMAL	1%	3.5% up to 2010 1.5% from 2010	0%	2%	1.5%
LOW DEMAND	0.5%	3.5% up to 2010 1.5% from 2010	0%	2%	1.5%
HIGH DEMAND	2%	3.5% up to 2010 1.5% from 2010	10%	2%	1.5%

The corresponding domestic water demand (million m^3) can be depicted from Figure 6-4.

The irrigation demand is considered to have stabilized and the FAO study assumes no future growth due to water resources limitations, costs and competition from imported goods. The anticipated increase of irrigation water price is also a major factor in maintaining the agricultural activity to its present levels. This has been adopted for the NORMAL and the LOW DEMAND scenarios. For the HIGH DEMAND scenario an increase in consumption rate of 10% has been assumed, indicating a change in cropping pattern requiring a higher demand of water.

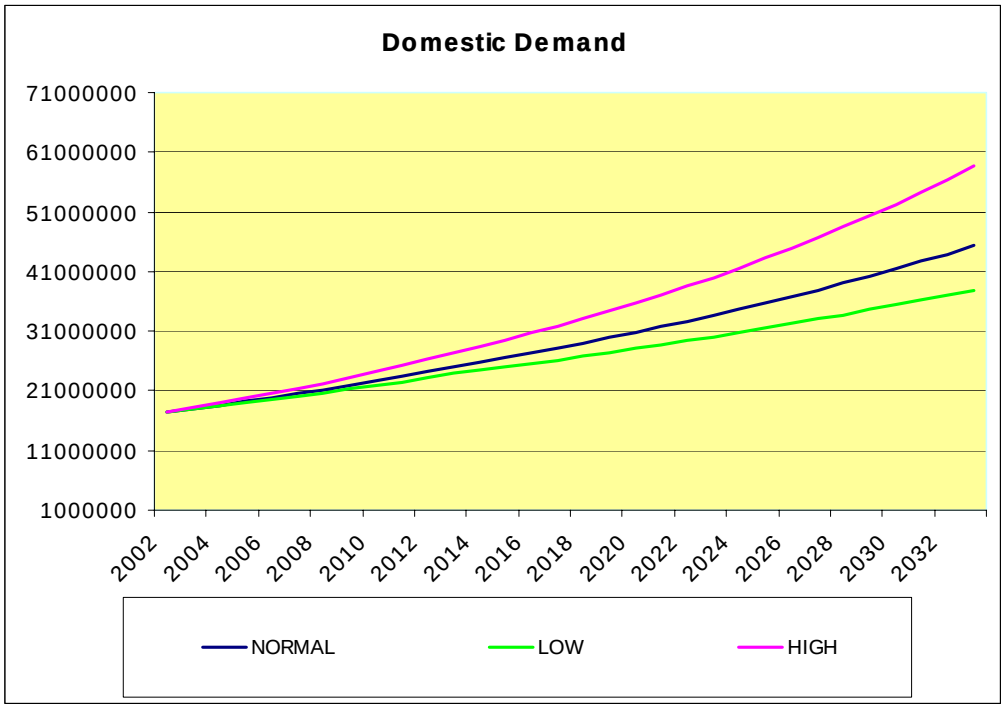


Figure 6-4. Domestic Demand Scenarios

Formulation of Availability Scenarios

Data

Cyprus has an intense Mediterranean climate with the typical seasonal rhythm strongly marked with respect to temperature, precipitation and weather in general. Hot dry summers from mid-May to mid-September and rainy, rather changeable, winters from November to mid-Match are separated by short autumn and spring seasons. During the last 30 years a considerable reduction of mean annual rainfall has been experienced in the island (Figure 6-5).

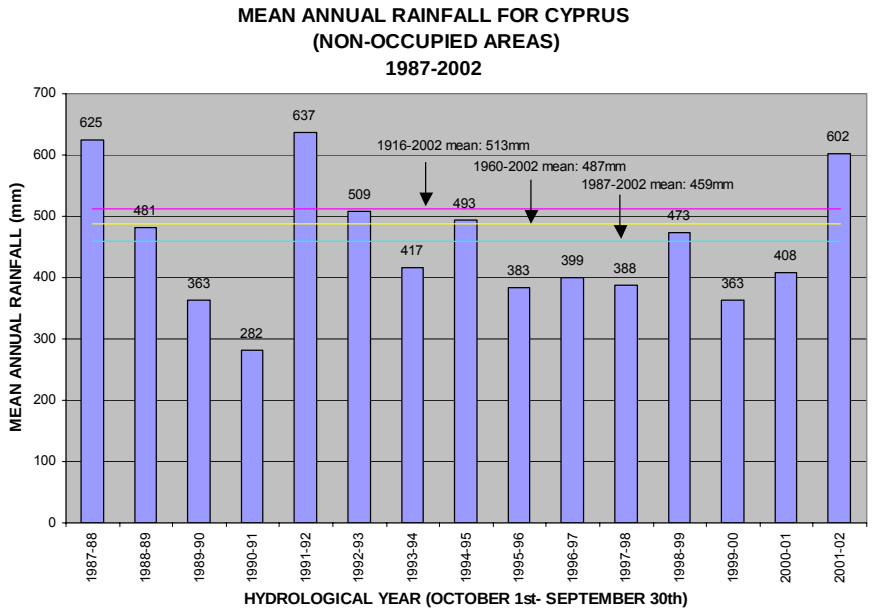


Figure 6-5. Mean annual rainfall for Cyprus (1987 – 2002)

The mean annual rainfall in Limassol is 409 mm according to the last 30 years measurements at the meteorological station of Limassol (Figure 6-6). In the same Figure 6-6, the mean rainfall throughout the region can be seen. The inflows into the surface storage reservoirs (Figure 6-8) depend on the catchment rainfall and they reflect this.

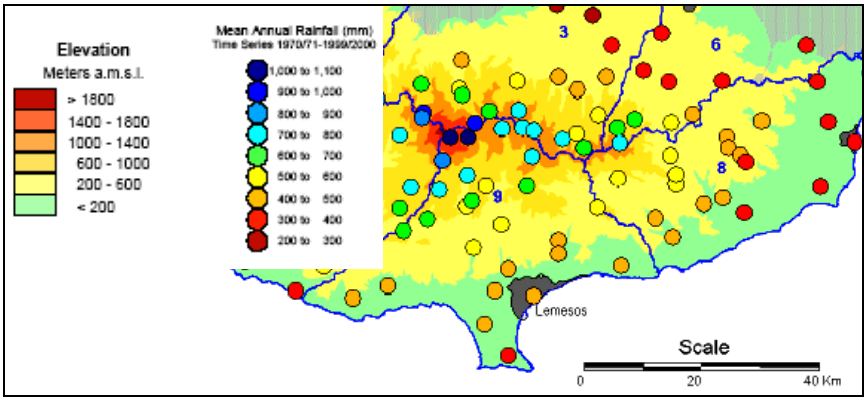


Figure 6-6. Mean annual rainfall for the Limassol region (1970 – 2000)

The distribution of the precipitation through the year is similar all over the island. In the Limassol region the mean precipitation increases to maximum in December and January. The decrease of the mean precipitation is slower than the increase, it spans over eight months from December – January to a minimum in July – August (Figure 6-7).

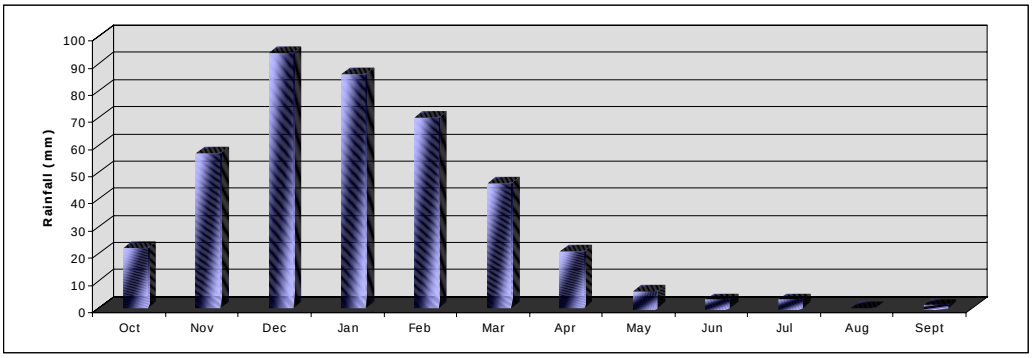


Figure 6-7. Annual distribution of the rainfall of the Limassol region (1970 – 2000)

Figure 6-8 shows the variations with time of the region's three dams inflows over the 1987/1988 – 2003/2004 period.

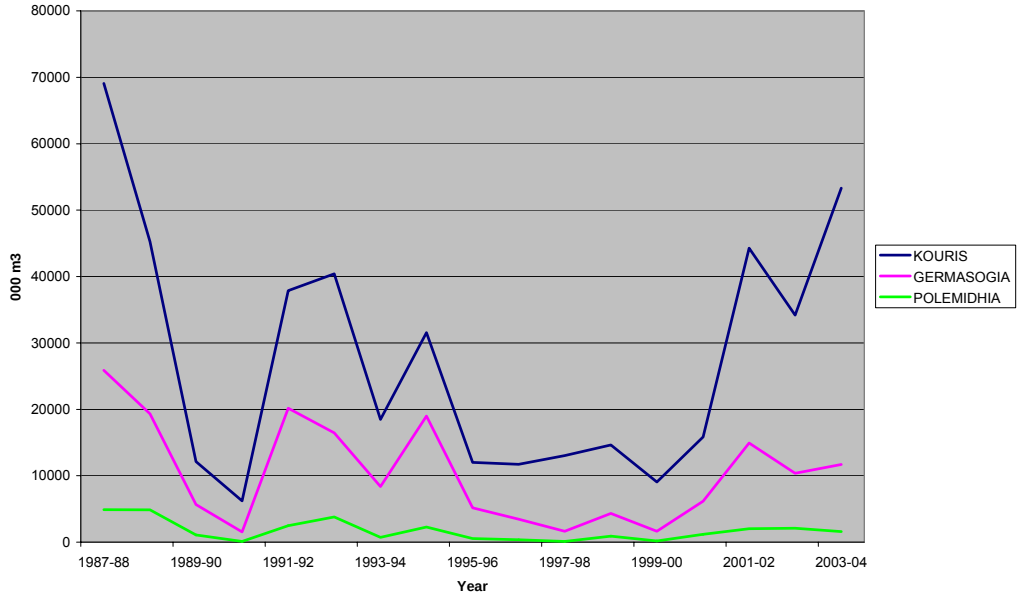


Figure 6-8. Annual distribution of the water inflows in the three dams of the region (1970 – 2000)

Scenarios

Since detailed data of water inflows were available for the region, the variable in the formulation of water availability scenarios was the sequence of years with respect to water inflows in the dams. Three different hydrological scenarios were used, reflecting the business as usual conditions (standard water availability) – BAU, the high frequency of dry years conditions (DRY) and high frequency of wet years (WET).

The three scenarios are depicted in Figure 6-9.

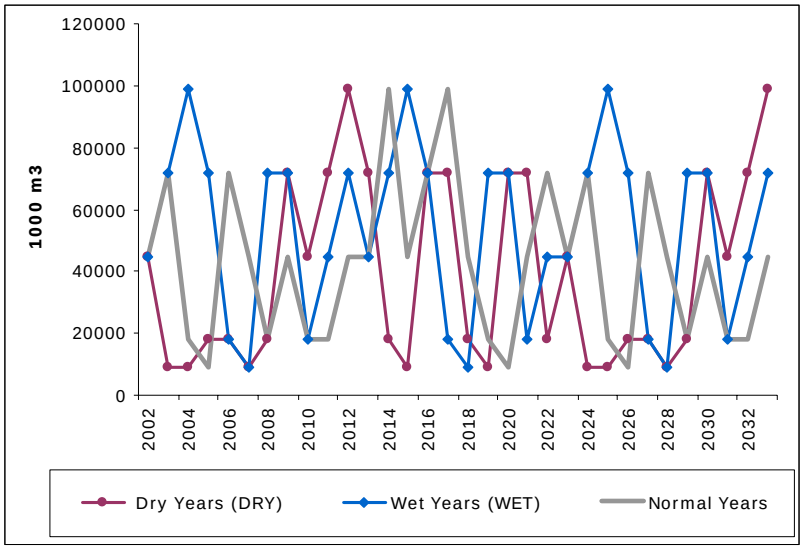


Figure 6-9. Water availability scenarios

Combinations of hydrological and demand scenarios

In order to cover all the possible responses of the water system of the region, a number of hydrological and demand scenarios have been developed related to the business as usual case scenario (BAU), the worst case scenario (WORST) and the best case scenario (BEST).

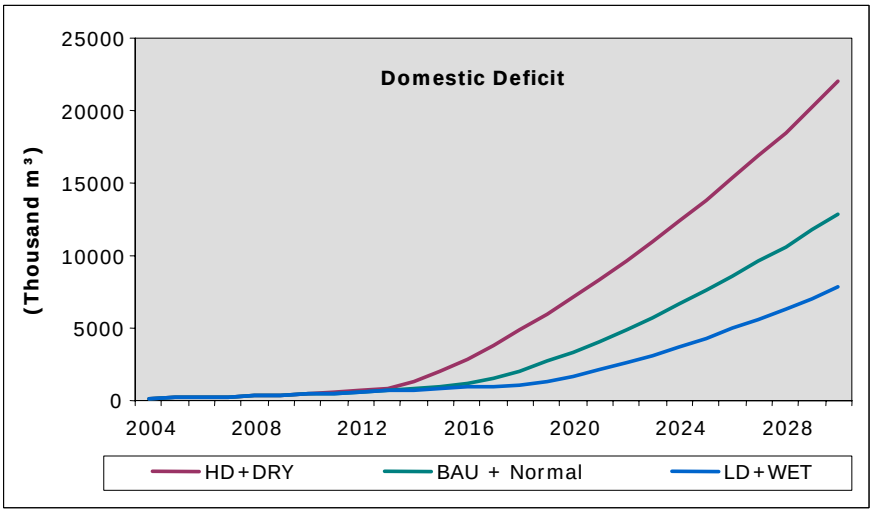


Figure 6-10. Estimated domestic unmet demand under the selected hydrological-demand combinations

The details of the adopted combinations are given in the following Table.

Table 6-2. Combinations of availability and demand scenarios

Combination Name	Availability Scenario	Demand Scenario
Business as Usual Scenario:	Normal years	Business as Usual demand
Worst case Scenario:	Dry years	High demand
Best case Scenario:	Wet years	Low demand

The domestic water deficit shows a steep increase (Figure 6-10) in all three combinations after year 2012, since by that time the water production of the water treatment plant of Limassol will reach the plant's capacity (40.000 m^3/day).

There is a pronounced seasonality of domestic water deficit peaking in the summer period due to increased influx of tourists (Figure 6-11). Certain choice tourist destination areas experience considerable stress in meeting the water demand.

At the beginning of the simulation period (year 2002), the domestic water unmet demand is less than 0.8% of the demand, experienced mainly in Limassol Tourist Area and Akrotiri, Assomatos and Kantou villages. By the end of the simulation period (2033) nearly all settlements in the study area face domestic water deficit, which reaches up to 31% of the demand.

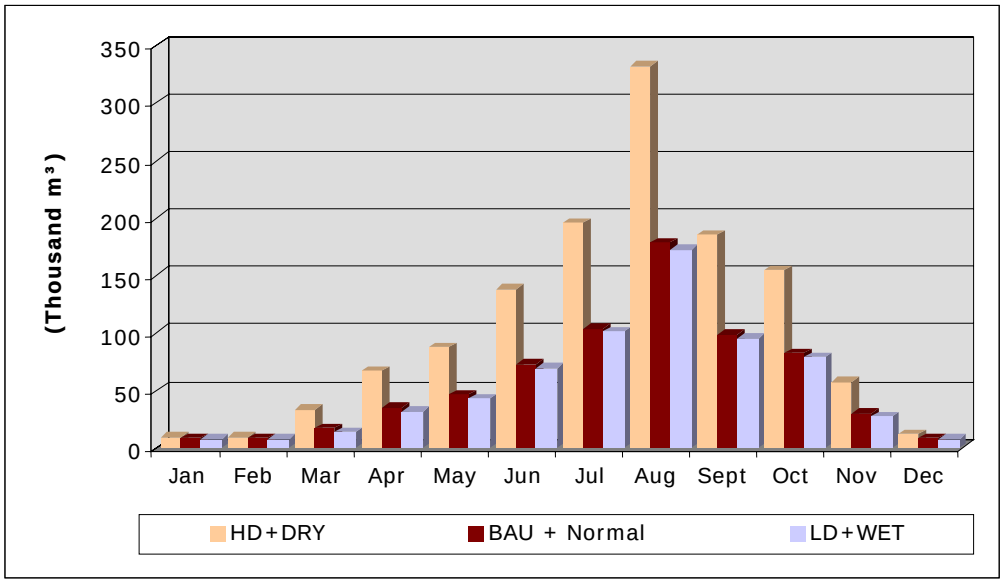


Figure 6-11. Monthly domestic deficit under the three scenarios (year 2011

6.2. Selection of management options and indicators

The management options that were developed and analyzed resulted from a synthesis of the current responses regarding water management, the responses proposed by the stakeholders and the requirements of the Water Framework Directive that can be implemented in this specific area.

Figure 6-12 illustrates a set of practices which will be combined to formulate strategies aiming at balancing the various pressures on water demand due to the conflicting water uses pertinent in the region (domestic – irrigation – tourist activities).

The set of practices or interventions was selected from the stakeholders' proposals – including structural and non-structural interventions related to demand and supply side – and Water Framework Directive requirements that can be implemented in the Limassol region. Environmental, social and economic constraints were included and considered in the approach.

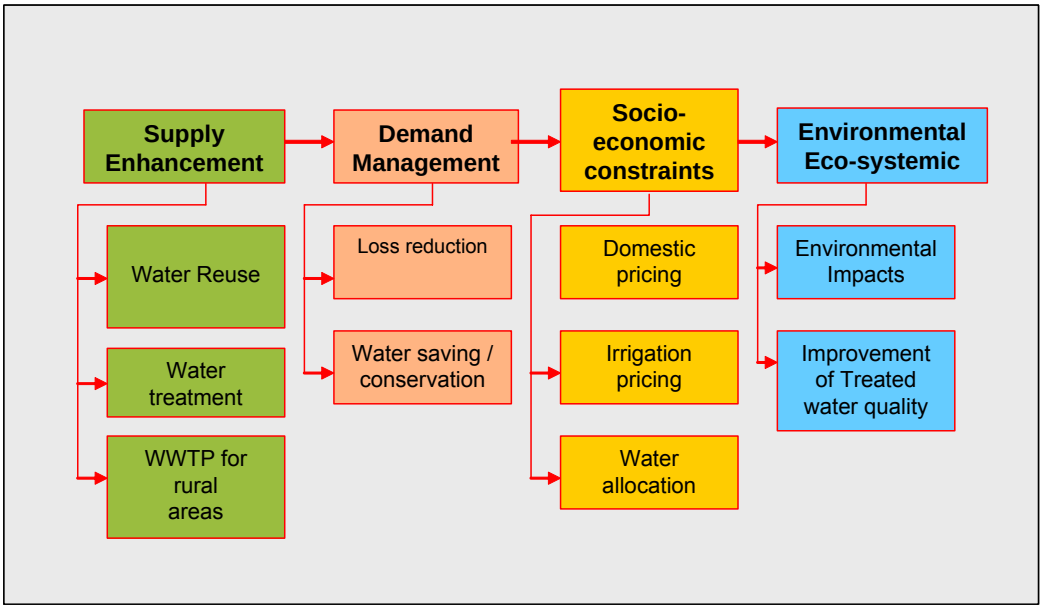


Figure 6-12. Summary of management options

A number of the above proposed interventions were analyzed using the WSM Decision Support System, and the results of this analysis are shown in the text that follows. The examined interventions fall into three main categories which include:

Table 6-3. Examined water management interventions

Interventions related to Supply Enhancement - STRUCTURAL	
GOALS	**INTERVENTIONS**
Agricultural Demand will be met by surface and recycled water freeing the burden on groundwater Domestic and tourist demand will be met by surface water	**ST1:** Water reuse **ST2:** Upgrade Program of the existing Water Treatment Plant – minimization of groundwater abstraction for drinking water **ST3:** Construction of a WWTP for the western rural areas
Interventions related to Demand Management – NON STRUCTURAL	
GOALS	**INTERVENTIONS**
	SE1: Conservation measures in the domestic sector **SE 3:** Loss reductions in the domestic sector
Interventions related to Socio-Economic context – NON STRUCTURAL	
Conciliate water availability with demand Water tariffs should reflect the true water costs allowing an adequate cost recovery	**SE 2:** Irrigation water pricing **SE 4:** Domestic water pricing

As a next step the examined interventions were evaluated through a series of indices and indicators describing the actual range of the activities applicable to the region reflecting the perception of the locals towards economic development, social and environmental sustainability. Since it is widely acceptable that future economic growth of the area is to rely to tourism, the analysis of options were assessed on the ground of the **coverage of domestic needs.** On the other hand due to the importance of the agricultural sector in the area, the options formulation was also assessed on the basis of the **irrigation demand coverage.** Finally, environmental protection was expressed through the **groundwater exploitation index**, since until recently a large part of the domestic water supply in the area relied upon groundwater from the existing aquifers. The major Akrotiri aquifer has been experiencing overdraft in the last 20 – 25 years since a major portion of the natural replenishment has been cut off by the Kouris dam. Pumping has been maintained closely to the same levels as before the construction of the dam due to the water price differential between surface and groundwater, the latter being much cheaper.

The satisfactory range of values and the weights assigned to the three indicators are presented in the Table 6-4. In addition to the three aforementioned indicators, it was

considered necessary to incorporate also the direct costs related to the application of each option, in order to select not only efficient, but also cost effective solutions.

Table 6-4. Evaluation indicators

Indicator	Satisfactory range of values	Weight
Domestic demand coverage	90-100%	0.50
Irrigation demand coverage	80%	0.25
Groundwater exploitation index	0-80%	0.25

The results of the analysis are presented in the text that follows for the worst hydrological/demand case scenario.

6.3. Analysis of water management instruments

Structural options

Water reuse

Cyprus has recently turned to the use of non-conventional water such as desalination and reuse of tertiary treated effluent to augment its available supplies. Within this framework the 100% utilization of the tertiary treated recycled water of the Limassol Waste Water Treatment Plant has been identified as a possible policy intervention to enhance the water supply of the region and to alleviate the burden on groundwater.

The realization of this intervention which is given schematically in Figure 6-13 is scheduled for the year 2008, and includes the following technical aspects:

Recycled water during the winter months (when the irrigation demand is at a minimum) will be stored in Polemidhia dam and/or will recharge the Kouris Delta aquifer. Under these circumstances, the Kouris Delta aquifer may not be used for domestic purposes.

The pipeline form the WWTP will be connected to the existing network to transfer water to Zakaki Ext., Ag. Nikolaos, Lanitis and Fassouri farms.

A new pipeline will connect Ypsonas reservoir with Zakaki farm to transfer fresh water from the Kouris dam to cover the irrigation demand of the farm. The cost of the pipeline is estimated to approximately 250.000 Euros.

A new 5 km pipeline will connect the existing network with the Kouris Delta aquifer. The cost of the new pipeline is estimated to approximately 1.7 mil. Euros.

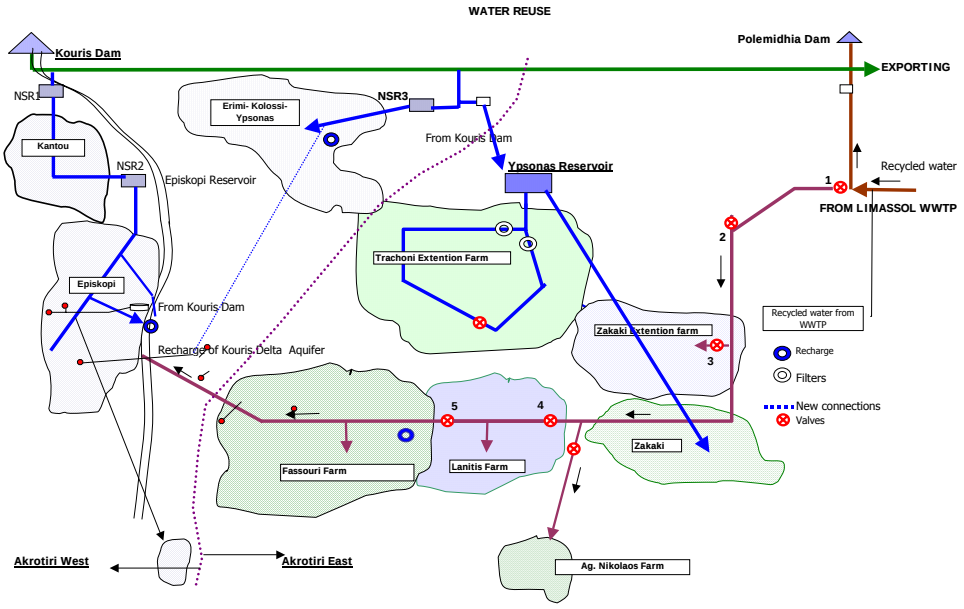


Figure 6-13. Proposed network modifications for recycled water reuse

This option results in substantial reductions (compared to the reference case where no intervention is adopted) in irrigation deficit (Figure 6-14), with a subsequent reduction in groundwater abstractions (Figure 6-15).

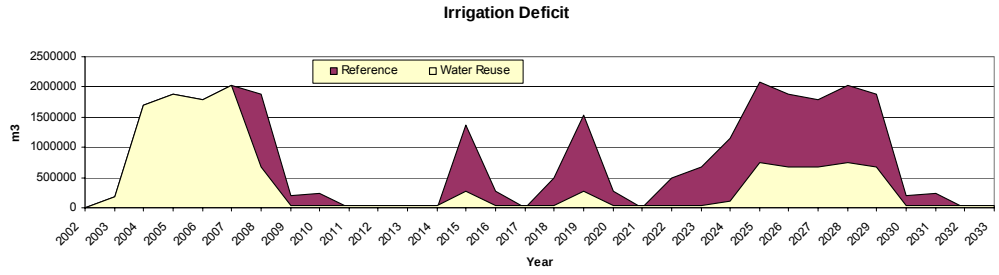


Figure 6-14. Reduction of irrigation deficit with respect to the reference scenario

This intervention also has positive effects in domestic demand coverage as can be seen from Figure 6-15. This is because, due to the reduction of surface water being used for irrigation purposes, there are quantities of fresh surface water available to cover domestic purposes. This is of great importance since as it was mentioned before, the Kouris Delta aquifer may not be used for domestic purposes. In this case the resulted domestic deficit is improved from saved surface water that would otherwise have been used for irrigation.

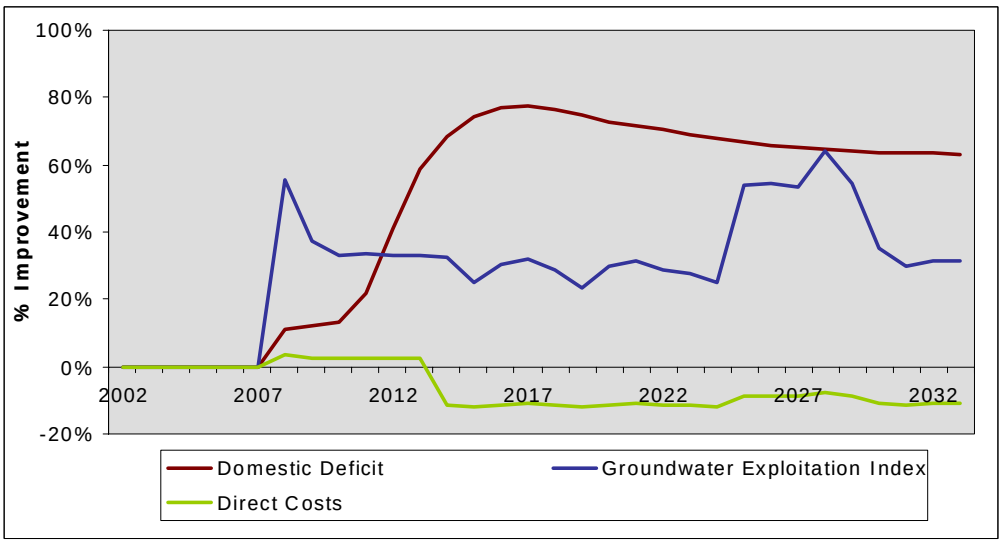


Figure 6-15. Improvement (%) with respect to the reference scenario

Under current conditions (Figure 6-3a) the 100% utilization of the recycled water can be accomplished only with the construction of a new 11 km pipeline from the Ypsonas reservoir to Kouris Delta aquifer. This alternative has a much higher cost than the examined option, and this is the reason why the examined option is promoted by the Water Development Department.

The comparison of the direct cost (present values adopting a discount rate of 10%) of the examined management option and the reference case under the three

hydrological/demand scenarios is presented in Figure 6-16. In all cases the anticipated increase of costs is less than 1% in line with the previous comments.

The associated increase of direct cost for the HD+DRY scenario is the highest since for the same incurred costs for the intervention, the water demand is highest and the water availability is lowest, the latter affecting also the availability of domestic water and consequently the quantity of produced treated effluent. Thus, relatively smaller quantities of treated effluent water are being recycled.

Contrary to the above, for the LD+WET scenario this change is the lowest of the three scenarios examined since it appears that in this case where the demand is lowest and water availability highest (increased treated effluent availability), full use of the intervention is made balancing the incurred cost for the intervention. This is also strongly suggested by the results shown in Figure 6-17. The evaluation of the water reuse intervention against the reference scenarios is by far highest for the LD+WET scenario. In this case the deficits for irrigation are the least, the groundwater exploitation is reduced and more water is available for the domestic sector.

In all the three scenarios the increase of the direct cost appears to be very small indicating the balancing of the incurred costs for the intervention by the mobilization of sufficient quantities of treated effluent water replacing fresh water which is freed for other use (domestic demand).

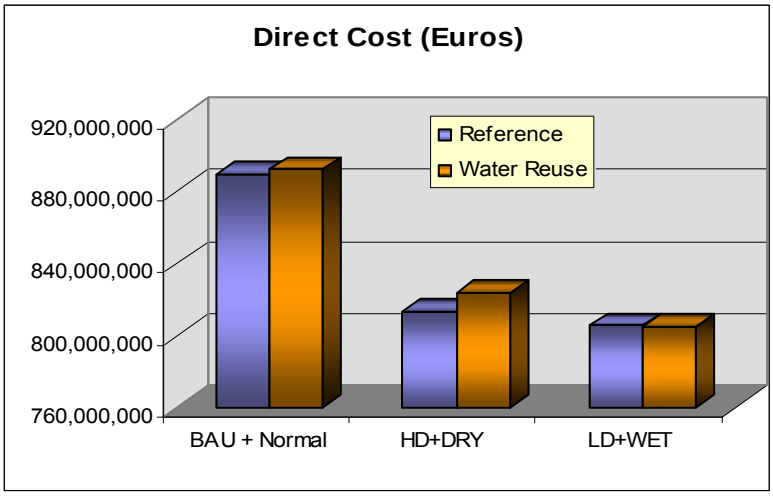


Figure 6-16. Comparison of the direct cost of the water reuse intervention against the reference scenarios

The associated environmental cost is presented in Figure 6-17. The estimation of the environmental cost was based on the French Agences de l'Eau method, and is related to renewable groundwater abstractions alone (the environmental cost for pollution was not calculated). The environmental cost after the introduction of the intervention is substantially lower than the environmental cost estimated for the reference scenario, due to the substantial reduction of the groundwater abstractions for irrigation purposes (see also Figure 6-15).

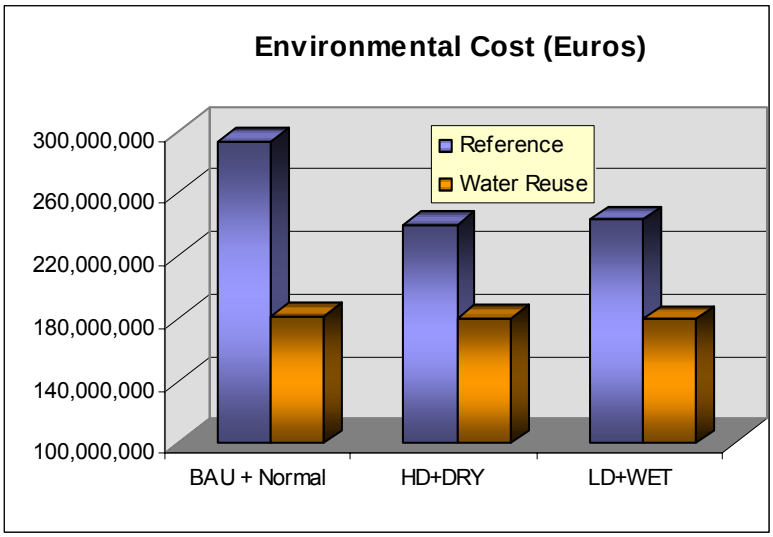


Figure 6-17. Comparison of the environmental cost of the water reuse intervention against the reference scenarios

The obtained evaluation scores for all three cases are presented in Figure 6-18. The higher score is obtained for the best case scenario (Low Demand and Wet). In all three cases the ground water exploitation index shows the greatest improvement in line with what it was mentioned before (Figure 6-15).

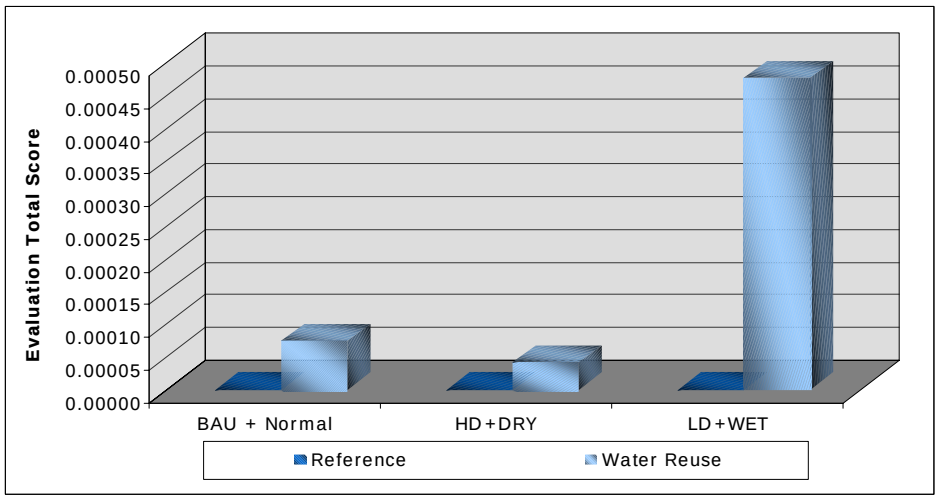


Figure 6-18. Evaluation of the water reuse intervention against the reference scenarios

Water treatment plant upgrade

As it was mentioned before (Figure 6-10) by the year 2012 the demand for treated fresh water from the Limassol Water Treatment Plant will overcome the capacity of the plant.

Based on the water demand projections and the seasonality patterns of the water consumption, the examined intervention involves the following technical aspects:

- upgrade of the existing Water Treatment Plant to reach a capacity of 80.000 m^3/d.
- minimisation of groundwater abstractions from the Garylis aquifer for domestic uses.

The intervention is examined coupled with the previously presented one.

Under the worst case scenario, this option results in substantial reductions in domestic deficit (Figure 6-19), with a subsequent reduction in groundwater abstractions (Figure 6-21).

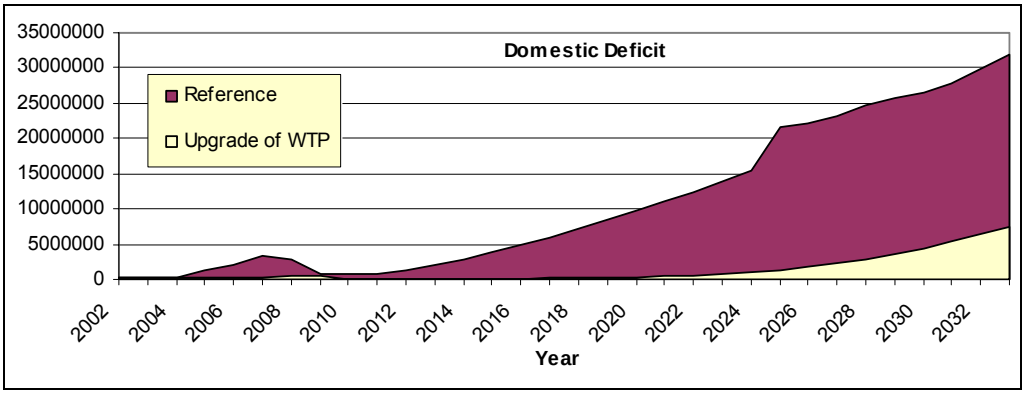


Figure 6-19. Reduction of domestic deficit with respect to the reference scenario

This intervention also has positive effects in irrigation demand coverage as can be seen from Figure 6-20, because more quantities of treated effluent and groundwater are available for irrigation uses.

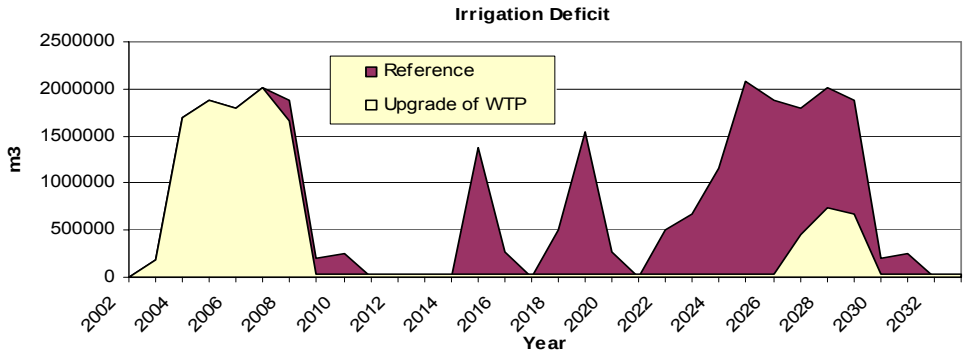


Figure 6-20. Reduction of irrigation deficit with respect to the reference scenario

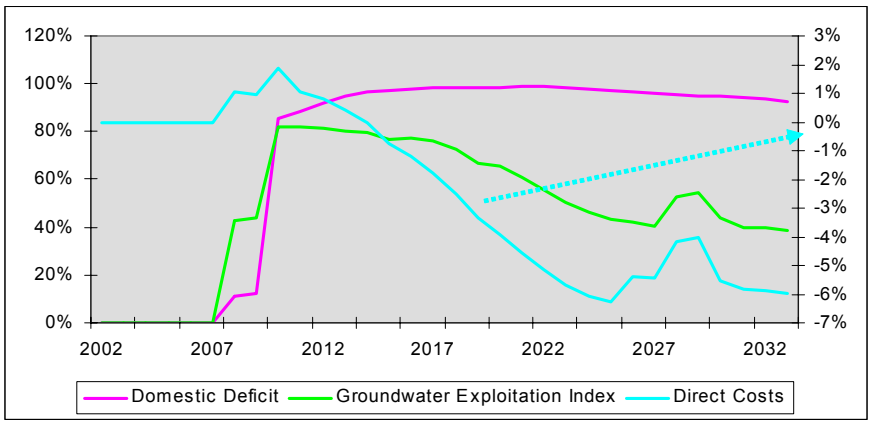


Figure 6-21. Improvement (%) with respect to the reference scenario

The comparison of the direct cost (present values adopting a discount rate of 10%) of the examined management option and the reference case under the three hydrological/demand scenarios is presented in Figure 6-22.

The most favourable case is the BAU+Normal scenario in which case the costs of the intervention are outweighed by the coverage of the normal demand under normal climatic conditions. The additional costs are practically balanced for the HD+DRY scenario whilst for the LD+WET the intervention is just slightly less effective (due to the lower demand assumed) than for the high demand and dry conditions. The beneficial effect of the water treatment plant upgrade which allows surface water to be used for domestic purposes and freeing the Garyllis aquifer (reduced groundwater exploitation) to help meet the irrigation demand is inherent in all the three scenarios examined.

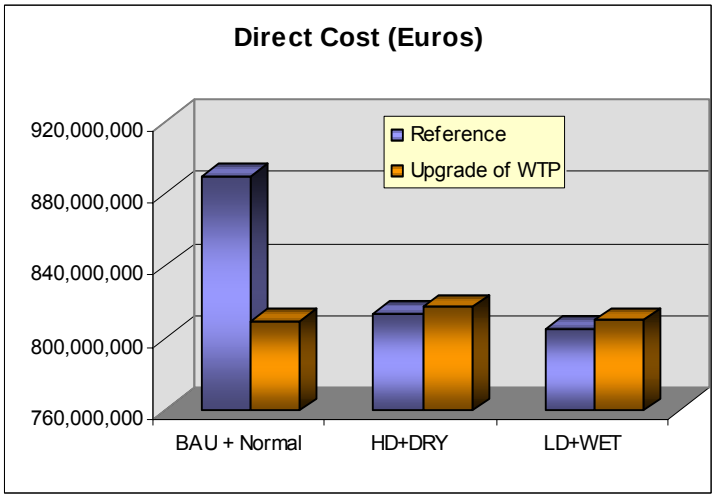


Figure 6-22. Comparison of the direct cost of the WTP upgrade intervention against the reference scenarios

The associated environmental cost is presented in Figure 6-23. The environmental cost after the introduction of the intervention is substantially lower than the environmental cost estimated for the reference scenario, due to the substantial reduction of the groundwater abstractions for domestic purposes (see also Figure 6-21).

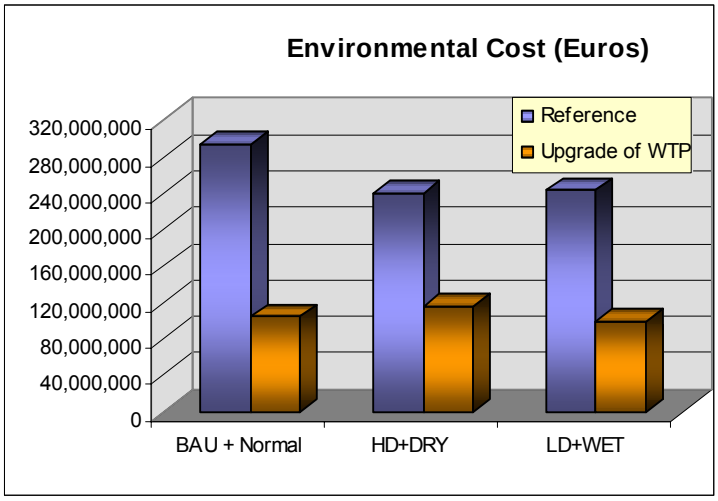


Figure 6-23. Comparison of the environmental cost of the WTP upgrade intervention against the reference scenarios

In the LD+Wet scenario both the irrigation and the domestic demand are covered to an increased level and at the same time the groundwater exploitation is reduced. This probably is the reason for the high evaluation score attained by this scenario as shown in Figure 6-23.

The obtained evaluation scores for all three cases are presented in Figure 6-22. The highest score is obtained for the best case scenario (Low Demand and Wet).

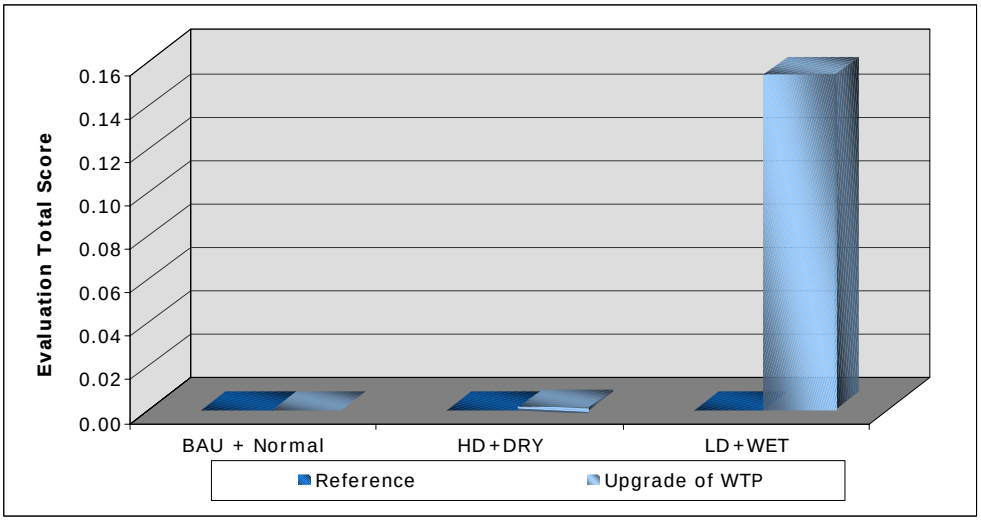


Figure 6-24. Evaluation of the water treatment plant intervention against the reference scenarios

Introduction of a new Waste Water Treatment Plant for the western rural areas

An additional measure to enhance the water supply of the region would be the construction of a WWTP to serve the western rural areas. According to the perceptions of the Municipalities of the region for the new water management strategy, such a solution promotes the acceptance of treated water for agriculture, since the "affected Municipalities" can participate in the operation of the plant

The realization of this intervention is scheduled for the year 2008, and includes the following technical aspects:

A new 4000 m^3/day WWTP will be constructed to treat the effluent of the villages Polemidhia, Ypsonas, Erimi., Episkopi and Kolosi.

The tertiary treated effluent will partially cover the needs of the Epikopi and Fassouri farms.

Under the worst case scenario, this option results in minimisation of the irrigation deficit (Figure 6-25), with a subsequent reduction in groundwater abstractions (Figure 6-26).

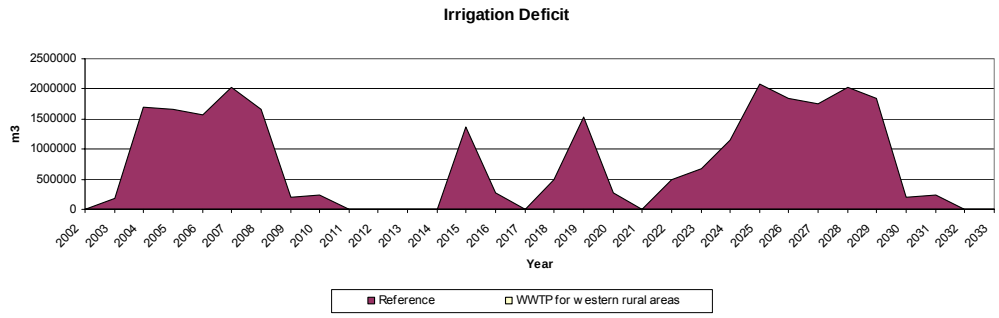


Figure 6-25. Reduction of the irrigation deficit with respect to the reference scenario

This intervention also has positive effects in domestic demand coverage as can be seen in Figure 6-26. This is because, due to the reduction of the groundwater abstractions for irrigation purposes, there are available quantities of fresh water to cover domestic purposes.

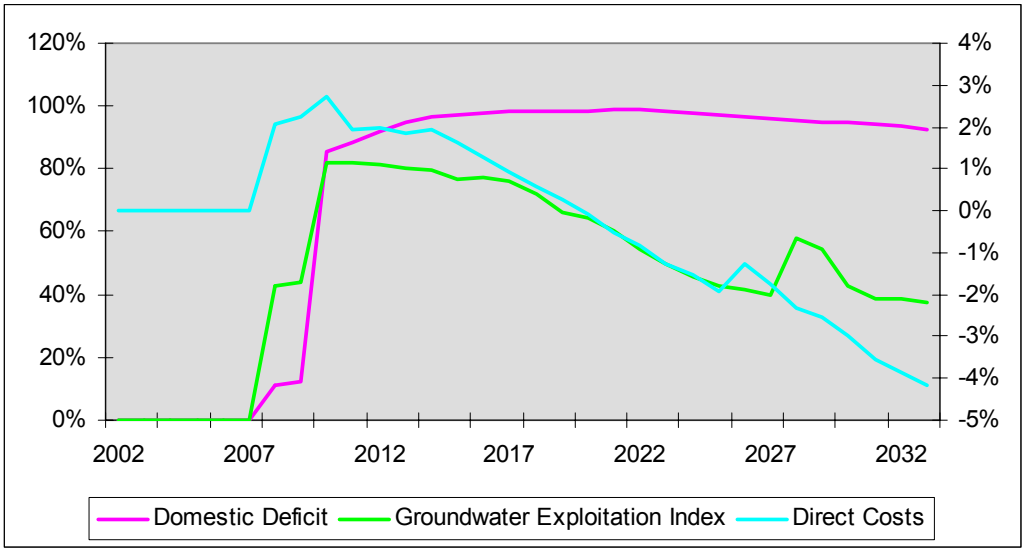


Figure 6-26. Improvement (%) with respect to the reference scenario

The comparison of the direct cost of the examined management option and the reference case under the three hydrological/demand scenarios is presented in Figure 6-27.

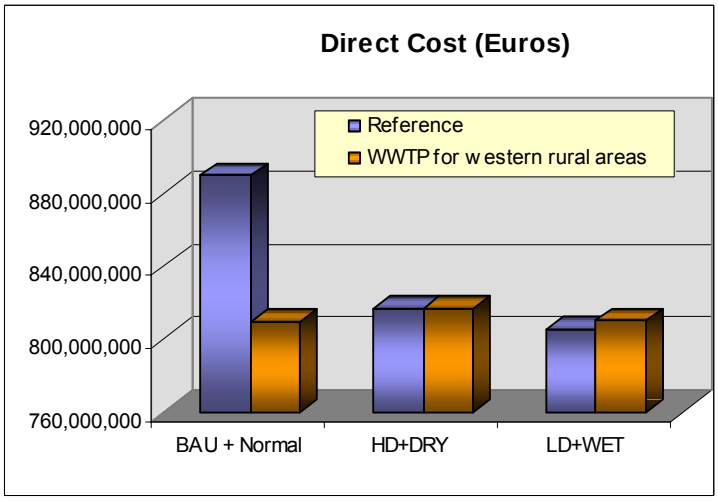


Figure 6-27. Comparison of the direct cost of the WWTP intervention against the reference scenarios

This intervention constitutes a new source of water which will be available for irrigation at reduced cost (treated effluent). Furthermore, the cost of the intervention is relatively small since the water can be used within the same general area that is being produced (no major pipelines are required). Thus, the costs are very favourable for the BAU+Normal scenario where the irrigation deficits are high. The high demand and low availability of water (less domestic supply and thus less treated effluent produced) render the relative cost of the intervention more expensive. The same holds true for the Low Demand but Wet scenario. Lower quantities of recycled water are mobilized but the meeting of the

demands renders the highest evaluation score against the reference for this scenario. Increased irrigation demand coverage and the reduced groundwater exploitation due to this intervention provide the highest score for this scenario.

The associated environmental cost is presented in Figure 6-28. The environmental cost after the introduction of the intervention is substantially lower than the environmental cost estimated for the reference scenario, due to the substantial reduction of the groundwater abstractions for irrigation purposes.

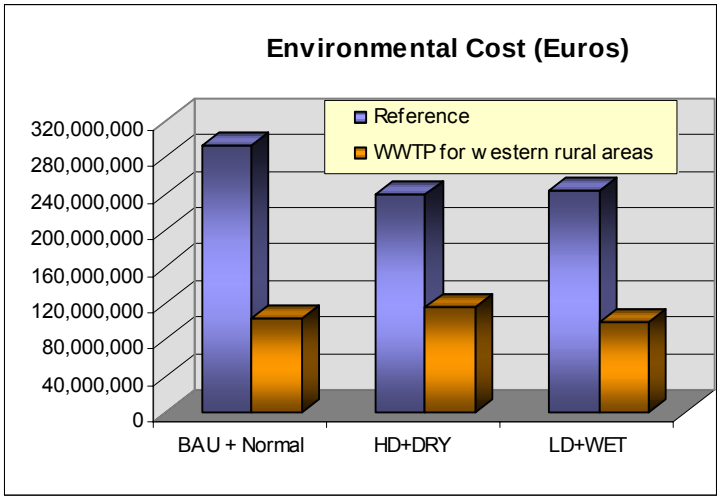


Figure 6-28. Comparison of the environmental cost of the WWTP intervention against the reference scenarios

The obtained evaluation scores for all three cases are presented in Figure 6-29. The highest score is obtained for the best case scenario (Low Demand and Wet) for which the efficiency indicator shows the greatest improvement.

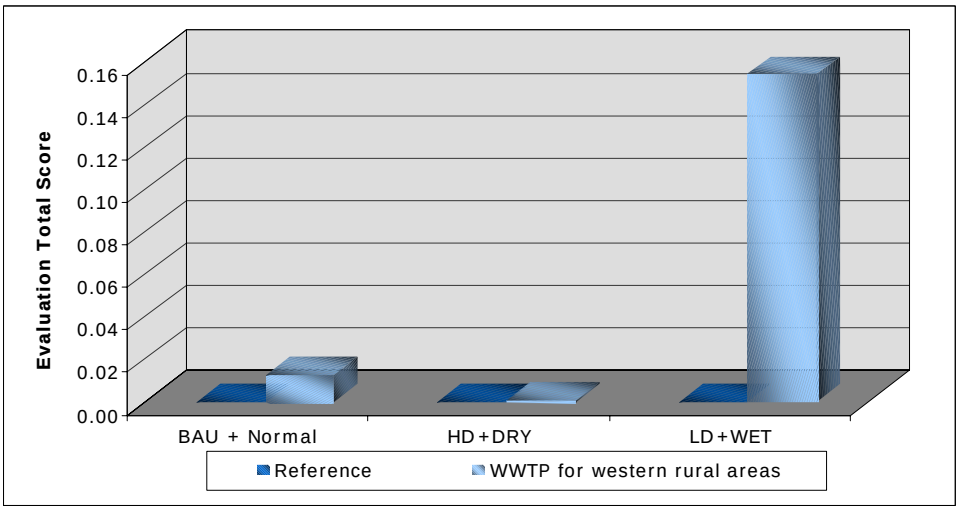


Figure 6-29. Evaluation of WWTP (western rural areas) against the reference scenarios

Demand management options

Conservation measures in the domestic sector

The application of conservation measures in the domestic sector was assessed assuming that a reduction in the domestic demand of 10% (excluding the seasonal demand) could be accomplished. In addition it was assumed that the measure will apply in year 2008. Figure 6-30 presents domestic demand after the implementation of the measure.

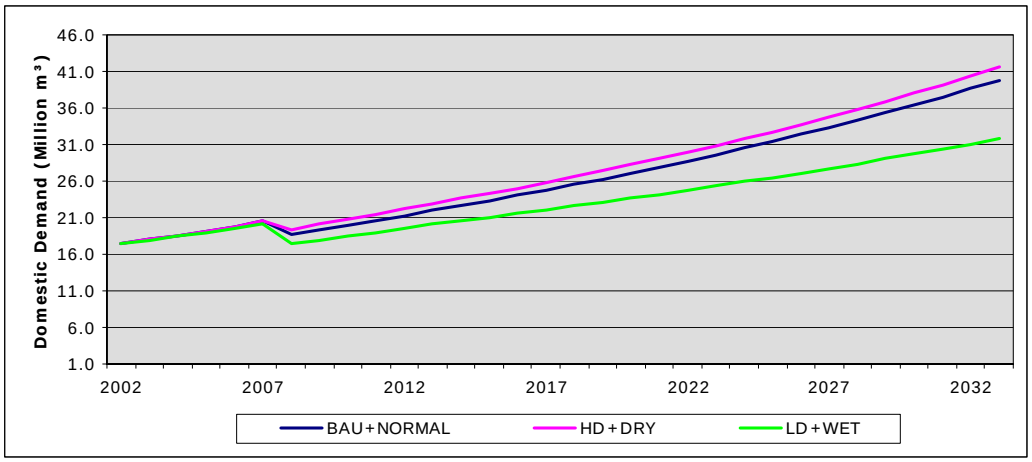


Figure 6-30. Domestic demand after the application of conservation measures for the three scenarios

Under the worst case scenario, this option results in substantial reductions in domestic deficit (Figure 6-31 and Figure 6-32).

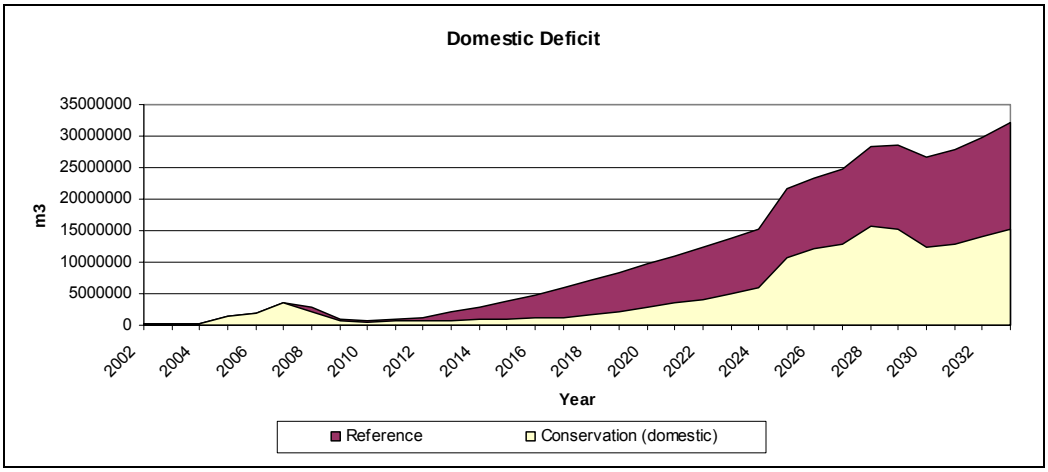


Figure 6-31. Reduction of domestic deficit with respect to the reference scenario

This intervention also has positive effects in groundwater exploitation index and direct cost as can be seem from Figure 6-32. This is due to the reduction of the groundwater abstractions in order to supply domestic purposes.

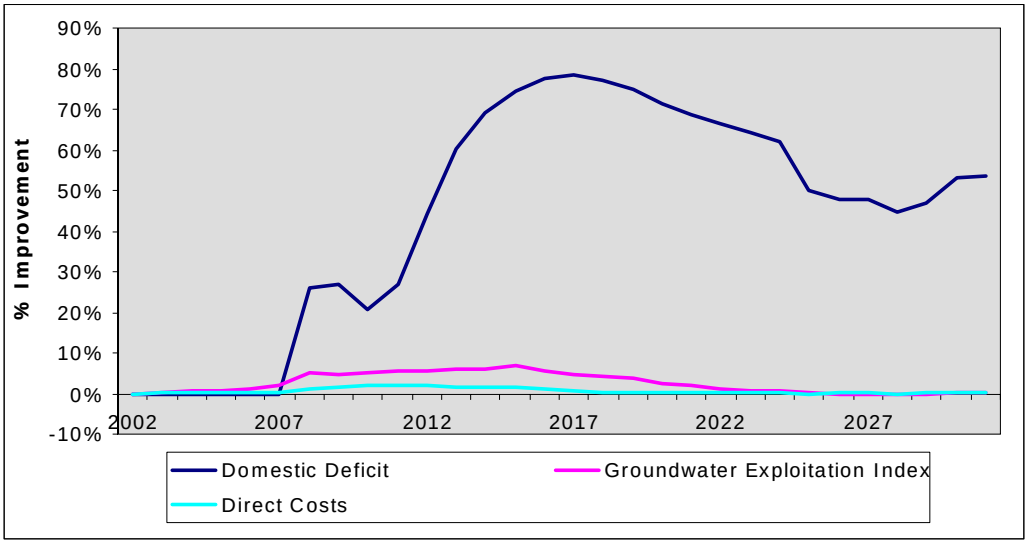


Figure 6-32. Improvement (%) with respect to the reference scenario

This measure alone can not ensure the coverage of the domestic needs, especially after year 2012 when the water production of the water treatment plant of Limassol is expected to reach the plant's capacity (40,000 m^3/day).

The comparison of the direct cost (present values adopting a discount rate of 10%) of the examined management option and the reference case under the three hydrological/demand scenarios is presented in Figure 6-33. In all cases the anticipated decrease of the total direct costs is less than 1%.

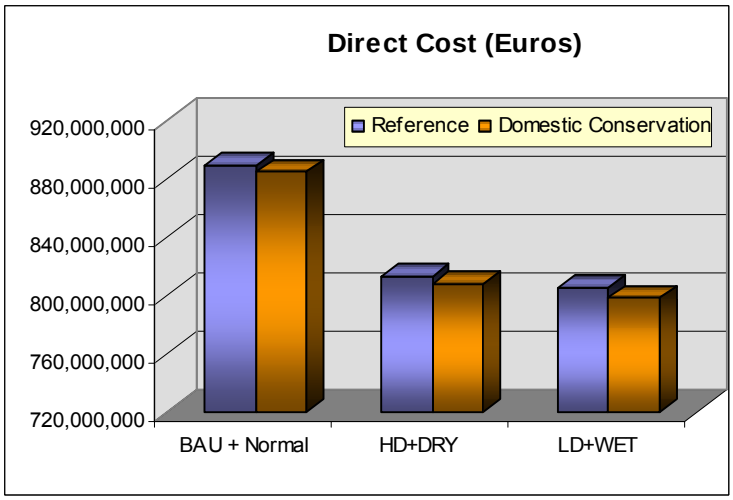


Figure 6-33. Comparison of the direct cost of the intervention against the reference scenarios

The assumed water conservation from the intervention compared to the incurred costs renders the costs favourable for all the examined scenarios.

In the case of the HD+DRY scenario the larger quantities of water saved (due to the High Demand) are possibly counterbalanced by the lower availability of water. Thus, the

intervention appears slightly more favourable for the LD+WET scenario where the large availability of water enables greater savings of water and improved demand coverage. This is probably the reason why the highest evaluation score is attained under this scenario.

The associated environmental cost is presented in Figure 6-34. The environmental cost after the introduction of the intervention is substantially lower than the environmental cost estimated for the reference scenario, due to the substantial reduction of the groundwater abstractions for domestic purposes.

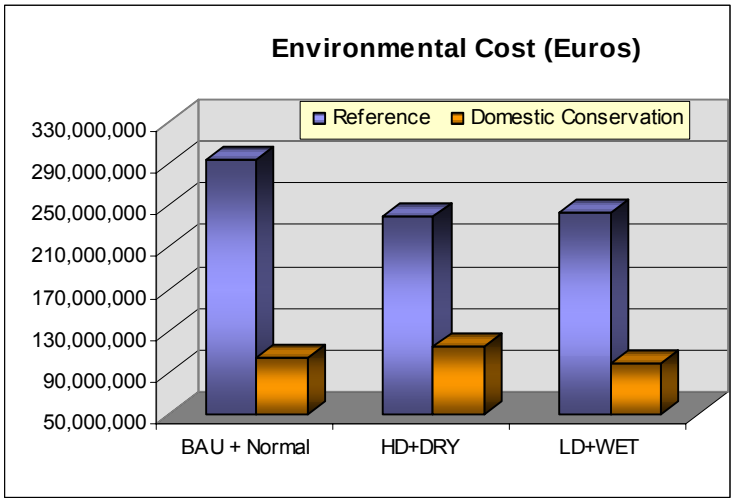


Figure 6-34. Comparison of the environmental cost against the reference scenarios

The obtained evaluation scores for all three cases are presented in Figure 6-35. The higher score is obtained for the best case scenario (Low Demand and Wet) for which the efficiency indicator shows the greatest improvement.

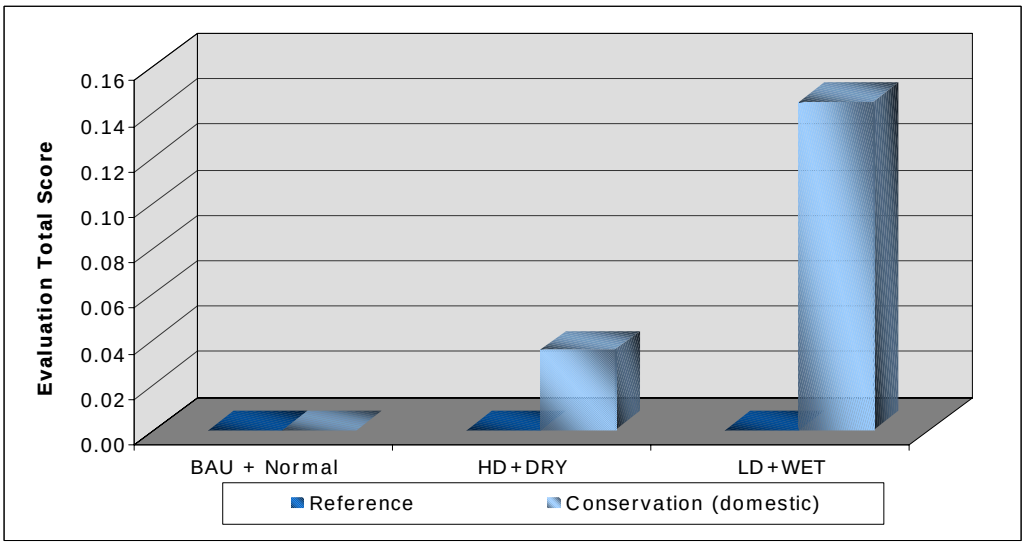


Figure 6-35. Evaluation of domestic conservation against the reference scenarios

Loss reductions in the domestic sector

Accurate data regarding the level of network losses throughout the study area are not available. Data exist for the area served by the Limassol Water Board where network losses are reported to be as low as 16%. In any case it is believed that losses can be of the order of 25% or more.

Thus, the reduction of the losses to 15% (through successive network replacements) was assessed as an alternative water management option for the three biggest settlements in the study area that is the Lemessos Municipality, Lemessos Touristic Part and Germasogeia Municipality. Figure 6-36 presents the new demand for each one of the settlements where the measure applies under the worst case scenario (DRY + HD).

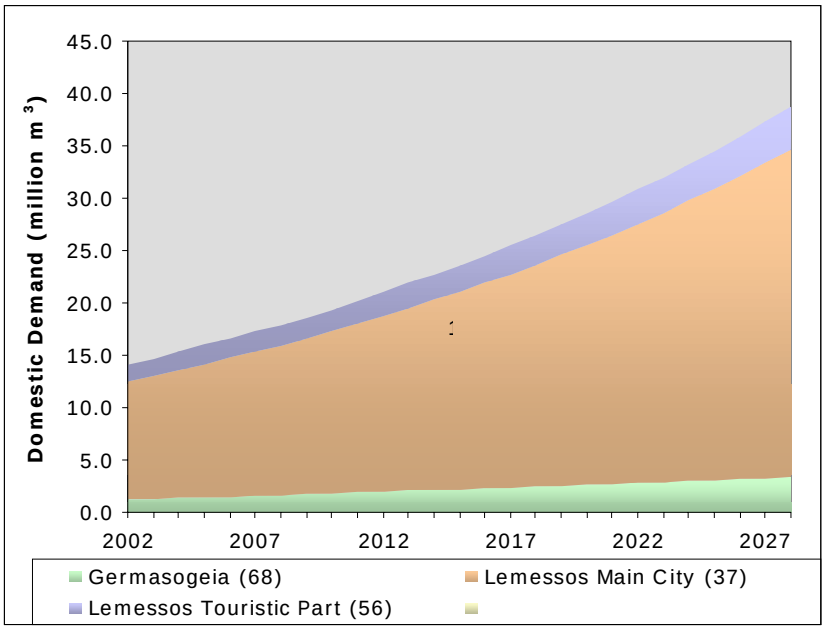


Figure 6-36. Domestic demand per municipal department under the network loss reduction option (DRY+HD)

Under the worst case scenario, this option shows an improvement in domestic deficit (Figure 6-37), and to a lesser extent in groundwater exploitation index. Again this measure alone cannot ensure the coverage of the domestic needs, especially after year 2012 when the water production of the water treatment plant of Limassol is expected to reach the plant's capacity (the improvement after 2012 falls from 25% to less than 5% in year 2033).

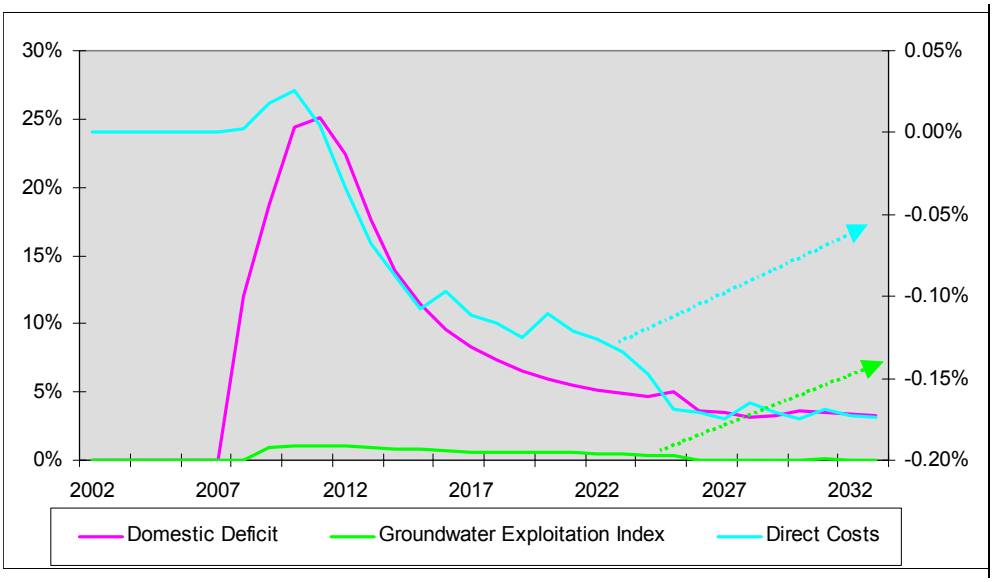


Figure 6-37. Improvement (%) with respect to the reference scenario

The option has little influence in irrigation deficit reduction, as can be seen from Figure 6-38.

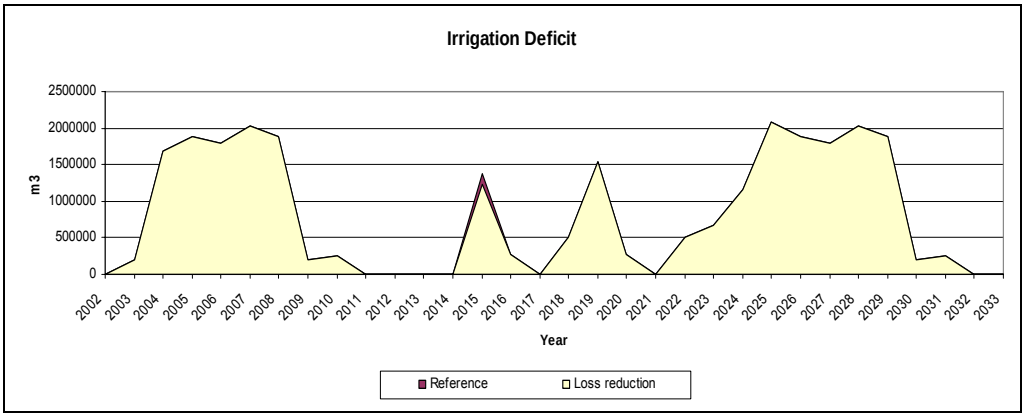


Figure 6-38. Improvement of irrigation deficit with respect to the DRY + HD scenario

The comparison of the direct cost (present values adopting a discount rate of 10%) of the examined management option and the reference case under the three hydrological/demand scenarios is presented in Figure 6-39, and the evaluation scores in Figure 6-41.

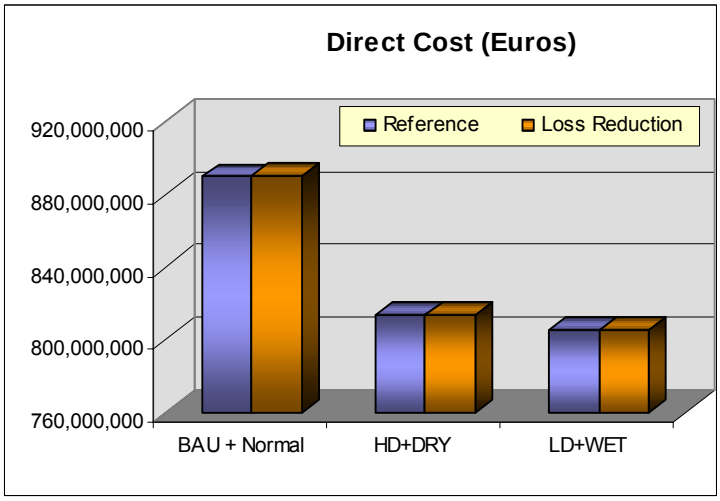


Figure 6-39. Comparison of the direct cost of the intervention against the reference scenarios

In the HD+Dry less water is available and thus less water is expected to be saved by this intervention, thus in this case the associated direct cost is slightly higher than the cost of the reference case. The difference among the three scenarios examined is very small due probably to the small change of the domestic water demand and the supply, irrespective of the climatic conditions.

The associated environmental cost is presented in Figure 6-40. The environmental cost after the introduction of the intervention is slightly lower than the environmental cost estimated for the reference scenario, due to the small influence of the intervention on the reduction of the groundwater abstractions (see Figure 6-37 groundwater exploitation index). Moreover the environmental cost (calculated based on the to renewable groundwater abstractions alone) is much higher than the estimated environmental cost of the previously described interventions, for the same reason.

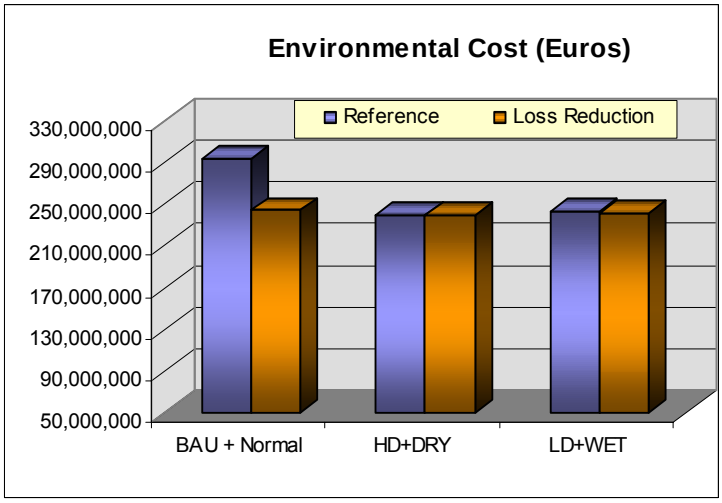


Figure 6-40. Comparison of the environmental cost against the reference scenarios

Both the HD+Dry and the LD+Wet attained a high evaluation score for the reasons stated above, the high water demand in the first case and the large availability of water in the second and the fact that the demand coverage is improved. In both cases relatively larger quantities of water are mobilized and thus more water is saved.

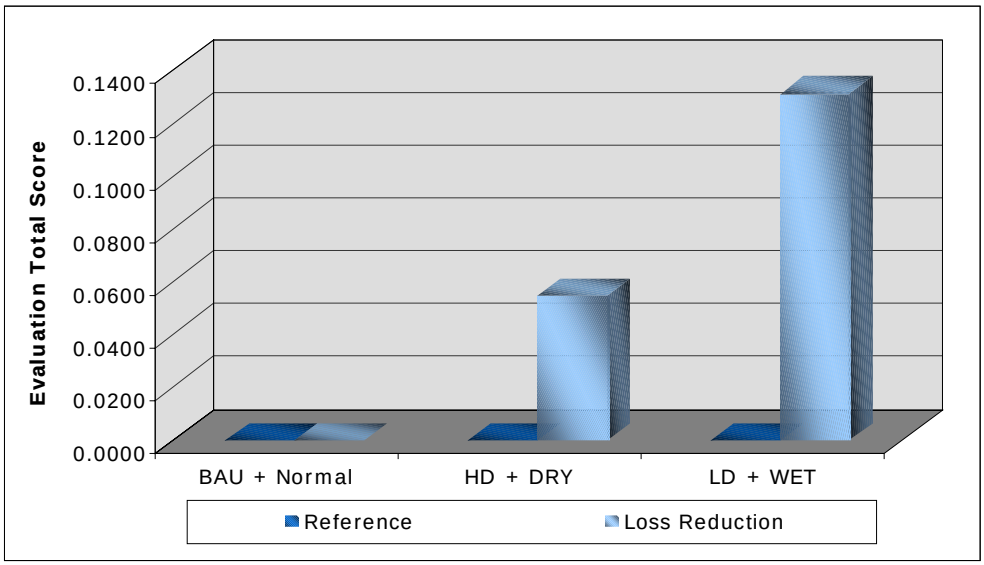


Figure 6-41. Evaluation of loss reductions against the reference scenarios

Pricing

Irrigation Water Pricing

Contrary to the costs of domestic water that is almost full charged to customers, the price of irrigation water covers neither the full financial nor the economic costs. The present tariff for the study area is Cy £0.07 /m^3 which is equivalent to 22.3% of the weighted average unit cost of water, although the Loan Agreements with the World Bank dictate that the price of the water should be at least 38% of the weighted average unit cost. As a result the WDD is examining the case to revise the prices upwards to reflect the true cost of the water. This will promote efficiency and water conservation measures contributing towards a sustainable water management alleviating the current water shortage problem. Such an approach complies also with the provisions of the new Water Framework Directive of EU, although it is well understood that its implementation will be very difficult.

This option examines the case of raising the irrigation water prices from 0.07C£/m^3 to 0.11 C£/m^3 within a period of three (3) years. Data for demand elasticities is available for individual agricultural products [1] and are given in the following table.

Table 6-5. Agricultural products price elasticities

Product	Price Elasticity
Potatoes (spring)	-0.33
Tomatoes (greenhouse)	-0.70
Cucumbers (greenhouse)	-0.58
Water melons (open)	-0.50
Oranges	-0.02
Grapefruits	-0.02
Lemons	-0.01
Mandarins	-0.02
Grapes	-0.02

As can be seen from Table 6-5 the value of the elasticities for the permanent crops is much lower than the seasonal crops. This is reasonable given that the production decisions for permanent crops are much more complicated and long term than in the case of annual / seasonal crops. This makes for very low short-term elasticities.

The application of this simple irrigation pricing scheme results in a reduction of irrigation demand of approximately 1,500,000 m^3 or 10% of the total irrigation demand (Figure 6-42).

[1] "Price elasticities of different products in Cyprus", Eri Nicolaides, MedPolicies Initiative METAP III, 2000)

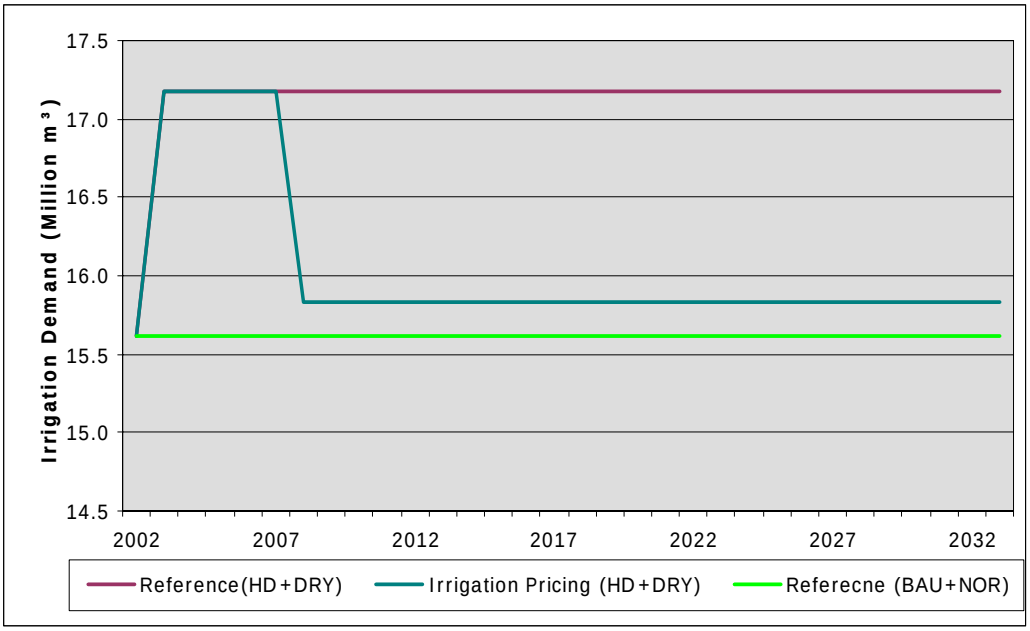


Figure 6-42. Irrigation demand under reference scenarios and irrigation pricing intervention

Under this management option the irrigation deficit throughout the simulation period (2002 – 2033) is reduced by almost 23%, from 24,489,795 m^3 to 19,684,766 m^3 (Figure 6-43).

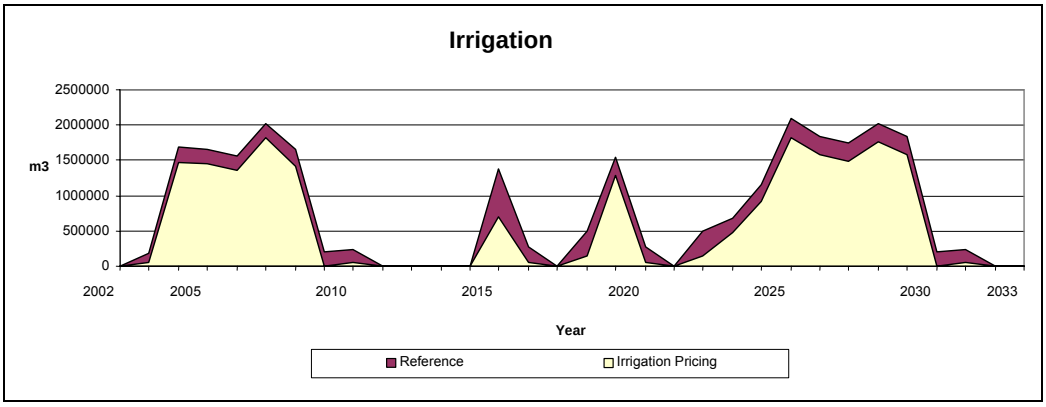


Figure 6-43. Improvement of irrigation deficit with respect to the reference scenario

This intervention has small positive effects in groundwater exploitation index but does not affect the domestic deficit (Figure 6-44).

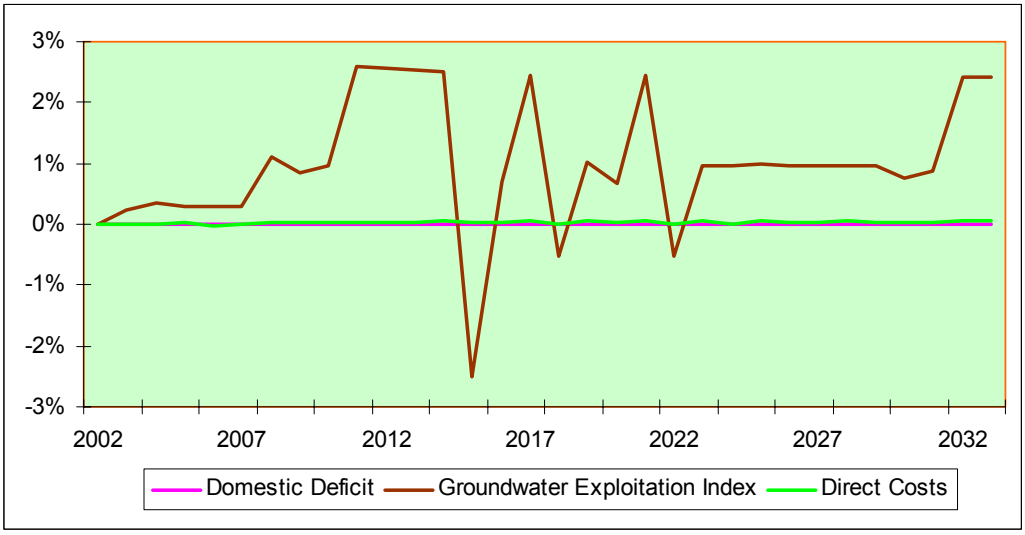


Figure 6-44. Improvement (%) with respect to the reference scenario

The comparison of the direct cost (present values adopting a discount rate of 10%) of the examined management option and the reference case under the three hydrological/demand scenarios is presented in Figure 6-45.

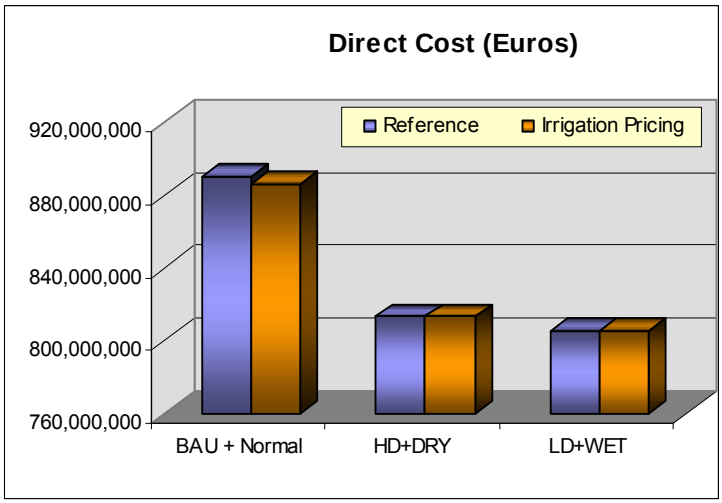


Figure 6-45. Comparison of the direct cost of the intervention against the reference scenarios

In all three scenarios the change in direct cost is favourable but very small, since this is a non structural intervention which does not involve real costs (see also Figure 6-44). It promotes water saving since water attains a price closer to its true value.

The associated environmental cost is presented in Figure 6-46. No difference is obtained compared to the reference cases, due to the small influence of the intervention on the reduction of the groundwater abstractions (see Figure 6-44 groundwater exploitation index).

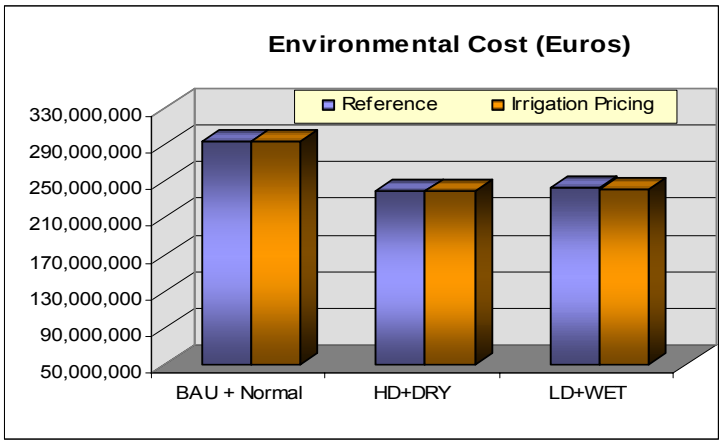


Figure 6-46. Comparison of the environmental cost against the reference scenarios

The obtained evaluation scores for all three cases are presented in Figure 6-47. The higher score is obtained under the best case scenario (Low Demand and Wet) where savings are more meaningful on the occasion of high water demand (less deficits) but also on the occasion of dry weather conditions. It is even higher on the occasion of LD+WET scenario where due to the availability of water larger quantities of water are involved given that the variation in the demand is not that great between the two scenarios. Higher proportion of irrigation demand coverage and reduced groundwater exploitation provide the higher score to this scenario.

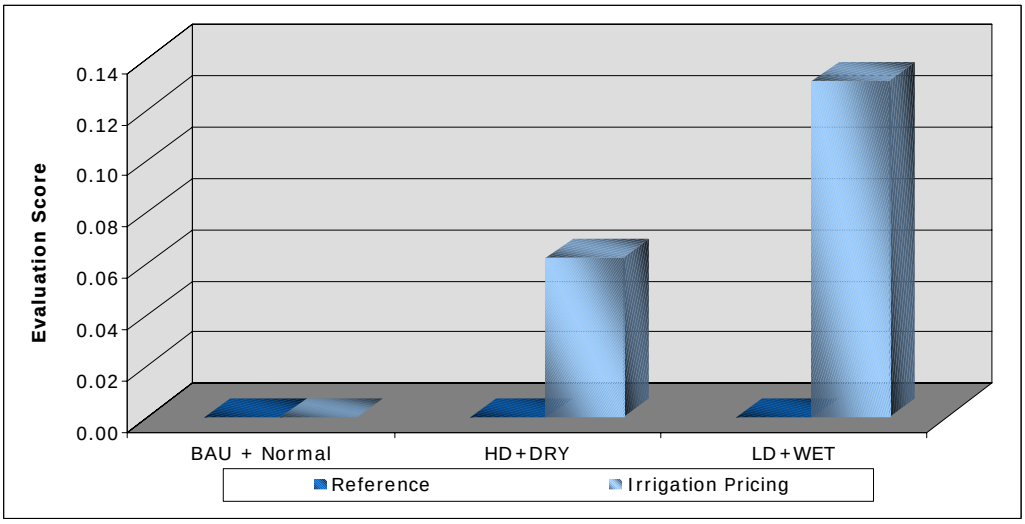


Figure 6-47. Evaluation of irrigation pricing against the reference scenarios

Domestic Water Pricing

The domestic water supplies in the study area are managed by the Limassol Water Board as well as the Municipalities, Improvement Board and Village Water Committees.

A block structured water tariff is applied in the study with an average cost of C£0.5 per m^3. The present water tariff charged by the Water Development Department to the three major city Water Boards is only C£0.27 per m^3, while charges to the Municipalities and Village Authorities is C£0.335 per m^3.

Although there is no relative data, it is believed that domestic demand is inelastic with regard to water tariffs. However, in order to investigate the effectiveness of such an option (in case water demand is not inelastic to water tariffs) we assessed this option based on the following assumptions / parameters:

- a 60% increase in the water tariffs will be imposed after 2008
- an elasticity of –0.25 was assumed for residential consumption

Figure 6-48 presents the new domestic demand under the examined pricing scheme for the worst case scenario (DRY + HD).

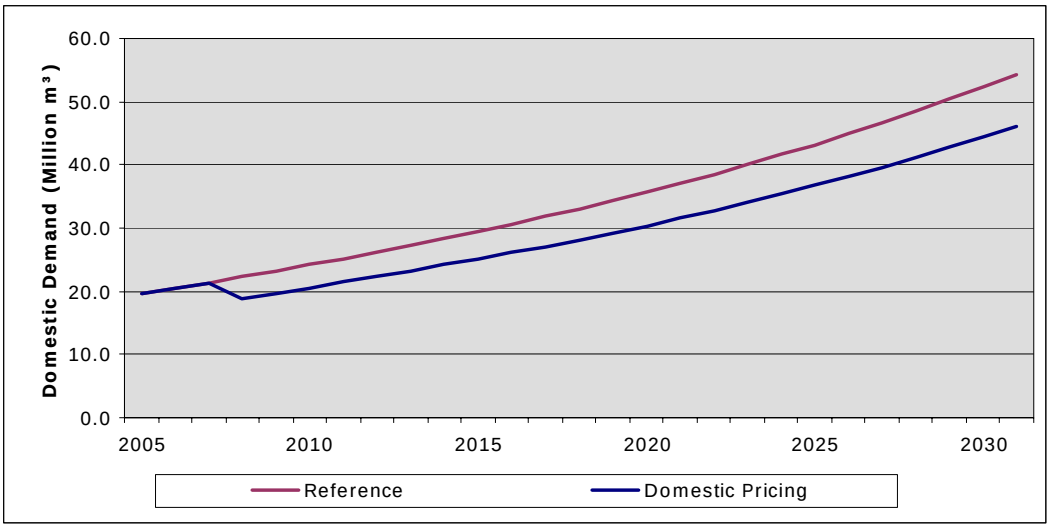


Figure 6-48. Domestic demand under reference scenarios and domestic pricing intervention

Under this management option the domestic deficit throughout the simulation period (2002 – 2033) is reduced by almost 38%.

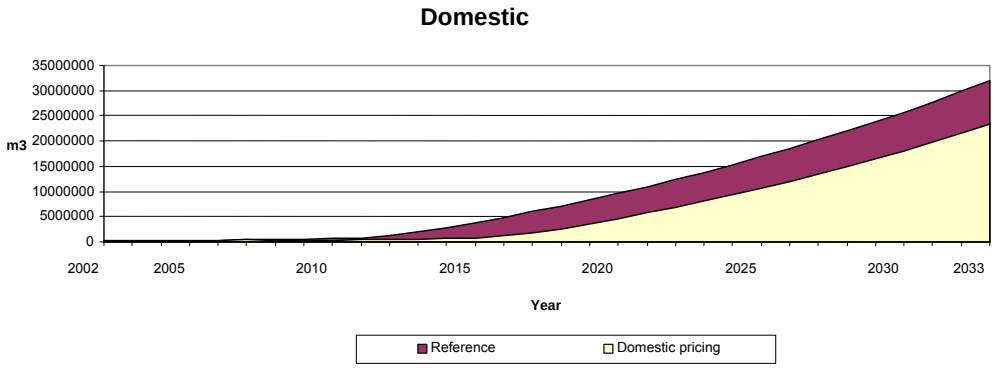


Figure 6-49. Improvement of domestic deficit with respect to the DRY + HD scenario

This measure alone cannot ensure the coverage of the domestic needs, especially after year 2012 when the water production of the water treatment plant of Limassol is expected to reach the plant's capacity (40,000 m^3/day).

This intervention has also positive effects in groundwater exploitation index and total direct costs (Figure 6-50).

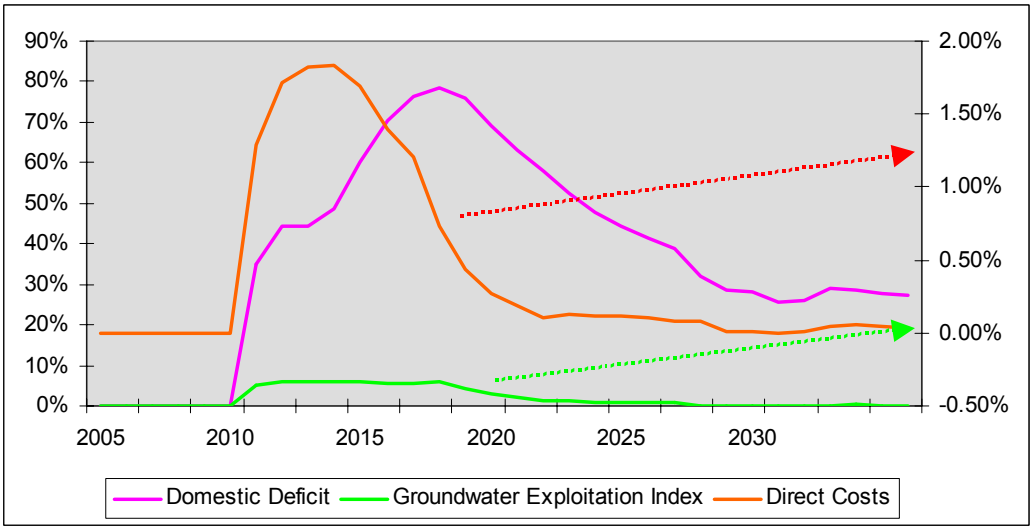


Figure 6-50. Improvement (%) with respect to the reference scenario

In all cases the option results in a reduction of direct costs. This is due to the fact that costs are only associated with domestic use. Consequently, the reduction of domestic water supplies inhibits a direct cost decrease of the order of 1% of the reference case present value.

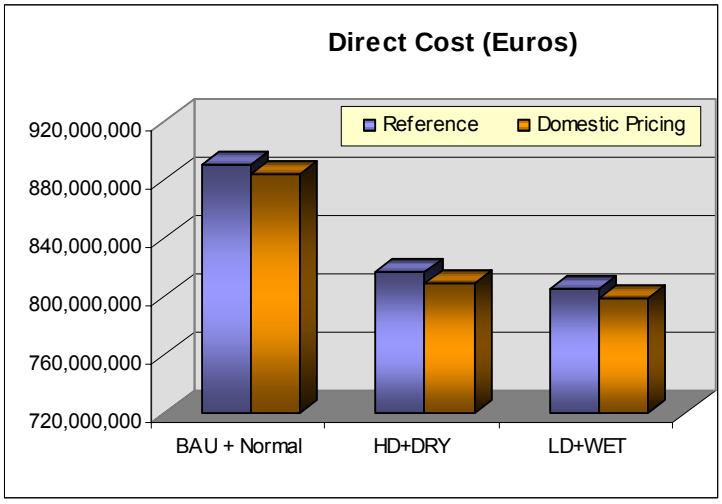


Figure 6-51. Comparison of the direct cost of the intervention against the reference scenarios

The intervention appears to be most effective on the case of the HD+Dry scenario when the water demand is highest and the climatic conditions are not favourable. This is also suggested by the evaluation score for the three examined scenarios which gives this scenario the highest mark where the demand coverage is increased, within the reduced proportion allowed by the price elasticity prescribed.

The associated environmental cost is presented in Figure 6-52. Small differences are obtained compared to the reference cases, due to the small influence of the intervention on the reduction of the groundwater abstractions (see Figure 6-50 groundwater exploitation index).

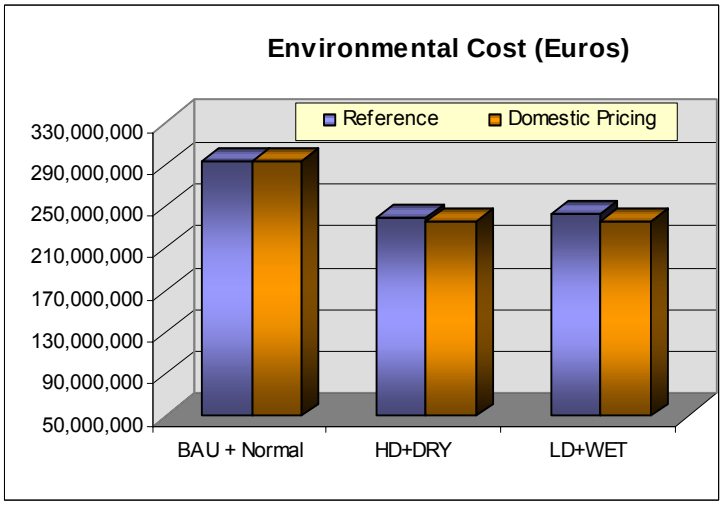


Figure 6-52. Comparison of the environmental cost against the reference scenarios

The obtained evaluation scores for all three cases are presented in Figure 6-53. The higher score is obtained under the worst case scenario (High Demand and Dry).

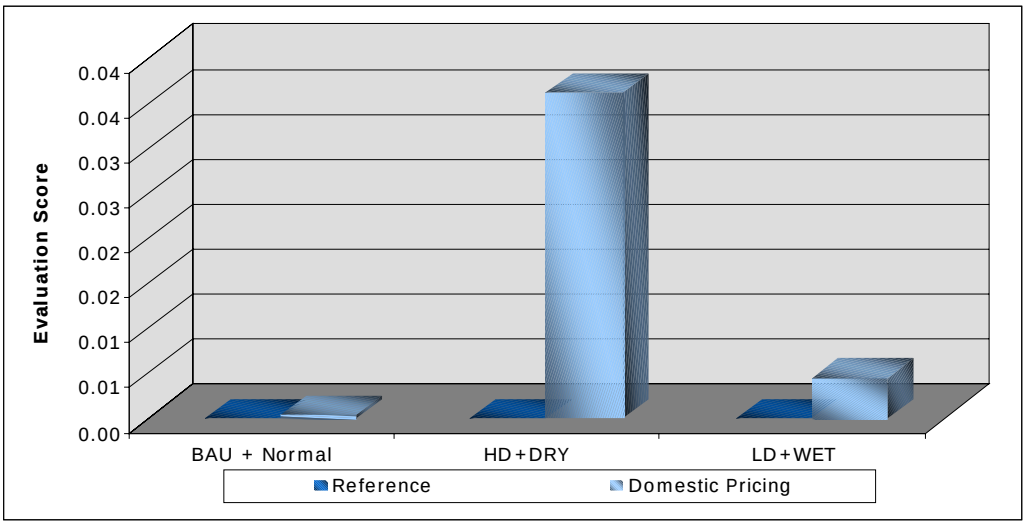


Figure 6-53. Evaluation of domestic pricing against the reference scenarios

6.4. Final Selection

The formulation of the strategies that will be developed during the Strategy Formulation Stage, will incorporate a set of management options (structural and non-structural). The selection of the appropriate options will be based on their performance with respect to a number of indicators.

Since it is widely accepted that the future economic growth of the area is to rely to tourism, as well as the importance of the agricultural sector in the area, the effectiveness of the options were assessed on the ground of the coverage of domestic needs and the irrigation demand coverage.

In addition, it was considered necessary to incorporate in the options evaluation process the direct costs related to the application of each option, in order to select not only efficient, but also cost effective solutions.

Environmental protection was assessed through the groundwater exploitation index, since until recently a large part of the domestic water supply in the area relied upon groundwater from the existing aquifers. The major Akrotiri aquifer has been experiencing overdraft in the last 20 – 25 years since a major portion of the natural replenishment has been cut off by the Kouris dam. Pumping has been maintained closely to the same levels as before the construction of the dam due to the water price differential between surface and groundwater, the latter being much cheaper.

The results of the options performance evaluation process are presented in Figure 6-54 and Table 6-6.

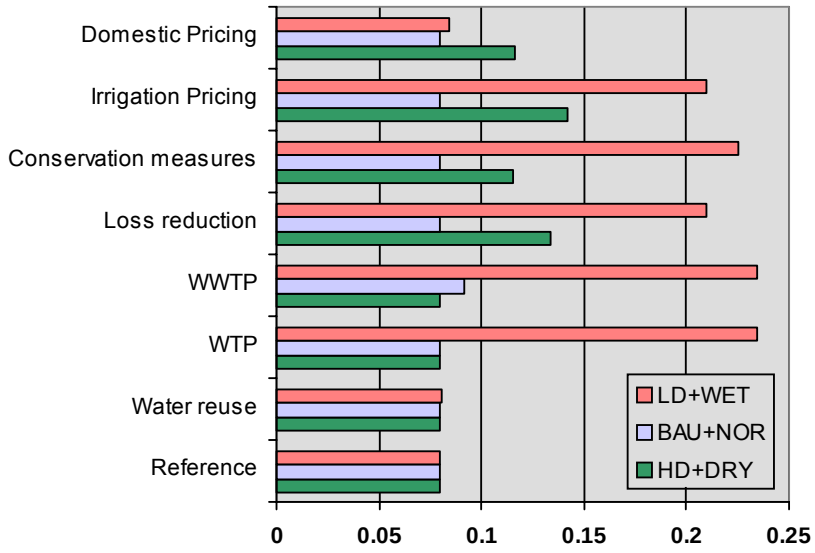


Figure 6-54. Overall evaluation score of all management options under the three reference scenarios

Table 6-6. Performance evaluation of the studied interventions (HD+DRY scenario)

Option	Effectiveness (Sustainability Index for Demand Coverage)	Economic Efficiency (B/C Ratio)	Environmental Cost (PV – million €)
Water reuse	0.0793	3.14	180
Water Treatment Plant	0.08	3.18	115.5
Waste Water Treatment Plant	0.08	3.19	115.6
Loss Reduction	0.134	3.31	239
Conservation measures	0.115	3.73	234.2
Irrigation Pricing	0.142	3.18	239.6
Domestic Pricing	0.116	3.65	235.1

Table 6-7 presents the normalised results of the performance evaluation (presented in Table 6-5) under a scale ranging from 1 to 5 (worst performance : 1 – best performance : 5). From the matrix it is apparent that the studied options do not perform the same with respect to the three adopted indicators. Soft measures perform better in relation to the relative sustainability index for demand coverage and economic efficiency, whilst they have a poor performance with regard the environmental sustainability (groundwater abstractions). On the other hand the structural options (water reuse – water treatment plant – waste water treatment plant) perform better in relation to environmental sustainability but show the weakest performance in relation to effectiveness and economic efficiency indicators.

Table 6-7. Normalised performance matrix of the studied interventions (HD+DRY scenario)

Option	Effectiveness (Sustainability Index for Demand Coverage)	Economic Efficiency (B/C Ratio)	Environmental Cost (PV – million €)
Water reuse	*	*	***
Water Treatment Plant	*	*	*****
Waste Water Treatment Plant	*	*	*****
Loss Reduction	*****	**	*
Conservation measures	***	*****	*
Irrigation Pricing	*****	*	*
Domestic Pricing	***	*****	*

7 Comprehensive Scenarios for Tel-Aviv Region

7.1 Background: The Israeli Water Economy

The Water Crisis

Chronic scarcity of water is a fact of life in Israel where aggregate demand exceeds the supply of fresh water in a largely semiarid environment. The commonly agreed upon policy of maintaining a long-term balance between potential available water and the utilization of water resources has not been able to keep up with consumer pressure, especially the pressure from the agricultural sector. The Israeli water economy is in the midst of a crisis, the main features of which are a shortage of fresh water and a steadily increasing deficit, poor and declining groundwater quality (gradual salinization), and pollution of most of the streams by untreated urban , industrial and agrochemical effluents (Zaslavski, 2001).

The main quantitative expression of the crisis is a sharp decrease in the ability to pump groundwater without crossing predetermined red lines, where the agricultural sector bears the brunt of the necessary cuts. Since all significant natural water resources in Israel are largely overexploited, attention is being increasingly focused on the development of unconventional water resources, namely, desalination of sea water and recycling of sewage effluents. The supply of reclaimed sewage is expected to grow substantially due to increases in water supply for the growing domestic and industrial sectors, and the expansion of irrigation with recycled effluents. Indeed, a large-scale transition in agricultural water use, from good-quality water to treated wastewater, is expected to occur within the next few years. This shift requires the development of many more environmentally safe water-treatment plans, reservoirs and conveyance systems. Treated wastewater can also be used for river restoration.

There is a total 351,460 hectares of cultivated land in Israel, 196,998 hectares of which are irrigated (56% of the total cultivated area). The continuing scarcity is an excellent economic incentive for breakthroughs in irrigation technologies that are invented in Israel, such as drip irrigation and micro sprinklers, which have reduced water loss by 20%. Computer-assisted irrigation management enhances these results. Despite the modest role of agriculture in the national product (less than 2% of the GDP), it consumes about 60% of the nation's limited freshwater supply for cultivation and export (water-intensive crops such as cotton and citrus are exported). There is a consensus among policy makers and water experts that the supply of potable water (i.e., urban consumption) should receive top priority. Nevertheless, some water experts point out that, while water used by industry or tourism is many times as productive as that used by agriculture, water is made available to farmers at about 65% of its price at the cities' gates.

Among the many factors contributing to the water crisis are population growth and economic development, resulting in increased domestic and industrial consumption of

fresh water. Additional crucial factors contributing to the crisis are inefficient institutional and administrative mechanisms for water allocation and control, and a poor decision-making culture (hydro-politics). The next subsection is a brief presentation of these factors.

Institutional and Administrative Framework

There is no private ownership of water in Israel. The Israeli Water Law of 1959 states that all water sources are publicly owned and that their utilization is controlled by the Water Commissioner. A single government-owned company, Mekorot, operates the National Water Carrier (NWC)1 and provides approximately 60% of the total water supply; regional cooperatives and municipalities and private well owners supply the rest.

The allocation is administrative: the Water Commission issues permits for production (extraction) to suppliers as well as allocations (quotas) for agricultural consumers. In the past, these quotas constrained the use of water in agriculture. However, more recently, with higher prices for water and lower prices for agricultural products, the agricultural sector fails to exploit all of its allocation. Households, on the other hand, were never constrained in their consumption and formal quotas for this sector were abolished several years ago. The current water laws do not permit trading in water quotas, and the transfer of water rights between sectors such as agriculture and industry is unlawful.

Water-Pricing Practices

Prices of water delivered by the national company Mekorot are set by the parliamentary finance committee, and are based on recommendations of the Ministry of Finance, the Ministry of Infrastructure and the Ministry of Agriculture. The prices are determined in consultation with the Water Council in a procedure which is open to political pressure (skilfully applied by the agricultural lobby). Viewing water prices not as an allocation instrument, but as a means of improving income distribution, water charges depend on the type of use: farmers pay the lowest charges, industry pays higher charges and households pay the highest ones. Within each sector, charges do not depend on location: users in all parts of the country face the same charges, regardless of the supply price of water (Kislev, 2002). Private water producers set prices independently.

[1] The NWC, which is made up of canals and pipelines, was constructed almost 40 years ago, and is designed to divert the Jordan water from the Sea of Galilee to the center of the country and to Negev desert, thus enabling the settlement of this extremely arid region. The uniqueness of this carrier goes beyond the transference of water from the north to the arid south. It has become an operational tool, connecting all three major water sources into one system (Kislev, 1993). During the wet winter season, when even the southern part of Israel gets some precipitation, water is still being pumped from the Sea of Galilee and injected into the Coastal Plain and the Mountains aquifers, to recharge the declining water tables. During the summer time, irrigation all over the country is a must, because there is no precipitation between May and November and water is pumped from both the Sea of Galilee and the aquifers.

Tiered pricing exists for agricultural users who pay a reduced price of $0.19 for the first 50% of their quota, a higher price of $0.23 for the additional 30%, and the full price of $0.31 for the rest of their quota (which in most cases is not fully utilized). Industries pay an average of $0.33 per m^3 and cities and towns pay $0.45 at the "city gate." Neither industries nor municipalities pay tiered charges. Households in cities face tiered charges, paying about $0.68 for the first block (typically 8 m^3 per household per month), $1.0 for the second block (typically 7 m^3 per household per month) and $1.47 per m^3 for any additional consumption. In other words, in addition to the prices that they pay to Mekorot for water, the municipalities impose two layers of surcharges on their households: one for the water-distribution system and for sewage removal, and the other in the form of taxes to help finance general municipal operations. This policy may be beneficial for the city in the short run but it might be very harmful in the long run, when funds will be required for reinvestment and renewal of the old water-delivery and treatment systems (Kislev, 1993). Water prices vary with quality. Water with over 400 mg of chlorides per litre is charged at a lower rate than fresh water according to its salinity level, with the average price being $0.16 per m^3. The charges for recycled waste water are according to a two-tiered pricing system: the first 50% of the quota is provided at the higher rate of about $0.15 per m^3 and the rest at the lower rate of $0.11 per m^3. The largest treatment plant of wastewater in Israel is the **"Shafdan"**. It is a plant for the treatment of urban and industrial effluents from the greater Tel-Aviv metropolitan area (which includes more than 30% of the country's population), and is responsible for conveying **all** of its recycled water, about 90-100 MCM per year, to the southern region (western and northern Negev) for agricultural use, which are located 100 – 150 km away from this plant. The Shafdan is operated by Mekorot; the capital, operation and conveyance costs are about 0.30 $\$/m^3$, almost double than the price charged for the agricultural consumers. In short, recycled water from the Shafdan is highly subsidized.

The prices charged by Mekorot are subsidized by the government which covers approximately 20% of the cost of supplying the water. In the past, part of the subsidy was implicit. While Mekorot operated the government-financed NWC, its capital cost was not reflected in the water prices. However, since 1993 Mekorot has been working according to a "cost agreement" under which it purchases the capital assets of the water economy, and their depreciation becomes a recognized component of its costs. Governmental support has therefore become explicit.

Hydro-Politics and Major Stakeholders

As already noted, decisions on water prices are made in the political arena and are affected by pressures applied by interest groups, each of which attempts to affect public decisions in its favour. The farmers' main interest lies in receiving a large allocation of water supply at the lowest attainable price. Water is a significant input in agricultural production in arid and semiarid regions like Israel, and many farmers strongly support their representatives in the political arena. The agricultural lobby is very well organized and until now, its influence on water policies and pricing decisions has been significant.

The share of water costs in household budgets or in manufacturing costs is relatively small. Therefore, urban and industrial water users have little incentive to organize political lobbies and, in effect, they do not offer up any strong opposition to the agricultural lobby (Kislev, 2002). The consequences of the success of the agricultural lobby have been the over-utilization of water for many years, hydrological deficits, the intrusion of sea water into the coastal aquifer, the contamination of reservoirs, and a reduction in the carry-over capacity of the system. These detrimental effects are among the major reasons for the current water crisis.

Although still very influential, the agricultural lobby has lost some of its political power in the last two decades. Agriculture in Israel is seen by many as an enterprise whose national value exceeds its contribution to the GNP via food production, which justifies governmental support (Netanyahu, 2000; Zaslavski, 2001). It contributes to security by protecting the country's lands, especially in peripheral areas, and by supplying food in times of emergency; it also contributes to the environment by protecting open spaces and preserving the natural and social landscape. In addition, its use of various qualities of water from various sources has been, and still is flexible, and it can serve as a safety net for the supply of water to local authorities (i.e., households) in times of emergency since it utilizes a large amount of fresh water.

Major Stakeholders in the Israeli Water Economy

Decision-making and management relating to the water economy take place in many forums and are greatly affected by special interest groups, each pulling in its own direction (Soffer, 2001). The main stakeholders in the water arena which are relevant to our analysis are:

(1) **The Water Commission,** which is the authority in charge of managing the water system. The authority is headed by the **Water Commissioner**, who is appointed by the government. The commissioner issues permits for production (extraction) to suppliers, as well as allocations (quotas) to agricultural consumers. The latter is coordinated with the **Ministry of Agriculture** and requires this body's agreement.

(2) **The Water Council** is a national entity appointed by the government to advise the Minister of Agriculture on a wide range of water issues, including water pricing. It includes representatives of interest groups and its decisions are subject to political pressure (hydro-politics).

(3) **Mekorot** is Israel's national water company, responsible for most of the supply and maintenance activities, including the operation of the National Water Carrier and the Shafdan. In effect, Mekorot is the only entity with significant financial and operational abilities in the field of water resources. Its role in the overall financial turnover of water resources reaches about 80% of the sector's business activity, since it operates a water system at high costs, conducts water for long distances and pumps water to elevated locations.

(4) **The Ministry of Agriculture**. The Minister of Agriculture is in charge of implementing many water laws, and can promulgate secondary legislation, such as determining norms for agricultural water use. His influence on decisions related to water pricing and on the Water Commissioner's decisions (regarding the allocation and distribution of water quotas) is crucial. **The Financial Committee of the Parliament** is in charge of determining water prices.

(5) **The Ministry of Finance** is responsible for the overall budget and for the allocation of financial resources (including subsidies) to the various entities involved in water resources. This ministry continuously supports a policy of raising water prices for farmers as a means of saving fresh water, reducing water subsidies, and increasing the efficiency of water use.

(6) The **Ministry of Health** is responsible for determining standards for the purification for all water types and their uses. This includes authorizing recycled wastewater irrigation of lands overlying groundwater aquifers. The **Ministry of Environmental Quality** is responsible for preventing water pollution and protecting water resources from contamination.

(7**) Farmers** (agricultural water users). As already mentioned, decisions on water prices are made in the political arena and are affected by pressure from special interest groups, each attempting to affect public decisions in its favor. The farmers' representatives are the strongest and most influential of such groups. The farmers' main interest lies in receiving large allocations of water, to be supplied at the lowest attainable price. The agricultural lobby is very well organized, and its influence on water policies and pricing decisions has been significant.

(8) The **Ministry of the Interior** is in charge of the local authorities. By controlling their budget, the ministry supervises the local authorities' water and sewage activities. Urban water consumption has the highest priority in the allocation of freshwater resources. The industrial sector also has high priority.

The large number of parties involved in the arena of water management hinders initiatives and changes, yielding a bureaucratic maze and a lack of synchronization of the different needs that the water economy has to fulfill.

Division into Water Regions

In principle, Israel can be examined as a single geographic entity for a few reasons:

(a) **Freshwater:** As mentioned above, the NWC connects all major sources of freshwater into a single network. Water can be transferred from one region to another, so that water from one aquifer may be used in a different geographical region. In addition to the NWC which transfers water from the Sea of Galilee in the north to the center and the south of the country (Negev), there are some additional major pipelines:

(i) Connection of the coastal aquifer (in the west) to the Jerusalem metropolis, Connection of the NWC to the Northern Coastal Plain and Western Galilee (in the north), and

(ii) Connection of the Hula Valley (near the source of the Jordan River) to the Mountains of Galilee.

(b) **Recycled water:** The Shafdan, a plant for the treatment of urban and industrial effluent of the greater Tel Aviv metropolitan area (home to more than 30% of the country's population), is responsible for transferring recycled water to the southern region (Western and Northern Negev) for agricultural use.

Two large additional networks convey recycled effluent from the Jerusalem metropolis to the Negev Plain and from the Haifa metropolis to the Western Jezreel Valley, respectively.

(c) **Pricing policy**: Water prices by quality and sector (agricultural, industrial, urban) are more or less uniform throughout the country.

The current analysis focuses on the sub-region of Tel-Aviv, a part of the national water system.

A Brief Description of the Region

The region is located in the Coastal Plain on the eastern shore of the Mediterranean Sea (see Figures 7-1a-1b below) and it lies above the Coastal Aquifer[2]. In terms of population, the Tel-Aviv region is the largest in Israel with two million people, 30% of the total population (Table 7-1).[3]

[2] The Coastal Aquifer underlies the coastal plain, adjacent to the Mediterranean Sea, and is composed of sandstone. The aquifer is bounded to the east by the foot hills of the mountain belt, in the north by the Carmel Mountain, in the South by the Sinai Desert, and in the west by the Mediterranean Sea. The major flow of the reservoir is toward the Mediterranean Sea where it eventually interfaces with seawater. The Coastal Aquifer is valuable storage basin since the sandstone layers hold water efficiently. The available storage capacity is 20,000 MCM. Average chloride concentrations range from 50-250 mg/l but reach 600 mg/l in some part of the coast. The aquifer has a mean annual recharge of 250MCM in addition to 50 MCM of agriculture drainage.

[3] Data in all tables refer to the year 2000.

Table 7-1. Distribution of Population by Type of Settlement

Type of Settlement	Tel-Aviv	
	thousands	%
Metropolitan areas (Pop. exceeding 200,000)	352	18
Big cities (Pop. 100,000-200,000)	902	47
Mid-sized cities (Pop. 20,000-100,000)	485	25
Small towns and cities (Pop. 2,000-20,000)	149	8
Villages and communities	42	2
TOTAL	**1,930**	**100**

The data for our analysis were collected from many sources, including

- The Master Program of the Water Commission for the years 2002 – 2010 for the prediction of future domestic, industrial and agricultural demands;
- Monthly publications and reports of the national water company, Mekorot for cost estimates;
- Publication of the parliament about water prices;
- Budget sheets for various crops published by regional offices of the Ministry of Agriculture for the calculation crops values;
- Data on population and weather published by the Israeli Bureau of Statistics;
- Maps and geographical data from the GIS Center of the Hebrew University;
- Regional officers of the Ministry of Agriculture for areas planted for various crops and for data on crop budgets, as well as best management irrigation practices.

The region has 14,700 hectares (ha) of cultivated agricultural land, 5% of the total cultivated land in the country. The region's water economy is therefore characterized by relatively high domestic and industrial consumption and relatively low agricultural consumption, as detailed below.

- The natural water sources in the area are:
- Supply from the national water system operated by Mekorot:
- Production from the coastal aquifer, above which the region lies.
- Water supply from the Sea of Galilee via the NWC.

In addition, part of the fresh water (some 35%) is provided by private producers from the coastal aquifer.

In the future, this region is slated to receive a significant amount of desalinated sea water.

It is important to emphasize that most of the urban and industrial waste water produced in the region are **not** utilized for agricultural irrigation within the region itself. Most of this water is treated in the Shafdan plant (90-100 MCM per year) and the treated water is exported to the southern region (western and northern Negev) for agricultural use, located 100 – 150 km away from this plant.

Aggregate supply is summarized in Table 7-2.

Table 7-2. Aggregate Water Supply for an average year

Source	Type	Quantity (MCM)
National System	Fresh	40
	Recycled	16
	Total	56
Local System	Fresh	267
	Total	267
TOTAL	Fresh+ Desalinated	307
	Recycled	16
TOTAL		**323**

The total aggregate water supply in the region reaches to 323 MCM per an average year. 82% of the total supply is produced by the Local system and the remaining 18% of the total supply is produce by the National system. Only 5% of the total supply (16 MCM) is recycled water which is used only by the agricultural sector (i.e. irrigation).

The quality of the fresh water is good, with a salinity level of 150-250 mg chlorine per litre. The future use of desalinated water should lead to an improvement in water quality.

The region's large population creates the potential for a large supply of recycled water for agriculture.

Water Demand and Actual Consumption

Summary of water demand and actual water consumption by sector and water type are presented in Table 7-3 and Table 7-4, respectively.

Table 7-3. Water Demand by Sector and water type (MCM/yr)

	Fresh water	Recycled	Total
Domestic	191	---	191
Industrial	58	---	58
Agricultural	25	49	74
Total	**274**	**49**	**323**

Table 7-4. Actual Water Consumption by Sector and water type (MCM/yr)

	Fresh water	Recycled	Total
Domestic	191	---	191
Industrial	58	---	58
Agricultural	58	16	74
Total	**307**	**16**	**323**

"Demand" for water may differ from "actual consumption" of water. In this case study the difference is limited to the agricultural demand and consumption of recycled water. Specifically, the demand for recycled water in Tel Aviv region is 49 MCM; while actual consumption is only 16 MCM, since it cannot exceed the available supply (Table 7-2).

The division of actual consumption of each sector between water supplied from the national water system and from the local system (i.e., pumping of fresh water from the coastal aquifer plus recycled wastewater) is presented in Table 7-5.

Table 7-5. Division of Actual Water Consumption by Source of Supply (MCM/yr)

	National System	Local System	Total
Domestic	25	166	191
Industrial	7	51	58
Agricultural	24	50	74
Total	**56**	**267**	**323**

With an average annual consumption of 100 m^3 per capita, which is similar to the national average, the total domestic consumption in the region reaches 191 MCM per year. 87% of the total domestic consumption is produced by the Local system and the remaining 13% of the total consumption is produced by the National system.

The total Industrial consumption in the region reaches 58 MCM per year. 88% of the total Industrial consumption is produced by the Local system and the remaining 12% of the total consumption is produce by the National system. The entire Industrial consumption is derived from fresh water (there are no saline water or recycled water in use).

The total Agricultural consumption in the region reaches to 74 MCM per year. 68% of the total Industrial consumption is produced by the Local system and the remaining 32% of the total consumption is produce by the National system. Unlike the other sectors (Domestic and Industrial), 21% of the total Agriculture consumption is obtained from recycled water (16 MCM) which is delivered by the National system.

Tel-Aviv region is characterised by a Mediterranean climate, with an annual precipitation of 450 mm. The aridity index is 0.05-0.2 and the region is characterised as semi-arid.

Tel Aviv is a part of the national water system, and therefore the prices charged to its consumers are determined within the national framework. Private producers are

subjected to a system of public compensations (production levies) if their production and operation costs exceed/fall short of the administrative price charged by Mekorot to its consumers. The aim of this public intervention is to equate the prices charged to the consumers of the private water suppliers to the prices charged to the consumers of Mekorot.

Land prices in this area are among the highest in the country. The region is therefore subject to further urbanization and a reduction in agricultural area. Agriculture in this region has value as a public good in conserving open areas and providing "green lungs".

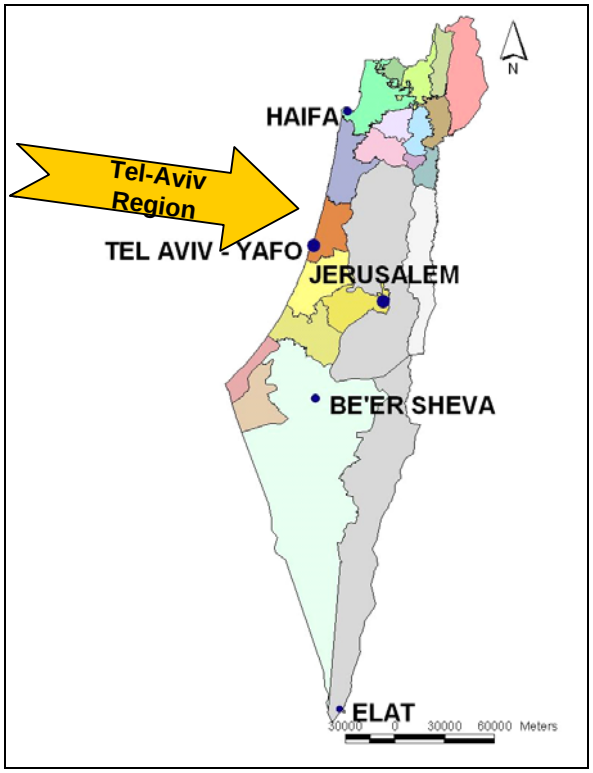


Figure 7-1a. Map of Israel and the selected region

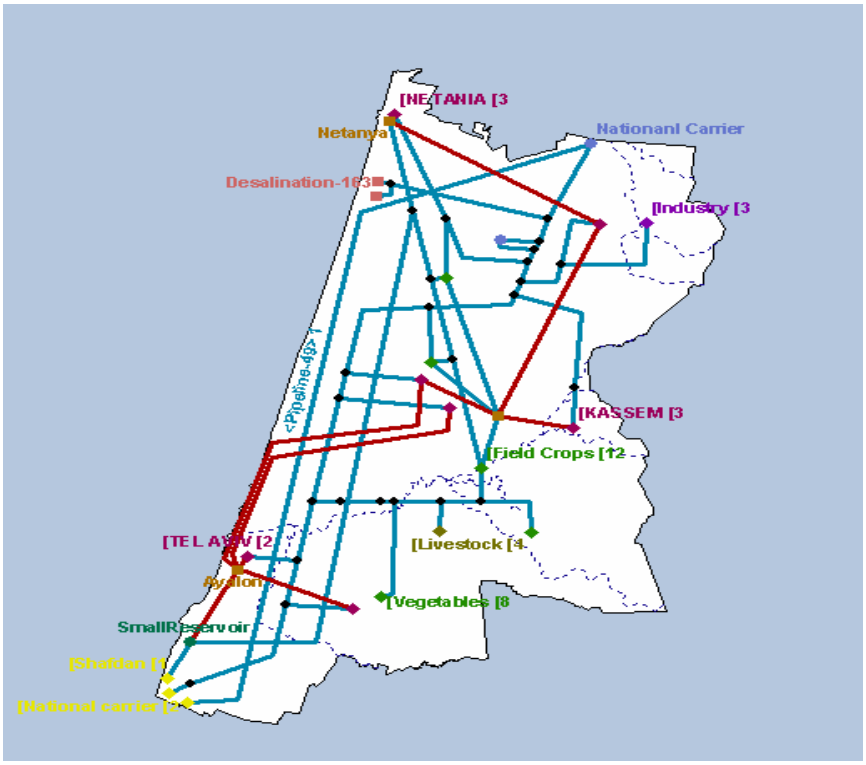


Figure 7-1b. The water network for the region of Tel Aviv

Formulation of Demand and Availability Scenarios; Priorities of water Allocation

Demand

As already noted, the region is characterized by relatively high domestic (191 MCM/year) and industrial (58 MCM/year) consumption, and relatively low agricultural consumption (74 MCM/year). Environmental water consumption is negligible (2 MCM/year) and is ignored in our analysis. The prediction of the future-demand scenario for the region is based on the recent Master Plan for the development of the Israeli water resources in the years 2002 to 2010, prepared by the planning department of the Water Commission. Specifically, we assume that:

(1**) Domestic demand** steadily increases at a constant annual rate of 0.5% due to population growth (the consumption per capita is assumed to be stable over the years);

(2) **Agricultural and industrial** demands are stable over time (the land in the region is very expensive, agricultural lands are under pressure from urbanization processes and it is very unlikely that additional land will be allocated for agricultural production);

Total agricultural demand is subdivided among a few crops representing the typical crop mix in the region: citrus, orchards (other than citrus, like Avocados, Grapes, Mangos, Olives and Pecans), field crops, vegetables, and flowers.

Availability (Supply)

Israel is a small and narrow country; half of its area is a dry desert. Precipitation, only in the winter, averages more than 700 mm per year in the north and less than 35 mm at the southern tip of the country. The natural supply is unstable since precipitation varies from year to year. Monthly rainfall variations in a given year are not relevant to our analysis.

As shown in Table 7-2, the water for the region is supplied from a few sources:

(a) supply of fresh water via local wells, pumping from the coastal aquifer (annual average of 267 MCM) and via the NWC [annual average of a net amount equal to 40 MCM (= import of 270 MCM from Lake Kineret minus export of 230 MCM)];

(b) recycled effluent for irrigation (16 MCM), and

(c) in the near future, the region is slated to receive a significant amount of desalinated sea water.

Two major availability scenarios of fresh water are assumed in our analysis:

(i) A sequence of 15 years with a stable supply of fresh water equal to the annual long-term average supply (hereafter the Stable or **Normal Scenario**), and

(ii) a cyclical sequence of 15 years with fluctuating supply, where three consecutive years with average supply are followed by three consecutive dry years with a supply that is 30% lower than the average (hereafter the **Cyclic Scenario**).

Major data on the demands of local consumers, and of consumers who live in the south and who receive water that is either exported to them from Lake Kineret (via the NWC) through Tel Aviv or produced in the region of Tel-Aviv, are summarized in Table 7-6. Relevant supply data are included as well.

Table 7-6. Supply and Demand in Tel-Aviv for an Average, Normal Year (MCM)

	Demand	**Supply**	
Local	323	307	Fresh water
		16	Reused water
The Southern Regions of the Country	320 (demand of domestic and agricultural consumers)	230	Fresh water (export for users in the southern regions via the NWC)
		90	Recycled water (export for agricultural users in the southern regions via the Shafdan)
Total	**643**	**643**	

Allocation (Supply and Demand) Priorities

While setting the supply and demand priorities for the tool, one should be aware of a couple of basic economic principles: (a) the cheaper sources should be used prior to the more expensive one, and (b) when the supply shifts from one resource to the next

(starting from the least expensive one), it should first be allocated to the demand with the highest value, then to the demand with the second highest value, and so on. Based on these principles we assume the following priorities (Table 7-7):

The highest priority ("1") is to allocate fresh water from local wells (the least costly resource) to local domestic consumers. Then, water from local wells should be allocated to industrial consumers and to livestock: priority "2".

The same high priority ("2") is assigned to the allocation of fresh water imported to the region through the NWC, which costs more than water from local wells, to local domestic consumers and to domestic consumers who live in the southern region of the country (via water export). In fact, most of the fresh water imported to the region via the NWC (an annual average of 270 MCM per year) is exported to southern consumers and only about 14% of it (40 MCM) is consumed within the region. Relatively high priorities ("3" and "4") are assigned to the allocation of imported fresh water to industrial consumers and livestock in Tel-Aviv and to the export of recycled effluents to southern farmers (via the Shafdan).

The lowest allocation priorities are assigned to the agricultural activities in the region. Among these activities, the highest priorities ("5" – "7") are the allocation of recycled effluents (which cannot be used for domestic or industrial consumption or for irrigating vegetable and flowers) to the orchards, citrus and field crops. The lowest priorities are assigned to the allocation of fresh water for the irrigation of field crops (priorities "12" and "13"); and to the export of fresh water from local wells to domestic and/or agricultural consumers in the south (priorities "14" and "15").

Table 7-7 .Supply and Demand Priorities

Supply source →	**Imported Fresh Water (NWC)**	**Fresh Water from Local Wells**	**Recycled Water**
Consumer ↓			
Domestic Sector	2	1	
Domestic Users in Southern Regions (exported water)	2	14	
Agricultural Users in Southern Regions (exported water)	4	15	
Industry	3	2	
Agricultural Demand			
Livestock	3	2	
Citrus	11	10	6

Supply source →	Imported Fresh Water (NWC)	Fresh Water from Local Wells	Recycled Water
Consumer ↓			
Orchards	9	8	5
Field Crops	13	12	7
Vegetables	9	8	
Flowers	9	8	
Exported Recycled water (Shafdan)			4

Costs, Prices and Benefits to Water consumers (€/m^3)

The relevant direct costs associated with the various sources supplying water to the region and the prices charged for agricultural, industrial and domestic consumers are summarized in Table 7-8.

Table 7-8. Direct Costs and Prices Charged to Consumers (€ /m^3)

Source	Cost	Price	Consumer
Imported Water (via the NWC)	0.32	0.18	Agriculture
		0.27	Industry
		0.31	Domestic
Local Drills	0.20	0.18	Agriculture
		0.27	Industry
		0.31	Domestic
Desalination	0.60	0.31	Domestic
Recycled Water	0.14	0.09	Agriculture

Direct Costs

The direct costs (DC) associated with "local drills" are based on the cost of lifting one cubic meter from the aquifer source, through a well and into the distribution system, taking into account the (age dependent) capital cost component of constructing the wells and the water conveyance system. The "imported water" is water imported to the region via the NWC from Lake Kinneret (Sea of Galilee), whose water level is regulated between 209m and 214m **below sea level**. The high pumping costs coupled with the significant distance of water transportation -- the length of the NWC between Lake Kinneret and the region of Tel-Aviv (more than 150 km) - - can explain why the costs of imported water is so much higher than water from local drills.

The development and operation of new desalination plants is governed by a "BOT agreement" (Build, Operate and Transfer) between the Israeli government and the

entrepreneurs. The agreement includes details about the financing, design, construction, operation and transfer of a seawater desalination facility with predetermined production capacity whose supply is guaranteed by the entrepreneurs. The government is committed to purchasing the predetermined production of the facility for a period of about 25 years, at a predetermined price. At the end of that period the facility will be transferred to the control of the government. The cost as per the latest tender for desalinated seawater is 0.53 US dollar/m^3 at the gate of the plant. Connection to the national water system and transportation add 0.15 US dollars/ m^3, implying desalination costs of about 60 € cents per cubic meter.

The vast majority of the domestic and urban waste water in the region are treated in the Shafdan treatment plant and exported to the south of the country. The "recycled water" in Table 7-8 represents recycled water treated to a secondary level in relatively small, not modern, local treatment plant and used only for agricultural irrigation. The direct costs associated with this water are relatively low and are composed of only 5 € cents of transportation costs and 9 € cents of maintenance, operation and capital costs.

Prices

As mentioned above, water prices are determined at the national arena and the water prices here considered represent actual water prices.

Environmental costs

The potential sources of environmental costs in the region are threefold:

(i) The major potential source is a gradual increase in the salinity of the groundwater aquifer located below irrigated agricultural land (a portion of the coastal aquifer). Salts are imported to the region with irrigation water conveyed from Lake Kinneret via the NWC. Even though the salt content of the Kinneret, the source for the NWC, is relatively low (200 to 240 ppm Cl), the salt brought in by the NWC gradually accumulates in the soil and ultimately percolates to the groundwater. In addition, in the "process" of domestic consumption, about 100 mg of chlorides per litre are added to the wastewater, some of which is recycled and used for irrigation within the region. However, the vast majority of domestic and industrial wastewater is treated in the Shafdan treatment plant and "exported" to southern regions of the country. We conducted a comprehensive salt-balance analysis for the region of Tel-Aviv and found that the annual amount of salts exported out of the region exceeds—by about 22,000 tons—the sum of the amount that is imported through the NWC and the amount added during the domestic and industrial consumption process. Thus, we assume that there are no salinity-associated environmental costs in this region.

(ii) Environmental costs associated with over-pumping of ground water from the coastal aquifer.

The local fresh water in the region are pumped from the coastal aquifer which is the largest reservoir of natural water in the country, situated in the coastal strip between the

Carmel mountain range and the Gaza Strip region. The available storage capacity is 20,000 MCM. The annual renewal from precipitation is 300-400 MCM, which is also the average annual pumping rate. As a result of over-pumping during the 1990s, the surface level descended, with penetration of seawater. As a result, the salination level of the aquifer has increased, affecting several wells. The chloride level has a broad range, from 50 to 600 mg chlorine/litre. About two-thirds of the water is still beneath the 250 mg level, the maximum permitted for domestic use. The current policy is to rehabilitate the coastal aquifer, with the aim of raising the average water level and putting a stop to the deterioration in quality. This is being done by selective limitation of pumping approval in areas with severe salinity and quality problems.

So far, we (implicitly) assumed that the current supply (=actual consumption) of water from local drills, 267 MCM/year (Table 7-5), does not exceed the natural (plus a limited, artificial) recharge implying the absence of over pumping.

Later on, we will evaluate the option to increase the supply of fresh water in the region via over-pumping. Over-pumping involves significant environmental costs, mainly because of the expected intrusion of sea water, resulting in an increased salinity level.

The environmental costs associated with over-pumping takes into account not only the present damages to consumers associated with the consumption of saline water, but also the costs resulting from the expected future need to rehabilitate (via desalination) increasing number of areas with severe salinity and quality problems.

The environmental costs resulting from over-pumping are assumed to be equal to 0.64 € cents.

(iii) Environmental costs associated with unmet agricultural demand.

As mentioned above, agriculture in the region of Tel-Aviv has value as a public good in conserving open areas and providing "green lungs". The estimation of the environmental costs associated with the unmet agricultural demand is based on studies conducted in Israel (details are available by request), which estimated the environmental value of cultivated land (relative to non cultivated one) and the average amount of irrigation water (m3/ha) applied in the region. Specifically, the environmental costs associated with a cut of 1 cubic meter of irrigation water demanded by the agricultural sector - a cut which yields reduction in the cultivated area - are assumed to be 0.09 € cents.

Benefits to water consumers

The calculations of the benefits gained by water consumers are less obvious and require an explanation (for more details see the recent working paper prepared by a few partners of the project, entitled: "Methods available for estimating financial resources and environmental costs.") In the absence of any knowledge of the urban demand curve for water or the aggregate willingness of the city residents to pay for water, we approximate the marginal value of water (assumed to be identical to the average value) for domestic and industrial consumers by the marginal cost of the most expensive source that is either

currently under use or should be utilized on the basis of economic considerations. In the current example, it is the cost of seawater desalination, 0.60 €/m3.

The average value of irrigation water applied to each of the annual crops (vegetables, flowers and field crops) is approximated here by calculating the average net profits per m3 of water applied to that crop, taking into account the alternative value of the agricultural land (measured by the net profits, in €/ha, of the best alternative non-irrigated crop, such as rain-fed wheat).

The calculation of the average value of water applied to mature citrus crops or other orchards is more complicated and its description is outside the scope of the current report. Details are available in the above-mentioned working paper. We just state that its value is composed of the sum of average net profits per m3 applied to the mature grove plus a loss term which measures the potential loss from the need to replace a mature grove by a new grove, in case the mature one is not irrigated and dry out.

The assumed water values for the various crops are summarized in Table 7-9.

Table 7-9. Assumed Water Values or Benefits (€/m^3)

Crop	Field Crops	Vegetables	Flowers	Citrus	Other Orchards	Domestic + Industrial Users
Average Net Benefits per m3	0.17	0.44	1.03	0.39	0.84	0.60

Social Welfare Surplus (SWS) and Private Welfare Surplus (PWS)

The total social welfare surplus (SWS) in the region is defined as the difference between the total value or benefit accrued by water consumers and the total direct and environmental costs. Following consultation with stakeholders and decision makers in the water economy of Israel, we came to conclusion that for the Israeli case studies, the SWS is the best criterion to rank the various scenarios. Obviously, a management option implying a high SWS value is preferred to one implying a lower value. Total private welfare surplus (PWS), accrue to water consumers, is defined as the difference between water values (benefits) and the water costs charged to the consumers.

While both SWS and PWS depend on the value of water for the various consumers, the former also depends on the actual, direct and environmental' costs of supplying the water while the latter depends on the prices charged to the consumers. Since in many cases water prices differ from water costs, it may well be that the PWS and SWS for a specific group of consumers do not coincide.

7.2 Analysis of Reference or Business as Usual (BAU) Scenario(s)

The two BAU scenarios, which are used as reference scenarios in our analysis, represent the current demand and supply conditions under the above mentioned two assumed water availability conditions:

(i) A sequence of 15 years with a stable supply of fresh water equal to the annual long-term average (normal) supply; denoted by BauN, and

(ii) a cyclical sequence of 15 years with fluctuating supply, where three consecutive years with average supply are followed by three consecutive dry years with a supply that is 30% lower than the average; denoted by BauC.

The BauN Scenario

The stream of annual demands depicted in Figure 7-2 is based on the assumption that domestic demand is steadily increasing at a constant annual rate of 0.5% due to population growth while agricultural and industrial demands remain constant. The schedule of unmet demands is depicted in Figure 7-3. The combination of stable supply and steadily increasing (domestic) demand for fresh water results in a water shortage after five years which increases over time. Given the assumed allocation priorities (Table 7-7), the agricultural sector bears all the necessary cuts (Figure 7-3).

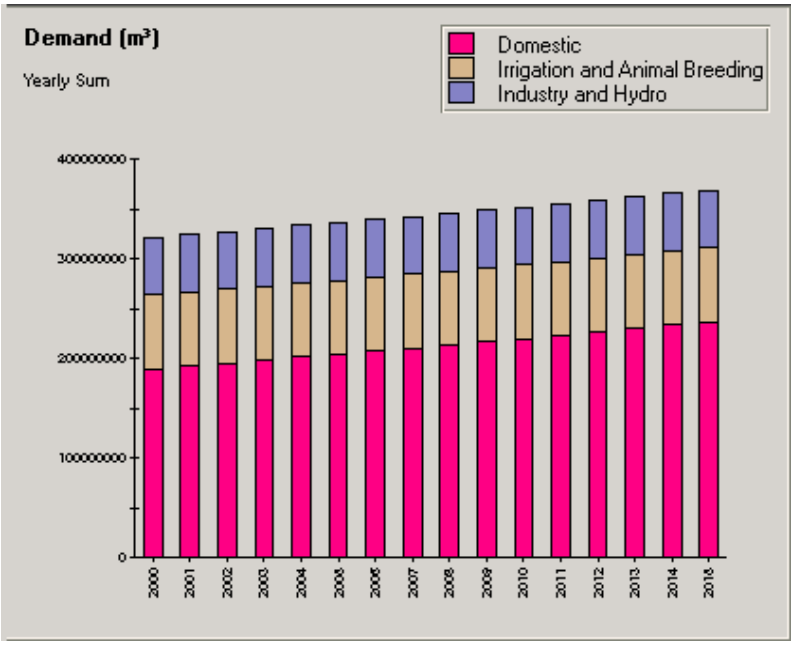


Figure 7-2. Predicted water demands by sector under the BauN scenario

The (stable) annual demand of the agricultural sector is composed of 49 MCM of recycled water and 25 MCM of fresh water (Table 7-3). However, the supply of recycled water is limited to 16 MCM for the first year of the time horizon (Table 7-4). We assumed that the supply of recycled water increases with the increased consumption of fresh water (0.5% per year) by the domestic and industrial sectors that are connected to

the treatment plants. Specifically, we assumed that 60% of the **increased** consumption is recycled. By the end of the time horizon, the quantity of recycled water available for irrigation has increased to 19 MCM.

At the beginning of the time schedule, the agricultural demand was fully supplied by 16 MCM of recycled water plus 58 MCM of fresh water. However, the steady increase in domestic demand for fresh water coupled with the assigned priorities implied that in the fourth year of the time horizon, total demand for fresh water would exceed total supply, with the agricultural sector bearing all the required cuts. The levels of unmet agricultural demand over the last 11 years of the time horizon are depicted in Figure 7-3.

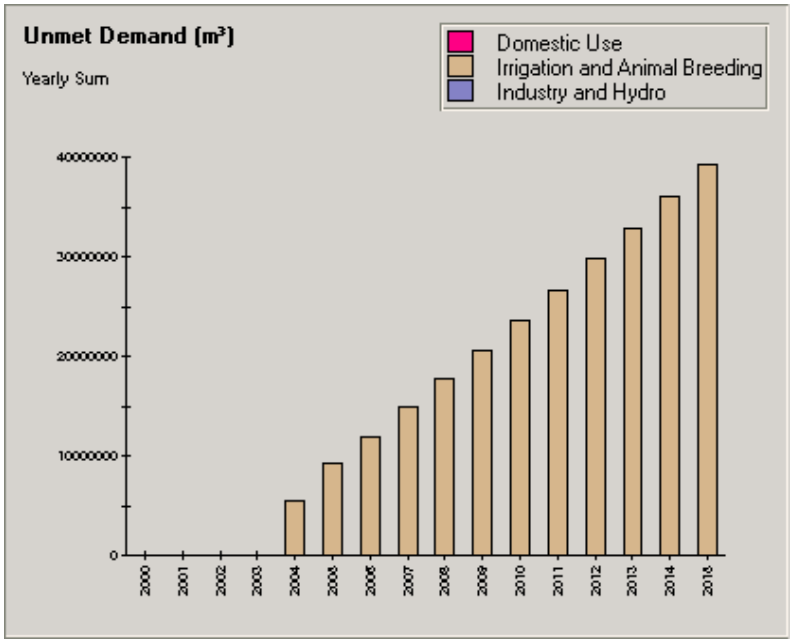


Figure 7-3. Unmet demand under the BauN scenario

Figure 7-4 illustrates the impact of water cuts on areas planted for various types of crops. The area planted for field crops is immediately sharply reduced when the water cuts take effect and vanishes completely within three years (and the land is left idle). The area planted for citrus is also reduced in the early stages until it decreases gradually and vanishes in the year 2012. These two crops are less profitable than the others. Later on, towards the end of the time horizon, the farmers are forced to give up some flowers and vegetables. Orchards other than citrus are the only crop that is kept constant over the entire time period.

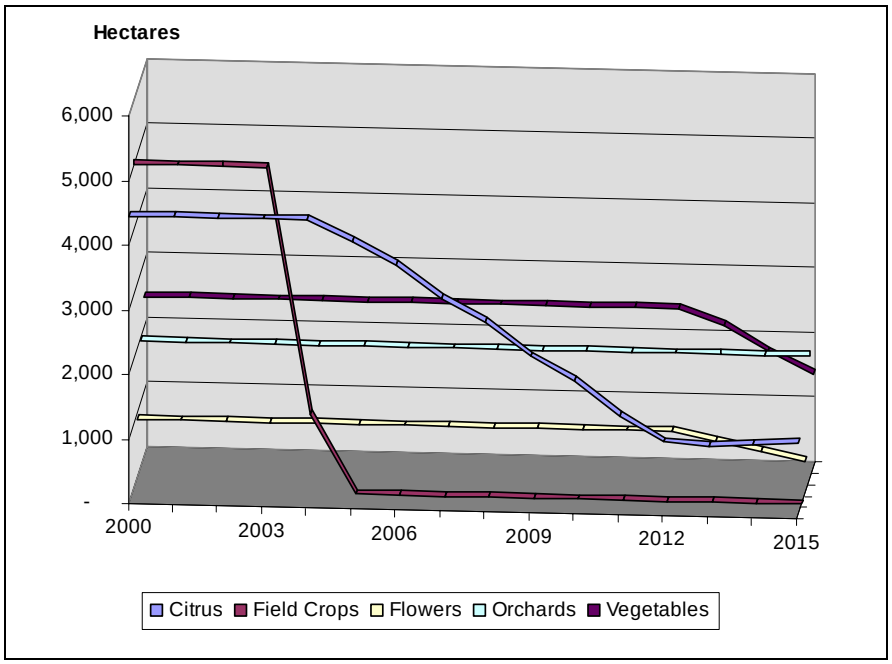


Figure 7-4. The impact of water cuts on areas planted for various crops under the BauN scenario

The total reduction in the area of cultivated land resulting from the water cut from about 14,000 ha in 2004 to only about 5000 ha in 2015 .

The Rate of Cost Recovery (RCR)

The RCR measures the percentage of the total costs associated with the production and supply of water to consumers that are covered by total water charges paid by the various consumers. Water prices in Israel are determined in the political arena and depend on the type of use: farmers pay the lowest charges, industry pays higher charges and households pay the highest ones. Within each sector, charges do not depend on location: users in all parts of the country face the same charges, regardless of the supply price of water. More than 87% percent of the fresh water consumed in the region is from local wells, and the direct costs of its production and supply, 0.20 €/m^3, are lower than the prices charged to domestic and industrial consumers, and only 2 cents lower than the agricultural water prices. Thus the total water charges collected from the region's consumers exceed total costs and the "total" (i.e., average) RCR (Figure 7-5) exceeds 1.1 (i.e. 110%). We also calculated the value of the RCR for each of the consumers. As can be seen from Figure 7-5, the RCR of domestic consumers, who pay the highest price for water (0.31 €/m^3) is higher than 140% and that of industrial consumers is close to 130%. Water charges that exceed water costs are not rebated to consumers, implying that domestic and industrial consumers in Tel-Aviv's region subsidize consumers in other regions of the country (in most of the other regions, including the Arava, average RCR is lower than 1). Finally, note from Table 7-4 and Table 7-5 that agricultural consumption is composed of 22% recycled water -the price of which (0.09 €/m^3) is lower than its cost (0.14 €/m^3) -and 78% fresh water, the price of which (0.18 €/m^3) is also lower than its cost. Thus, the

value of the RCR for agricultural consumers is lower than 1 (and ranges between 80% and 73%), implying that even in Tel-Aviv's region, agricultural consumption is slightly subsidized.

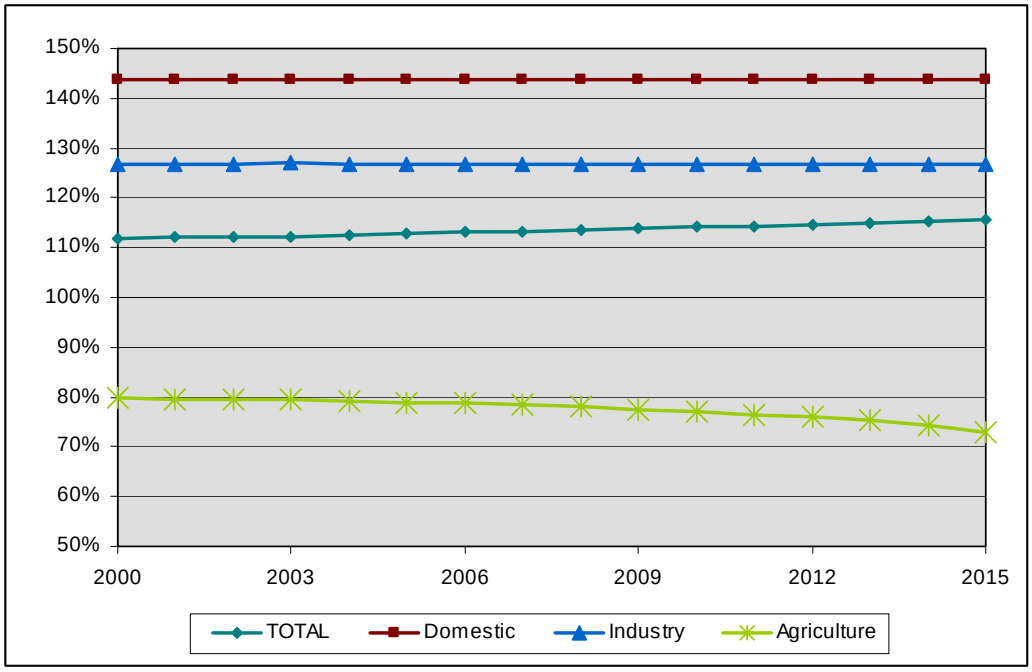


Figure 7-5. The RCR under the BauN scenario

Effectiveness

The "effectiveness" is defined as the ratio of supply delivered (i.e., actual consumption) to the level of water demanded. Since unmet demand is limited to the agricultural sector, the effectiveness for domestic and industrial uses is 100% (Figure 7-6). As can be seen from Figure 7-3, the effectiveness for agricultural uses is 100% in the first 4 years of the planning period and then it steadily reduces, reaching level lower than 45% at 2015 (Figure 7-6).

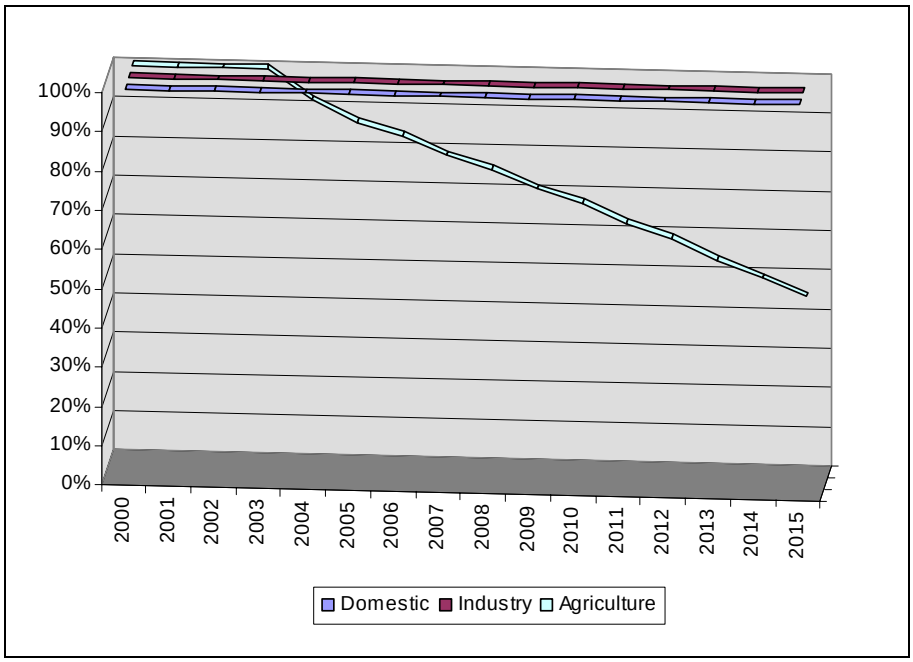


Figure 7-6. Effectiveness for Domestic, Industrial and Agricultural use under the BauN scenario

The values of Social welfare surplus for the 15 years of the time horizon are depicted in Figure 7-7.

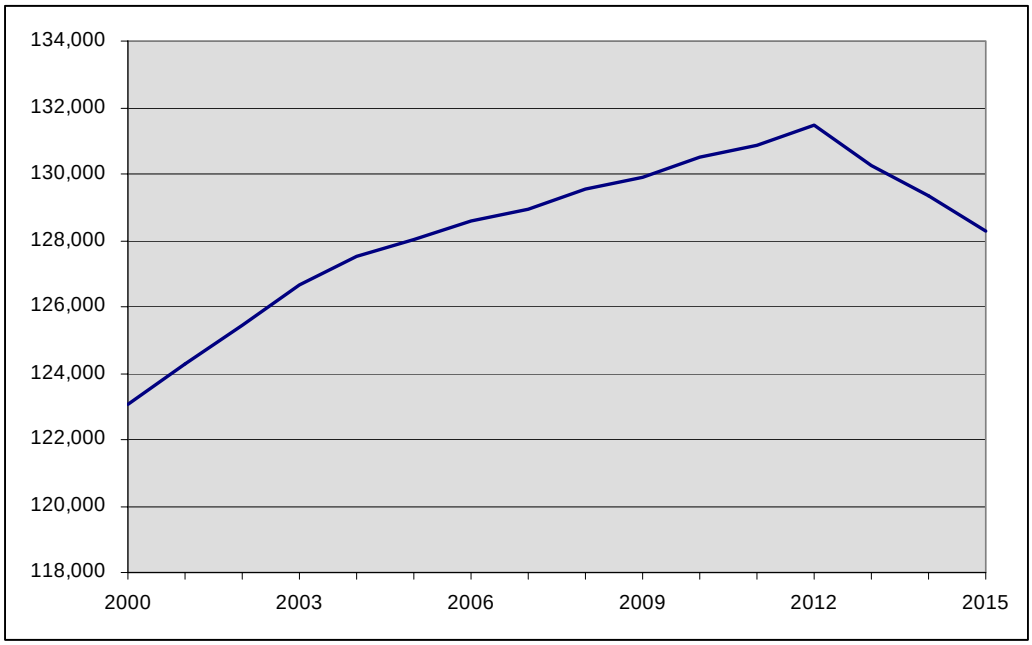


Figure 7-7. Social Welfare Surplus (SWS) under the BauN scenario

The increase in SWS over the period 2000 to 2015 is due to the positive and steady shift in domestic demand which increases the aggregate welfare of domestic and industrial users (i.e., the marginal value of water for these consumers is multiplied by larger quantities of water). In the first four years, the cultivated area is not affected by the

increased domestic and industrial demand and thus agricultural consumption of water and its associated SWS are constant. From the fifth year and on, the agricultural sector bears increasing water cuts, implying a reduction in the cultivated area and in the contribution of this sector to aggregate SWS. However, until the year 2012, the annual increase in SWS resulting from increased consumption by the domestic and industrial sectors is larger than its reduction in the agricultural sector. In the last 4 years, farmers are forced to cut the area planted for flowers, the most profitable crop (see Table 7-9). Since the average value of water applied to flowers (1.03 €/m^3) is higher than the average value attributed to domestic and industrial consumption (0.60 €/m^3), the aggregate value of SWS declines in the last four years.

For ranking purposes, we calculated for each of the scenarios the present value of the stream of SWS values, denoted by NPV (SWS). A management option implying a high value of NPV (SWS) is preferred to one implying a lower value.

In this, BauN, scenario, NPV(SWS) = 1,409.7 million € with an assumed real interest rate of r = 4%.

Present values (r=4%) of PWS, SWS, and environmental and direct costs are presented in Figure 7-8.

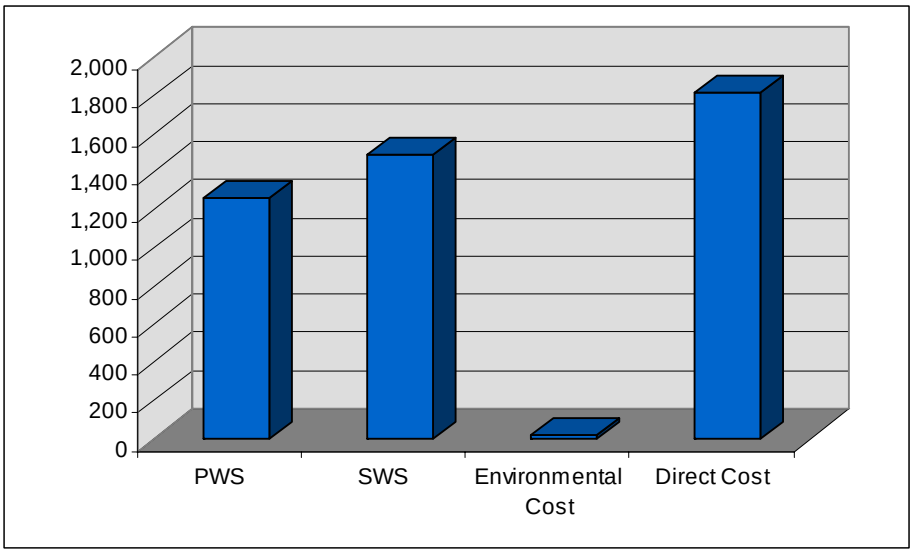


Figure 7-8. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauN scenario

With the exception of the agricultural sector, consumer prices of fresh water exceed water costs (the gap for water from local drills is the highest), implying that NPV (PWS) -- 1263.7 million € – is lower than NPV (SWS). The present value of total direct costs – 1812.6 million € - is about 122 times higher than the one of total environmental costs (14.8 million €). In other words, the environmental costs caused by the water shortage, implying a reduction of water supply for the agricultural consumers and subsequently, reduction of the cultivated area, is relatively quite small under the BauN scenario.

The second reference or business as usual scenario is the BauC scenario which is presented below.

The BauC Scenario

This scenario assumes a cyclical sequence of 15 years with fluctuating supply, where three consecutive years with average supply are followed by three consecutive dry years with a supply that is 30% lower than the average. As can be seen from Figure 7-9, unmet demand in the drought periods (2003-2005, 2009-2011 and 2015) is not limited to the agricultural sector (as was the case under the BauN scenario (Figure 7-3). In fact, during the dry years, the agricultural and industrial sectors do not receive fresh water at all, a situation that cannot be tolerated by society, and cannot be left untreated.

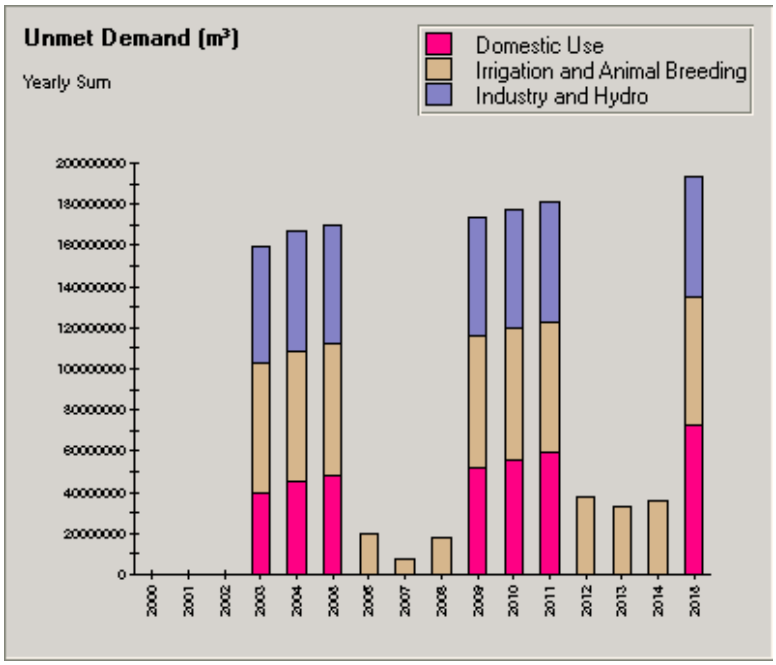


Figure 7-9. Unmet demand under the BauC scenario

The impact of water cuts on the cultivated area is presented in Figure 7-10.

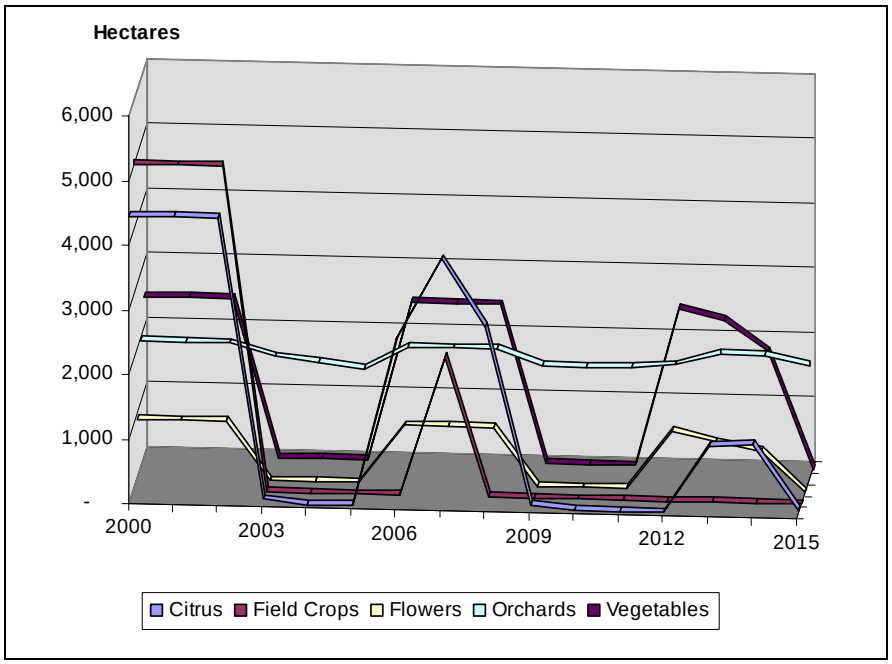


Figure 7-10. The impact of water cuts on the areas planted for various crops under the BauC scenario

The figure clearly demonstrates that during the dry periods, the areas planted for flowers and vegetables, which are irrigated with fresh water, vanish. The area planted for field crops, which are less profitable, vanishes completely from the year 2003 until the end of the time horizon. Citrus and other orchards are irrigated with recycled water and the latter are more profitable (Table 7-9). During the dry periods, all the available recycled water is supplied to the orchards, the area of which is quite stable over the time horizon. Citrus receives no water during those periods and dries out. Obviously, since citrus and orchards are perennial crops, the area planted for them cannot fluctuate sharply from year to year. While calculating the SWS value associated with the agricultural sector, we assume that a grove that is not irrigated dries out and is replaced by a new grove.

RCR

The RCR values are presented in Figure 7-11. The values associated with domestic consumption are higher during the dry years. This is because the supply of the relatively expensive imported water is cut off during the dry years and all consumption is satisfied from local wells. The cost of the latter is much lower (see Table 7-8) than the cost of imported water; meanwhile, urban consumers pay the same price for water from both sources. The RCR associated with the industrial sector drops to zero in dry years since it does not receive any fresh water. The RCR values associated with the agricultural sector are lower during the dry years because the portion of recycled water in total water consumption increases during these periods, and the price paid for that water is much lower than the cost of supplying it.

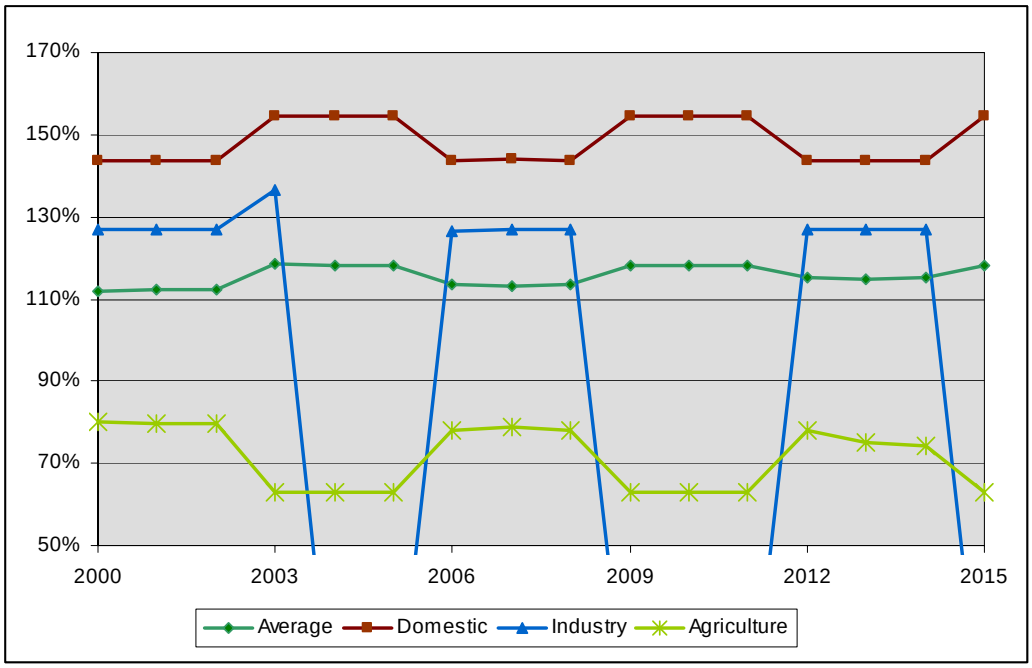


Figure 7-11. The RCR under the BauC scenario

Effectiveness

In contrast to the BauN scenario (see Figure 7-6) the "effectiveness" for domestic and industrial uses is not 100% for the whole planning horizon. Inspection of Figure 7-12 shows that during the sequences of dry years its values drop below 70% for the domestic sector and to zero for the industrial sector. The effectiveness for agricultural fluctuates, dropping to about 10% during the dry periods.

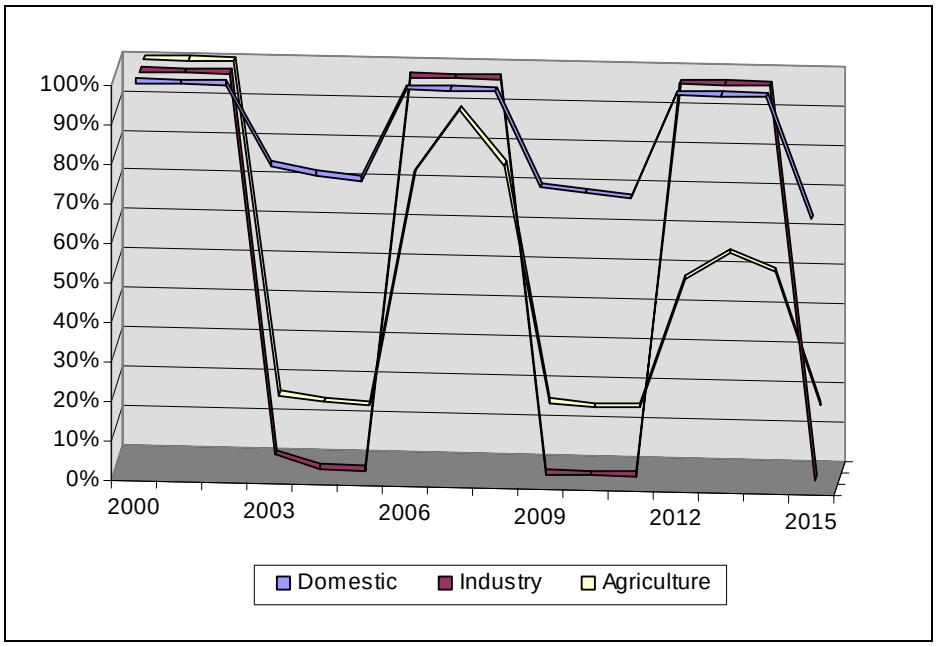


Figure 7-12. Effectiveness for Domestic, Industrial and Agricultural use under the BauC scenario

SWS

The annual SWS values for the BauC scenario are depicted in Figure 7-13. The sharp reduction in SWS during the dry periods is quite large.

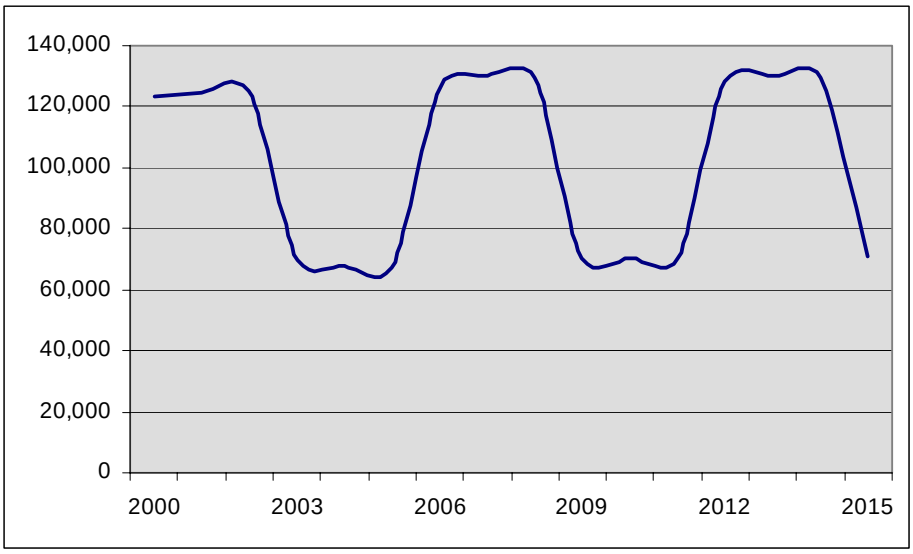


Figure 7-13. SWS under the BauC scenario

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauC scenario are presented in Figure 7-14 together with the respective values for the BauN scenario.

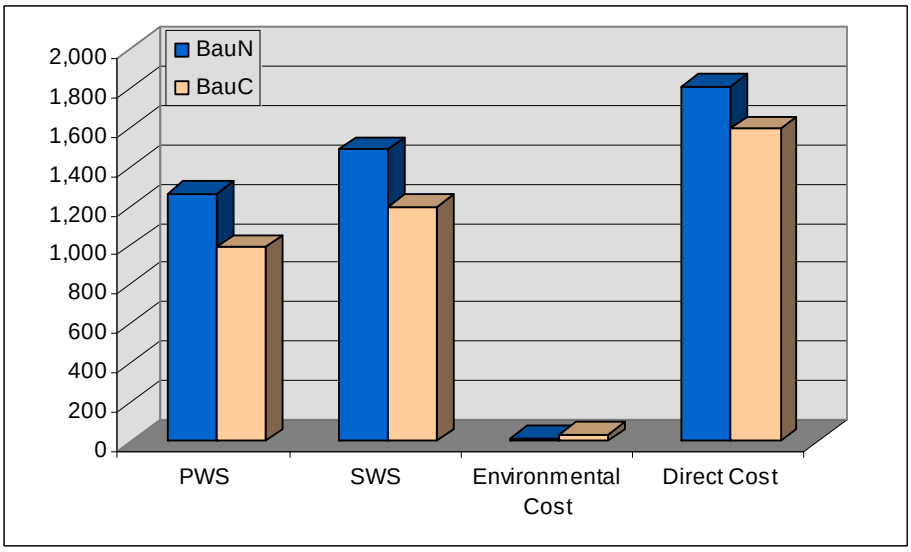


Figure 7-14. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauC and the BauN scenarios

As expected the value of both, NPV (SWS) and NPV (PWS) under the BauC scenario are lower than the respective values under the BauN scenario. Obviously, a state of nature with a sequence of 15 years with a stable supply of fresh water are preferred to a sequence with fluctuating supply, where three consecutive years with average supply are

followed by three consecutive dry years. Unfortunately, the choice of the state on nature is not in the discretion of the decision makers. The present value of total direct costs – 1,596.1 million € - - is about 45 times higher than the one of total environmental costs (35.1 million €). The direct costs under the BauC scenario are lower than the respective costs under the BauN scenario simply because less water is supplied in the former. On the other hand, the larger water shortage for the agricultural sector under the BauC scenario implies that its associated environmental costs are about 2.4 higher than these costs under the BauN scenario.

7.3 Selection and Analysis of water Management Options

For each one of the aforementioned availability scenarios, we evaluated the impacts of the following management options:

(a) Increasing the annual supply of recycled wastewater (via the connection of additional cities in the region to the existing wastewater treatment plants) by 12 MCM; (scenarios **BauN+R; BauC+R**).

(b) Increasing the annual supply of fresh water by establishing one desalination plant, capable of desalinating 50 MCM of sea water annually, in the second year of the time horizon, and then establishing an identical desalination plant in the seventh year of the planning period. The plants are operated only in periods of freshwater shortage; (scenarios **BauN+D; BauC+D**).

(c) Increasing the annual supply of fresh water via over pumping of ground water from the coastal aquifer, taking into account that it involves significant environmental costs assumed to be equal to 0.64 € cents**;** (scenarios **Bau+OP; BauC+OP**).

(d) Reducing gross annual domestic demand for water by 20% via investment in water conservation; (scenarios **BauN+WC; BauC+WC**).

Before proceeding, we briefly elaborate here on the last management option for the sake of clarity. Conservation efforts in the urban sector in Israel focus on improvements in efficiency, repair, control and monitoring of municipal water systems, controlled exploitation, spatial distribution of new boreholes, promotion of household pressure reducer devices, dual flush toilets, pull handle taps and cisterns with double quantity dispensers, and increased public awareness and media campaigns.

Based on a comprehensive study that was conducted in Israel, the direct costs required to save 20% of water consumed in the domestic sector are 0.12 €.

Table 7-10 presents the acronyms for all combinations of the scenarios for Tel Aviv.

Table 7-10. Abbreviations of Assumed Scenarios for Tel-Aviv's Region

Water Availability ↓	**Institutional Setting →**	**Normal (average) Replenishment of Freshwater**	**Cyclical Replenishment of Fresh Water**
The Current Supply Situation		BauN (reference)	BauC (reference)
Increased Supply of Recycled Water		BauN+R	BauC+R
Increased Supply via seawater desalination		BauN+D	BauC+D
Increased supply via over pumping		BauN+OP	BauC+OP
Reducing gross domestic demand via water conservation		BauN+WC	BauC+WC

7.4 Analysis of the Selected Management Options

Increased supply of recycled water

The BauN+R scenario

Currently, only a few cities in the region are connected to wastewater-treatment plants other than the Shafdan, which supplies recycled water for agricultural irrigation within the region itself, at a level of 16 MCM. Under the BauN+R scenario, we assume the establishment of additional treatment plant which enables the treatment of wastewater from a few additional municipalities and increases the annual amount of recycled water available for irrigation within the region (at the beginning of the time horizon) by 12 MCM. Thus, in this scenario, the supply of recycled water is limited to 28 MCM for the first year of the time horizon. Then, it increases with the increasing consumption of fresh water (0.5% per year) by the domestic and industrial sectors which are connected to the treatment plants. Specifically, we assume that 60% of the **increased** consumption is recycled. By the end of the time horizon, the quantity of recycled water available for irrigation increases to 49 MCM, which is equal to the total demand for recycled water (see Table 7-3). Figure 7-15 and Figure 7-16 depict the unmet demands and the agricultural cultivated areas, respectively.

Comparison with the corresponding Figure 7-3 and Figure 7-4 for the BauN scenario (a reference scenario) shows that the period under which agricultural demand for 74 MCM per year is fully satisfied increases from 4 (Figure 7-3) to 10 (Figure 7-15) years. Moreover, the level of unmet demand under the BauN scenario (i.e. about 40 MCM in the last year of the time horizon) is much higher than the one under the BauN+R scenario (i.e. "only" about 9 MCM in the last year).

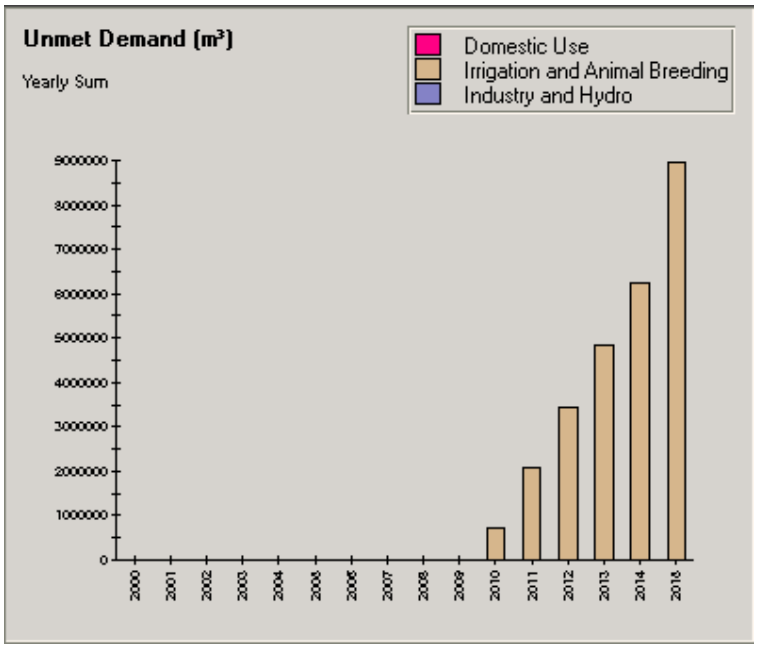


Figure 7-15. Unmet demand under the BauN+R scenario

Inspection of Figure 7-4 and Figure 7-16 clearly illustrates that the aggregate cultivated area under the BauN scenario is significantly smaller than the one under the BauN+R scenario for each year.

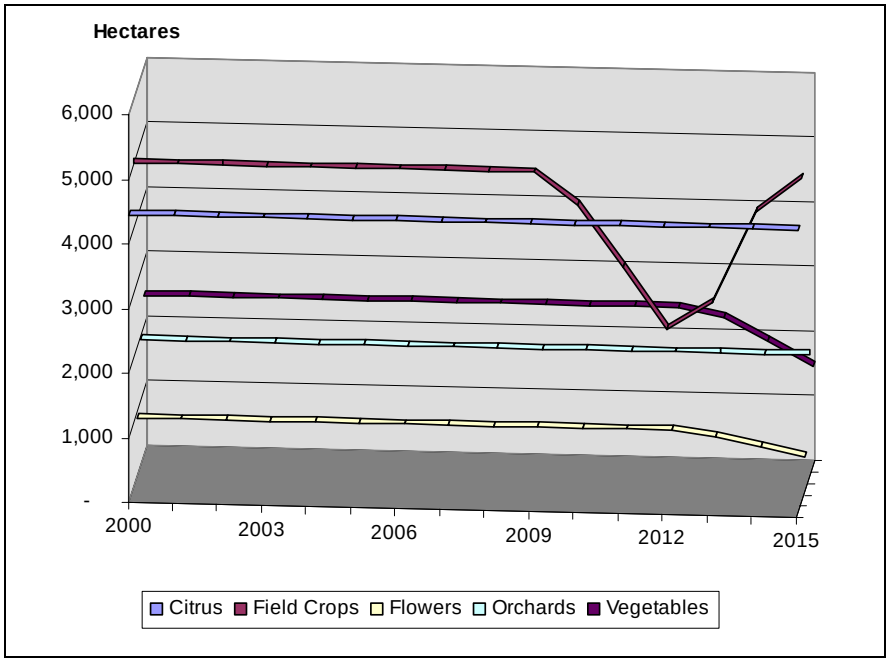


Figure 7-16. The impact of water cuts on the areas planted for various crops under the BauN+R scenario

RCR

To economize space, we do not present the figures showing the annual RCRs for this scenario. We found that the RCR for domestic and industrial demand are very similar to

those derived under the BauN scenario. However, for the agricultural sector, the RCR under the BauN+R scenario is lower by about 2 to 5% than the one under the BauN scenario. The gradual increase in the supply and consumption of recycled water, the price of which, for the agricultural users (0.09 €/m^3), is much lower than its costs (0.14 €/m^3), is the reason for that difference.

Effectiveness and Improvement

The "effectiveness" indices for domestic, industrial and agricultural uses for the BauN+R scenario are presented in Figure 7-17. Comparison with the corresponding Figure 7-6 for the BauN scenario shows that under both scenarios domestic and industrial demands are fully met for all the years of the planning horizon. As for the agricultural sector: the effectiveness is 100% in the first 4 years of the planning period under the BauN scenario and in the first 10 years under the BauN+R scenario. Moreover, under the BauN scenario it steadily drops to a low level of about 45% at 2015 (Figure 7-6), while under the BauN+R scenario it drops "only" to level of about 85% at 2015 (Figure 7-17).

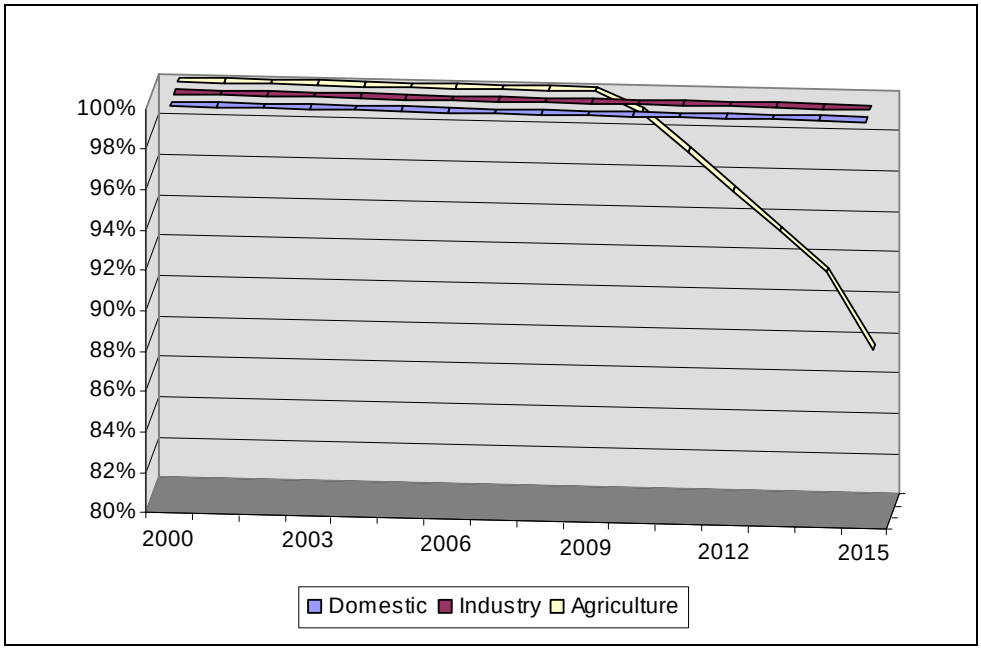


Figure 7-17. Effectiveness for Domestic, Industrial and Agricultural use under the BauN+R scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauN+R scenario with respect to the reference BauN are depicted in Figure 7-18:

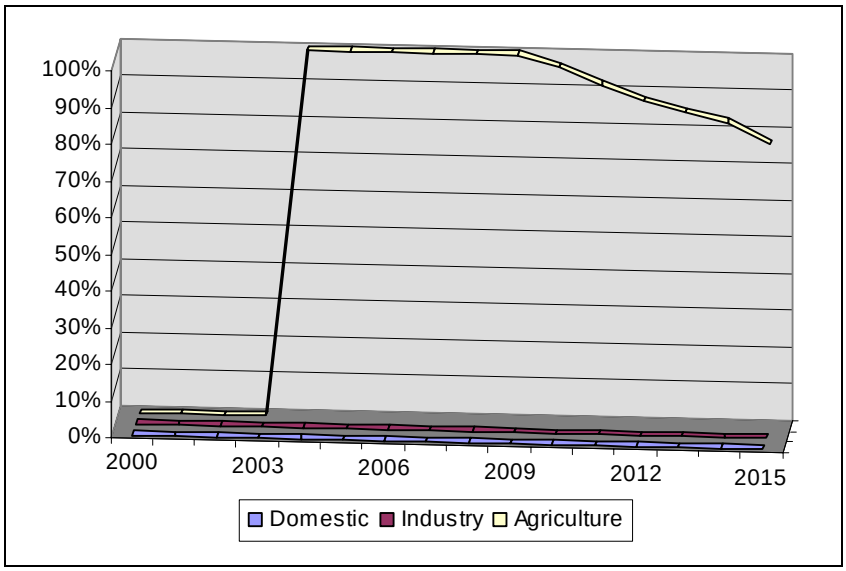


Figure 7-18. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauN+R scenario relative to the reference BauN scenario

Since unmet demand under the reference scenario is limited only to the agricultural sector, there is no improvement of deficit in the domestic and industrial uses. The improvement in agricultural deficit after the fourth year of the time horizon is very significant and equal to 100% for all the years in which agricultural deficit under the BauN+R scenario vanishes.

SWS

As for the welfare indicator, we found that the values of NPV(SWS) associated with the BauN+R scenario(1,533.5 million €) is higher by about 43 million € than the respective value under the reference, BauN, scenario. This implies that **the option to reduce agricultural water shortages by increasing the supply of recycled water is socially profitable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauN+R scenario are presented in Figure 7-19 together with the respective values for the reference BauN scenario.

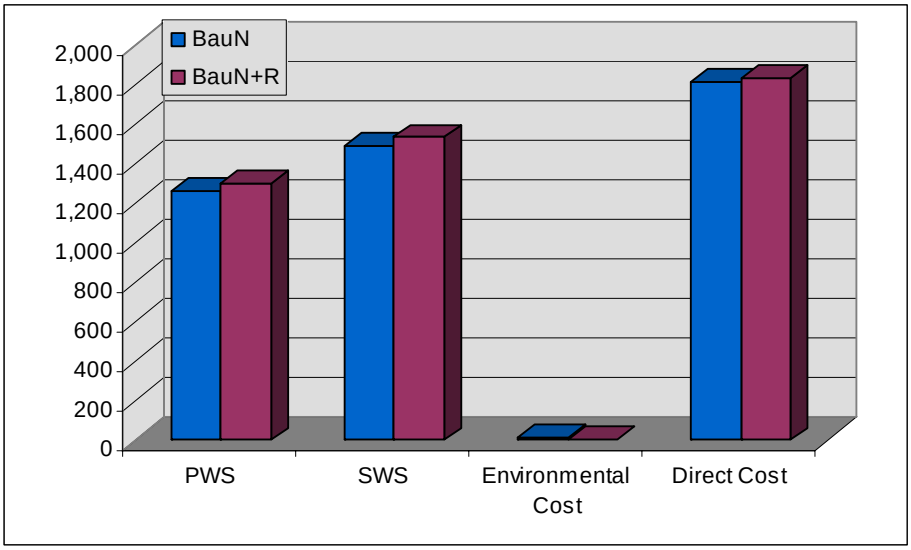


Figure 7-19. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauN+R and the BauN scenarios

The values of both, NPV (SWS) and NPV (PWS) under the BauN+R scenario are higher than the respective values under the reference, BauN scenario. The direct costs under both scenarios are similar (1812.6 and 1831.6 million € under the BauN and under the BauN+R scenarios, respectively. Due to the relatively small water shortage for the agricultural sector under the BauN+R scenario, its associated environmental costs are negligible (1.3 million €).

The BauC+R scenario

Figure 7-20 and Figure 7-21 depict the unmet demands and the agricultural cultivated areas, respectively. Comparison with the corresponding Figure 7-9 and Figure 7-10 for the reference BauC scenario shows an improvement in all sectors especially in the agricultural one. The period under which agricultural demand for 74 MCM per year is fully satisfied decreases from 13 (Figure 7-9) to 11 (Figure 7-20) years.

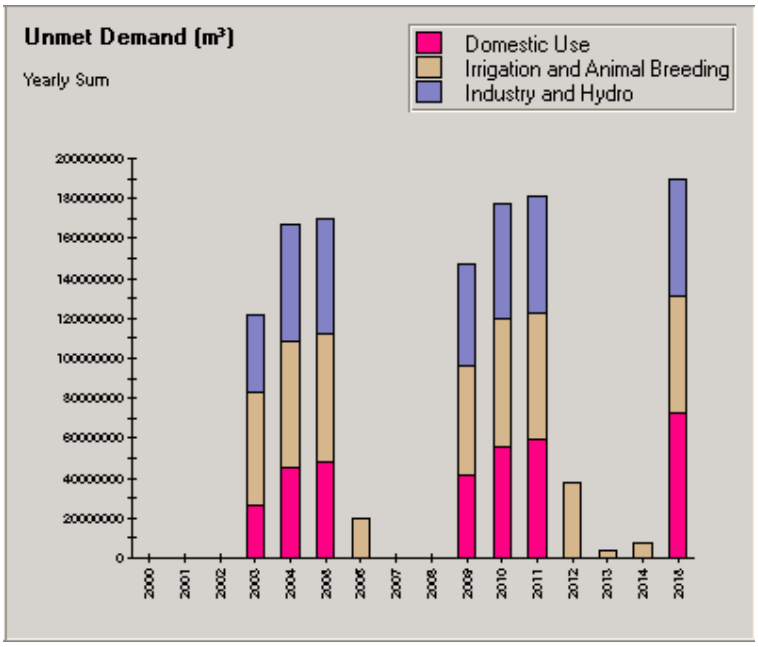


Figure 7-20. Unmet demand under the BauC+R scenario

Inspection of Figure 7-10 and Figure 7-21 clearly illustrates that the aggregate cultivated area under the BauC scenario is significantly smaller than the one under the BauC+R scenario for each year.

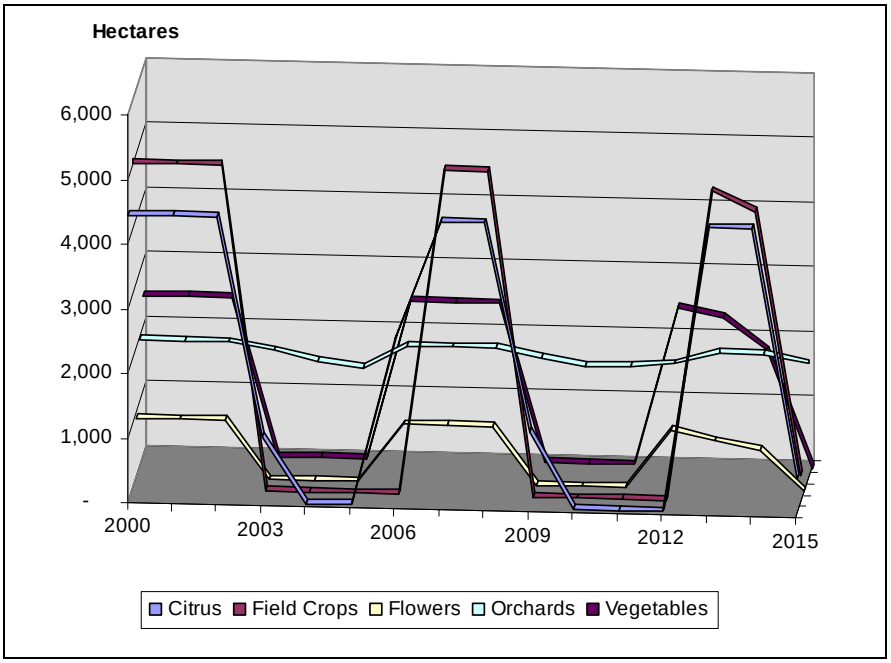


Figure 7-21. The impact of water cuts on the areas planted for various crops under the BauC+R scenario

RCR

We found that the RCRs for domestic and industrial demand are very similar to those derived under the BauC scenario. However, for the agricultural sector, the RCR under

the BauC+R scenario is lower by about 2 to 5% than the one under the BauC scenario. The gradual increase in the supply and consumption of recycled water, the price of which, for the agricultural users (0.09 €/m^3), is much lower than its costs (0.14 €/m^3), is the reason for that difference.

Effectiveness and Improvement

The "effectiveness" indices for domestic, industrial and agricultural uses for the BauC+R scenario are presented in Figure 7-22. Comparison with the corresponding Figure 7-12 for the BauC scenario shows that the effectiveness related to the domestic and industrial uses are the same under both scenarios. As for the agricultural sector: the effectiveness is 100% in the first 4 years of the planning period under the BauC scenario as well as under the BauC+R scenario. From the fifth year and on the effectiveness level is much higher under the BauC+R scenario.

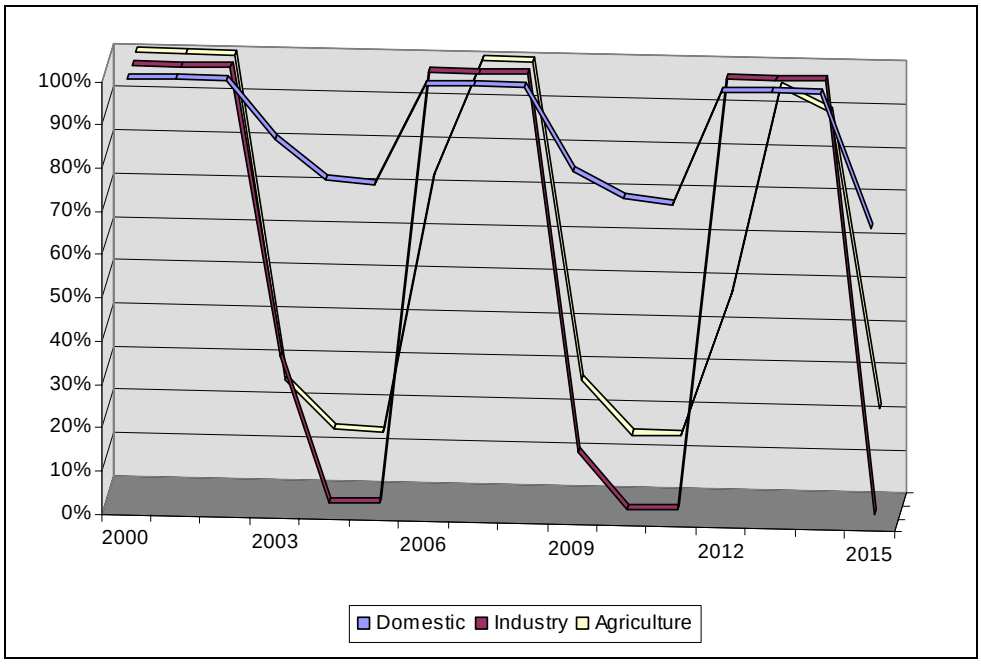


Figure 7-22. Effectiveness for Domestic, Industrial and Agricultural use under the BauC+R scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauC+R, with respect to the reference BauC, are depicted in Figure 7-23

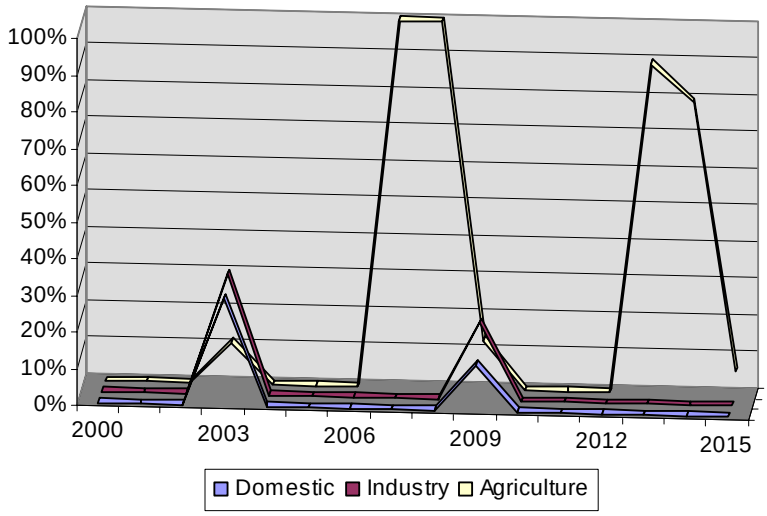


Figure 7-23. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauC+R scenario relative to the reference BauC scenario

Since unmet demand under the reference scenario is similar to that under the BauC+R scenario for both, the industrial and domestic sectors, the improvement is limited to two years. Specifically, the improvement for the industrial sector is 33% in 2003 and 21% in 2009 and the improvement for the domestic sector is 28% in 2003 and 13% in 2009. The significant improvement is in the agricultural sector especially in the years 2007 and 2008 (100%) and in the years 2013 (90%) and 2014 (79%).

SWS

As for the welfare indicator, we found that the values of NPV(SWS) associated with the BauC+R scenario (1,230.7 million €) is higher by about 36 million € than the respective value under the reference, BauC, scenario. This implies that **the option to reduce agricultural water shortages by increasing the supply of recycled water is socially profitable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauC+R scenario are presented in Figure 7-24 together with the respective values for the reference BauC scenario.

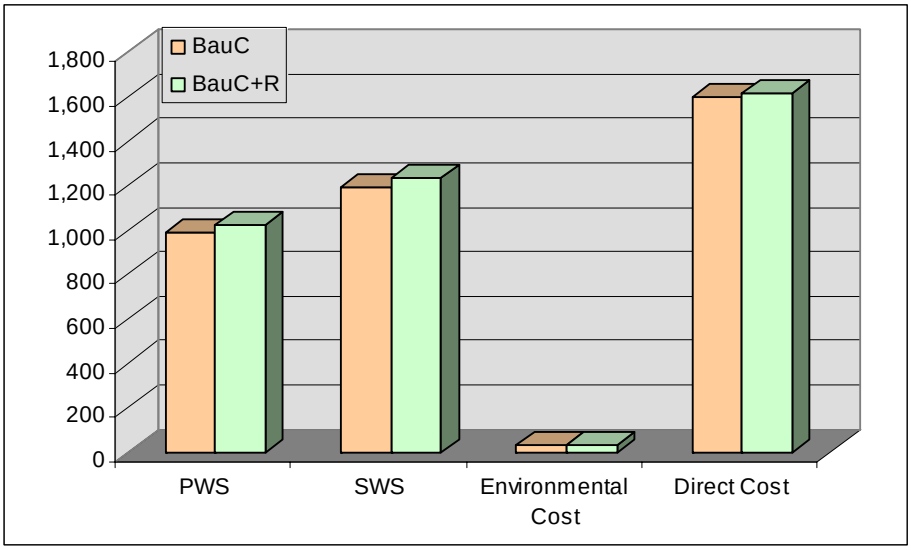


Figure 7-24. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauC+R and the BauC scenarios

The values of both NPV (SWS) and NPV (PWS) under the BauC+R scenario are somewhat higher than the respective values under the reference, BauC scenario. The direct costs under both scenarios are similar (1,596.1 and 1,611.1 million € under the BauC and under the BauC+R scenarios, respectively). Due to the relatively small water shortage for the agricultural sector under the BauC+R scenario, the environmental cost decreases by almost 17% under the BauC+R scenario (29.3 million €) comparing to the reference scenario (35.1 million €).

Increased supply via seawater desalination

The BauN+D scenario

Relative to the basic BauN scenario, this one assumes an increase in the annual supply of fresh water via the establishment of one desalination plant, capable of desalinating 50 MCM of sea water annually, in the second year of the planning horizon and the establishment of an identical desalination plant in the seventh year of the planning period. The desalination plants are only operated in periods of freshwater shortage. We implicitly assume that the desalination plants can supply water to additional regions other than Tel-Aviv, but Tel Aviv's region has the highest priority for this water. When the consumption of desalinated water in Tel Aviv falls short of the total supply, the extra supply is conveyed to other regions (which are not included in our case study).

Under this scenario, the demand of all consumers is met for all the years of the time horizon, and all agricultural plots are fully cultivated (see Figure 7-25).

As shown in Table 7-11, only one of the two desalination plants is operated during the years 2004 to 2015, to meet the deficit in the agricultural sector. The total supply of desalinated water during the planning horizon is 267.8 MCM.

Table 7-11. Quantities of Desalinated Water Under the BauN+D Scenario (MCM)

Desalination Plant	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1st	5.5	9.2	12.0	14.8	17.7	20.6	23.6	26.7	29.7	32.8	36.0	39.2
2nd	-	-	-	-	-	-	-	-	-	-	-	-
Total	5.5	9.2	12.0	14.8	17.7	20.6	23.6	26.7	29.7	32.8	36.0	39.2

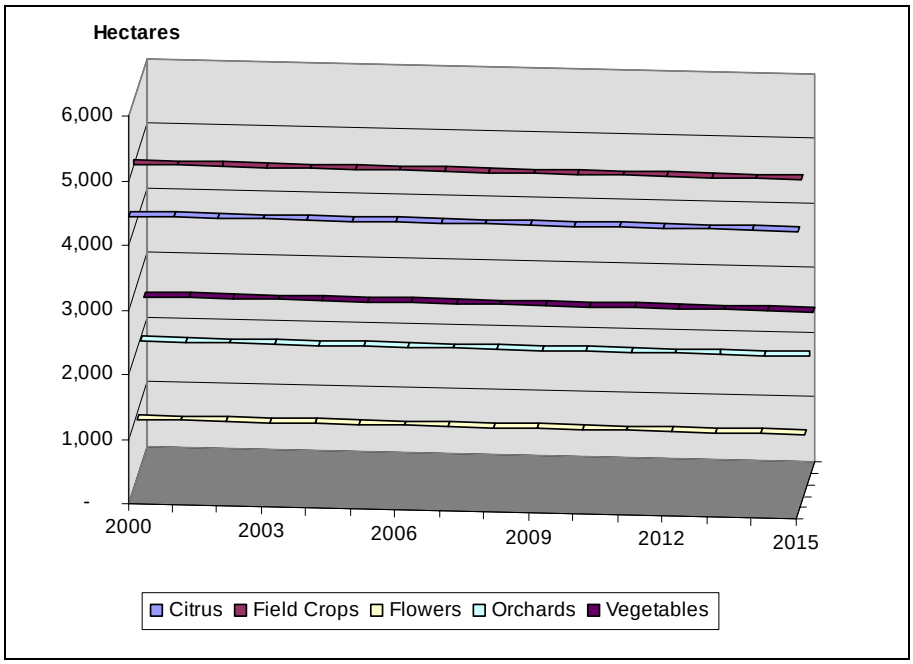


Figure 7-25. The impact of water cuts on the areas planted for various crops under the BauN+D scenario

RCR

The RCR values for the industrial and agricultural users under this scenario are quite similar to those of the reference BauN scenario, but there is a notable difference with respect to the domestic sector. Under the reference scenario, the RCR values for the domestic sector are practically stable at a level of 143%, whereas under the BauN+D scenario, they decline steadily from the fifth year of the planning horizon, when the expensive desalinated plants are being operated, reaching a level of 110% in the year 2015.

Effectiveness and Improvement

The "effectiveness" indices for domestic, industrial and agricultural uses for the BauN+D scenario are presented in Figure 7-26. Comparison with the corresponding Figure 7-6 for the BauN scenario shows that under both scenarios domestic and industrial demands are fully met for all the years of the planning horizon. As for the agricultural sector: the effectiveness is 100% in all years of the planning period under the

BauN+D scenario while under the BauN scenario it steadily drops to a low level of about 45% at 2015 (Figure 7-6).

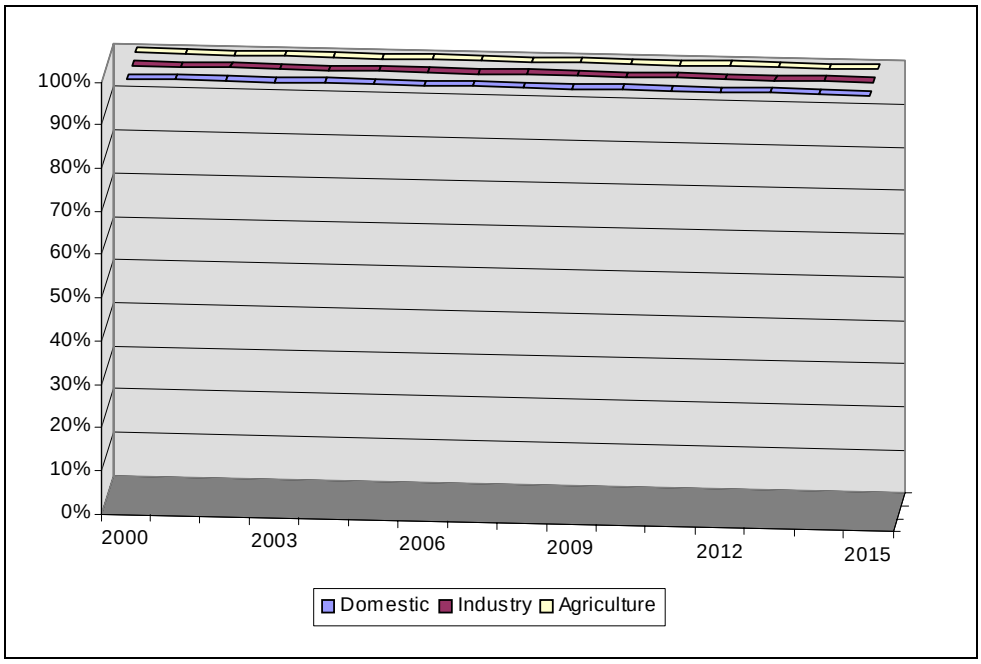


Figure 7-26. Effectiveness for Domestic, Industrial and Agricultural use under the BauN+D scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauN+D with respect to the reference BauN are depicted in Figure 7-27. Since unmet demand under the reference scenario is limited only to the agricultural sector, there is no improvement of deficit in the domestic and industrial uses. The improvement in agricultural deficit after the fourth year of the time horizon is very significant and equal to 100% for all the years in which agricultural deficit under the BauN+D scenario vanishes.

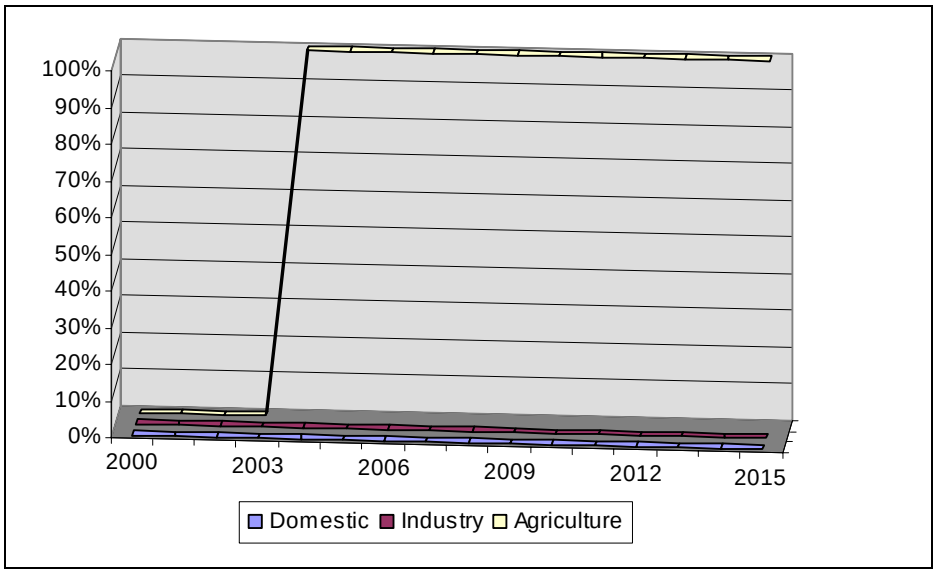


Figure 7-27. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauN+D scenario relative to the reference BauN scenario

SWS

As for the welfare indicator, the values of NPV(SWS) associated with the BauN+D scenario (1,463 million €) is lower by about 27.7 million € than the respective value under the reference, BauN, scenario. **Thus, it can be concluded that under normal weather conditions, meeting all unmet demands via the establishment of desalination plants (the BauN+D) scenario is socially undesirable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauN+D scenario are presented in Figure 7-28 together with the respective values for the reference BauN scenario.

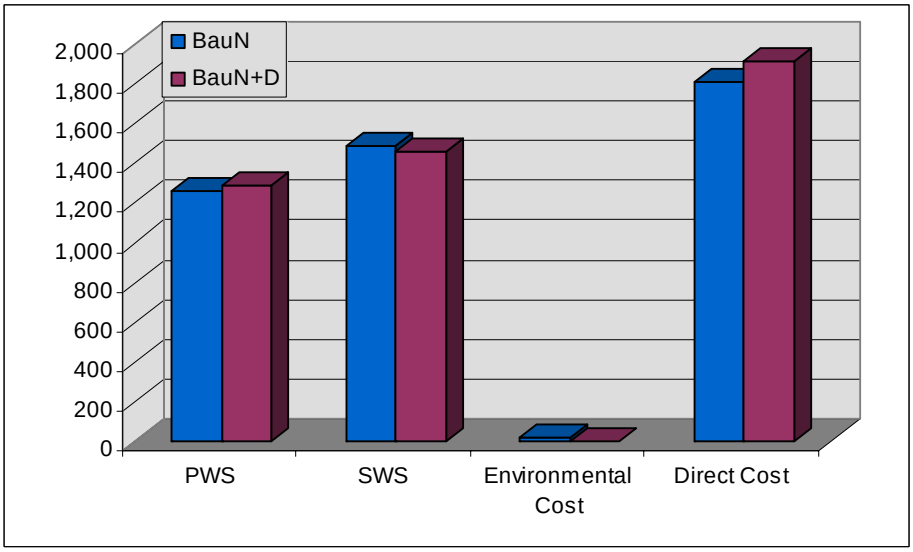


Figure 7-28. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauN+D and the BauN scenarios

While NPV(SWS) under the BauN+D scenario is smaller than the one under the reference BauN scenario, the relationships are reversed with respect to the present values of private welfare surpluses, NPV(PWS). The reduction in social welfare surplus is attributed to the utilization of costly desalinated water to overcome the water deficit in the agricultural sector. Since the price of fresh water charged to each one of the users is independent of the water source (see Table 7-8), the private welfare surplus increases (from 1263.7 million € under the BauN scenario to 1292.2 million € under the BauN+D scenario) due to the increased consumption by the agricultural sector. This result may explain the political pressure of the agricultural lobby in Israel to increase water supply via desalination without changing the agricultural water prices. The direct costs under the BauN+D scenario (1,913.8 million €) are higher by 101.2 million € than those associated with the reference scenario. Due to the absence of water shortage for the agricultural sector under the BauC+D scenario, its associated environmental cost is zero.

The BauC+D scenario

Unlike the parallel scenario under a stable supply of fresh water, BauN+D, where the demand of all consumers is met for all the years of the time horizon, the unmet demands in dry years under this scenario are quite large. Despite the desalination, the region still suffers from water shortages during the dry periods. This is especially true for the first dry period when only one desalination plant is available. Inspection of Figure 7-29 shows that almost all the water cuts were imposed on the agricultural sector; nevertheless, the industrial and the domestic sectors suffered some small water cuts as well.

Figure 7-29 and Figure 7-30 depict the unmet demands and the agricultural cultivated areas, respectively. Comparison with the corresponding Figure 7-9 and Figure 7-10 for the reference BauC scenario shows an improvement in all sectors especially in the agricultural sector. The period under which agricultural demand for 74 MCM per year is not met decreases from 13 (Figure 7-9) to 7 years (Figure 7-29). The level of unmet demand under the BauC scenario (about 19 MCM in the last year of the time horizon) is higher than the one under the BauC+D scenario ("only" 11 MCM in the last year).

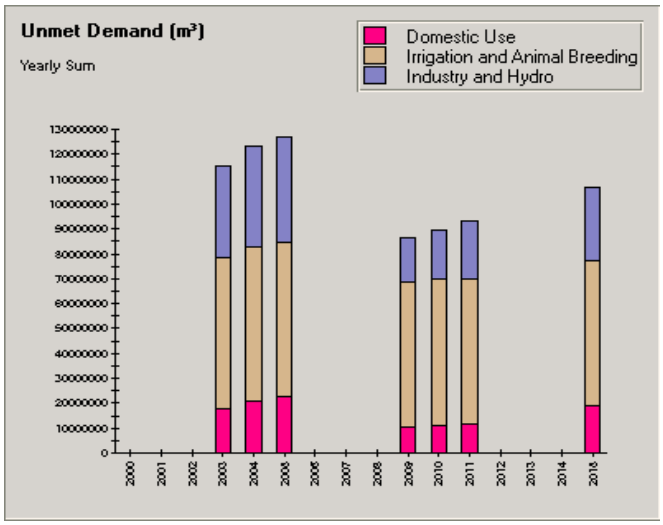


Figure 7-29. Unmet demand under the BauC+D scenario

Inspection of Figure 7-10 and Figure 7-30 clearly illustrates that the aggregate cultivated area under the BauC+D scenario is significantly larger than the one under the BauC for each year. But still, the agricultural sector faces significant water deficit during dry periods even in the presence of desalination plants.

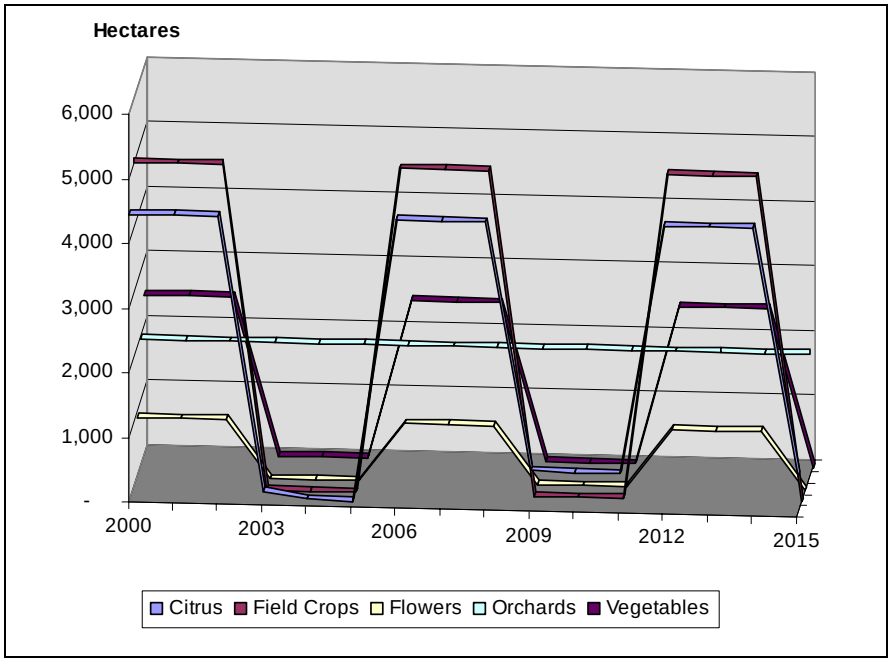


Figure 7-30. The impact of water cuts on the areas planted for various crops under the BauC+D scenario

The quantities supplied from the two desalination plants are summarized in Table 7-12.

Table 7-12. Quantities of Desalinated Water Under the BauC+D Scenario (MCM)

Desalination Plant	2003-2005	2006	2007	2008	2009-2011	2012	2013	2014	2015
1st	50.0	12.4	-	-	50.0	-	-	-	50.0
2nd	-	-	14.8	17.7	50.0	29.9	32.8	36	50.0
Total	50.0	12.4	14.8	17.7	100.0	29.9	32.8	36	100.0

The total amount of desalinated water during the planning horizon is 692.2 MCM, more than 2.5 times higher than the total under the reference BauC scenario. During the first series of dry years, 2003 to 2005, the first (and only) desalination plant supplied at its full capacity in each of the following two years. The same observation applies to both desalination plants during the second series of dry years, 2009 to 2011 and in 2015.

RCR

The RCR values for the agricultural sector under this scenario are quite similar to those under the basic BauC scenario; however there is a notable difference with respect to the industrial and domestic sectors.

Table 7-8 shows that while the consumer price of fresh water to a specific consumer is independent of the water source, the cost of desalinated water is three times higher than the cost of local drills and almost twice as high as the cost of imported water. Thus, the larger the share of desalinated water in the total supply to a specific consumer, the smaller the RCR value associated with this consumer. This explains why the domestic-associated RCR values dropped in dry years, to levels of about 100% during the first dry period and to about 80% during the second one, while under the reference BauC scenario, they fluctuated around 150%.

Under the basic scenario, the industry-associated RCR values drop to zero in dry years (Figure 7-12), only because the industry does not receive any fresh water. In the BauC+D scenario, it fluctuates around 130% and does not drop sharply during dry years because almost all the desalinated water is supplied to only the domestic sector.

Effectiveness and Improvement

The "effectiveness" indices for domestic, industrial and agricultural uses for the BauC+D scenario are presented in Figure 7-31. Comparison with the corresponding Figure 7-12 for the reference BauC scenario shows that under the current scenario, the level of effectiveness in all sectors is much higher than the one under the reference scenario, especially during the dry years period

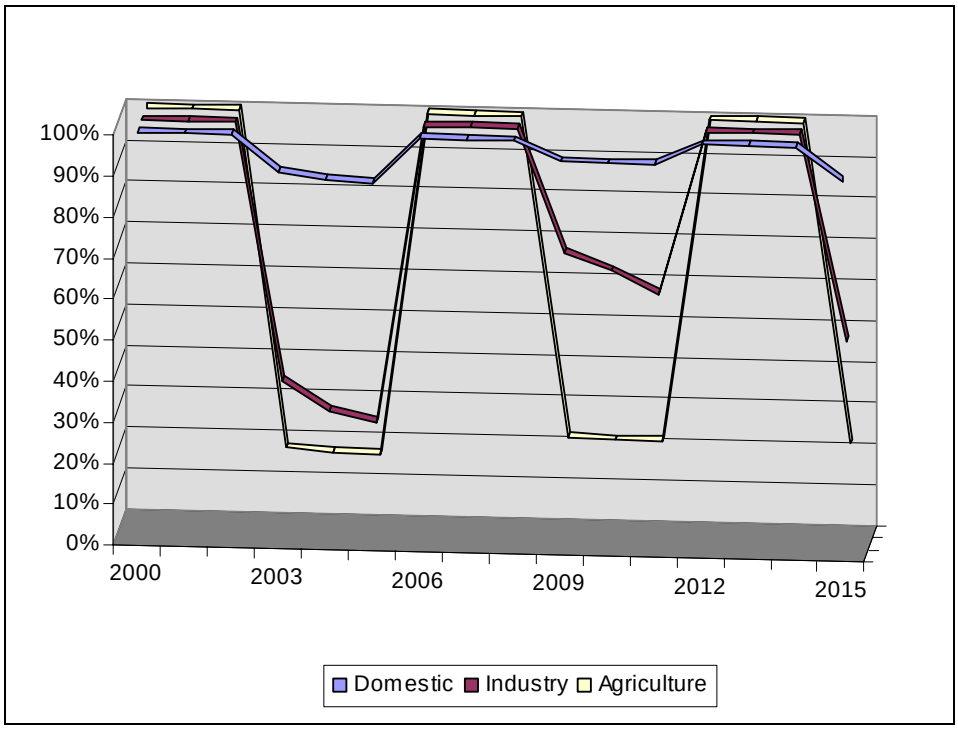


Figure 7-31. Effectiveness for Domestic, Industrial and Agricultural use under the BauC+D scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauC+D relative to the reference BauC are depicted in Figure 7-3**2.**

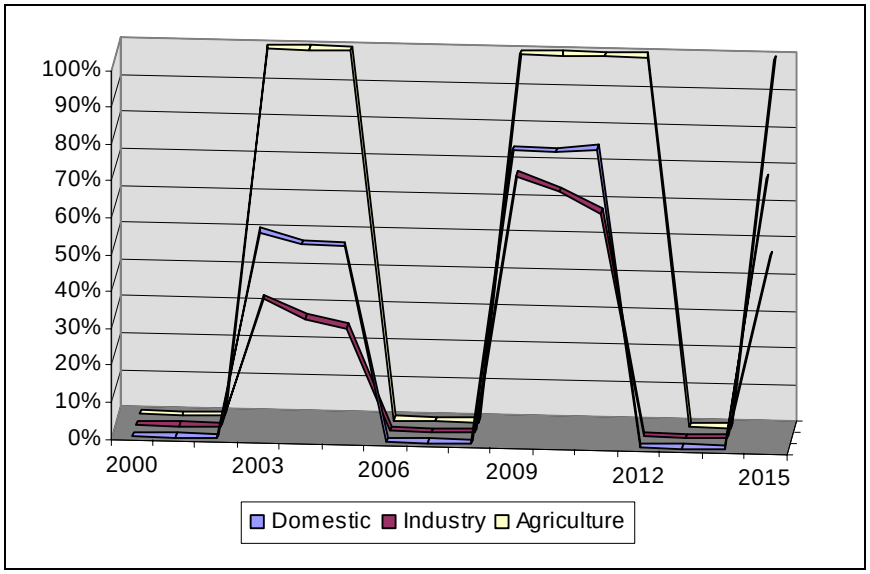


Figure 7-32. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauC+D scenario relative to the reference BauC scenario

The improvement in the deficit of all sectors during the dry periods is very significant. .

SWS

As for the welfare indicator, we found that the values of NPV(SWS) associated with the BauC+D scenario (1,175.1 million €) is lower by about 20 million € than the respective value under the reference, BauC, scenario. This implies that **the option to reduce agricultural water shortages by increasing the supply of recycled water is socially undesirable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauC+D scenario are presented in Figure 7-33 together with the respective values for the reference BauC scenario.

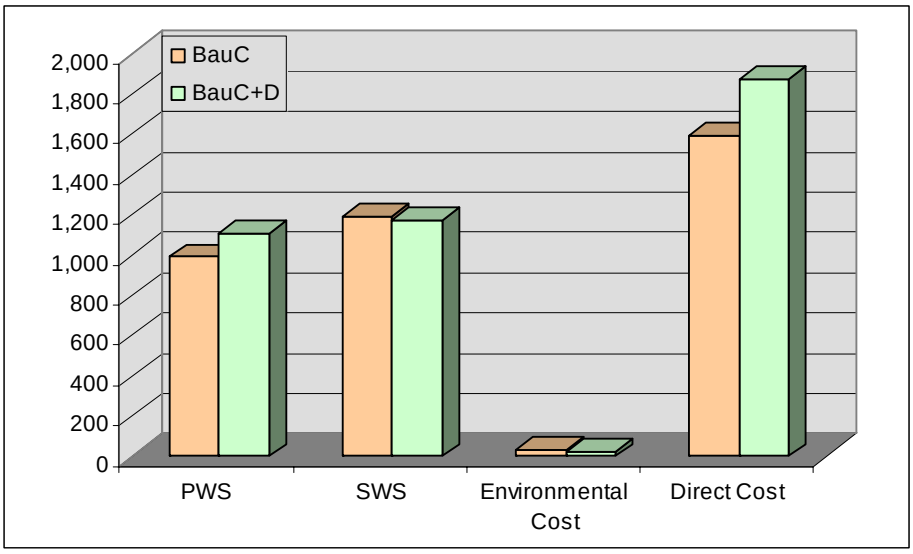


Figure 7-33. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauC+D and the BauC scenarios

As illustrated above, NPV(SWS) under the BauC+D scenario is smaller than the one under the reference BauN scenario. Like the result of the previous, BauN+D scenario, the present values of private welfare surpluses, NPV (PWS) – 1,110.4 million € – is higher than the one associated with the reference scenario. Namely, the social and the private interests diverge. The direct costs under the BauC+D scenario (1875.6 million €) are higher by 279.5 million € than those associated with the reference scenario. Due to the reduction of water shortage for the agricultural sector under the BauC+D scenario, its associated environmental cost reduced from 35.1 million € under the reference scenario to 25.2 million € under the BauC+D scenario.

Increased supply via over pumping

The BauN+OP scenario

Relative to the basic BauN scenario, this one assumes an increase in the annual supply of fresh water via over pumping of water from the coastal aquifer to overcome water

deficits. Covering water shortage via over pumping involves very high environmental costs assumed to be equal to 64 € cents.

Under this scenario, the demand of all consumers is met for all the years of the time horizon, and all agricultural plots are fully cultivated (see Figure 7-34).

The quantities of over pumping are presented in Table 7-13. The total level of over pumping during the planning horizon is 267.8 MCM, and is equal to the level of desalination under the BauN+D scenario (see Table 7-11).

Table 7-13. Quantities of Over Pumping Under the BauN+OP Scenario (MCM)

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
5.5	9.4	11.7	15.1	17.5	20.9	23.4	26.9	29.5	32.8	36.0	39.2

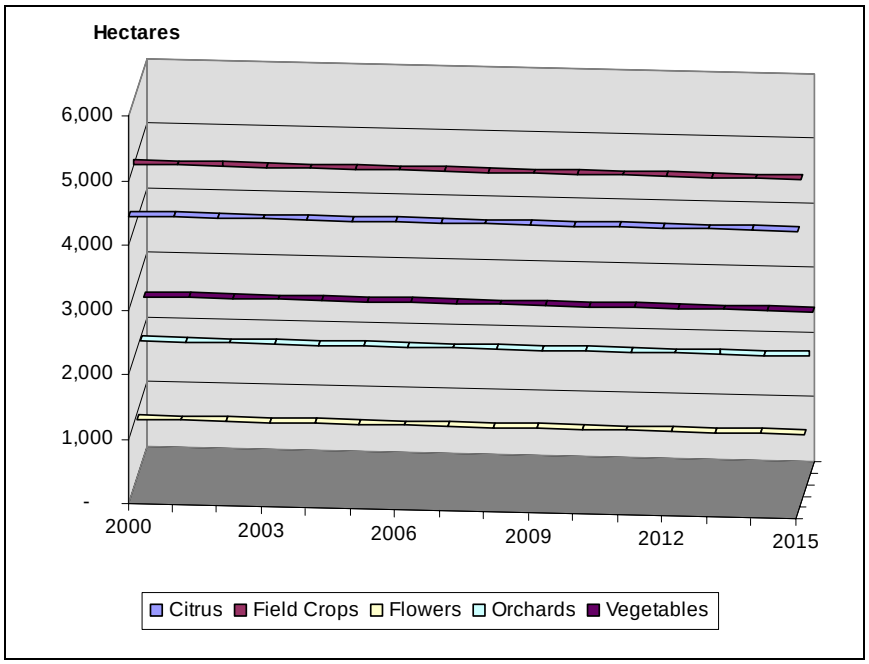


Figure 7-34. The impact of water cuts on the areas planted for various crops under the BauN+OP scenario

RCR

The shapes of the RCR vs time curves for all users are similar to those obtained under the BauN+D scenario. Since the cost associated with over pumping (64 € cents per cubic meter) is higher than the one associated with desalination (60 € cents), the RCR values associated with BauN+OP are somewhat lower than those associated with BauN+D.

Effectiveness and Improvement

The "effectiveness" for domestic, industrial and agricultural uses for the BauN+OP scenario is presented in Figure 7-35. The absence of water deficit for all users during the whole time horizon implies "effectiveness" of 100% for each user (Figure 7-35). Comparison with the corresponding Figure 7-6 for the BauN scenario shows that under

both scenarios domestic and industrial demands are fully met for all the years of the planning horizon. As for the agricultural sector: while the effectiveness is 100% in all years of the planning period under the BauN+OP scenario it steadily drops to a low level of about 45% at 2015 under the reference BauN scenario (Figure 7-6).

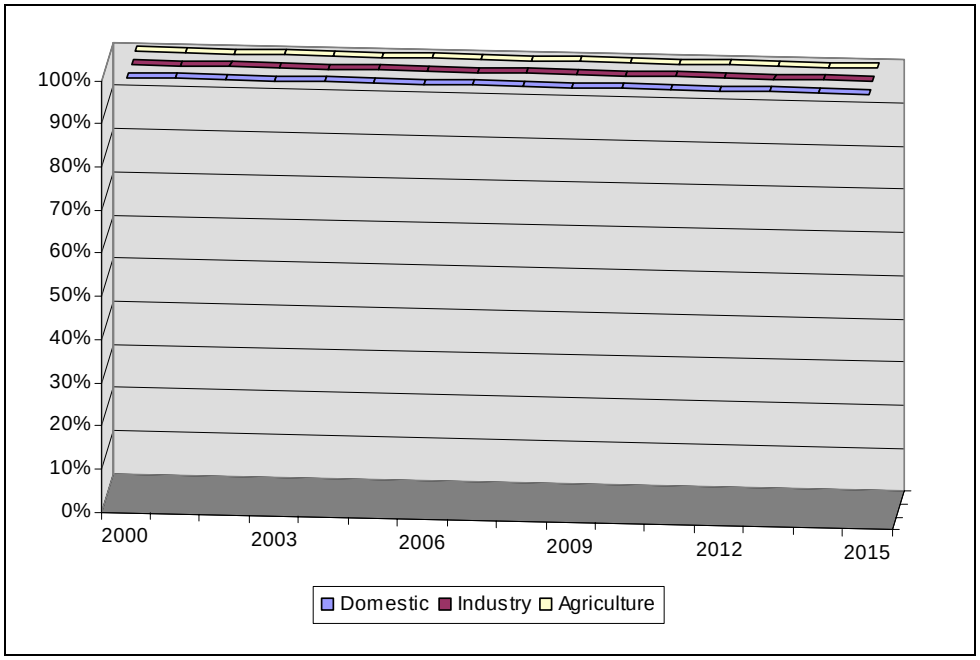


Figure 7-35. Effectiveness for Domestic, Industrial and Agricultural use under the BauN+OP scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauN+OP with respect to the reference BauN are depicted in Figure 7-36:

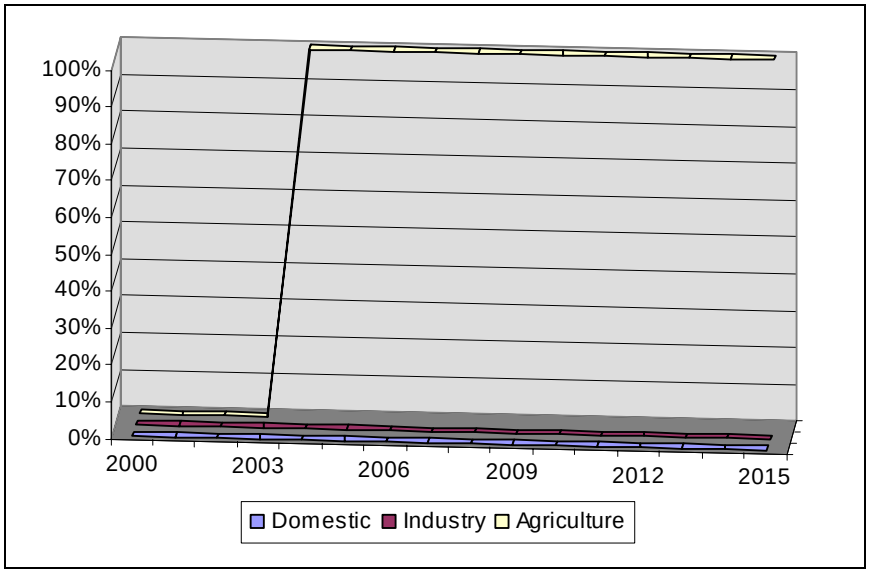


Figure 7-7-36. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauN+OP scenario relative to the reference BauN scenario

Since unmet demand under the reference scenario is limited only to the agricultural sector, there is no improvement of deficit in the domestic and industrial uses. The improvement in agricultural deficit after the fourth year of the time horizon is very significant and equal to 100% for all the years in which agricultural deficit under the BauN+OP scenario vanishes.

SWS

The values of NPV(SWS) associated with the BauN+OP scenario(1,422.7 million €) is lower by about 68 million € than the respective value under the reference, BauN, scenario. The high (environmental) cost associated with over-pumping explains the above reduction.

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauN+OP scenario are presented in Figure 7-37 together with the respective values for the reference BauN scenario.

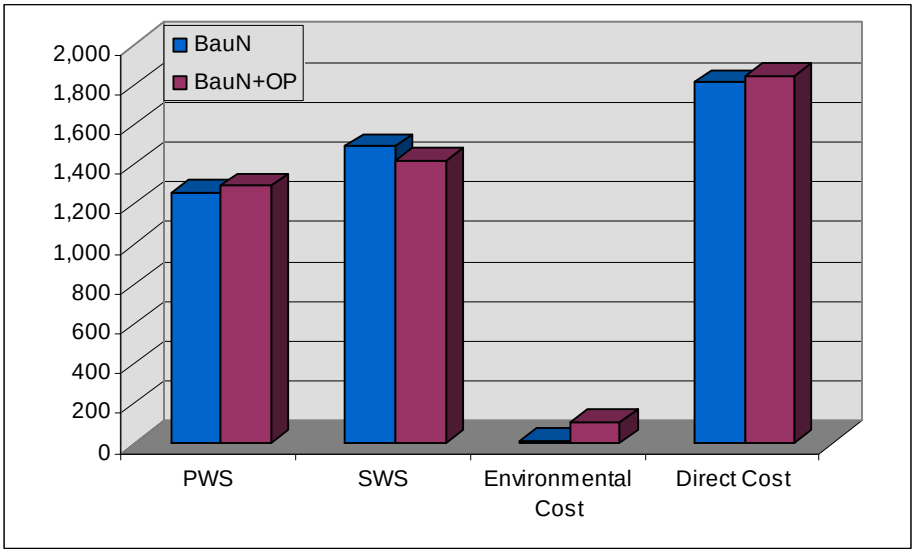


Figure 7-37. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauN+OP and the BauN scenarios

As illustrated in the figure, NPV(SWS) under the BauN+OP scenario is smaller than the one under the reference BauN scenario. The relationships are reversed with respect to the present values of private welfare surpluses, NPV (PWS). The reduction in social welfare surplus is attributed to the utilization of costly over pumped water to overcome the water deficit in the agricultural sector. Since the price of fresh water charged to each one of the users is independent of the water source (see Table 7-8), the private welfare surplus increases (from 1263.7 million € under the BauN scenario to 1292.3 million € under the BauN+OP scenario) due to the increased consumption by the agricultural sector. The values of NPV(PWS) under the BauN+D and the BauN+OP are exactly the same. The direct costs under the BauN+OP scenario (1,846.5 million €) are higher by 34 million € than those associated with the reference scenario. Due to the absence of water

shortage for the agricultural sector under the BauN+D scenario, the environmental cost associated with the reduction of cultivated area vanishes. However, the environmental costs associated with **over-pumping** of ground water from the coastal aquifer are very high, 107.6 million €.

The BauC+OP scenario

Like the previous scenario, in the current scenario the demand of all consumers is met during all the years of the time horizon and all agricultural plots are fully cultivated.

The quantities of over pumping are presented in Table 7-14. The total level of over pumping during the planning horizon is very large, 1,395.1 MCM. It is much higher than the total amount of desalination under the BauN+D scenario (see Table 7-11), since annual desalination cannot exceed the capacity of the desalination plants while over pumping in our analysis is not administratively constrained.

Table 7-14. Quantities of Over Pumping Under the BauC+OP Scenario (MCM)

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
54.3	168.4	171.2	25.6	7.9	18	175.7	185.6	188.7	36.6	32.7	36	194.5

RCR

The shapes of the RCR vs time curves for all users are similar to those obtained under the BauC+D scenario. Since the cost associated with over pumping (64 € cents per cubic meter) is higher than the one associated with desalination (60 € cents), the RCR values associated with BauC+OP are somewhat lower than those associated with BauN+D.

Effectiveness and Improvement

The absence of water deficit for all users during the whole time horizon implies "effectiveness" of 100% for each user (Figure 7-38). Comparison with the corresponding Figure 7-12 for the BauC scenario illustrates the significant impact of over-pumping on water deficits. Indeed, the percent-improvement of water deficit in all sectors under the BauC+OP scenario relative to the reference BauC scenario, especially during the dry periods, is impressive (Figure 7-39).

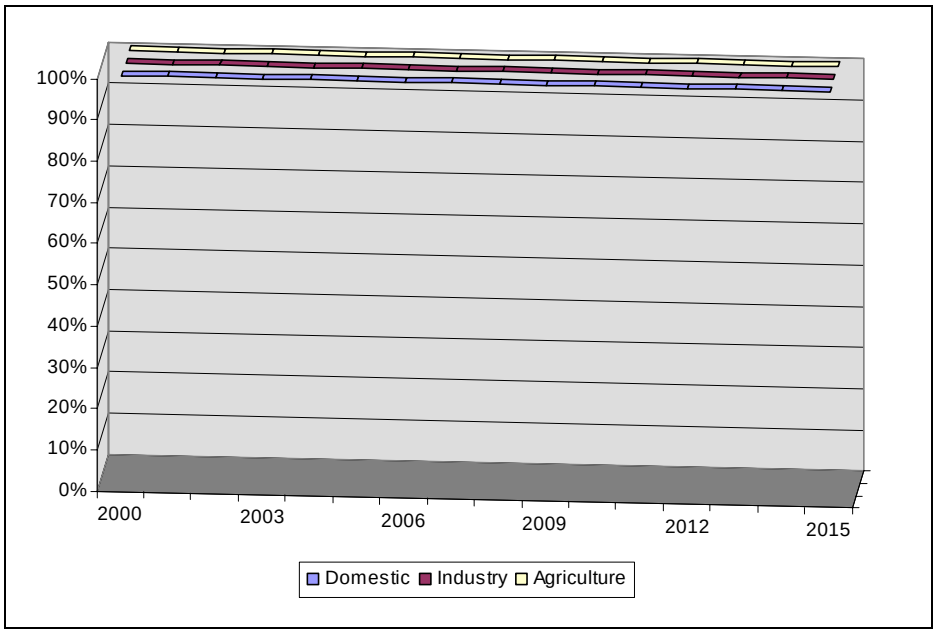


Figure 7-38. Effectiveness for Domestic, Industrial and Agricultural use under the BauC+OP scenario

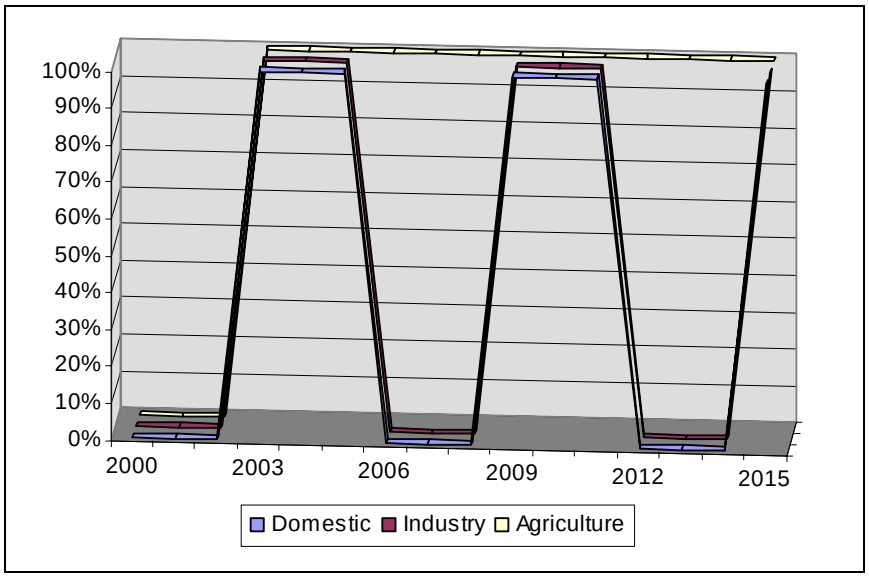


Figure 7-39. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauC+OP scenario relative to the reference BauC scenario

SWS

The values of NPV(SWS) associated with the BauC+OP scenario (958 million €) is lower by 236.5 million € than the respective value under the reference, BauC, scenario. This implies that **the option to reduce agricultural water shortages via over-pumping is socially undesirable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauC+OP scenario are presented in Figure 7-40 together with the respective values for the reference BauC scenario.

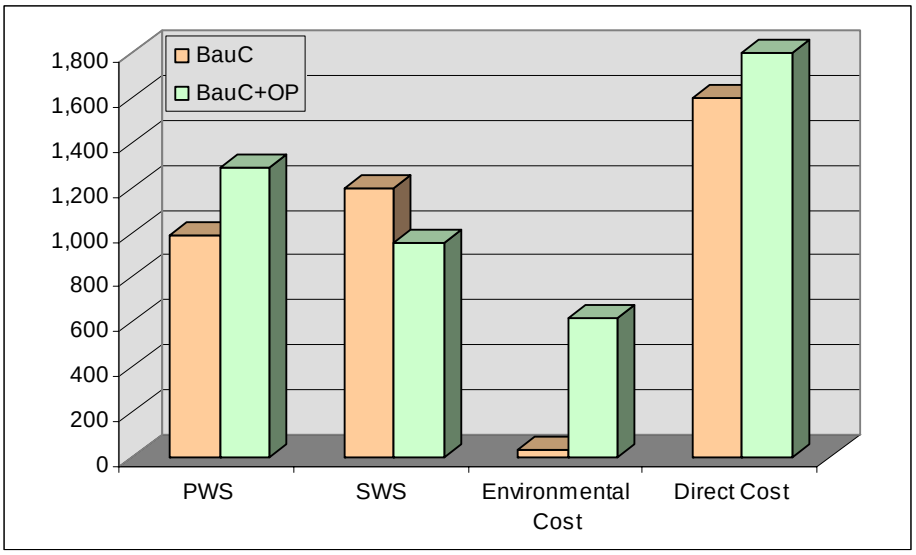


Figure 7-40. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauC+OP and the BauC scenarios

As illustrated in the Figure, NPV(SWS) under the BauC+OP scenario is smaller than the one under the reference BauC scenario. The relationships are reversed with respect to the present values of private welfare surpluses, NPV (PWS). The reduction in social welfare surplus is attributed to the utilization of costly over pumped water to overcome the water deficit in the agricultural sector. Since the price of fresh water charged to each one of the users is independent of the water source (see Table 7-8), the private welfare surplus increases significantly (from 990.2 million € under the BauC scenario to 1292.3 million € under the BauC+OP scenario) due to the increased consumption by the agricultural sector. The values of NPV(PWS) under the BauN+D ,the BauN+OP and the BauC+OP are exactly the same. The direct costs under the BauC+OP scenario (1,800.0 million €) are higher by 203.9 million € than those associated with the reference scenario. Due to the absence of water shortage for the agricultural sector under the BauC+OP scenario, the environmental cost associated with the reduction of cultivated area vanishes. However, the environmental costs associated with **over-pumping** of ground water from the coastal aquifer are very big, 618.7 million €.

Reduction of gross domestic demand via water conservation

In the next two scenarios we assume that gross annual domestic demand for water can be reduced by 20% - - via investment in water conservation - - **without affecting the water benefits or values accrue to domestic consumers**. A simple example can explain our assumption in the above emphasized statement. In the absence of conservation the value of water to domestic consumer who consumes a **"gross**

amount" of 100 cubic meters per year from local drills is 100x(0.6) = 60 € (see Table 7-9). The direct cost associated with this consumption is 100x (0.2) =20 € (see Table 7-8). We assume that only 80% of the gross amount should be regarded as an **"effective consumption,"** i.e., actually serves the consumer's needs while the remaining 20% are wasted. The waste can be avoided by increasing the efficiency of water consumption via investment in water conservation. In other words, the value accrue to the domestic consumer from the consumption of a gross amount of 100 m^3 (60 € in our example) is identical to the value obtained from the consumption of an effective amount of 80 m^3. Recalling that the direct conservation costs are 12 € cents, the total direct costs associated with the supply (from local drills) of 80 m^3 of effective water is 80x0.2+20x0.12= 18.4 € cents.

The BauN+WC Scenario

Under this scenario, the demand of all consumers is met for all the years of the time horizon, and all agricultural plots are fully cultivated. The water deficit in the agricultural sector that existed under the reference, BauN scenario, vanishes due to the reduction in the demand of the domestic consumers.

RCR

The RCR values for the industrial and domestic users under this scenario are quite similar to those of the reference BauN scenario, but there is a small difference with respect to the agricultural sector. Under the BaucN+WC scenario, the RCR values for the agricultural sector are practically stable at a level of 80%, whereas under the reference scenario, they decline steadily from the fifth year of the planning horizon, reaching a level of 72% in the year 2015.

Effectiveness and Improvement

The "effectiveness" for domestic, industrial and agricultural uses for the BauN+WC scenario is presented in Figure 7-41. In the absence of water deficit the level of effectiveness is 100% for each one of the three sectors. Comparison with the corresponding Figure 7-6 for the BauN scenario shows that under both scenarios domestic and industrial demands are fully met for all the years of the planning horizon. As for the agricultural sector: the effectiveness is 100% in all years of the planning period under the BauN+WC scenario while under the BauN scenario it steadily drops to a low level of about 45% at 2015 (Figure 7-6).

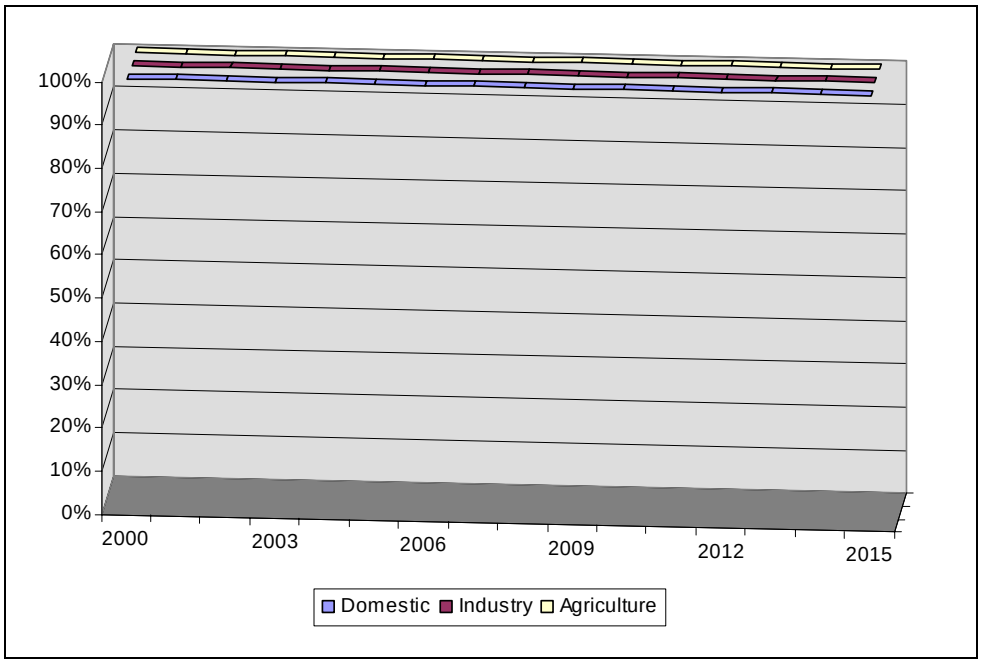


Figure 7-41. Effectiveness for Domestic, Industrial and Agricultural use under the BauN+WC scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauN+WC with respect to the reference BauN are depicted in Figure 7-42.

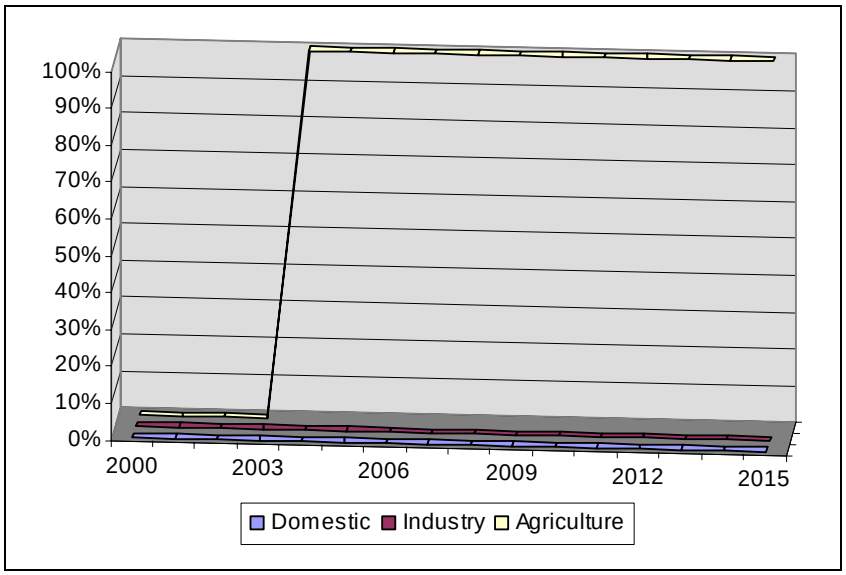


Figure 7-42. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauN+WC scenario relative to the reference BauN scenario

Since unmet demand under the reference scenario is limited only to the agricultural sector, there is no improvement of deficit in the domestic and industrial uses. The improvement in agricultural deficit after the fourth year of the time horizon is very significant and equal to 100% for all the years in which agricultural deficit under the BauN+WC scenario vanishes.

SWS

As for the welfare indicator, the values of NPV(SWS) associated with the BauN+WC scenario (1,504.7 million s) is higher by 14 million € than the respective value under the reference, BauN, scenario. This implies that **the option to reduce agricultural water shortages by the water conservation approach (BaucN+WC) is socially profitable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauN+WC scenario are presented in Figure 7-43 together with the respective values for the reference BauN scenario.

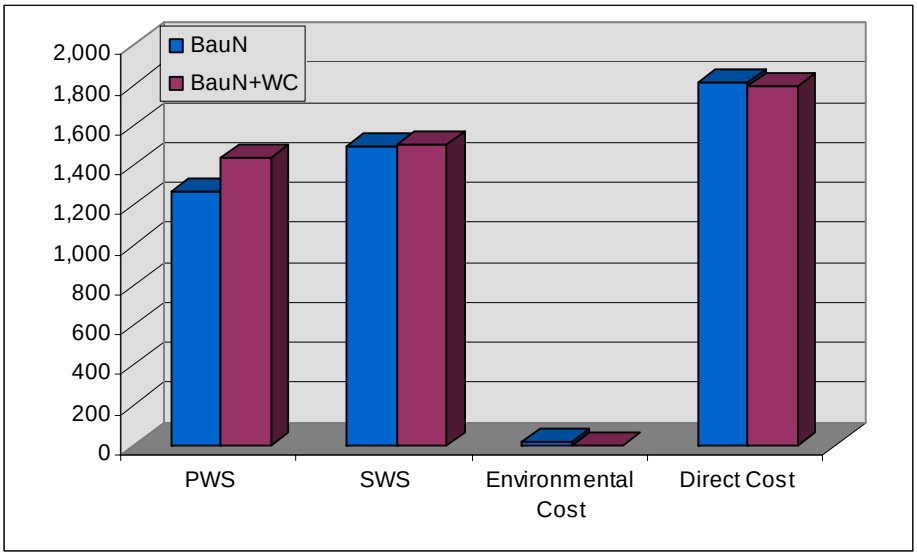


Figure 7-43. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauN+WC and the BauN scenarios

The value of both NPV (SWS) and NPV (PWS) under the BauN+WC scenario are higher than the respective values under the reference, BauN scenario, implying that the private and the social interests coincides. The direct costs under both scenarios are relatively similar (1812.6 and 1792.6 million € under the BauN and under the BauN+WC scenarios, respectively. The direct costs for the BauN+WC scenario include water conservation costs of about 61 million €. Due to the lack of water shortage for the agricultural sector under the BauN+WC scenario, its associated environmental costs are zero.

The BauC+WC Scenario

Unlike the parallel scenario under a stable supply of fresh water, BauN+WC, where the demand of all consumers is met for all the years of the time horizon, the unmet demands in dry years under this scenario are quite large. During the dry years, the supply was reduced to consumers of all sectors, but agricultural and industrial consumers bore the brunt of the necessary cuts. Figure 7- 44 and Figure 7-45 depict the unmet demands and the agricultural cultivated areas, respectively. Comparison with the corresponding Figure 7-9 and Figure 7-10 for the reference BauC scenario shows an improvement in all sectors

especially in the agricultural sector. The period under which agricultural demand for 74 MCM per year is not met decreases from 13 (Figure 7-9) to 7 years (Figure 7-44).

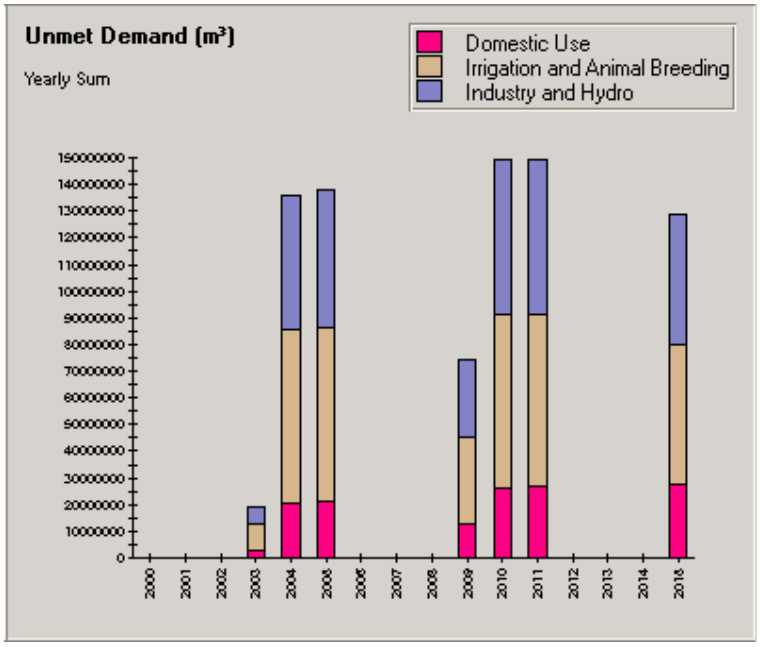


Figure 7-44. Unmet demand under the BauC+WC scenario

Inspection of Figure 7-10 and Figure 7-45 clearly illustrates that the aggregate cultivated area under the BauC scenario is significantly smaller than the one under the BauC+WC scenario for each year.

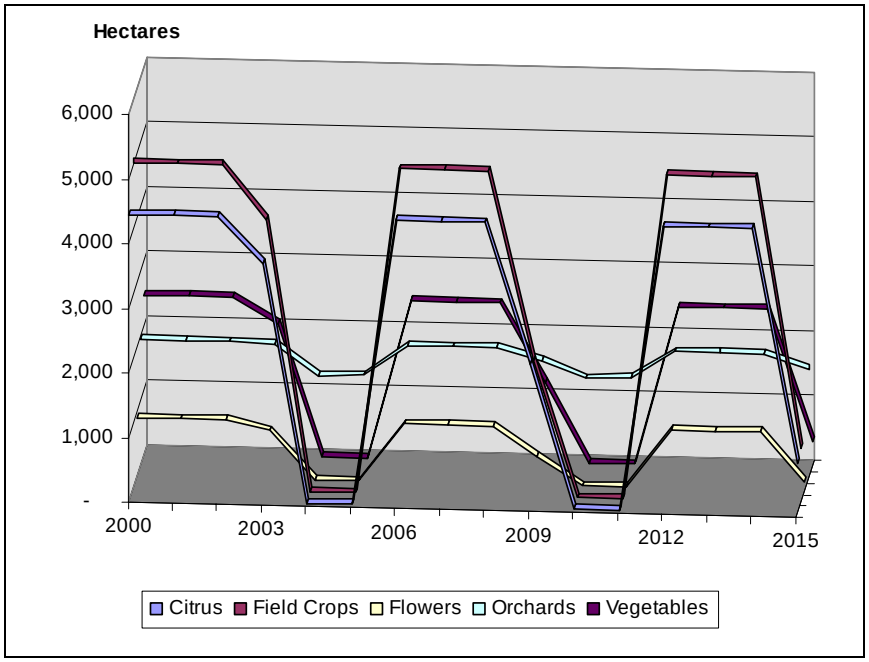


Figure 7-45. The impact of water cuts on the areas planted for various crops under the BauC+WC scenario

RCR

We found that the RCR values for each one of the consumers are similar to those obtained under the reference BauC scenario.

Effectiveness and Improvement

The "effectiveness" indices for domestic, industrial and agricultural uses for the BauC+WC scenario are presented in Figure 7-46. Comparison with the corresponding Figure 7-12 for the reference BauC scenario shows that under the current scenario, the level of effectiveness in all sectors is much higher than the one under the reference scenario, especially during the period of dry years.

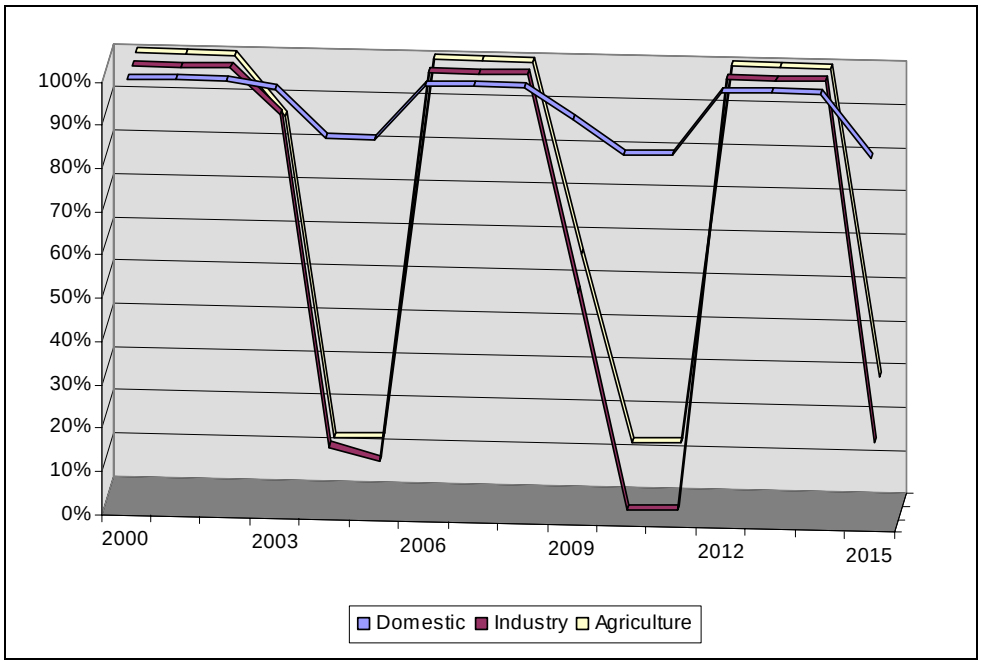


Figure 7-46. Effectiveness for Domestic, Industrial and Agricultural use under the BauC+WC scenario

Percent improvements of water deficit in the domestic, industrial and agricultural uses under the BauC+WC relative to the reference BauC are depicted in Figure 7-47**:**

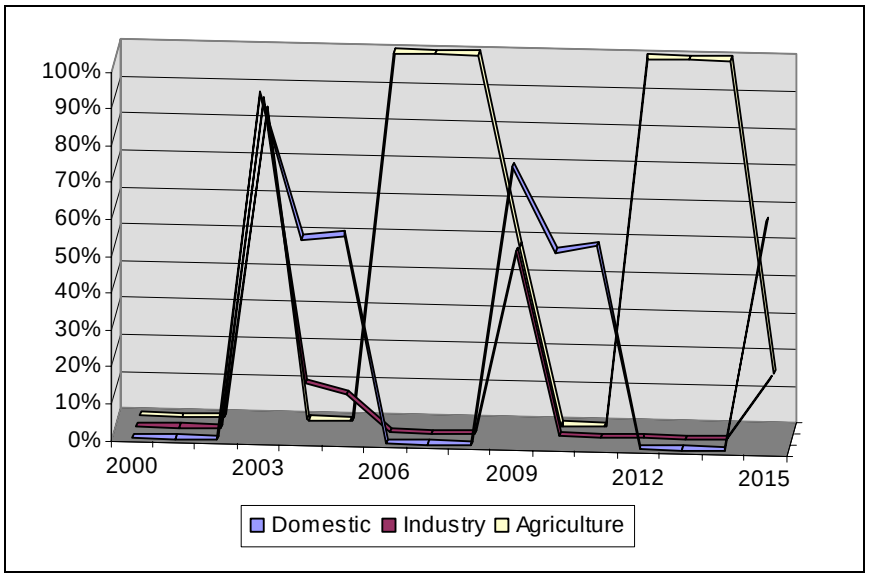


Figure 7-47. Percent improvements of deficit in domestic, industrial and agricultural uses under the BauC+WC scenario relative to the reference BauC scenario

The improvement in the deficit of all sectors during the dry periods is very significant.

SWS

As for the welfare indicator, the value of NPV(SWS) associated with the BauC+WC scenario (1,324.4 million €) is higher by about 30 million € than the respective value under the reference, BauC, scenario. This implies that **the option to reduce agricultural water shortages by the water conservation approach (BaucN+WC) is socially desirable.**

Present values (r=4%) of PWS, SWS, and environmental and direct costs for the BauC+WC scenario are presented in Figure 7-48 together with the respective values for the reference BauC scenario.

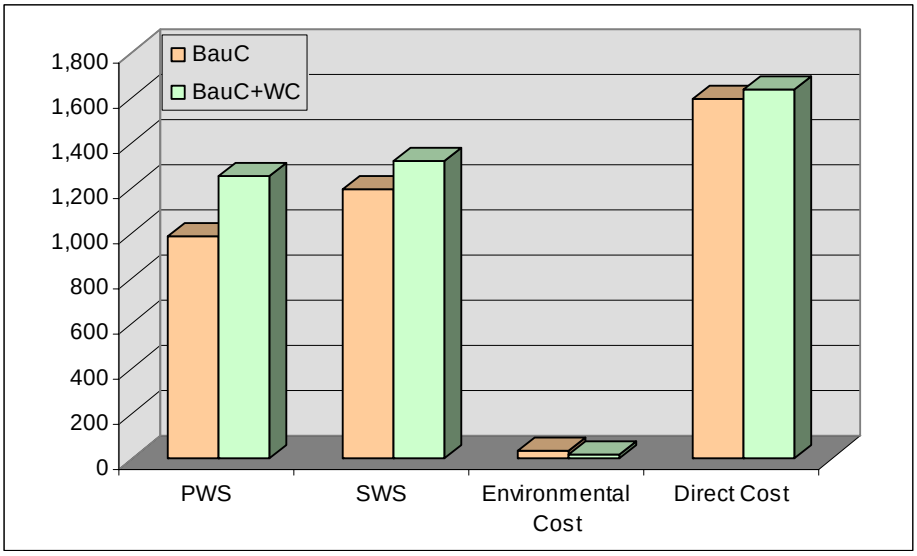


Figure 7-48. Present values (r=4%) of PWS, SWS, environmental and direct costs under the BauC+WC and the BauC scenario

The values of both NPV (SWS) and NPV (PWS) under the BauC+WC scenario (1,324.4 and 1254.5 million €, respectively) are higher than the respective values under the reference, BauC scenario. The direct costs under the BauC+WC scenario (1,635.1 million €, including 61 million € invested in water conservation) is higher by 39 million € than the respective value under the reference, BauC, scenario. The environmental cost under the BauC+WC scenario - - that are associated with the reduction in cultivated area - - is lower by about 14.1 million € than the respective value under the reference, BauC, scenario.

7.5 Final selection

The final selection of instruments to be further analysed during the strategy formulation phase depends on the performance of the options examined regarding the indicators that were presented throughout the analysis.

Results are summarized in Table 7-15 and Figures 7-49a – 53c below. The rest of this section is aimed at comparing the performances of the various management options and identifying the scope of integrated management scenario into promising water management strategies.

Table 7-15. Evaluation of Management Options; Financial Indicators: NPV (r=4%) of PWS, SWS, Environmental and Direct Costs (Million €)

Scenario	PWS	SWS	Environmental Cost	Direct Cost
	Million €, 4%			
BauN	1,263.7	1,490.7	14.8	1,812.6
BauN+R	1,303	1,533.5	1.3	1,831.1
BauN+D	1,292.2	1,463	0	1,913.8
BauN+OP	1,292.3	1,422.7	107.6	1,846.5
BauN+WC	1,440.7	1,504.7	0	1,792.6
BauC	990.2	1,194.5	35.1	1,596.1
BauC+R	1,021.5	1,230.7	29.3	1,611.1
BauC+D	1,110.4	1,175.1	25.2	1,875.6
BauC+OP	1,292.3	958	618.7	1,800
BauC+WC	1,254.5	1,324.4	21	1,635.1

The SWS and PWS criteria

The **net present value of the total social welfare surplus (SWS)** in the region (defined as the difference between the total value or benefit accrued by water consumers and the total direct and environmental costs) **is the best criterion to rank the various scenarios.** Obviously, a management option implying a high SWS value is preferred to one implying a lower value. **Total private welfare surplus (PWS),** accrue to water consumers, is defined as the difference between water values (benefits) and the cost of water charged to the consumers.

While both SWS and PWS depend on the value of water for the various consumers, the former also depends on the actual, direct and environmental costs of supplying the water while the latter depends on the prices charged to the consumers. Since in many cases water prices differ from water costs, it may well be that the PWS and SWS for a specific group of consumers do not coincide.

Inspection of the third column of Table 7-15 and Figures 7-49a and b imply:

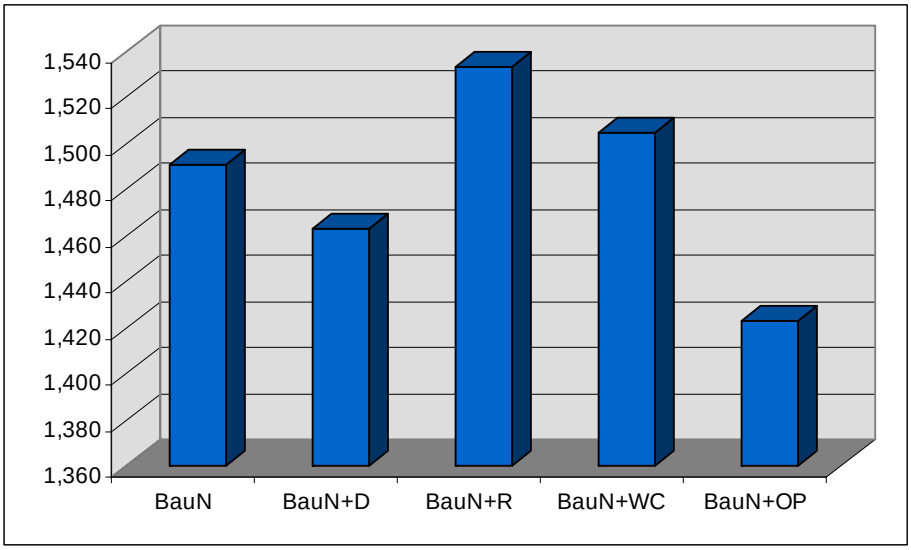


Figure 7-49a. NPV of SWS for all BauN scenarios (million €)

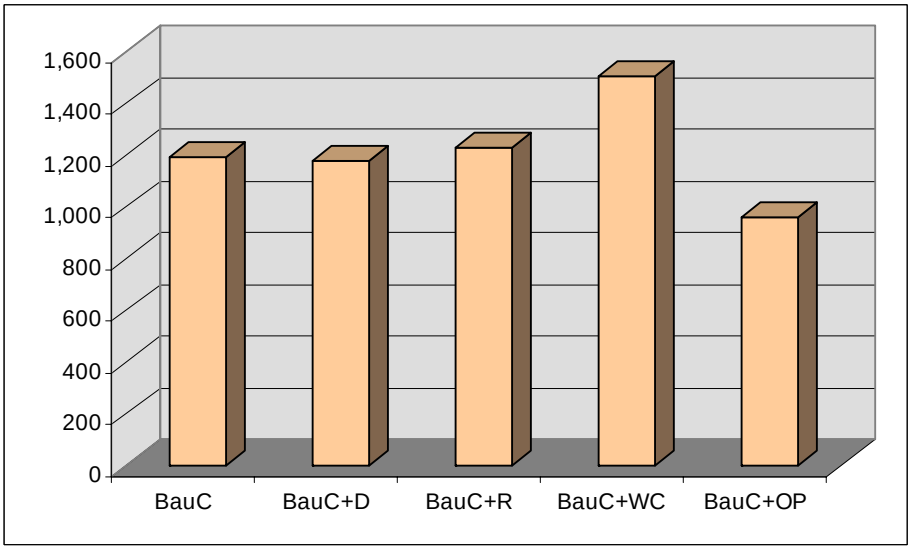


Figure 7-49b. NPV of SWS for all BauN scenarios (million €)

Under normal weather conditions, the management option to increase the supply of recycled water, BauN+R, yields the highest SWS, which is about only 2% higher than the second-best scenario, BauN+WC. Increasing water supply via over-pumping, the BauN+OP scenario, yields the lowest SWS.

Under cyclical weather conditions, the management option to reduce gross domestic demand via water conservation, BauC+WC, yields the highest SWS, which is about 8% higher than the second-best scenario, BauC+R. As when under normal weather conditions, the BauC+OP scenario is the least preferred one.

Inspection of the second column of Table 7-15 and Figures 7-50a and b imply:

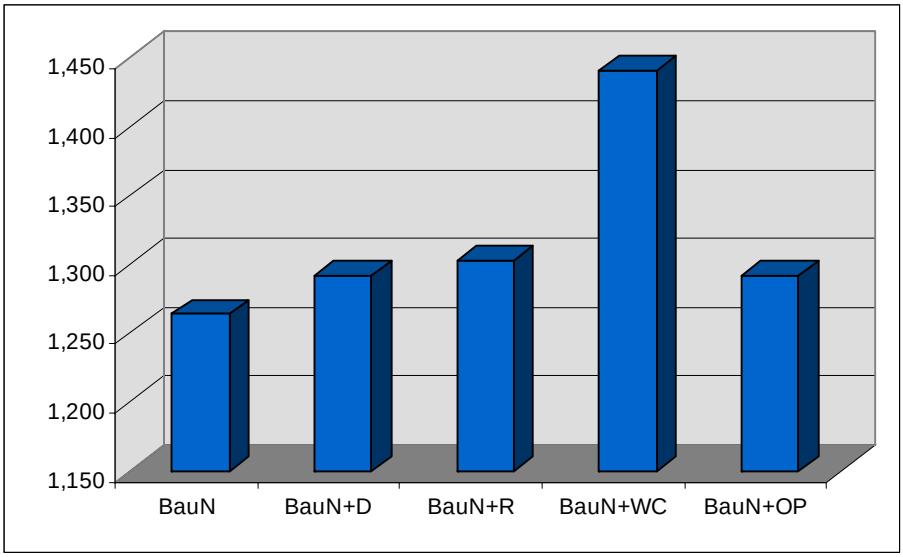


Figure 7-50 a. NPV of PWS for all BauN scenarios (million €)

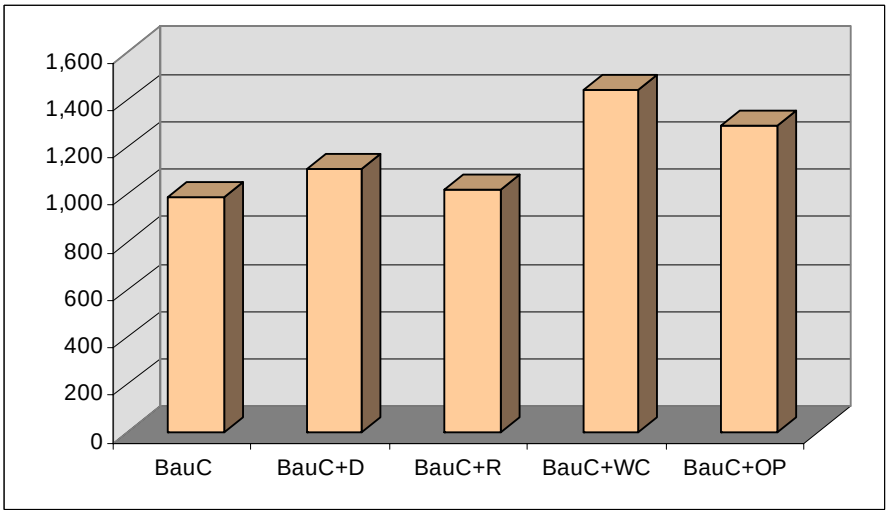


Figure 7-50 b. NPV of PWS for all BauN scenarios (million €)

The highest private welfare surplus (PWS) under normal weather conditions, is obtained under the "second-best" BauN+WC scenario, and is higher by about 11% than the PWS associated with the socially preferred scenario, BauN+R.

The highest value of PWS under cyclical weather conditions is obtained under the BauC+OP scenario with the lowest SWS. This value is higher by about only 3% than the PWS associated with the socially preferred scenario, BauC+WC.

Environmental Costs

Inspection of the fourth column of Table 7-15 and figures 51a, b imply:

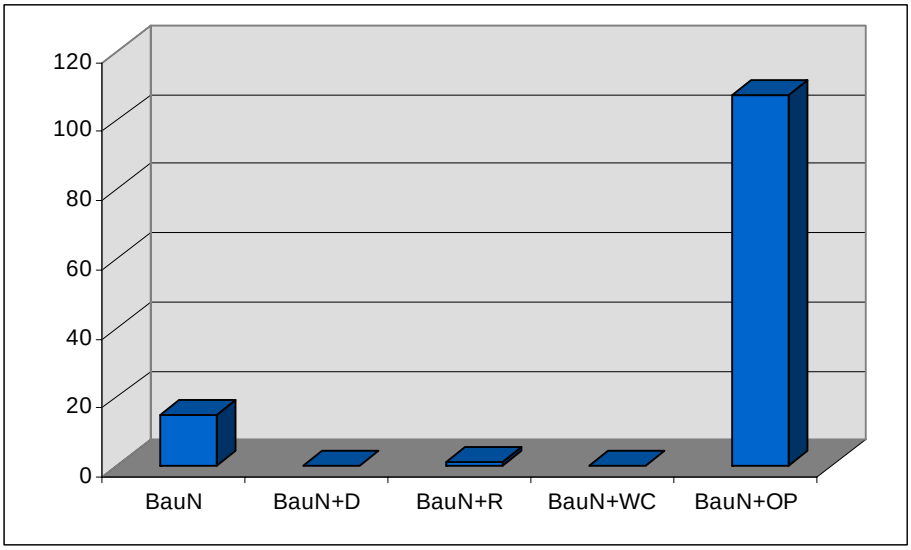


Figure 7-51a. NPV of Environmental Cost for all BauN scenarios (million €)

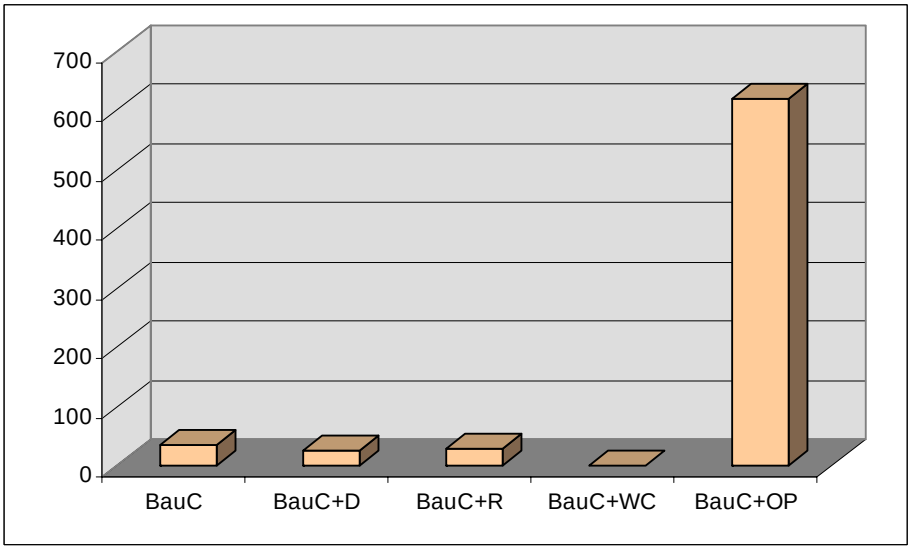


Figure 7-51b. NPV of Environmental Cost for all BauC scenarios (million €)

The source of the environmental costs associated with scenarios BauN+OP and BauC+OP is over-pumping of ground water from the coastal aquifer, which are assumed to be equal to 64 € cents. The source of environmental costs for all other scenario (where over-pumping is not an option) is the reduction in cultivated are resulting from agricultural water deficit. The environmental costs associated with a cut of 1 cubic meter of irrigation water demanded by the agricultural sector - - a cut which yields reduction in the cultivated area - - are assumed to be 9 € cents. Since the environmental costs associated with over-pumping are 7 times higher than those associated with agricultural water shortage, it should not come as a surprise the environmental costs associated with scenarios BauN+OP and BauC+OP are much relative to all other management options.

Obviously, for environmentalists or "Greens", the increase of water supply via over-pumping is the by far the worst management option.

Under normal weather conditions, the environmental costs associated with all management options other than over-pumping are practically negligible. Under cyclical weather conditions, the environmental costs associated with the corresponding management options are low relative to the direct costs but not negligible; the costs associated with the BauC+WC are lower than those associated with BauC+D and BauC+R.

Direct Costs

Inspection of the fourth column of Table 7-15 and Figures 7-51a, and b imply:

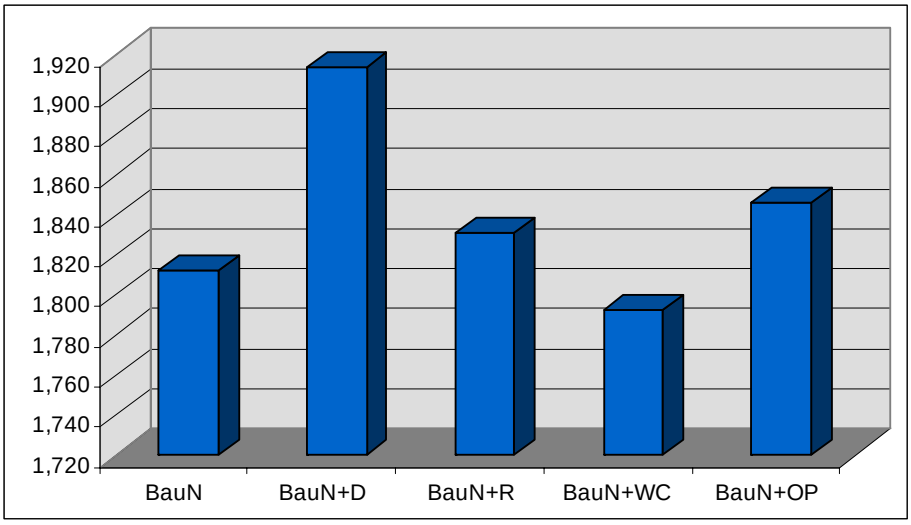


Figure 7-51a. NPV of Direct Cost for all BauN scenarios (million €)

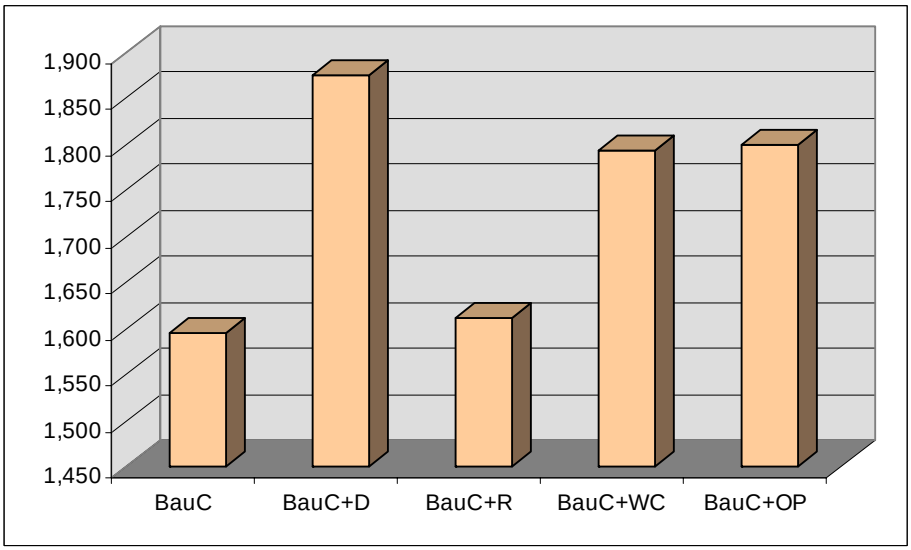


Figure 7-51b. NPV of Direct Cost for all BauC scenarios (million €)

Under both normal and cyclical weather conditions the direct costs associated with the option to increase supply via desalination of seawater (BauN+D, BauC+D) are higher than those implied by all other management options. The direct costs associated with the increased recycling (BauN+R, BauC+R) are the lowest.

It should be emphasized that direct costs is only one (commonly very important) component of the social welfare associate with water utilization. As long as water benefits vary between scenarios and management option, direct costs alone cannot be used as a criterion for economic efficiency.

Percent improvement of deficit in domestic, industrial and agricultural uses

Under the reference BauN scenario domestic and industrial demands are fully met, i.e., the "effectiveness" associated with each one of them is 100% (Figure 7-6). This necessarily implies a 0% improvement for theses two sectors under each of the management options BauN+R, BauN+D and Baun+WC. The agricultural supply is fully met only during the first 4 years of the time horizon (see Figure 7-3) and then it steadily increases. Thus, the effectiveness for agricultural uses is 100% in the first 4 years of the planning horizon and then it steadily decreases. This leaves a lot of room for improvement from the fifth year of the time horizon and on. The percent improvement of deficit for the agricultural sector under normal weather conditions is presented in Figure 7-52. Inspection of this figure show that the agricultural deficit completely vanishes under the BauN+D and the BauN+OP. Under the BauN+R scenario, the deficit vanishes until the year 2009 and then it steadily increases (i.e., the percent improvement decreases).

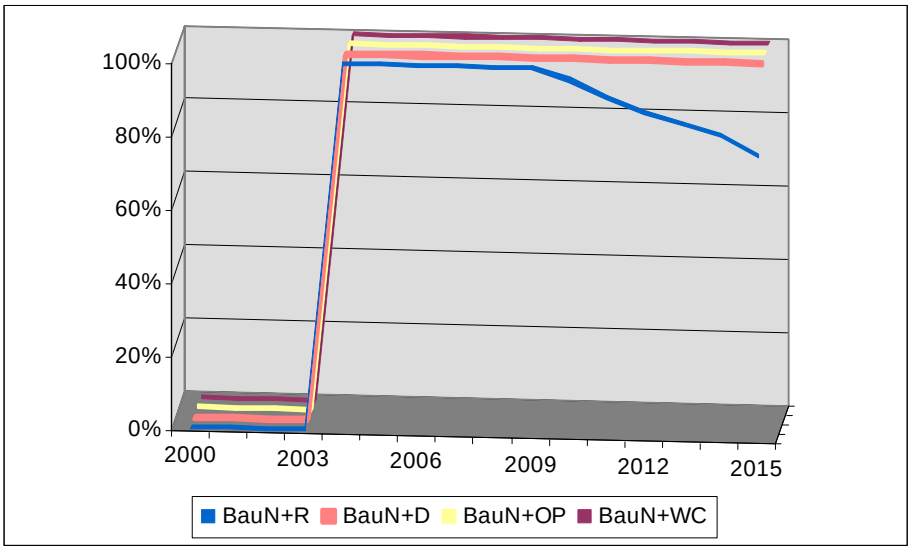


Figure 7-52. Percent improvement in agricultural deficit under the normal weather conditions (%)

Under the reference BauC scenario, none of the demands is fully met during the whole planning horizon, namely the "effectiveness" associated with each one of them is not 100% during all the years examined ((Figure 7-12). This leaves a lot of room for improvement, especially during the dry periods. The percent improvements of deficit for the domestic, industrial and agricultural sectors under cyclical weather conditions are presented in Figures 7-53a, 7-53b and 7-53c, respectively. Inspection of these depicts that:

(i) The highest percent improvement in the deficit of all sectors obtained under the BauC+OP management options which enables to increase supply (via over-pumping of ground water from the coastal aquifer) as much as needed. Under the BauC+D scenario, for example, the increased supply of fresh water is limited by the capacity of the assumed desalination plants (50 MCM between the years 2003 and 2008 and 100 MCM from 2009 and on).

(ii) The lowest percent improvement of all sectors is obtained under the BauC+R management option. This can be explained by the fact that the amount of **additional** recycling is low relative the quantity of desalinated water, the quantity of over-pumping and the reduction in domestic demand via water conservation.

(ii) The percent improvement in the deficit of the domestic and the agricultural sectors is higher under the BauC+WC scenario than under the BauC+D scenario (see Figures 7-53a and 7-53c). The ranking between the impacts of these two scenarios on the industrial sector is indeterminate (see Figure 7-53b).

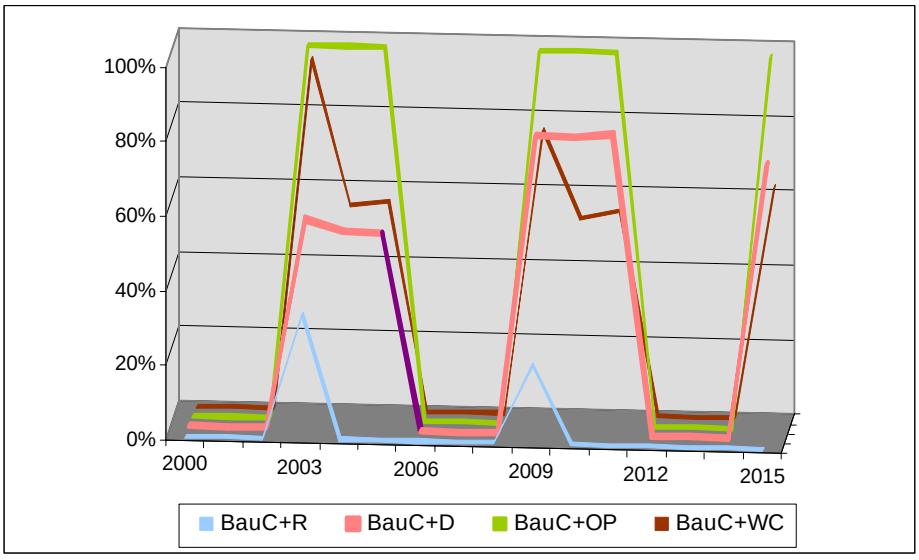


Figure 7-53a. Percent improvement in domestic deficit under the cyclical weather conditions (%)

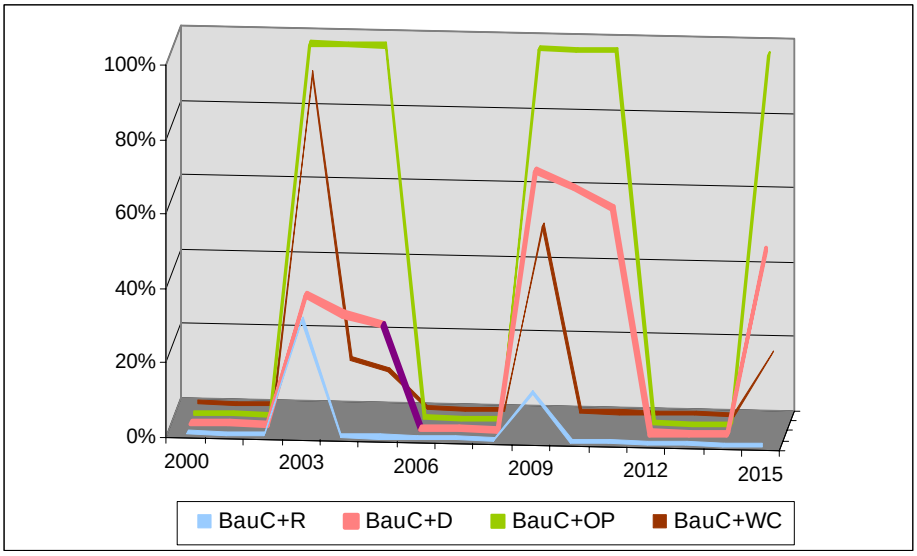


Figure 7-53b. Percent improvement in industrial deficit under the cyclical weather conditions (%)

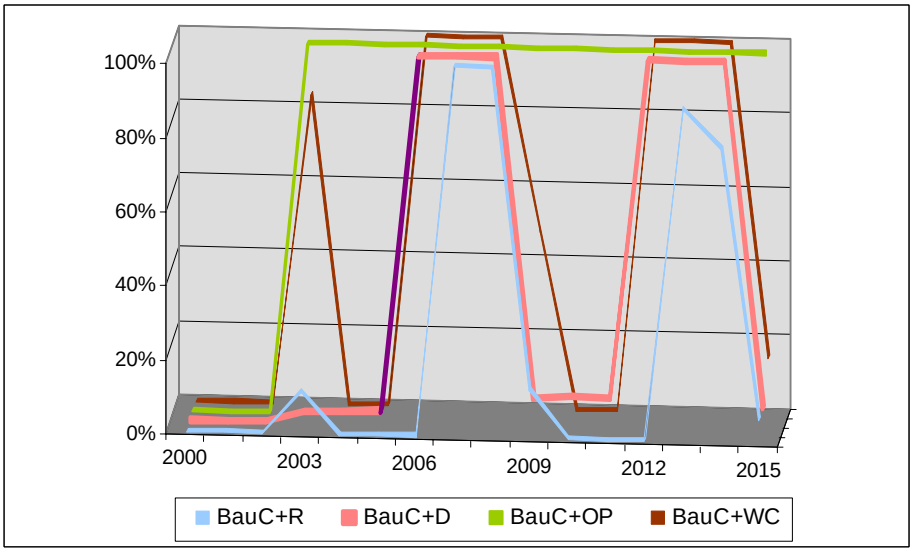


Figure 7-53c. Percent improvement in agricultural deficit under the cyclical weather conditions (%)

Concluding Remarks

Normal weather conditions

A social planner will prefer the BauN+R management option (i.e., to increase the supply of recycled water), that yields the highest value of SWS. The environmental costs associated with this scenario are negligible, so a fierce opposition of environmentalists (or green lobbies) to this scenario is unlikely. On the other hand, this is the only management option under which agricultural supply is not fully met during all the years of the time horizon, and its associated PWS is lower than the one associated with the

BauN+WC scenario. On this ground, this scenario may be opposed by the (strong and effective) agricultural lobby.

The second best scenario from social point of view is BauN+WC, with the second highest value of SWS; the lowest values of both environmental and direct costs and the highest value of PWS.

From a social point of view and from the point of view of the greens' lobby, the worst scenario is BauN+OP, with the lowest value of SWS and the highest value of environmental cost. The greens' lobby is indifferent between the BauN+D and BauN+WC scenarios, as both imply zero environmental costs.

Cyclical weather conditions

From a social point of view the best management option is BauC+WC and the second-best one is BauC+R. The environmental costs associated with the former are lower than those associated with the latter, so the greens' lobby will probably also prefer BauC+WC to BauC+R.

The lowest percent improvement of all sectors is obtained under the BauC+R management option. Indeed this option involves the lowest value of PWS. On this ground, this scenario may be opposed by political lobbies of all sectors.

The highest percent improvement in the deficit of all sectors obtained under the BauC+OP management options which enables to increase supply (via over-pumping of ground water from the coastal aquifer) as much as needed. Indeed this option involves the highest private welfare surplus (PWS). However it is the worst scenario from social point of view and from the point of view of the greens' lobby since it involves the lowest value of SWS and the highest value of environmental cost.

Based on the results obtained so far, it can be concluded that the option to enhance supply via over-pumping of ground water is not desirable. It involves the lowest social welfare surplus and the highest environmental costs. The option to increase supply of recycled water and/or to reduce gross domestic demand via water conservation seem to occupy advantageous positions in terms of social welfare surplus and environmental costs. Although it involves the highest direct costs, the option to increase supply via seawater desalination, which improves social welfare and has no negative environmental impacts, cannot be rejected a-priori.

It is apparent that in the scope of integrated management scenarios into promising water management strategies, we should seriously examine the impacts of various combinations of the following management options, to enhance supply via recycling or desalination of seawater, and to reduce domestic demand via water conservation. We also plan to evaluate the option of creating a partial institutional and economic separation of Tel-Aviv's water resources from the national water system and operating it as a balanced economic entity with respect to the industrial and domestic sectors.

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8. Comprehensive Scenarios for Tenerife

With a surface area of 2,034 km^2, the island of Tenerife presents a singular hydrological behaviour. Most of the available water is concentrated in the subterranean resources, as there are no major permanent water courses and there is little chance of harnessing surface run-off water.

With limited resources of just over 200 hm^3/year on average, Tenerife has faced a spectacular growth in recent decades. From subsistence farming, it has shifted to developing a major export agricultural industry based on crops that have a high demand for water (bananas, tropical fruit, citric fruits, flowers, etc.) apart from tomatoes, which used up 123 hm^3 of water in 1993. All of this has been possible because of the development of a water "mining" sector. Traditional crops start to decline and agricultural water is directed fundamentally to support export crops and "out of season" productions. At present, of 18,162 ha of cultivated land, 14,180 are used for irrigated crops, although it must be said that the new policy aimed at stopping European subsidies for export crops such as bananas, may substantially change the agricultural production panorama.

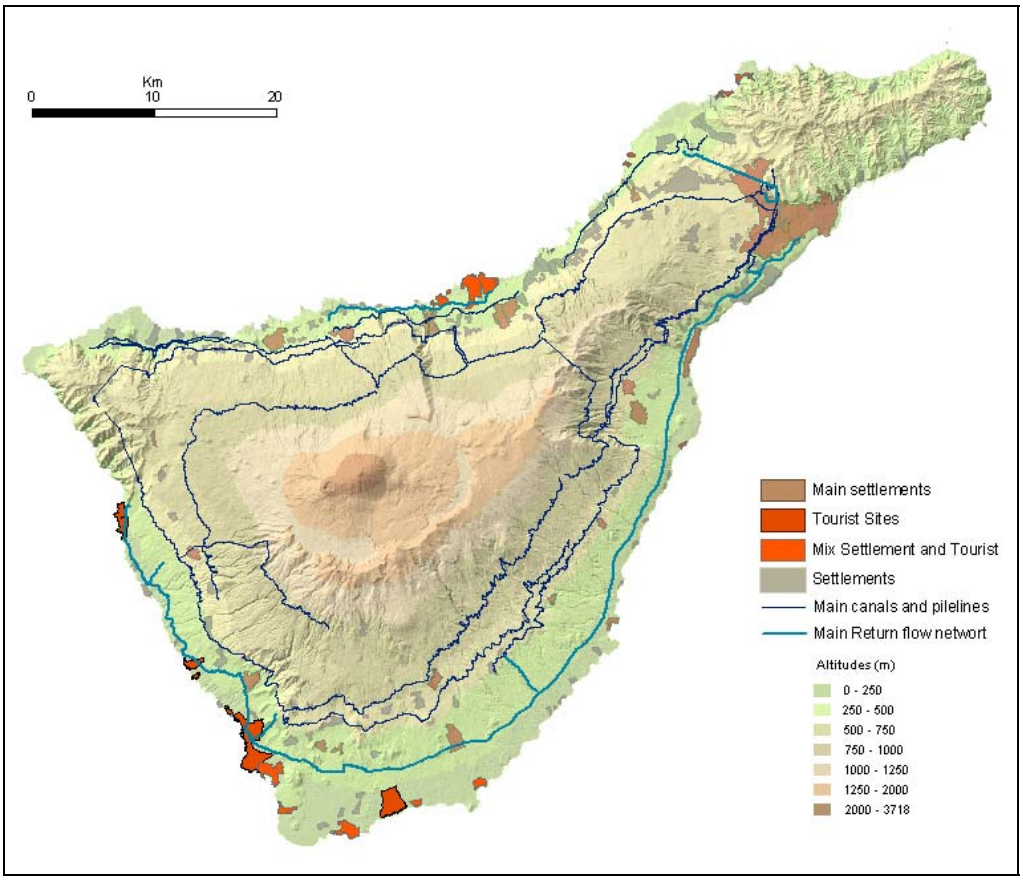

Figure 8-1. Map showing main populated areas and the insular ring for water distribution, differentiating the main return flow network

At the same time, the demand for water from the domestic and tourist sectors, which was no more than 30 hm^3 twenty years ago, has shot up drastically with the progressive growth of the tourist industry and the enormous population growth driven by this activity. In recent years, as a result of this phenomenon, variations in the annual population growth of over 4.5% have been recorded.

The growth of the tourist industry has been relatively intense. Growth numbers are really spectacular, as we have grown from 0.5 million international arrivals at the end of the 70's to break the 4 million arrivals barrier in 2001. The increase in tourist inflow, as well as the increase in the number of beds (around 180,000), represents the biggest investment phenomenon of recent years on the Spanish coasts.

Having reached growth limits and speeds that have outstripped those registered in most historic phenomena of island development, conflicts appear to be inevitable. The over-exploitation of the aquifer marks a process of environmental deterioration that has serious consequences in many areas, especially in the infiltration of salt water into coastal aquifers. The water courses and natural water systems are gravely affected in the low lying areas of the island. Water stopped welling up to the surface a long time ago, in order to cover the incessant growth in production.

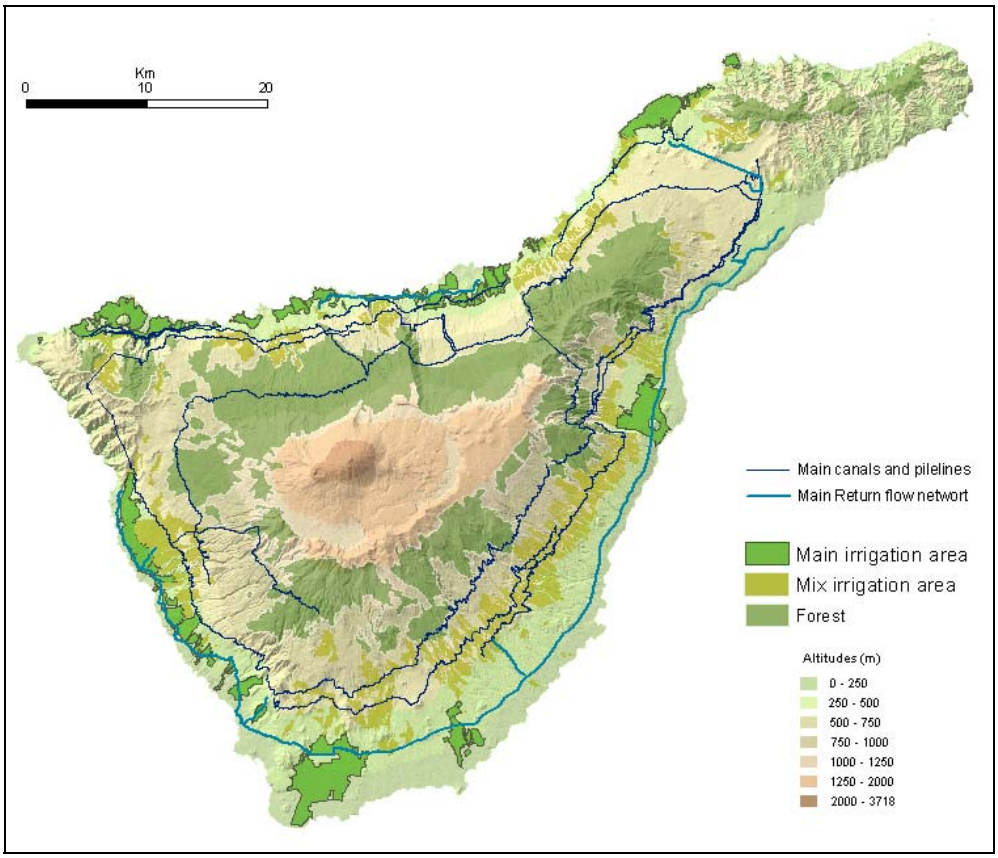

Figure 8-2. Map showing crop distribution. Main irrigation areas, corresponding to export crops, are clearly located in coastal regions

In recent years, the delicate balance between resources and use has been broken and, therefore, new incompatibilities arise, the competition between domestic and tourist

industry demand, on the one hand, and, on the other, traditional farming, the weaker of the two forces. Moreover, the tremendous dispersion of the population, very often without running water, has created serious problems of contaminated aquifers.

Covering the shortfall in the domestic and tourist sectors has found an ally in desalination, but, in the current situation, growth is so fast that the planning forecasts (Island Hydrological Plan) have been outstripped in a few short years, forcing the authorities to maintain a permanent relief policy to cover the growing needs.

In this context, the goal of formulating scenarios and strategies for the island of Tenerife, is not just a question of **re-conciliating** supply and demand, it is also a question of **establishing acceptable risk thresholds** in such a fragile and now dependent system. That is, to help to bring water on board as the central object in the on-going process of reconsidering growth policies and planning strategies for sustainable development in Tenerife.

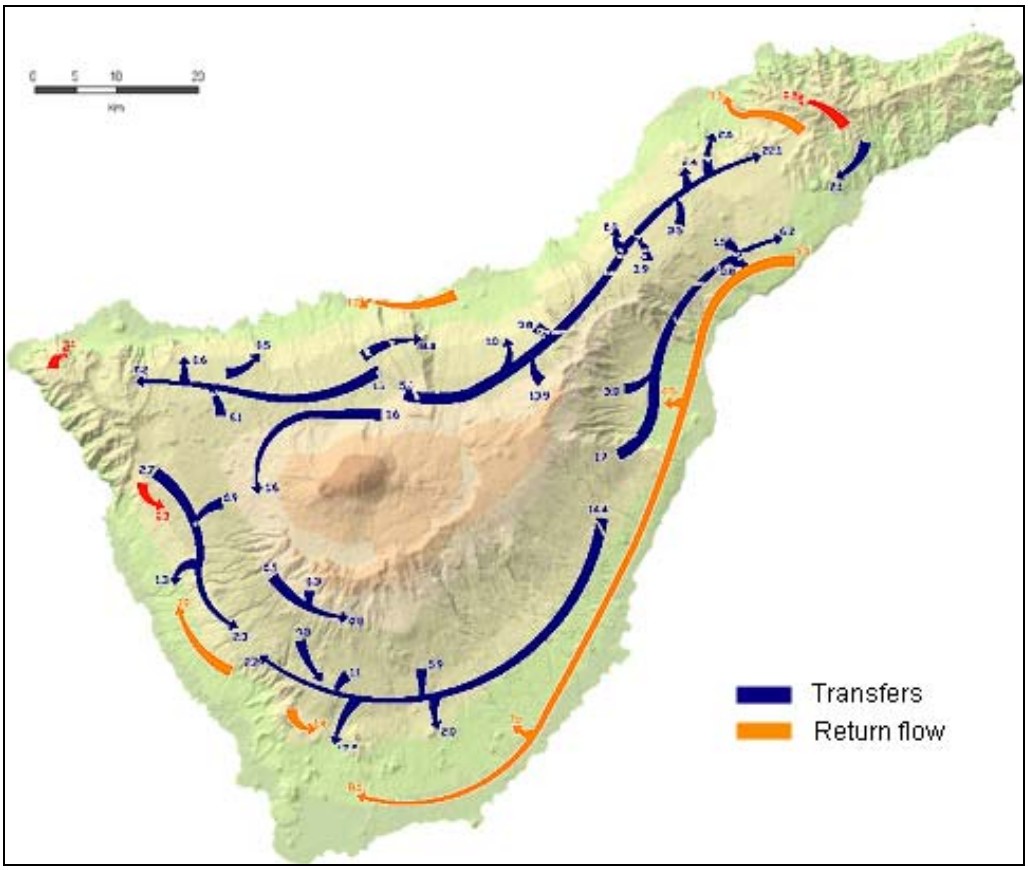

Figure 8-3. Sketch showing water transfers between different areas of the island, evidencing resource mobility and the system that behaves as a closed distribution system (Source: PHI)

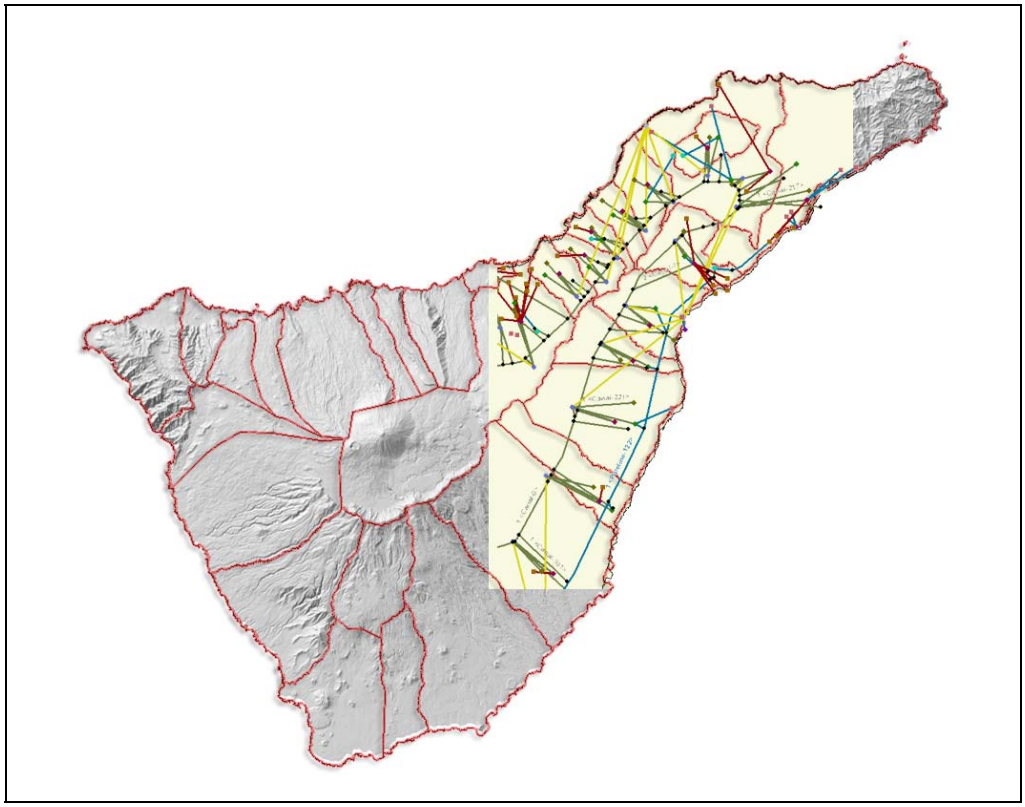

Figure 8-4. Map showing municipal division consequent model distribution integrated in the WSM DSS tool, based on aggregation of data from municipalities

8.1. Demand and Availability Scenario Components

Formulation of Demand Scenarios

Data

Formulation of different demand scenarios has been carried out paying attention to the big debate on development policies formulated during the last years, which are at present conditioning most initiatives of governments, of administrations, and social groups. Explosive tourist and population growth happened in the last years, as well as crisis and fluctuations within the agricultural sector, brought to the reformulation of development policies from different standpoints, and the development of planning systems and directives by administrations, which start to set new containment and sustainability frameworks.

Data used for the formulation of scenarios took into account, besides basic information supplied by authorities and other stakeholders with a competence, also the wide range of documents dealing with planning that are directly or indirectly related with water management in the island of Tenerife. In this sense, the framework document is the Island Hydrological Plan (PHI), connected to the island's Land Use Plan (*Plan Insular de Ordenación*).

Nevertheless, PHI's determinations (a few of them are already obsolete) are not strictly related to tendencies and data of other planning scenarios and sectoral sources more specialised: tendencies in the tourist sector, population variations or desalinated water production.

Another eye-catching aspect is that, at both insular and regional planning levels, and even at local level, water is not a basic factor within development tendency analyses, unlike land, communication infrastructures or energy. This omission is paradigmatic for an island that since several years has exceeded its exploitation rate of renewable water resources and, for example, water is never taken into account in any environmental planning. For this reason, to guarantee the design of comparable and useful scenarios, the sources and forecasts most appropriate for each sector and field have been selected.

For this purpose, a variety of data and estimations have been collected and analysed from associations and the local and governmental authorities, regarding population fluctuations, consumptions, network losses and unaccounted consumptions. Table 8-1 and Table 8-2 show which water actors have been contacted, and the data that have been collected from each one.

Table 8-1. Available information on domestic and tourist demand components

Authority/source	Available Information
Island Hydrological Plan	• Water Supply Provision and Fluctuation • Consumption Fluctuation
Regional Statistical Service ISTAC	• Permanent Population
Local Administrative Authorities	• Prices and demands • Correction of population data
Statistics on receptive tourism of the Cabildo Insular de Tenerife	• Number of Hotels, Rooms and Beds • Occupancy • Overnight stays
ITER	• Tourist Consumption Data • Energy Costs
Canary Islands' Water Centre	• Typology of consumption • Collection, distribution and energy costs

One important conclusion that was drawn from data cross-referencing concerned the real permanent population of the island. The registered population according in the 2001 census was 744,076 inhabitants. However, this number needs two corrections: in fact it does not include the high percentage of non-registered inhabitants (sometimes higher than 4.5%) and tourist population. For the last correction it was decided to use the number of overnight stays, since it is a reliable and easily checkable datum that also reflects water consumption, instead of data such as the number of visitors that are not linked to resource use.

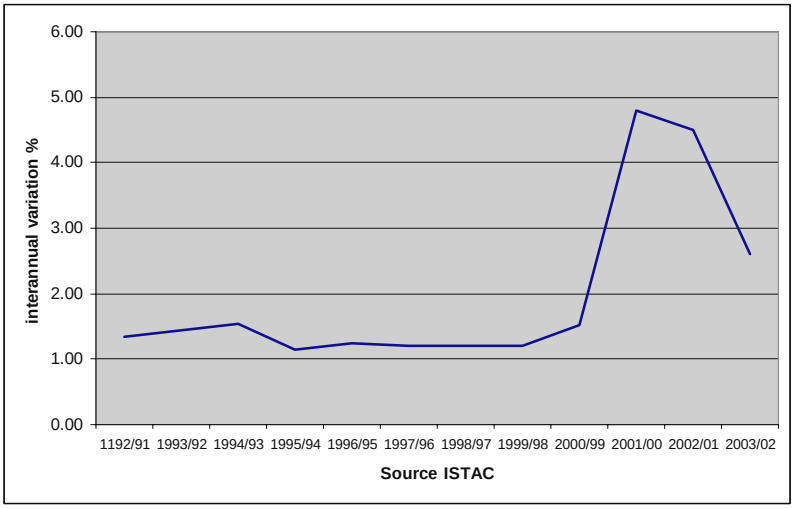

Figure 8-5. Yearly variation of permanent population

Tourist population is mostly concentrated in the island's southern municipalities and practically only in one municipality of the north (Figure 8-1). Demand is increasing in the South and in the metropolitan area (NW of the island). This clear spatial influence of tourist development is shown in Figure 8-5, and involved an important change of the water distribution and allocation parameters in the island.

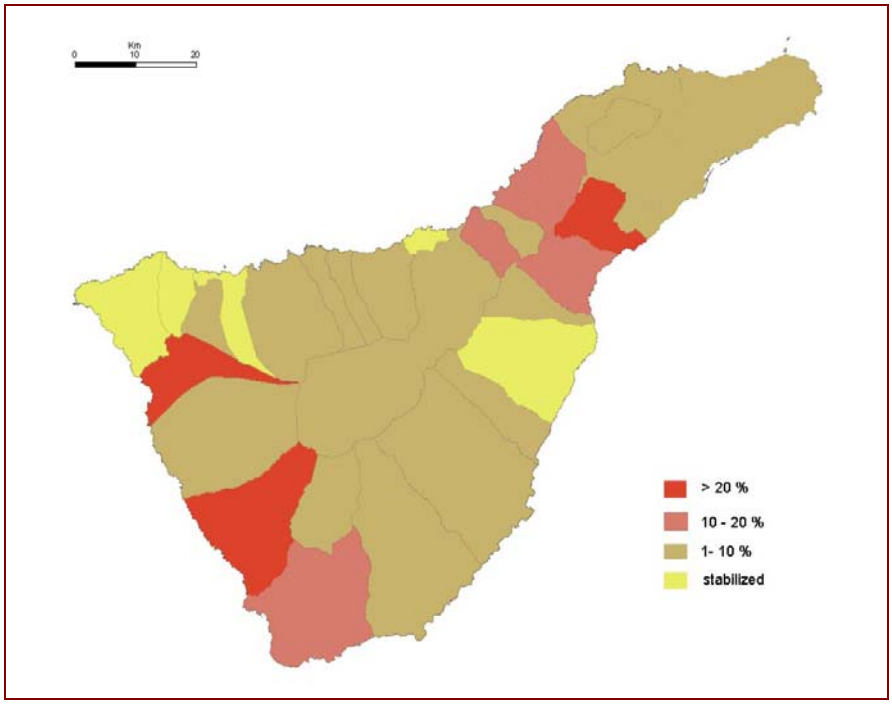

Figure 8-6. Spatial distribution of the population growth tendencies in the last decade. Two focuses are clearly detected: the surroundings of the metropolitan area and the tourist areas in the south of the island (Source: ISTAC)

Estimation of demand parameters, such as consumption rates and loss coefficients, have been obtained from the different sources indicated in Table 8-1 and Table 8-2., according to the following methodological system:

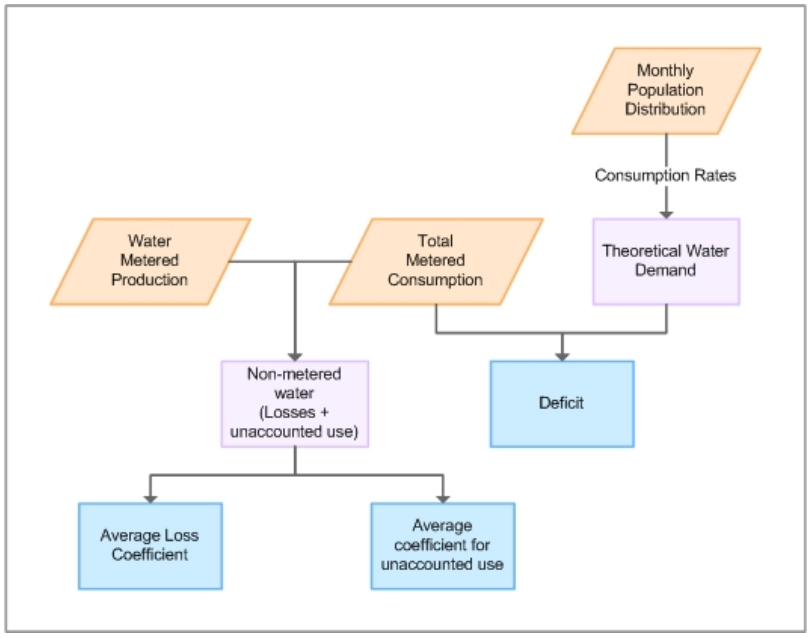

Figure 8-7. Flowchart for the estimation of demand parameters

Domestic consumption rates, estimated on the basis of real consumption and excluding losses, were estimated at approximately 160 and 180 l/capita/day for permanent and floating population. For tourist consumption, average values of 310–350 l/capita/day have been used, depending on main tourist accommodation in the area considered (hotels or tourist apartments). Numbers on domestic consumption are higher than the national average (147 l/capita/day in the year 2000), and also higher than those of the eastern islands of the archipelago, where scarcity of water generated a particular water-saving culture.

Table 8-2. Available information on agricultural and animal components

Authority/source	Available Information
Island Hydrological Plan	• Water Supply Provision and Fluctuation • Transfers and flows
Regional Statistical Service ISTAC	• Population working in agriculture
Ministry of Agriculture and Fisheries	• Municipal statistics for crop areas • Allocated consumption
Baltén (Tenerife Reservoir Plan)	• Agricultural water distribution • Storage data
Several sources	• Water consumption for each crop
Canary Islands' Water Centre	• Watering methods • Watering efficiency

Generic data on tendencies and regional consumption have been extracted from the PHI (Insular Hydrological Plan). However, the best updated sources of information for data on groundwater abstraction, agricultural exploitations and, obviously, population, are municipalized. This brought to the result that all the information of the case is based on municipal nodes.

Projections

Projections made for the formulation scenarios are conditioned by the following phenomena:

a) **Population and tourism**. Rapid tourism growth and resulting increase in population is maintained upward (1.35 % average) until achieving unusual growth peaks in the last years (Figure 8-5). Last years' unusual growths are clearly of conjunctural nature, due both to the migratory explosion happened in the last years after the entry into the European Community, and to an unusual immigration, with population increases up to 4.9% (2001), only comparable with +3.5% recorded in 1994, marking the take-off of tourist development in the south of the island. Therefore they have to be considered as an exception. Figure 8-8 shows official population projections made by the ISTAC. Nevertheless, the tourist growth needs to be clarified, since tendency is suddenly due to the evident saturation of the tourist destination.

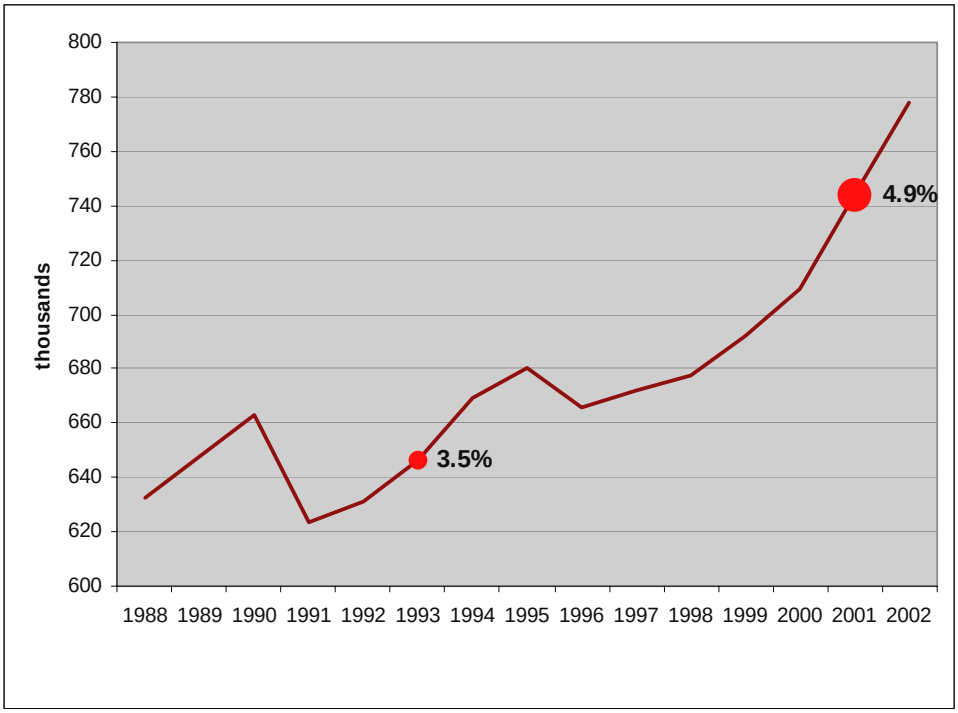

Figure 8-8. Evolution of population (Source: ISTAC - Canary Islands' Institute of Statistics)

b) **Agriculture**. Great consumption of water in the last decades has been marked by the evolution of export crops, mainly bananas and, later, new water consumer crops (tomatoes, flowers, tropical fruits, etc.). But growth rates in this sector need to be clarified as well, since several decisive phenomena take place: technologicalization of the sector, massive urbanisation of areas previously occupied by watered crops, and abandon of non-rentable or non specialised exploitations and, especially, the effects of the Common Agricultural Policy (reduction of subsides) and the GATT agreements that threaten the survival of export crops (bananas) that without subsides start to be non-competitive because of water and labour prices. Nevertheless, there is an evident process of crop substitution. In a few years the vineyards have surpassed in area the total of banana plantations, which had for decades dominated island's irrigated lands. This evolution was clearly reflected by the evolution of water consumption for agricultural use between 1986 and 2000, which maintained a yearly decrease of 1.57%, now stabilised.

c) **Industry**. The industry sector has two main water consumers (oil refinery and power station). Both are at present self-sufficient, being therefore closed systems that do not intervene in the system. The rest of the industry sector maintains its consumption constant, and it is not a determinant factor within the island's water balance.

Table 8-3 shows the evolution of the agricultural sector during the last years, as regards the main water-consuming crops.

Table 8-3. Evolution of the cultivated areas of main water-demanding crops

Crop	1998	1999	2000	2001
Avocado (ha)	234	233	227	251
Onions (ha)	141	111	96	96
Green beans (ha)	144	92	91	87
Cucumbers (ha)	21	13	15	15
Red peppers (ha)	50	36	38	38
Potatoes (ha)	3,809	3,384	3,064	2,935
Tomatoes (ha)	1,382	1,248	1,236	1,116
Vineyards (ha)	7,637	7,741	7,818	11,774
Bananas (ha)	4,103	4,141	4,085	4,180

As a result of these interactions, absolutely feasible and foreseeable in function of development policies that are being examined as possible options on the island, the following scenarios have been elaborated:

BAU (HD)

A scenario where demand increases at a steady rate, equal to that currently observed, and corresponding to a "business as usual" state (BAU).

It has been built in accordance with the tendencies recorded in the latest years, although all parameters have experienced big variations.

The basic parameters for the scenario are:

- Population growth follows the tendencies recorded in the last 8 years, with a yearly increase of 3%. Non-registered population is considered in this scenario. After 2008, rate growth stabilises on 2%.
- Tourist continuous growth of 2%. This rate reflects the average tendency of the last 10 years, without taking into account the recession recorded in the last period. It corresponds to the projection numbers handled by the island tourist authorities. After 2008 (maximum saturation), rate growth stabilises on 1.5%.
- Industrial demand increase of 1%.
- Agriculture stabilises its trend, and maintains present-day very fragile tendency.
- With regard to desalination, growth rate relative to the projects approved or underway until 2008 has been adopted. Forecasts of the PHI.

STABILISED (MD)

It is established according with the objectives outlined by the Canary Islands Government and the Tenerife Island Government projections, whose results converge into a scenario that put some barriers to growth. All sectoral policies, including water policy, direct towards this scenario. It is a scenario that restrains growth, reflecting the institutional planning view. It tends to stabilise after 2008.

- Population growth 1%. Non-registered population is considered in this scenario. Peaks due to immigration are considered anomalous, and due to conjunctural reasons. Rate growth of 2.5% only until 2008
- Tourist continuous growth of 1.5% until 2008, and stabilisation after this date. It is in harmony with the policies restraining accommodation building, which will not be effective until that moment.
- Industrial demand increase of 1%.
- Agricultural demand decrease of -1%. It corresponds to the actual tendency recorded in the last 10 years, which is the expected one if we exclude the possible crisis of export crops.
- With regard to desalination, growth rate relative to the projects approved or underway until 2008 has been adopted and a growing rate reflecting present-day water resource policy.

LOW DEMAND (LD)

It is a scenario combining the effective application of limited growth policies promoted by the administration with a realistic view of the tourist growth, which has already reached its saturation. It also reflects the negative growth of the agricultural sector.

- Population growth of 1.5% until 2008. Progressive decrease until reaching the level of natural growth in 2015.
- Tourist continuous yearly decrease of -1%. It corresponds to the actual tendency not officially expressed but shown by the local statistical data showing a clear recession when looking at the number of overnight stays and the occupation rate, in spite of the increase in hotel facilities. Zero growth is set after 2015.
- Industrial demand increase of 0%. In this scenario the appearance of new industries in the focuses of development compensates the announced abandon of some productive processes.
- Agricultural demand decrease of 1.5%. Same tendency until 2015, mainly caused by the foreseeable slump of export agriculture. It stabilises after 2015.

Table 8-4. Population trends for the three scenarios

Scenario	Period	Growth Rate (%)	
		Permanent Population	Tourist Population
BAU	2001 – 2008	3	2
	2008 - 2030	1.8	1.5
Stabilized Demand	2001 – 2008	2.5	1.5
	2008 - 2015	1.3	1.5
	2015 – 2030	0.5	0.0
Low Demand	2001 – 2008	1.5	-1
	2008 – 2015	0.0	-0.5
	2015 – 2030	-0.5	-0.0

Table 8-5. Projection of agricultural demand in the three scenarios

Scenario	Period	Growth Rate (%)
		Irrigation Demand
BAU	2001 – 2008	0
	2008 - 2030	0
Stabilized Demand	2001 – 2008	-1
	2008 - 2015	0
	2015 – 2030	0
Low Demand	2001 – 2008	-1.5
	2008 – 2015	-2
	2015 – 2030	0

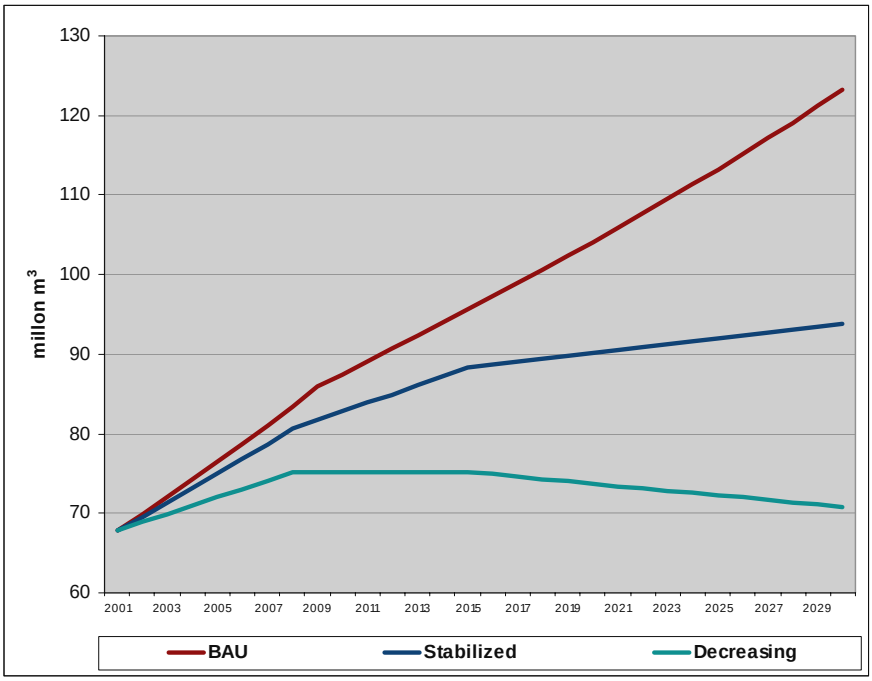

Figure 8-9. Domestic Demand Scenarios

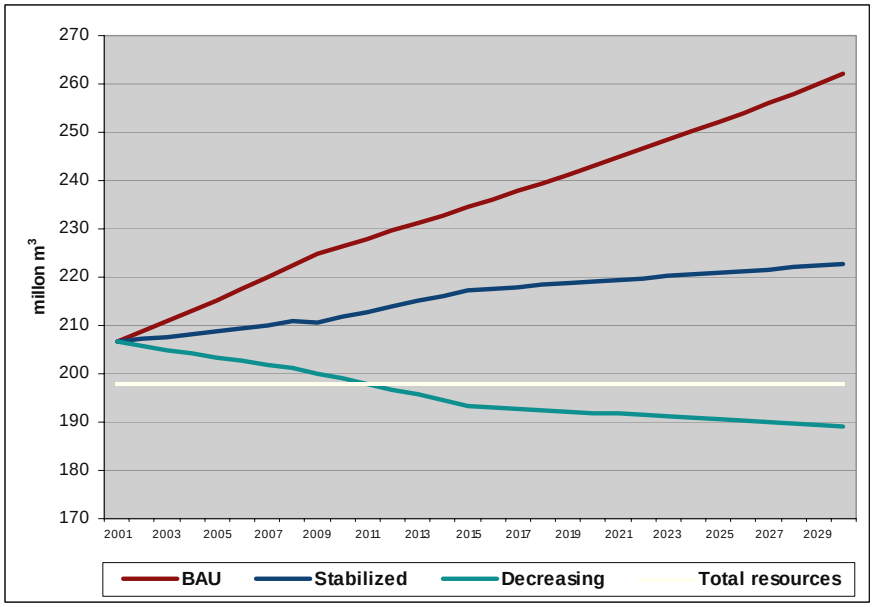

Figure 8-10. Evolution of global demand in the three scenarios, considering all sectors, with reference to total resources

Figure 8-10 shows how, starting from a situation where the index of exploitation of available renewable resources (mainly underground water) has exceeded recharge limits, and fossil water resources of the aquifer started to be abstracted, two of the scenarios move away from sustainability, under the hypothesis of exclusive dependency on these resources.

Formulation of Availability Scenarios

Data

Trade-winds are the main factor that conditions climate and precipitations on the island of Tenerife. Average annual temperature on the island is between 17.9 and 24.2ºC. Marked altitudinal variation and different orientation (trade-winds blow from the North-East in the northern hemisphere) greatly influence the water regime. This variability is reflected by the existence of 371 meteorological stations (one per 5.5 km^2). The recorded data allowed calculating a quite reliable island precipitation average, shown in Figure 8-11.

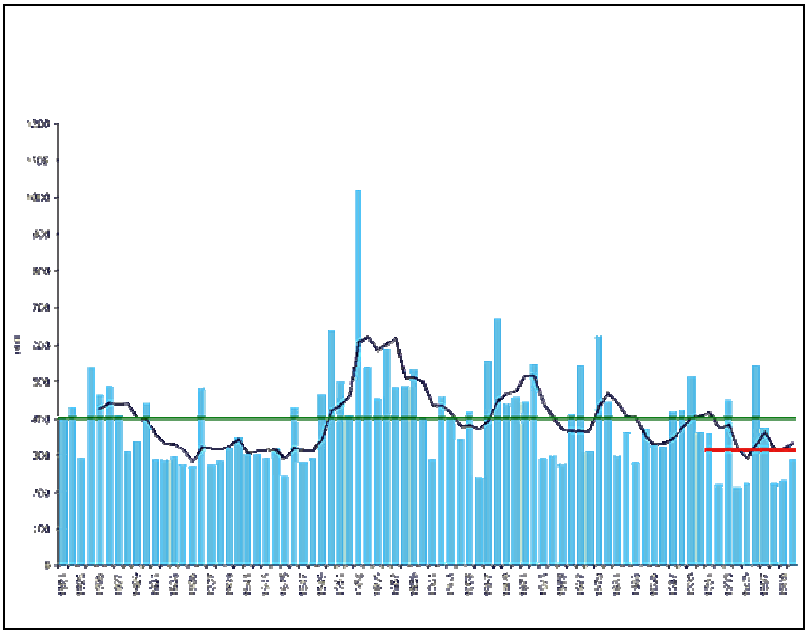

Figure 8-11. Evolution of average precipitations on the island of Tenerife between 1920 and 2001. Curve of 5-years moving averages *(Source: PHI)*

Records reflect great regional difference in precipitations. The highest pluviometry is recorded in the summits of the NE mountain ridge, reaching averages higher than 1000 mm/year, (municipalities of La Matanza and La Victoria). On the other hand, coastal areas of the South of the island are very dry, recording averages of 150 mm/year. Figure 8-12 shows this difference in pluviometry (isohyets), as well as the distribution of the meteorological stations whose data have been considered in the model.

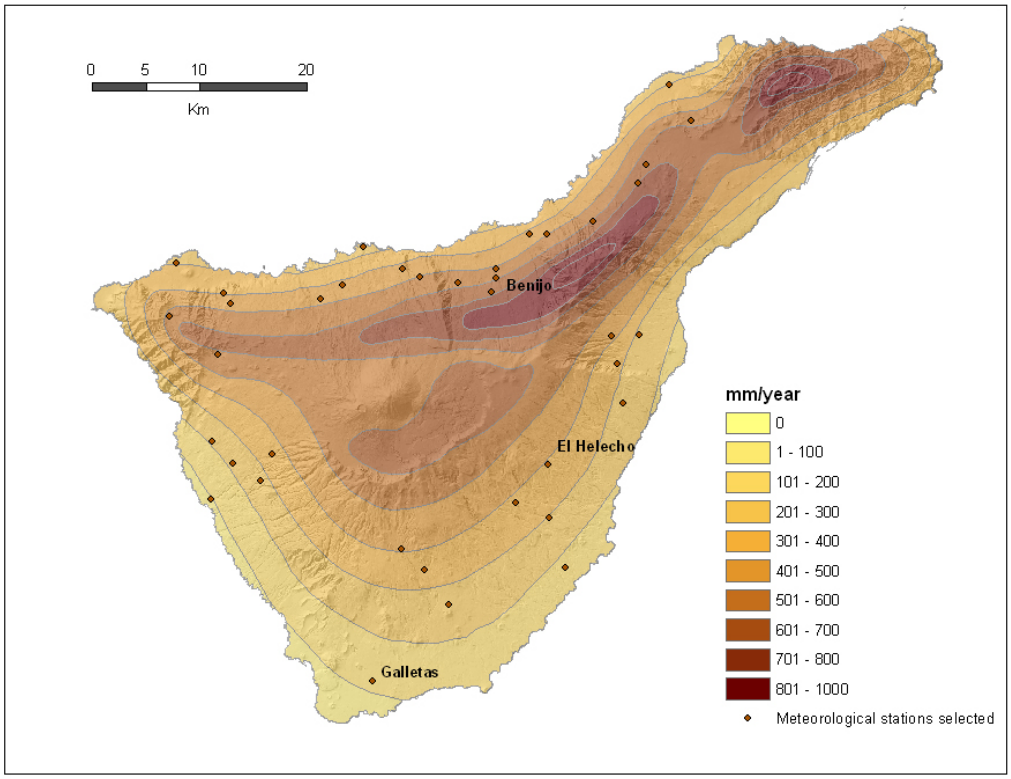

Figure 8-12. Selected meteorological stations and isohyets

Monthly variation can be clearly seen both in the driest and wettest areas.

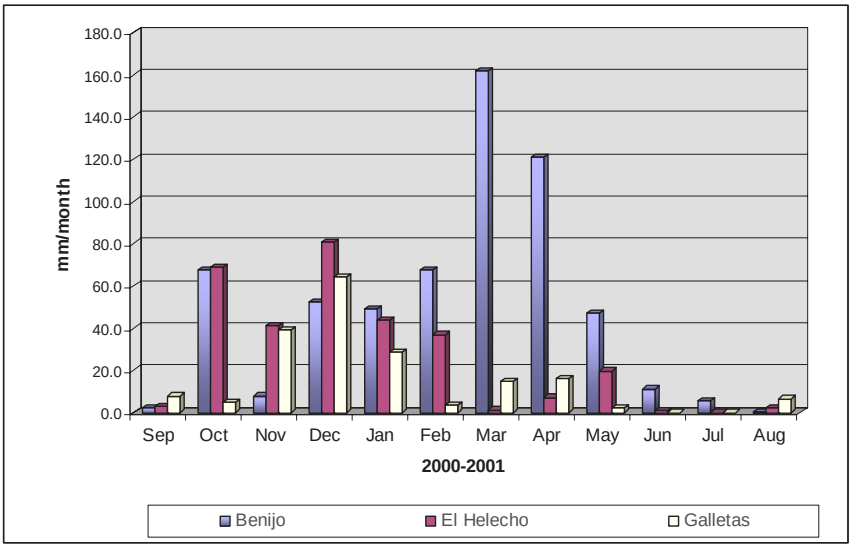

Figure 8-13. Average monthly rainfall en three representative areas

But, since almost the totality of water resources are based on aquifer exploitation, the most significant factor is infiltration, which conditions aquifer recharge. To have a good evaluation of this factor, besides the data series regarding pluviometry, evapotranspiration and surface water flow (all available), we also need to assess the role

of horizontal rain within total precipitation values. That is why extrapolation of the data of the Hydrological Plan on horizontal rain and its infiltration also have been taken into account besides the other factors conditioning water regime. This phenomenon is not deeply known yet but it has a fundamental role in aquifer recharge. Average yearly infiltration from horizontal rain calculated for all the island of Tenerife is of 23 hm^3 (normal year).

Data used to establish Dry Limit and Wet Limit, are obtained calculating 5-years moving averages within the 1920-2000 period, that vary between 299 and 610. The extreme cases exceed 1000 mm/year in 1952 and record 250 mm/year in 1993. The dry tendency of the last period 1993-2000 with an average of 236 mm/year is noticeable.

Exploitation of surface water shows a theoretical maximum of 20 hm^3, but actually it does not exceed 5 hm^3.

Nevertheless, another municipalized value of interest is the production of underground water produced in a normal year through water galleries and wells exploitation (totality). Since all areas have reached the maximum exploitation level, and production decrease from this point, after which no new wells or galleries are made, this limit can be considered in the model as yearly recharge, the maximum volume of renewable underground water, that in a normal year is about 212.7 M m^3. Out of this amount, average renewable resources actually available in a normal year are 180 M m^3 (PHI). The different scenarios are built on this basis, whose validity is corroborated by the fact that the inflexion point corresponds to a group of years close to average values.

Scenarios

Starting from the distribution of precipitation within the period 1920-2000

1. a period of 30 years with a high frequency of dry years (**HD**),
2. a period of 30 years with a high frequency of wet years (**HW**),
3. a period of 30 average water availability years, which signifies the assumption of standard water availability, reflecting the baseline scenario (**Normal**).

The three availability scenarios are depicted in Figure 8-14.

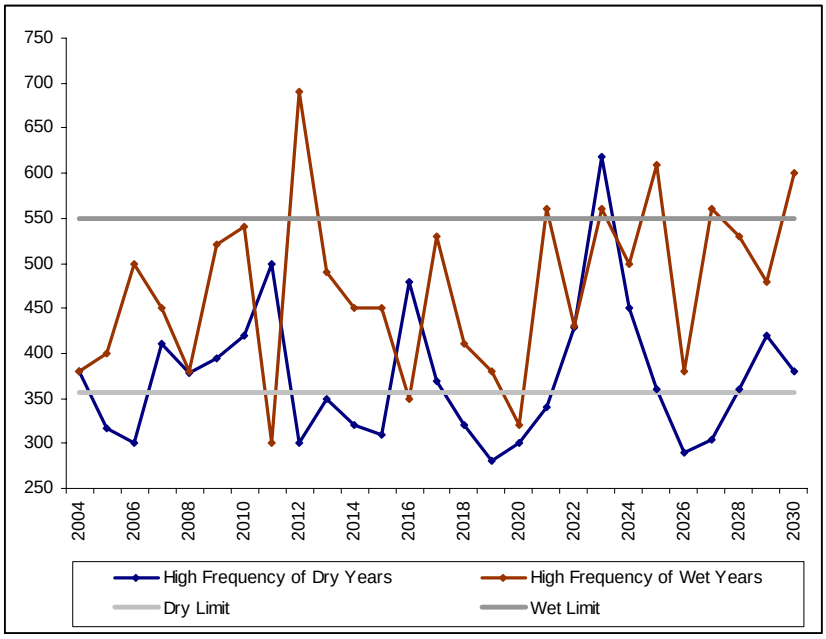

Figure 8-14. Water Availability Scenarios

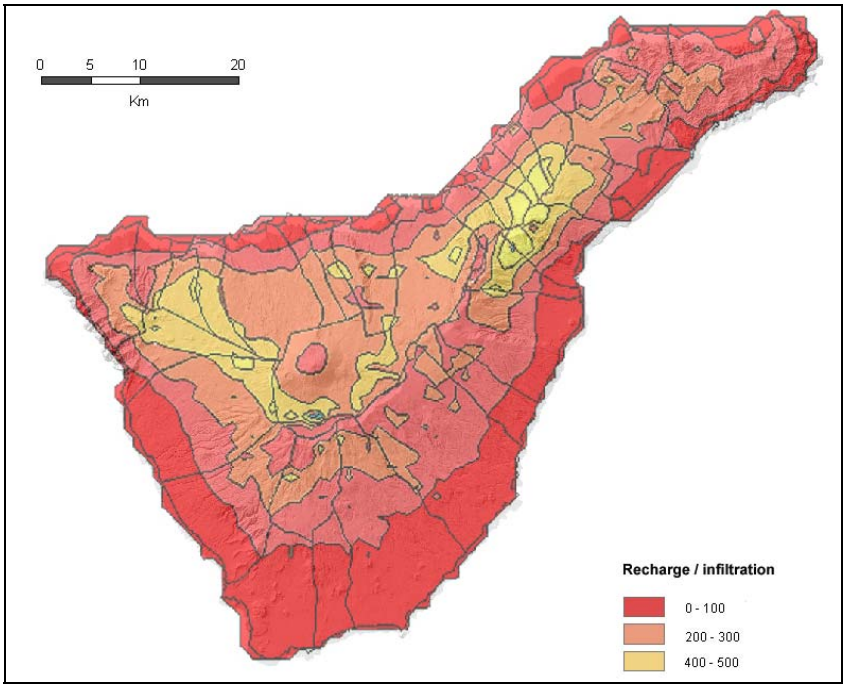

Figure 8-15. Main recharge areas are located in within the trade/wind influence zone and coincide with the forested areas, except a few areas with exceptional geological features (Source: PHI)

Combinations of hydrological and demand scenarios

To determine the representative behaviour of the system in the different projections, and under different resource availability conditions, four combinations are established for comparison:

- 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 combination of high demand with a series of average years (**STABILIZED+Normal**), showing the institutional projection under normal conditions.
- A combination of reduced demand with a high frequency of wet years (**STABILIZED+HD**), reflecting the worst case scenario that can be foreseen on the basis of official projections.
- A combination of high demand with a series of average years (**LD+Normal**), that reflects the behaviour of the system after the application of a set of limitation measures, based on the different sustainable development strategies promoted.

Figure 8-16 and Figure 8-17show the overall deficit under the three scenarios. From the temporal and spatial variation of domestic and agricultural shortages throughout the island, the following conclusions are reached:

- Capacity for desalination programmed until the period 2006-2008, included in the three projections, will not be sufficient to meet the increasing domestic and tourist demand except in the LD case.
- Due to the actual interconnection of all systems, the evolution of the agricultural deficit condemns the survival of several cultivated areas. Small parcels of non water-owners located in non export-crops areas will be the first to disappear.
- In the first two cases there is an actual risk of massive over-exploitation of the aquifer, already happening in some areas.
- Series of very dry years would bring, in the case of the institutional projections (STABILIZED) an actual, definitive transfer of water resources for agricultural use to other sectors, condemning recovering of weakest agricultural systems, which nevertheless are at the basis of local resources such as landscape.
- The big deficits detected would require water mobilizations and transfers through the insular ring a lot larger than at present, increasing energy, storage and transportation costs.

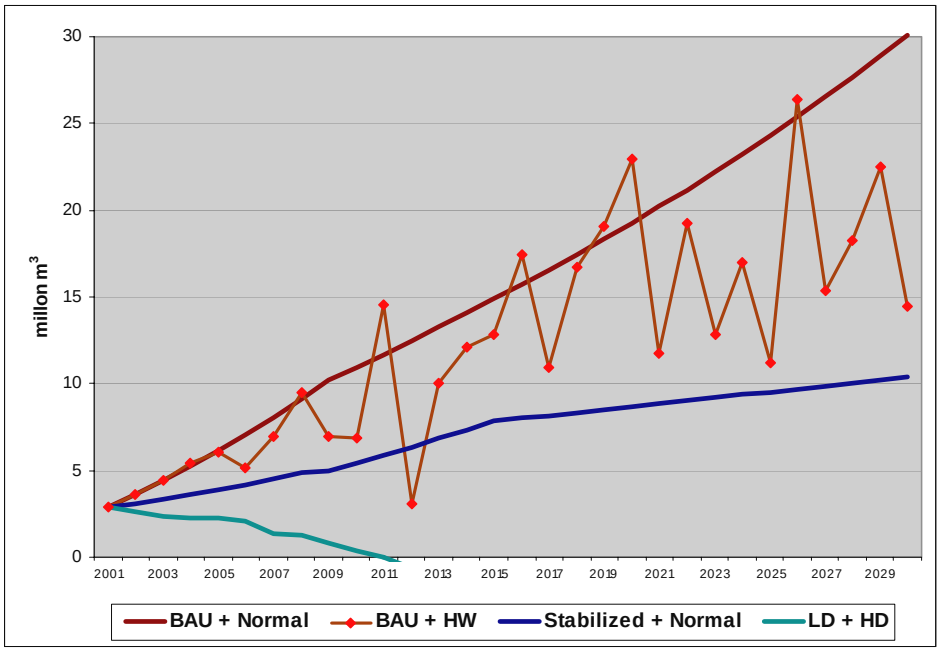

Figure 8-16. Estimated domestic deficit under the selected demand and availability scenario combinations

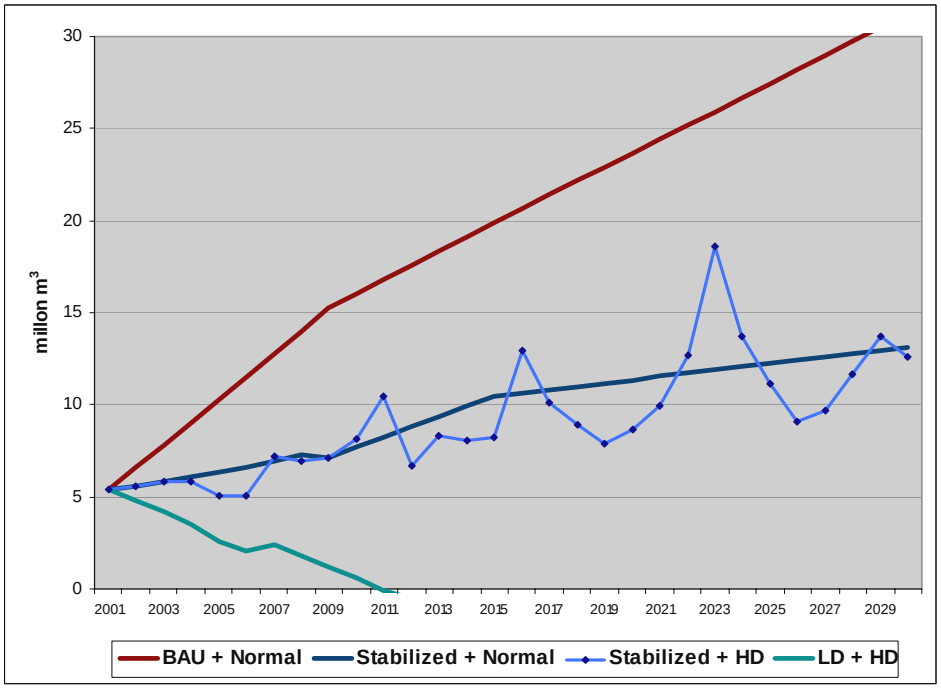

Figure 8-17. Estimated irrigation deficit under the selected demand and availability scenario combinations

8.2. Selection of management options and indicators

The potential policy options identified in the course of the WSM Project were subsequently analysed in their applicability to each region through consultation with the

local stakeholders. As expected, for Tenerife all locals proposed different approaches to water resources management, according to their different targets and economic interests.

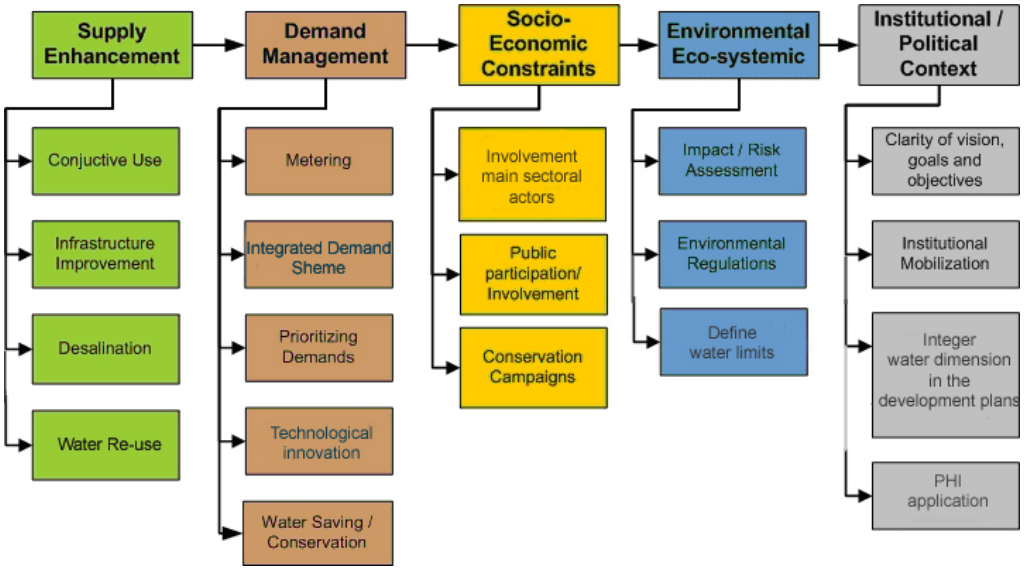

Figure 8-18. Summary of management options

Of these instruments only a number can be modelled through the Decision Support System. The rest, expressing the governance and capacity building mechanisms (e.g. institutional mobilization, clarity of vision), are to be examined at a later stage of the project, during the Protocol Development Stage. Examined options pertain to three major categories:

- **Structural options** for supply enhancement, including:
  - *Network Unifications*, aiming at the integration of the fragmented water networks of the island. This option is not relevant for main canals and transfer infrastructures, since the network making up the insular ring is already practically closed. They will focus on interconnection of treated wastewater and water transfer networks.
  - *Desalination units construction*, to provide additional water supplies. Options considered are the additional units planned until 2006 in the programme approved, since these units are already built or in the process.
  - *New Boreholes*, it is not considered as an option, since the maximum exploitation limit has been reached in all the areas.
  - *Storage Reservoirs construction* to provide a means of storing run-off during low consumption periods to be used later. In the case of Tenerife, they are basically big regulatory reservoirs;
  - *Reuse of wastewater,* aiming at lessening deficit through the reuse of treated urban wastewater for irrigation and gardens.
  - *Recovery and increase of forested area.* Horizontal rain is one of the most important factors in the aquifer recharge, and it is directly related to the type and extension

of the forested area at the altitude where mists, produced by trade-winds, are generated. This aspect is the subject of one of the most important environmental programmes of the island. Nevertheless, studies carried out until this moment, do not allow us yet to quantify this option that, therefore, has not been included in the system.

- **Demand management options**, including:
  - *Reduction of Network losses*, working on two lines: renovation of the big distribution and transfer canals and improvement of urban networks;
  - *Conservation Methods* in the Domestic Sector and the tourist areas;
  - *Improvement in Irrigation Methods*, for better irrigation efficiency and savings in water consumption;
  - *Exploitation of Surface Water* is considered as an option, although with the limitations of its scarce possibilities.
- **Socio-economic measures** including,
  - *Pricing* aiming to examine to what extent a difference of pricing structures would influence the targeted indicators of the analysis. Price policies are not considered in this phase since they have already been implemented with different modalities (including differential price in tourist municipalities), and they are therefore already included in the BAU scenario.
  - *Incentives to change of crops*. It includes conversion of agricultural crops and of species used in landscaping, being the last one very important in tourist areas.

The selection of appropriate indicators for ranking the above options also reflects the perception of the local stakeholders towards economic development, social and environmental sustainability. In a present-day system where the service sector is determinant, covering the domestic demand, that includes tourist activity, is a social and economic priority. In Tenerife this indicator expresses the efficiency of the operation of the water resource system, but also establishes risk limits that are unacceptable for the productive structure of the. **Irrigation demand coverage** includes two aspects of land sustainability. The first one refers to preservation of agricultural activities (in particular the traditional ones as an extremely important factor of economic diversification, also maintaining population in rural areas and supporting therefore an important share of the social and cultural system. The second aspect is about its importance in landscape maintenance, on an island whose economy partially depends on this type of offer.. Environmental protection is expressed through the **groundwater exploitation index**. Currently, aquifer overexploitation and salinisation is one of the key environmental problems that threaten not only the provision of supply but also the future resources of the island, especially when the fossil water of the aquifer has already started to be exploited.

The satisfactory range of values and the weights assigned to the three indicators are presented in Table 8-6. In addition to the three aforementioned indicators, it was considered necessary to incorporate also the **direct costs** related to the application of each option, in order to select not only efficient, but also cost effective solutions.

Table 8-6. Satisfactory range of values and weights for the indicators of the Tenerife case study

Indicator	Satisfactory range of values	Weight
Domestic demand coverage	90-100%	0.40
Irrigation demand coverage	60-100%	0.20
Groundwater exploitation index	0-90%	0.20
Direct Costs		0.20

8.3. Analysis of water management instruments

Structural options

Network Unifications

The network of main canals and pipelines make up an insular ring from which water is distributed. It is through the ring that territorial and infrastructural connectivity exists between different water supplies and centres of distribution (water galleries, wells, desalinating plants, wastewater treatment plants). Therefore there are no important actions that can have an influence on this model, since:

a) The unification of those irrigation supply pipelines/canals made by private individuals owning water shares is considered as an instrument under the point "*Reduction of Network losses*".

b) Connectivity of treated wastewater network and its influence on the different scenarios is considered as an instrument under the point "*Storage Reservoirs construction*".

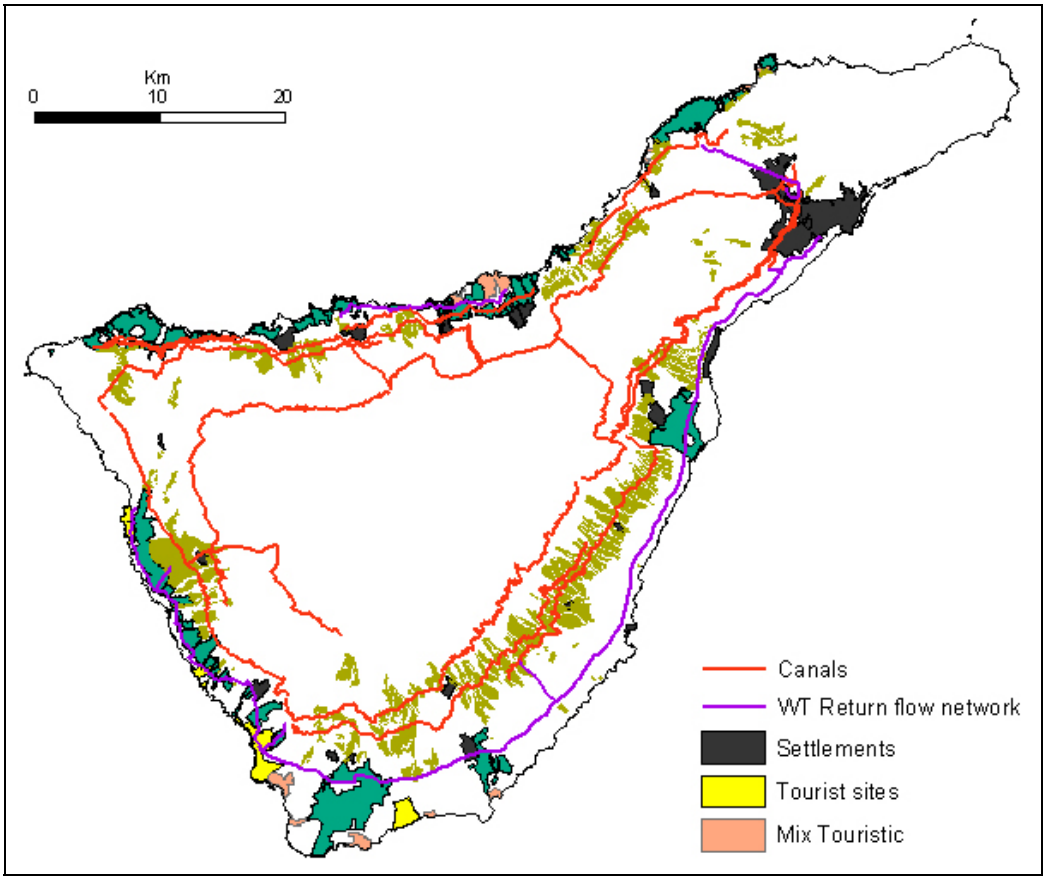

Figure 8-19. Map showing main networks and water uses

Desalination

The Canary Islands are among the most advanced areas in the world with regard to water desalination. During the last three decades, several desalination solutions using the different technologies that have been appearing in the market have been implemented to desalinate both subterranean and seawater: Vapour compression, Multi-stage-flash, Multi-effect-distillation, electrodialysis reversal process, and, finally, reverse osmosis (RO).

In the specific case of Tenerife, the experience starts in 1976, and the volume of water treated has been increasing to reach 28 hm^3 at the present time, which is 14% of the total island water demand. At present 29 major desalinating plants are operating, with a total desalinating capacity of 109,690 m^3/day, and the number of plants will increase to 41 in the next few years.

Desalination has been the main reply to the increase in water demand and over-exploitation of the island's aquifers. The accumulated increase in desalinated water production has been 12%/year.

Improvement of reverse osmosis membranes technology, as well as the new energy-recovery water systems called "isobaric chambers", which allow desalinating seawater at very accessible prices (Table 8-7), have contributed to this clearly technical-political option. Application of these energy saving methods and other ones (reverse osmosis with energy recovery devices, two steps RO with two different types of membranes and intermediate booster, electrodialysis reversible, advanced multi-effect-distillation plants) allowed to lower energy consumption reaching 2-3.1 kWh/m^3 of desalinated water, a number that is quite far from 29 kWh/m^3 needed in 1976. In this new technological scenario, automatic devices also achieved a notable reduction of operational and maintenance costs, achieving water production prices of 0.5 €/m^3. This has been the main reason for new proposals to increase desalinated water production, since from this price it is more competitive than pumping water from wells deeper than 100m.

Table 8-7. Breakdown of present-day desalination costs in medium and large plants

Concept	Cost €
Water pumping to plant (50m)	0.026
Energy 3.1 Kwh/m^3	0.225
Pre-treatment (sodium bisulphite, anti-incrustation)	0.006
Post-treatment	0.008
Personnel	0.066
Substitution of membranes	0.006
Substitution of filters	0.009
Maintenance of pumps and other equipment	0.012
	0.079
SUBTOTAL	**0.437**
Industrial benefit -plant operator (15%)	0.066
TOTAL (not including plant amortisation)	**0.503**
Plant amortisation	0.060
TOTAL (including plant amortisation)	**0.563**

The desalination units were designed to have a lifetime of 20 years, although the experience in Tenerife shows actual lifetime is not exceeding 12-13 years. Tenerife Hydrological Plan forecasts achieving 12% of water supply from desalination. The increase in desalination in the different scenarios involves doubling present-day desalinating capacity, with an increase rate similar to the one produced in the last years (16-18 hm^3 /year). Table 8-8 lists the larger capacity desalination plants planned to be built in the period 2001-2006. Plants built before 2002 have been included in the evaluation of the basic scenario in the WSM DSS tool.

Table 8-8. Main desalination plants and foreseen date when they will come into operation.

NAME	Capacity – m^3/day	Year
SANTA CRUZ (DAM0102) 2nd phase	20000	2006
CEPSA (DAS0109) 2nd phase	3800	2006
GRANADILLA (DAM0803) 2nd phase	5000	2006
ICOD-III	4000	2003
VALLE SAN LORENZO (DAS0904) 2nd phase	8000	2002
LAS AMERICAS (DAM1001)	20000	2002
SANTA CRUZ (DAM0102) 1st phase	20000	2001
ICOD-II (DAS1916) 1st phase	2100	2001
SAN ISIDRO (DAS0810) 1st phase	3800	2000
LOS MENORES (DAS1211) 1st phase	1900	2000
ABAMA (DAS1317) 1st phase	1900	2000
LAS CHARQUETAS (DAS1307) 1st phase	1900	2000
ARIPE (DAS1306) 2nd phase	8000	2000
BUENAVISTA (DAS1505) 1st phase	1200	2000
EL TANQUE (DAS1815) 1st phase	1100	2000
LA GUANCHA (DAS2002) 2nd phase	4000	2000
VALLE OROTAVA (DAS2212) 1st phase	1900	2000

NAME	Capacity – m^3/day	Year
COSTA TEJINA	1400	1997
ARIPE (DAS1306) 1st phase	4000	1997
VALLE SAN LORENZO (DAS0904) 1st phase	4000	1996
LA GUANCHA (DAS2002) 1st phase	1900	1995
CEPSA (DAS0109) 1st phase	4600	1994
CHIO (DAS1303) 1st phase	2100	1994
CHIO (DAS1303) 2nd phase	3000	1994
ICOD-I (DAS1901)	1200	1994
UNELCO	1100	1992

Changes derived from this situation have been so fast that desalination is now the primary source of water in certain areas (a few tourist and urban areas, and even some areas with specialised agricultural productions). The clearest case is that of the plant supplying two tourist municipalities in the south of the island (Adeje and Arona), whose evolution is shown in Table 8-9.

Desalination is the structural solution that performs the best among all examined. Therefore, when renewable water resources are depleted, desalination starts to cover water domestic demand.

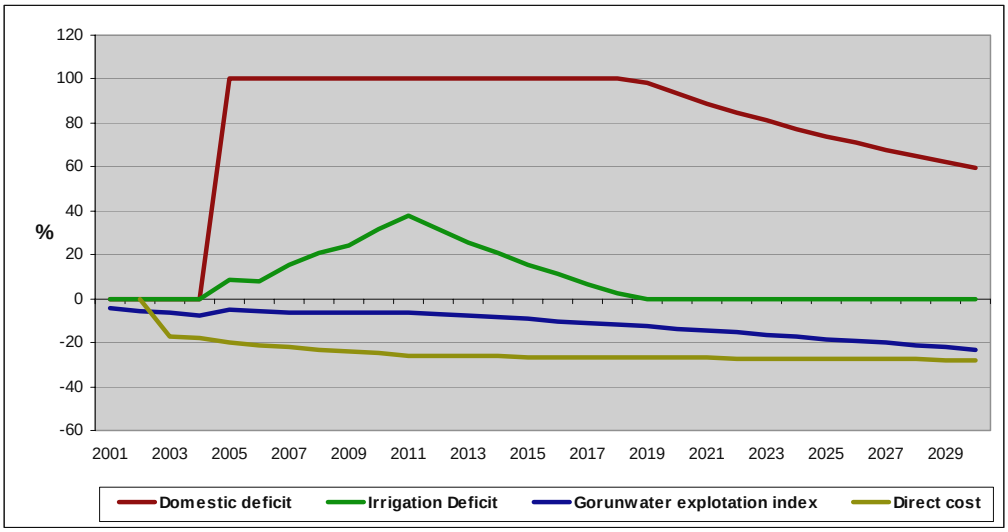

Figure 8-20. Improvement with respect to the BAU + Normal scenario

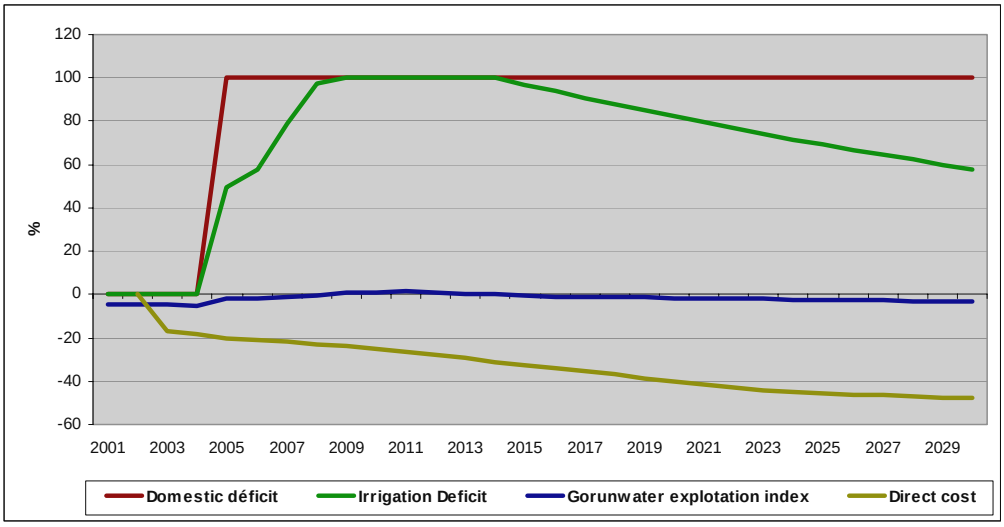

Figure 8-21. Improvement with respect to the STABILIZED + Normal scenario

The evaluation of these scenarios (Figure 8-22) shows that this measure improves domestic demand deficit in the STABILISED case as well as the irrigation deficit. Owing to the moderated decrease of the agricultural sector established within this scenario, the influence of this option is evident. On the contrary, the BAU case shows only a limited improvement if compared with the previous case. Its repercussion would be effective only with very big increases, which would involve a technological and investment effort almost impossible to assume. It is important to observe that groundwater exploitation index does not recover the sustainable rate (BAU and STABILISED).

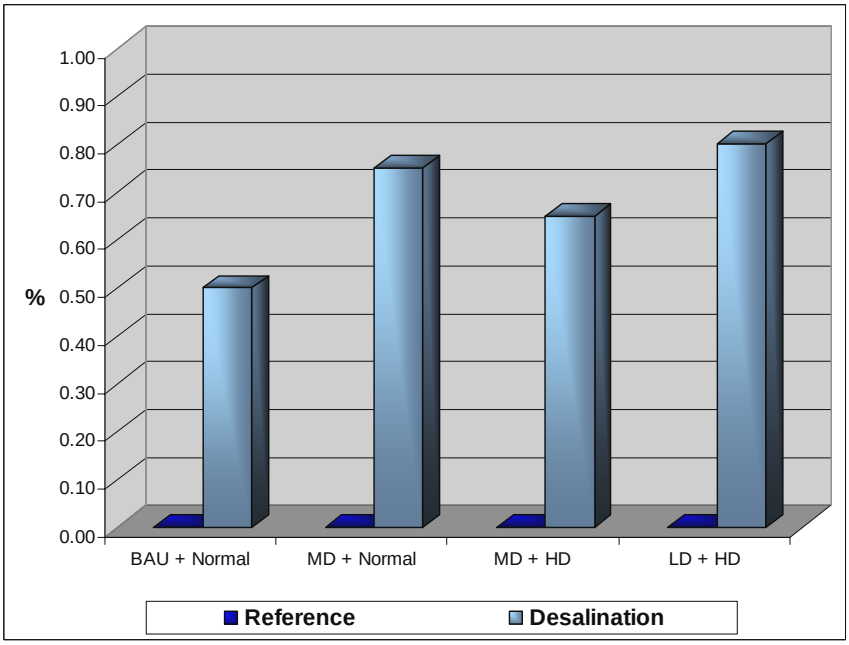

Figure 8-22. Evaluation of desalination under the four reference scenarios

Direct cost development for the different scenarios obligatorily involves renewal of plants as soon as they become obsolete.

As Figure 8-23 shows, the problem exists also in the LD+HD scenario, in the middle term, since the investment costs have negative repercussions on the system because of plant inoperability and lack of generation demand.

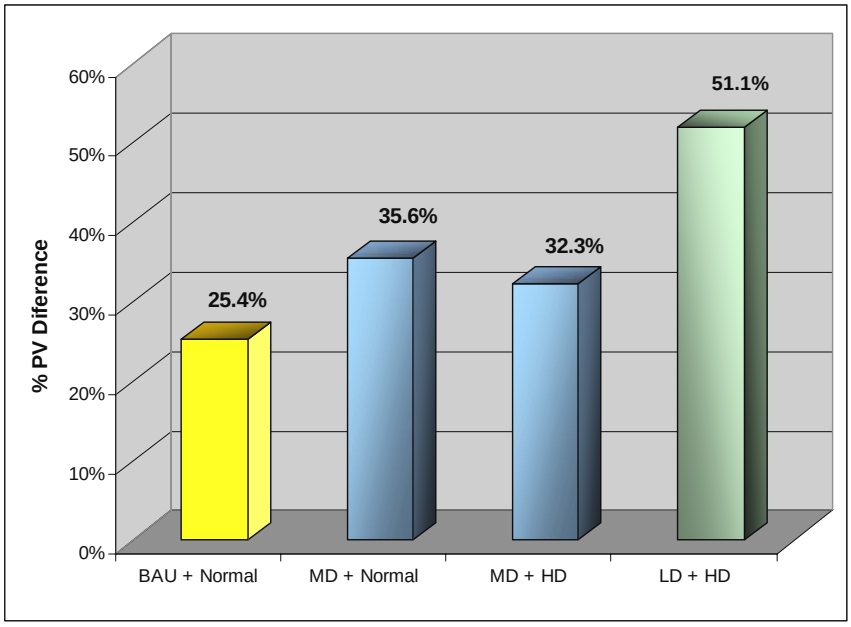

Figure 8-23. Present Value difference over the four reference scenarios (Desalination option)

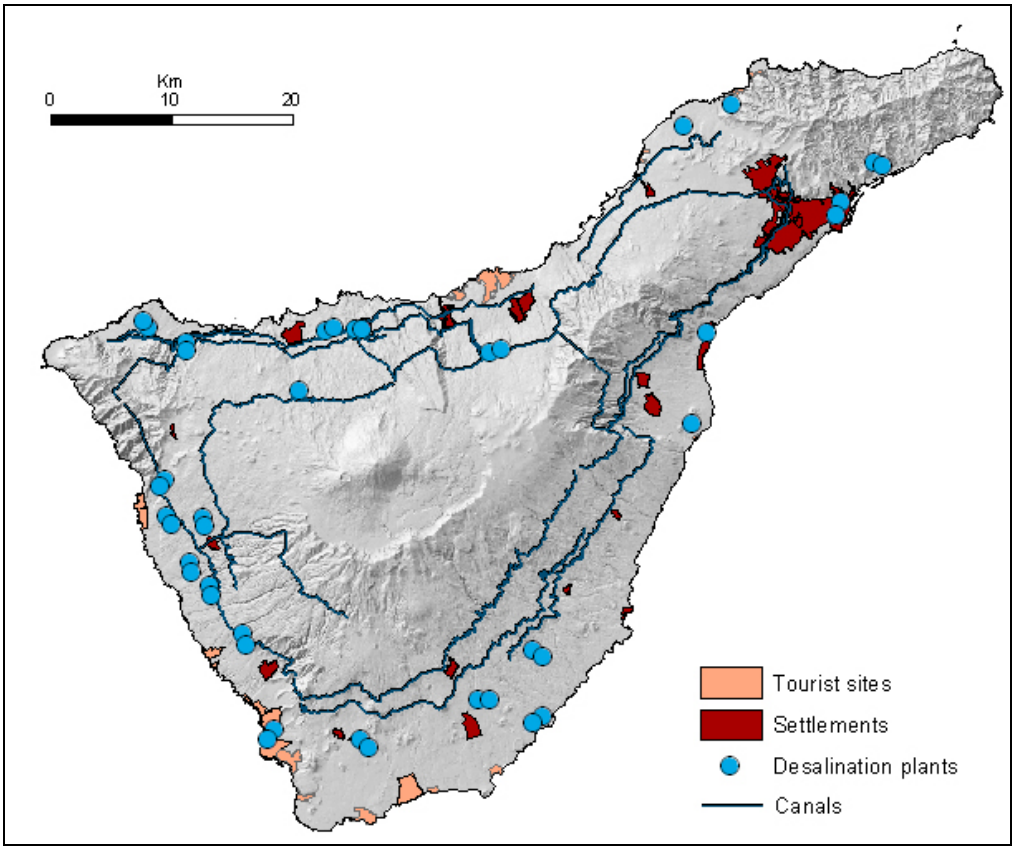

Figure 8-24. Localisation of desalination plants in Tenerife, including those planned and under construction

Table 8-9. Adeje's Integrated System (Tourist Centres of the South). All data in m^3/year.

	1998	1999	2000
Desalination	1,882,108	3,835,848	5,025,259
Treatment	1,977,308	8,468,315	9,033,483
Biological treatment	784,131	2,621,610	3,090,625
Water re-use	430,325	1,555,032	2,006,760

New Boreholes (water galleries and wells)

As has already been explained, underground water is still the main water resource on the island, representing more than 90% of total available water. Nevertheless, the problem does not lie in further exploitation of the aquifers, since at present their use is facing two basic problems: overexploitation and quality deterioration.

Starting from the maximum exploitation period that has been recorded, from 1970 to 1975, coinciding with the maximum values of discharge to sea due to the high return flow rate of irrigated areas, a slow descent of abstraction capacity is produced. This effect was not the same for the entire island, being less pronounced in the slopes of the central massif (depending of the altitude of water galleries). On the other hand the biggest reductions are recorded in the wells of the southern areas, or in a few deep wells such as those of the aquifer of La Laguna, located in the metropolitan area. The system has in

fact found a point of equilibrium in the abstraction through water galleries, which only catch new resources and not the reserves. But reductions of both the costal gradient and discharge to sea have been registered, and saline contamination is more and more pronounced in coastal wells.

Present-day abstraction that, as we have seen, scarcely exceeds 212 hm^3/year, is based on systems that are in operation at present: 8 springs, 55 wells and 148 water galleries. Under the above conditions the possibility to cover the existing deficit through new boreholes is rejected, only excepting a few cases of low significance that do not affect the established scenarios.

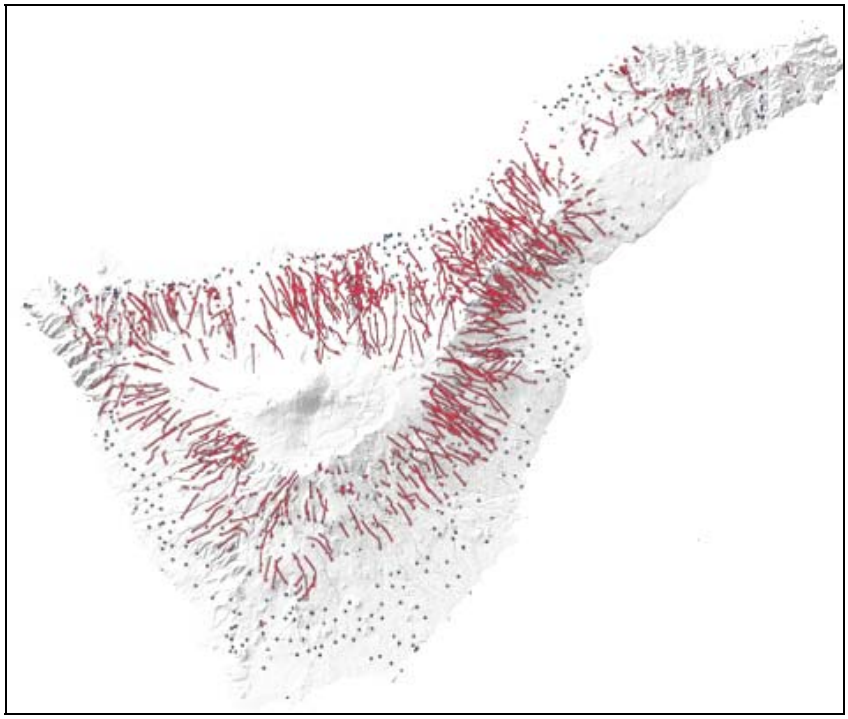

Figure 8-25. Map showing location of water galleries and wells

Storage Reservoirs

The development of reservoirs to harness surface run-off water was one of the greatest failures of all the hydraulic projects implemented between 1940 and 1970, because of the irregular nature of the rainfall and the difficult characteristics of the terrain. The current inventory of reservoirs (45 operating irregularly) provide a storage capacity of 4.5 M m^3, used occasionally for storing subterranean water from galleries or for harnessing surface run-off water.

The special characteristics of private water management, especially of gallery water management, the constant supply of which is handed over for a previously agreed upon period of time to owners of water rights and which does not coincide with immediate irrigation needs, forced the authorities to build a large number of small storage reservoirs. The PHI (Island Hydrological Plan) lists a total of 8105 storage pools and tanks, with a total capacity of 24 M m^3.

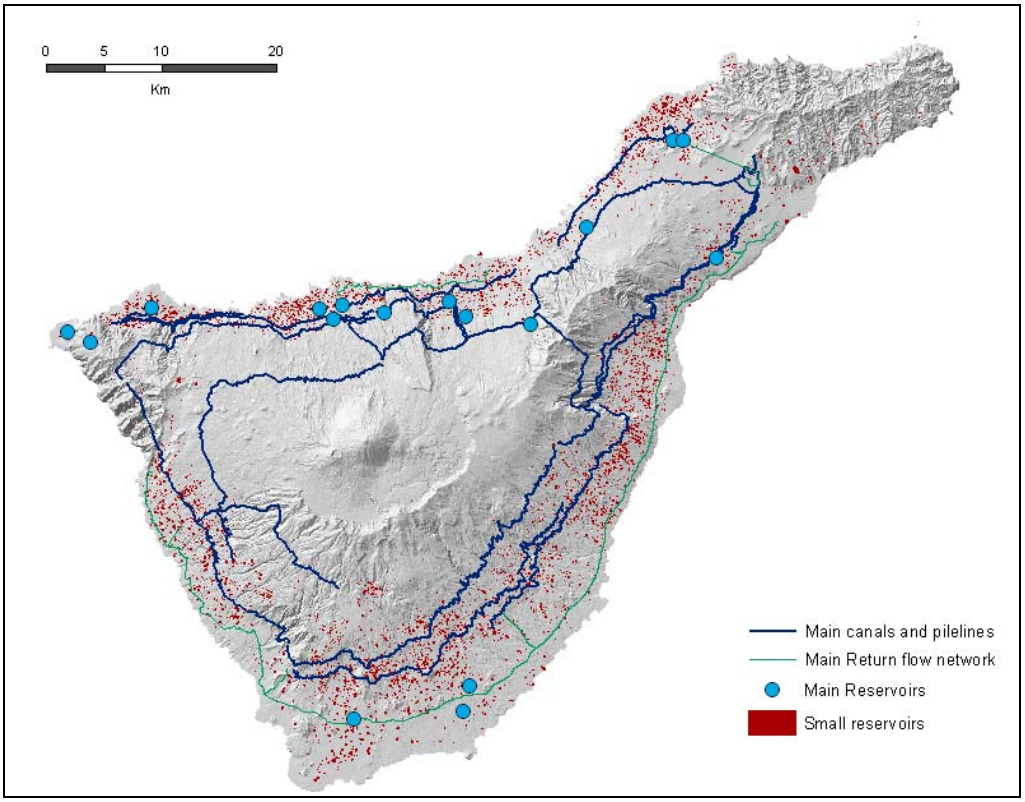

Figure 8-26. Localisation of main storage and regulatory reservoirs, close to general distribution networks. The figure shows the huge dispersion of the more than 8000 smaller private reservoirs

Obviously, maintenance of an infrastructure of this kind is highly inefficient and causes major losses from the system. For this reason, the Tenerife Cabildo (Island Government) developed a Regulation Reservoir Plan and its own agency (Balsas de Tenerife – BALTEN) to run and maintain the regulating reservoirs. All 13 of these storage reservoirs represent a storage capacity of 4.38 M m^3.

They work by users feeding water into the reservoir when they have a surplus at certain times of year. They can recover the water they have put in later on in exchange for a fee for storage, which is charged in kind by the users granting a percentage of the water they have pumped into the reservoir to the reservoir company. This water, along with the water resources harnessed by other means (run off water and rainfall) is also put up for sale by BALTEN, with different prices, depending on the area of the island in question.

This way, the Plan means to implement an efficient progressive storage system that will allow for an appropriate assignation of resources at the right time and in the right place and prevent losses that can amount to a maximum of 1.5 M m^3/year.

Island authorities have started to implement the introduction of this initiative, and are facing some reticence of private water owners, and it does not offer a long place solution in the BAU scenario, although it is significant in the STABILIZED one. Finally, within the LD scenario, the solution presents an outstanding benefit in environmental terms,

although costs over raise, compared with the reference scenario in water shortage periods.

Nevertheless, the final evaluation of this measure has to be read as linked with *Re-use of water* and *Reduction of Losses*, since the reservoir strategy involves the possibility to unify and distribute treated water production for irrigation, avoiding losses.

Figure 8-27 and Figure 8-28 demonstrate that this option has no influence on domestic deficit covering, also in a regional-scale analysis.

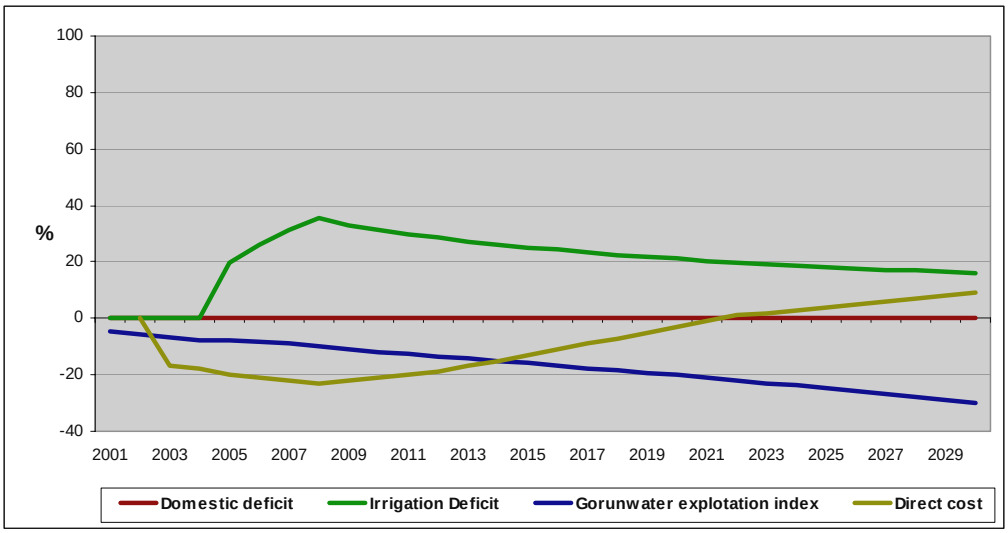

Figure 8-27. Improvement with respect to the BAU + Normal scenario

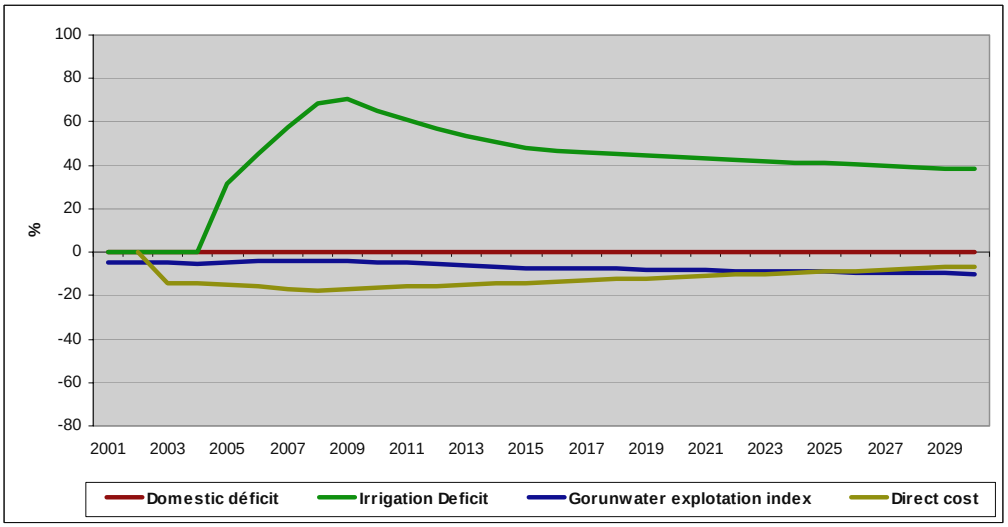

Figure 8-28. Improvement with respect to the STABILIZED + Normal scenario

Wastewater treatment and reuse

More than two decades ago the search for solutions aimed at mitigating water deficit in Tenerife did not focus only on desalination. When development of wastewater treatment plants started at that time, an innovative project was designed to transfer treated wastewater from the metropolitan area to the new tourist centres of the south.

Therefore, from the first attempts, wastewater treatment strategies on this island have always been linked with to water re-use, in order to compensate the island water balance.

The Hydrological Plan set a first phase that foresaw:

- 11 wastewater treatment plants with a whole capacity of 144,300 m^3/day.
- 588,000 habitants and 148.000 tourist places connected to the plants.
- 131,600 m^3/day of treated wastewater, ready to be re-used.

Present/day situation of wastewater treatment on the island of Tenerife is reflected in the following table, elaborated by the Canary Islands' Water Centre (CCA).

Table 8-10. Production, discharge and re-use of wastewater in 2001 *(Source: Manuel Fernández -CCA)*

Production, discharge and reuse of treated wastewater	
Domestic, tourist and industry water consumption (M m^3/a)	67.9
Total wastewater production (M m^3/a)	56.2
% of W.W. going to septic tank or directly to sea or riverbed	37%
W.W. collected through wastewater network (M m^3/a)	35.4
Loss of W.W. in wastewater network (%)	20%
Urban W.W. available for treatment (M m^3/a)	28.3
Treated urban W.W. (M m^3/a)	14.2
% of treated water on total W.W. production	25%
% of treated water on available urban W.W.	50%
Reused urban W.W. (M m^3/a)	8.0
% reused water on treated W.W.	56%
% reused water on total water available on the island	4%
Treated W.W. discharged to sea or riverbed (M m^3/a)	6.2
N. of operative urban wastewater treatment	11.0

A sample of the possibilities of this deficit reduction, that also reflects some of the barriers faced by this solution, can be found within the results of the integrated project for the tourist centres of the south of the island (CIAFTE). After the enlargement of the desalinating plant mentioned in desalination chapter (5,025,259 m^3 of water production in the year 2000), the integrated project of wastewater treatment was complete. According with data of the 2002, 9,033,483 m^3 of wastewaters have been collected and appropriately treated. Due to the problems of salt contamination of wastewaters in this area, it was not possible to biologically treat and reuse the totality of water collected. Out of 9 hm^3 disinfected and sent to primary treatment, only 3 hm^3 had an acceptable salinity and were sent to complete secondary treatment, and 2,405,957 m^3 have been reused. Therefore 26.63% of the total quantity of wastewaters collected by the wastewater network has been reused, meaning an increase of 39.16% on the volume of water reused in 1999.

Starting from the supplied data, the truly realistic objective is set of reusing, for gardening and irrigation, 25% of the water available for treatment. Considering that only 82% of

used water is collected by the sewing network, it means that 21% of the total water for domestic and tourist use would be re-used, reducing the deficit.

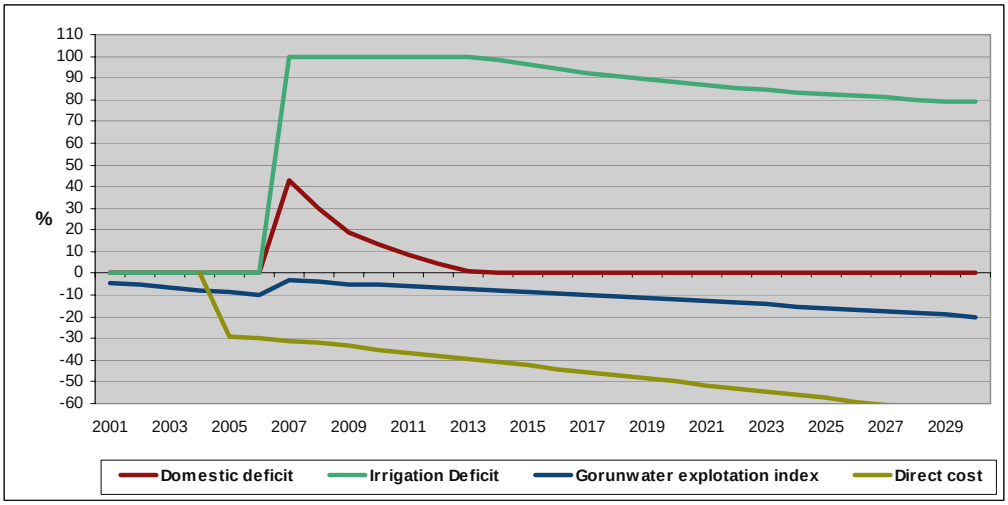

Figure 8-29. Improvement with respect to the BAU + Normal scenario

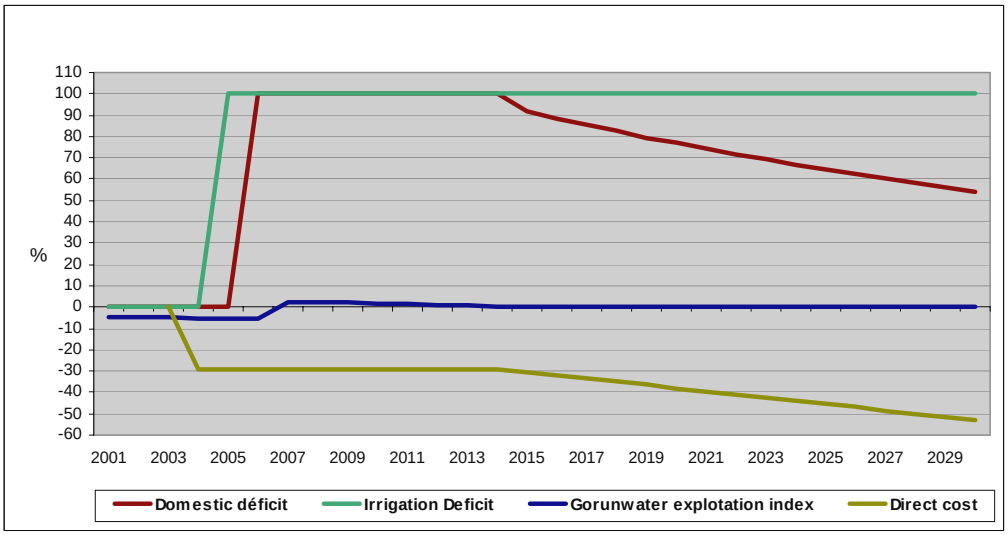

Figure 8-30. Improvement with respect to the STABILIZED + Normal scenario

The evaluation of these scenarios shows that this measure improves domestic demand deficit in the STABILISED case as well as the irrigation deficit. Owing to the moderated decrease of the agricultural sector established within this scenario, the influence of this strategy is evident. On the contrary, the BAU case shows only a limited improvement if compared with the previous scenario. Its repercussion would be effective only with very big increases, which would involve a technological and investment effort almost impossible to assume.

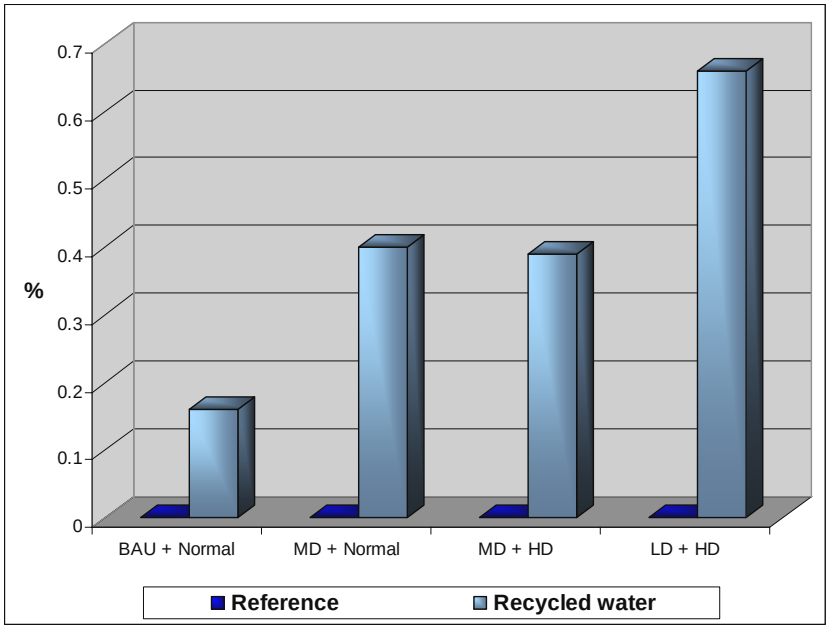

Figure 8-31. Evaluation of wastewater treatment and reuse under the four reference scenarios

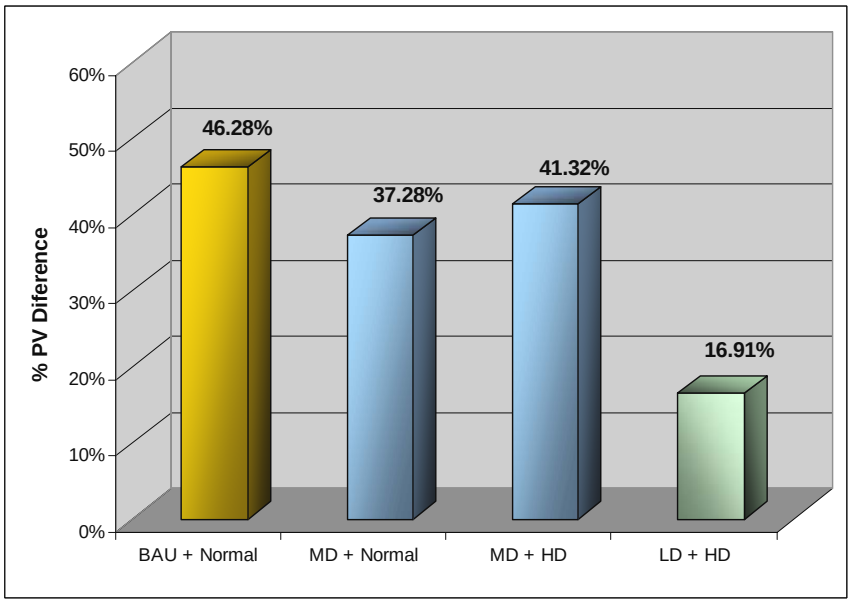

Figure 8-32. Present Value difference over the four reference scenarios (Wastewater treatment and reuse option)

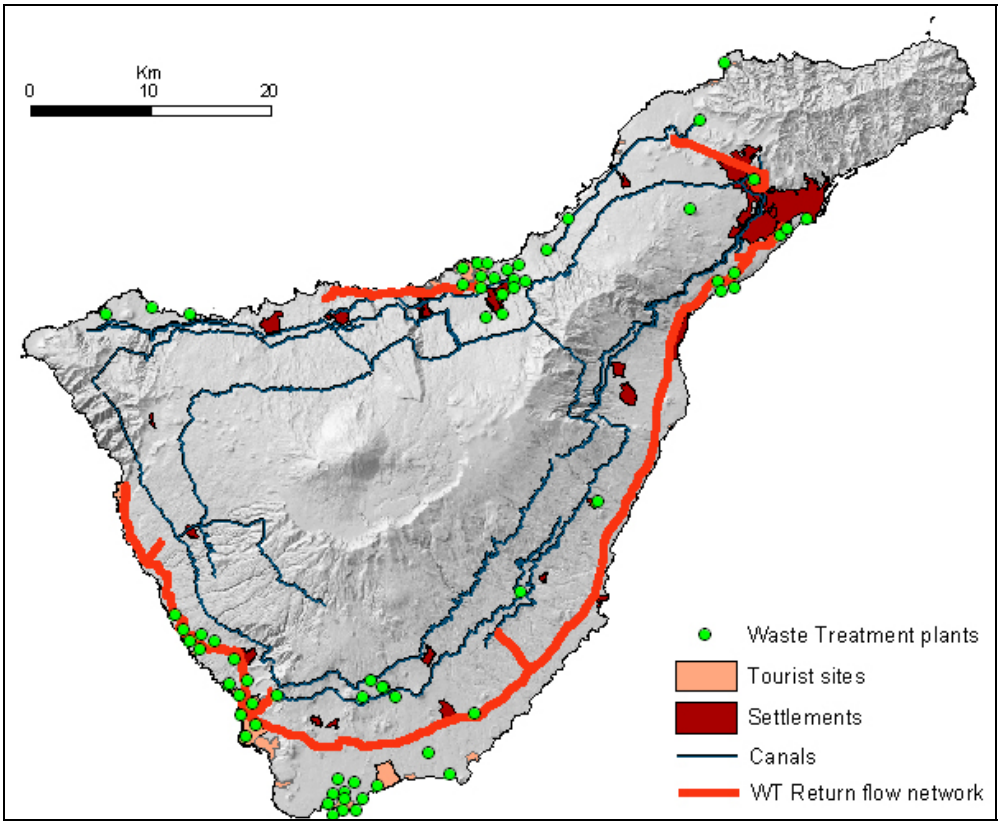

Figure 8-33. Main network for treated wastewater reuse and location of wastewater treatment plants

Figure 8-33 clearly shows that the water distribution ring is actually closed. The reason why direct costs of integral exploitation exceed even those of desalination is the lack of a complete parallel infrastructure for treated water distribution (TW return flow network).

Recovery and increase of forested area

Although its functioning is not well known yet, horizontal rain contributes at least of 10% of total infiltration. Beside ecological landscape needs, taking this factor's influence into account in covering water deficits, the Cabildo (Island Council) of Tenerife several years ago launched a programme of reforestation to restore this double functionality, bringing the forested area to conditions similar to the historical ones.

Logically, the results of this programme are projected in the long term, and do not constitute a short or medium term reply to deficit covering. But indeed, they have an influence within the temporal term outlined in the scenarios. The proposal is to progressively increase the forested area, in the trade-winds influence zone, up to 15% more than present-day covering. The elaboration of this scenario took into account that present-day main reforestations were started more than ten years ago, and therefore it is possible to rely on reforested areas fulfilling their function in 2007.

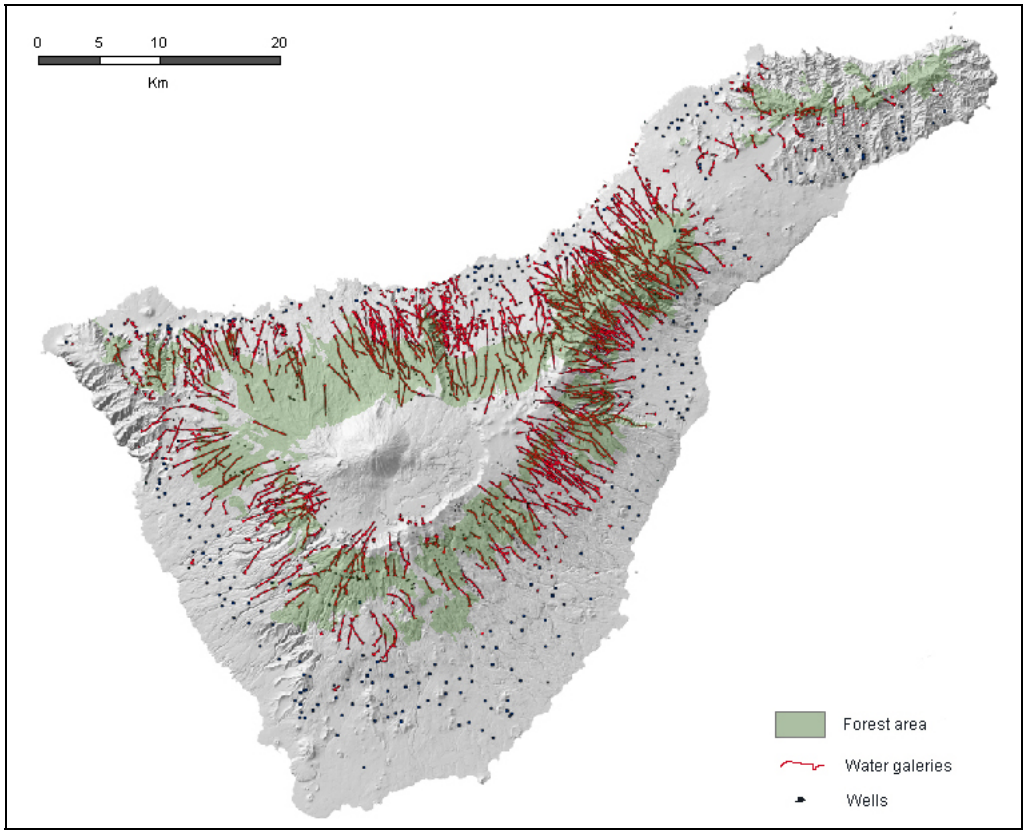

Figure 8-34. Forested area and location of water galleries and wells. Main water canals are also shown

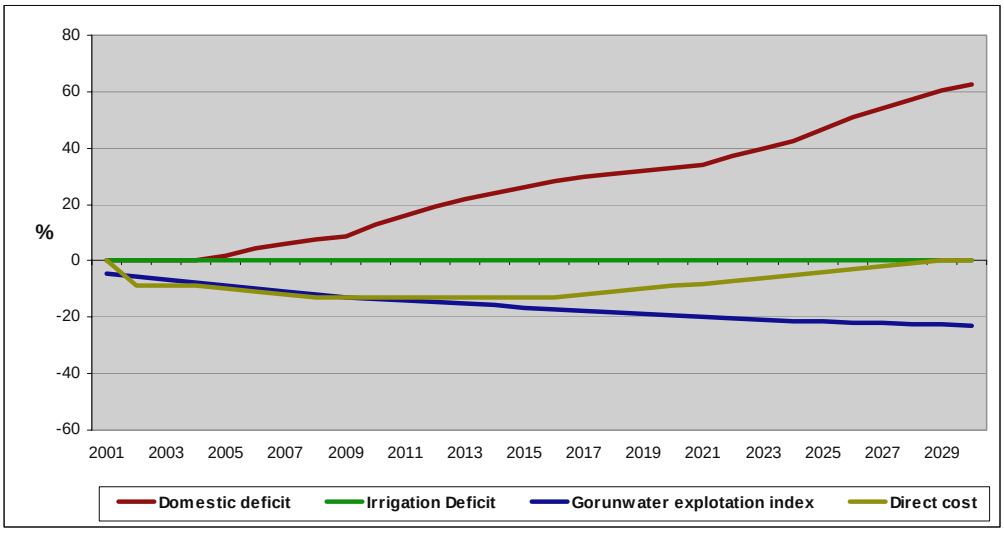

Figure 8-35. Improvement with respect to the BAU + Normal scenario

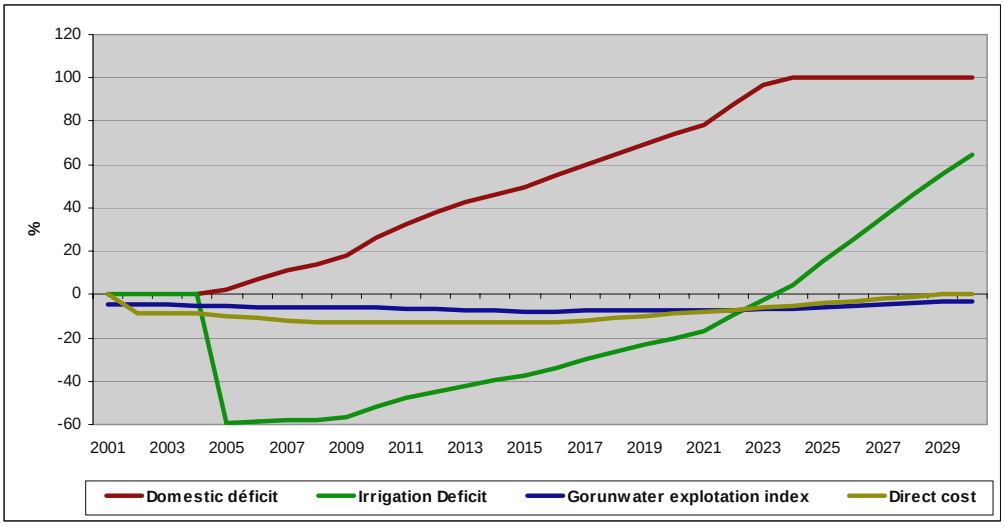

Figure 8-36. Improvement with respect to the STABILIZED + Normal scenario

The evaluation score obtained for this option under the four reference scenarios is presented in Figure 8-37. The highest score is obtained under LD+HD availability conditions. As it can be clearly seen, this is a very interesting option that can even cover domestic deficit in the long term in the STABILISED case, and a large part of it in the BAU case.

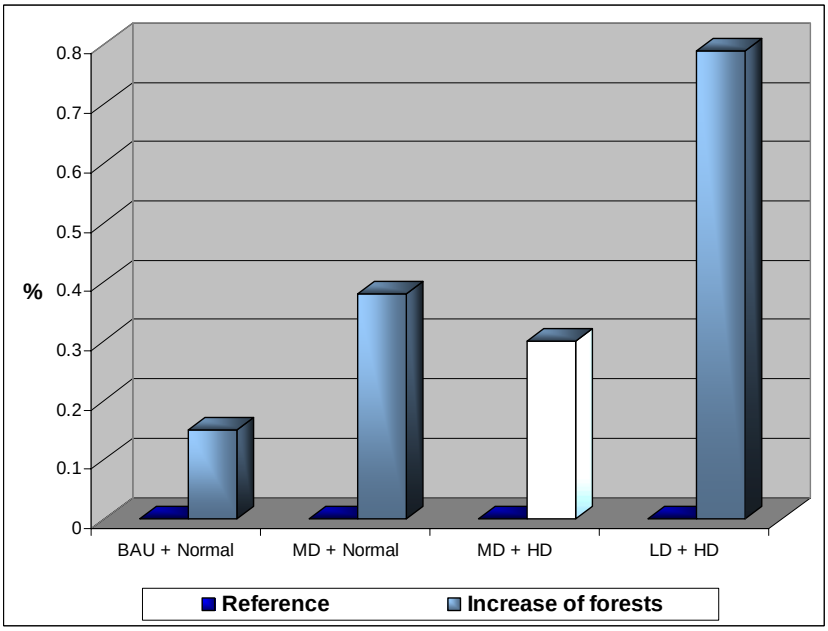

Figure 8-37. Evaluation of recovery and increase of forested area under the four reference scenarios

Costs are clearly reduced in the LD scenario since this option would be superabundant in comparison with resource availability.

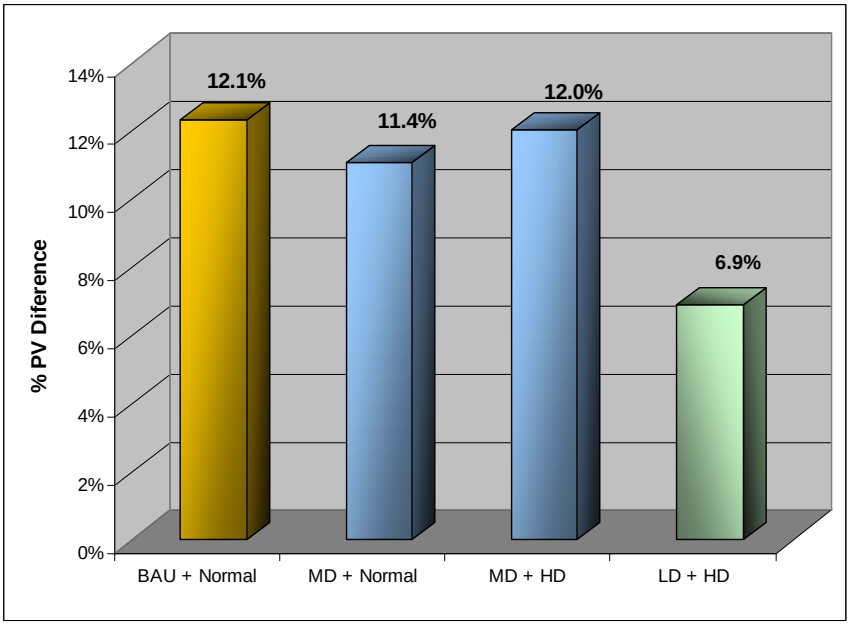

Figure 8-38. . Present Value difference over the four reference scenarios (Recovery and increase of forested area option)

Demand Management options

Reduction of Network Losses

In the case of Tenerife, it presents some singularities at the moment to face the problem of network losses. A particular system of exploitation, private ownership and characteristics of distribution resulted in more than 1200 inventoried canals and pipelines, for a length of more than 4000 km. The urban internal distribution network is not included in these numbers. 36 main canals and pipelines, for a length of 775 km, make up the basic network that transfer the almost totality of water collected. Management of an important share of these main networks is private, and corresponds to the water distribution system for irrigation. In spite of the continuous actions carried out, estimated network losses at this level are of about 18%. Given the extreme fragmentation of water canals and pipelines for irrigation by each owner who in several occasions brings water directly from a gallery or well until their plot, it is absolutely impossible to exactly measure this phenomenon. Nevertheless the Infrastructure Management Plan (2000) evaluated the average total network losses in 22 M m^3/year.

With regard to big water transfers, the same Plan evaluated network losses from transfer between different hydrographical regions of the island in 11.5 M m^3/year, corresponding to 5.5% of the total transferred water.

At the second level we find the municipal distribution network. Logically, efficient management of the networks at this level greatly depends on municipal capability, or on the body who has a concession to run the service, this level situation varies greatly. On the one hand, some municipalities such as Los Silos or Garachico, with network losses higher than 60%, and, on the other, municipalities belonging to the metropolitan area

with losses lower than 20%. Network losses in this level, estimated as a whole sum up to 22%, which is about 7 M m^3/year.

An ambitious estimation of network intervention and improvement has been considered by the PHI, for a total amount of 44 M €, 8.9M € of which correspond to main networks and 15 M € to urban supply networks.

A realistic position towards lessening network losses would aim at a 10% progressive reduction in each one of the cases. This aspect is being developed within the infrastructure renovation plans undertaken in the last years. Taking the starting situation as a reference, it would mean a deficit reduction of 5.7 M m^3/year for irrigation water and 6.7 M m^3/year for water supply to settlements.

In the STABILISED scenario it can be seen how this strategy allows broadly covering both domestic and irrigation deficit during a large period of time (moderately in the BAU one). Nevertheless, the potential of this instrument can also be seen in Figure 8-39, which shows the evolution of the aquifer exploitation index, notably improving in all cases.

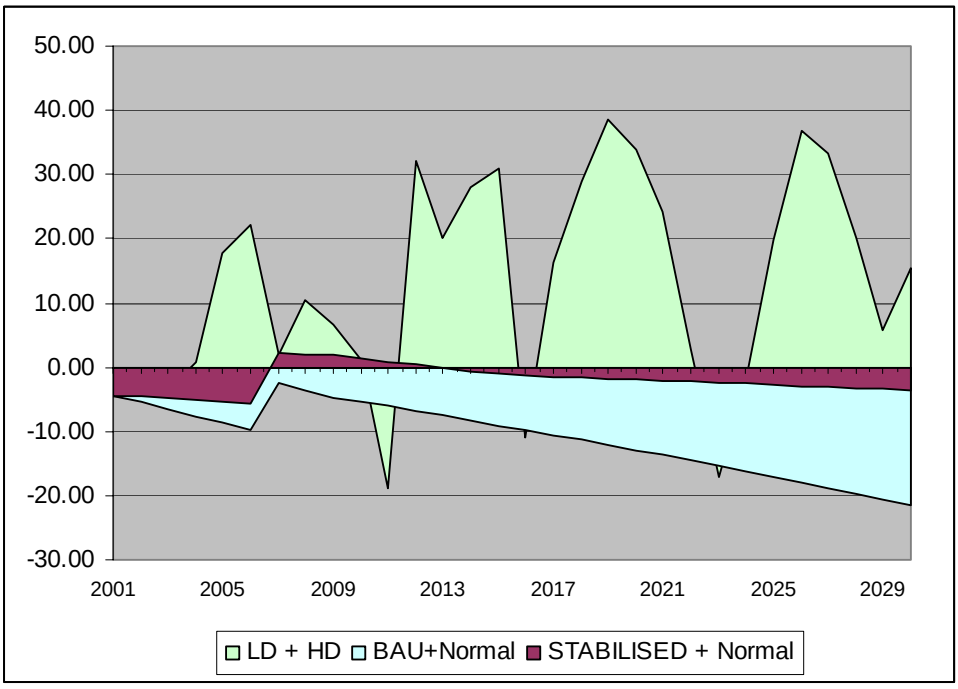

Figure 8-39. Evolution of the groundwater exploitation index in the different scenarios

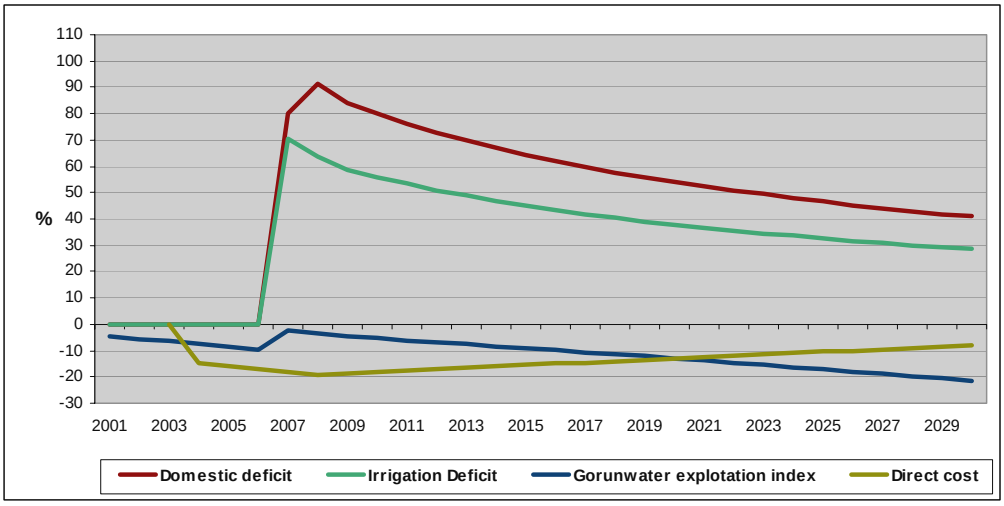

Figure 8-40. Improvement with respect to the BAU + Normal scenario

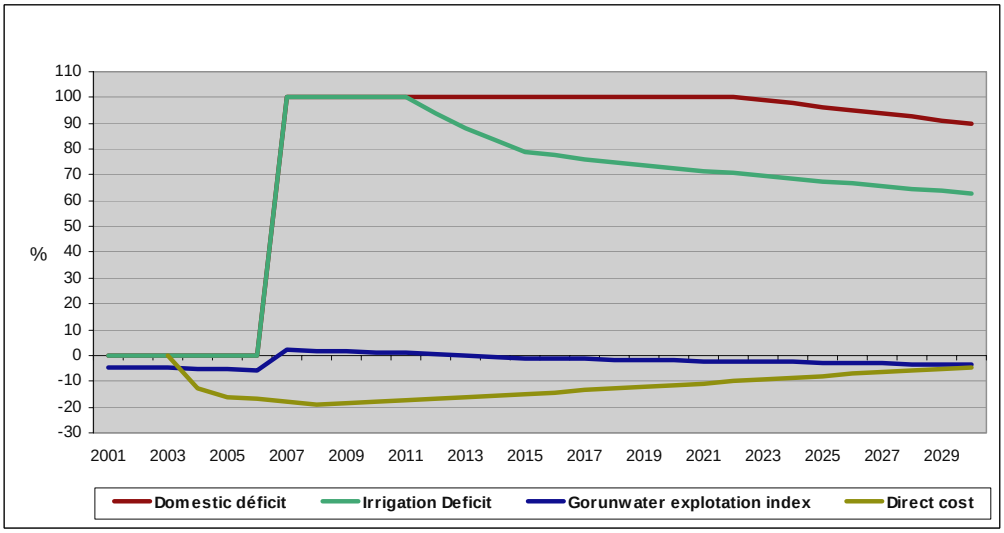

Figure 8-41. Improvement with respect to the STABILIZED + Normal scenario

The evaluation of these scenarios in Figure 8-42 shows that this measure improves domestic demand deficit in the STABILISED case as well as the irrigation deficit. Logically in the LD case it turns to be a very strong complementary instrument to guarantee resource sustainability.

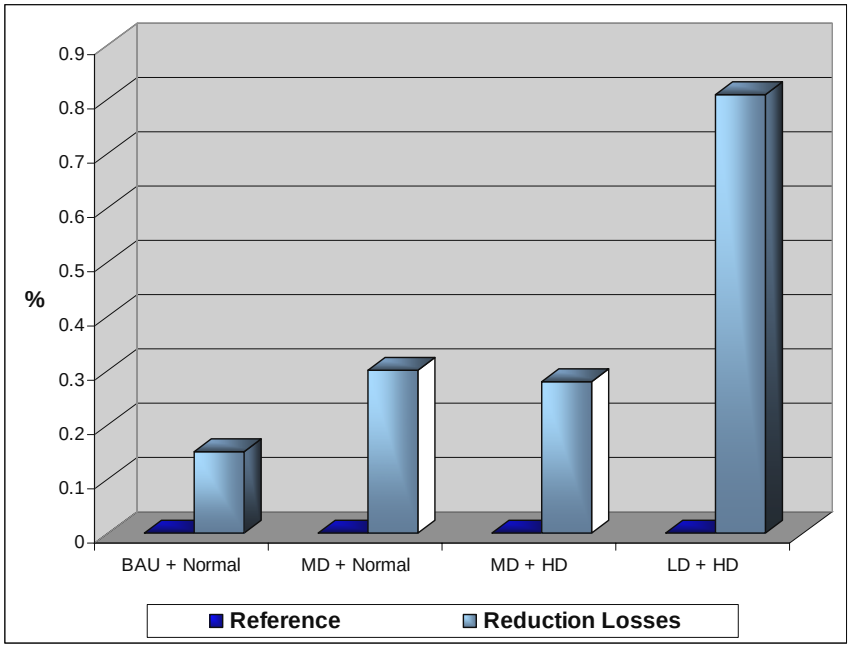

Figure 8-42. Evaluation of reduction of network losses under the four reference scenarios

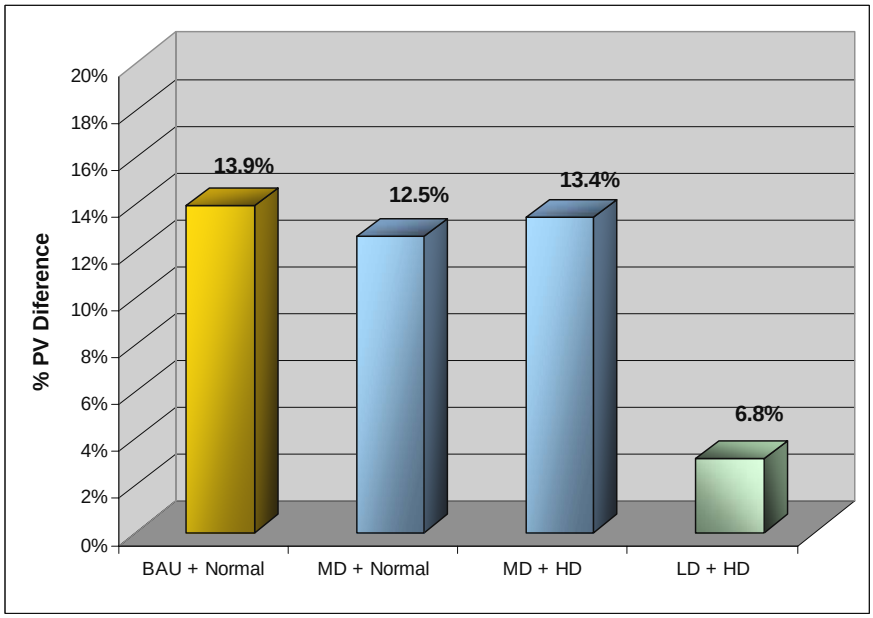

Figure 8-43. Present Value difference over the four reference scenarios (Reduction of network losses option)

Conservation methods in the domestic sector and tourist areas

In the Canary Islands, and in Tenerife in particular, most water policies, have been directed towards the implementation of structural solutions to the detriment of demand management possibilities. Only automatized export crops, which constitute an important share of water demand, do not follow this tendency and achieved quite important reductions.

Present average values registered in the domestic sector are of 160-180 l/person/day) are substantially high, if compared with the national average (147 l/person/day). But they are also high if compared with other islands of the Canary archipelago, such as Lanzarote, where the average water consumption registered is of 103 l/person/day (including tourist consumption, 50% of the total).

Change in traditional habits under the influence of tourism, and the fact that in large areas of the island until few years ago water availability for domestic use has never been a problem, contributed to leave aside this essential issue of island water management.

Application of flexible price policy had some influence, although major consumption happens in the lower rate group of consumers, making difficult to increase these rates because of unpopularity of the action.

Nevertheless, the debate on growth and crisis of resources put again this issue on the table. Changes in the municipal policy are being produced through the implementation of Agenda 21, while in the tourist activities introduction of standards (EMAS, ISO 14000) or ecolabels (BIOSPHERE Hotels) are fast spreading.

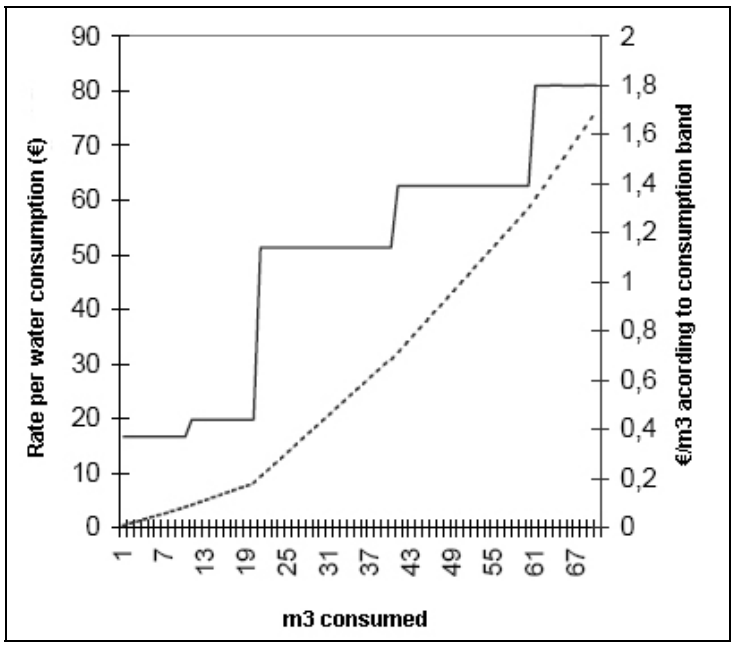

Figure 8-44. Water price depending of consumed bi-monthly volume and for different levels of consumption (Source: M. Fernández)

Data extracted from the works carried out by the Canary Islands Water Centre show that the objective of 10% of progressive saving in 5 years is absolutely feasible. Calculating it on present-day domestic and tourist consumption within the starting scenario, this corresponds to a water amount of 6.7 million m^3.

Among factors to be considered, it is worth to mention that this reduction would involve a higher polluting load in wastewater, which could affect the treatment system as it is at present. On the other hand, energy costs, calculated on the whole water system's needs, could decrease of 4 million €/year. Given users' difficulties to integrate saving devices,

except strictly management-related practices, it is supported that water supply companies, municipal or supra-municipal should take on the responsibility to implement water saving measures.

Estimations carried out by CCA on the basis of the island's different rating systems show for this objective a saving amount equivalent to 55.50 €/person /year.

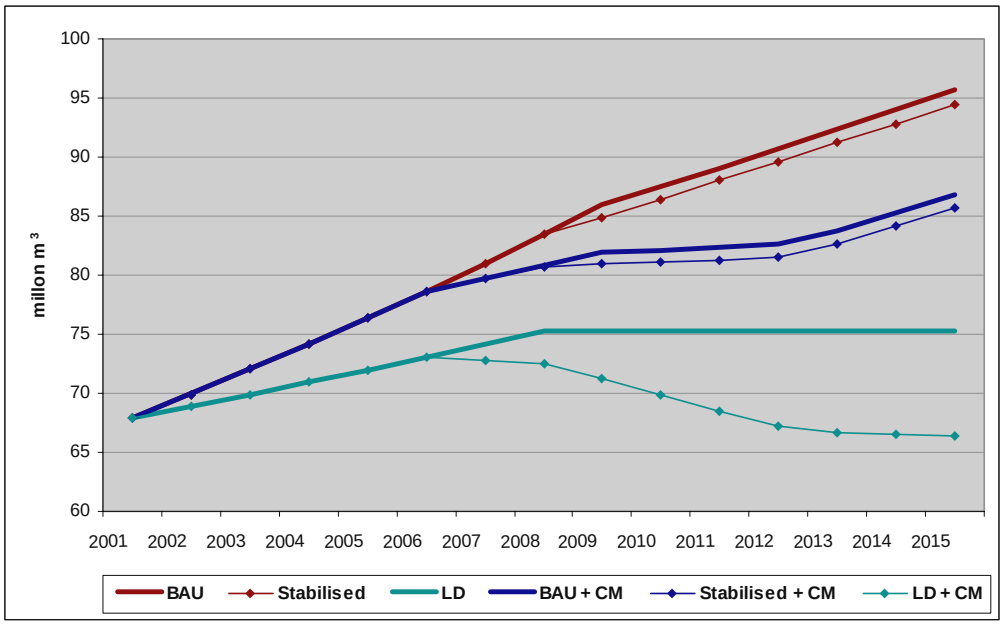

Figure 8-45. Effects of conservation measures application for the four scenarios

The application of this instrument has been established as the result of a campaign that would have effects until 2015, and stabilises after that date. The big differential effect of these measures on the low demand scenario is remarkable.

With regard to deficit improvement, Figure 8-46 shows a satisfactory positive effect that the application of this instrument would bring in the STABILIZED scenario, compared with the BAU one.

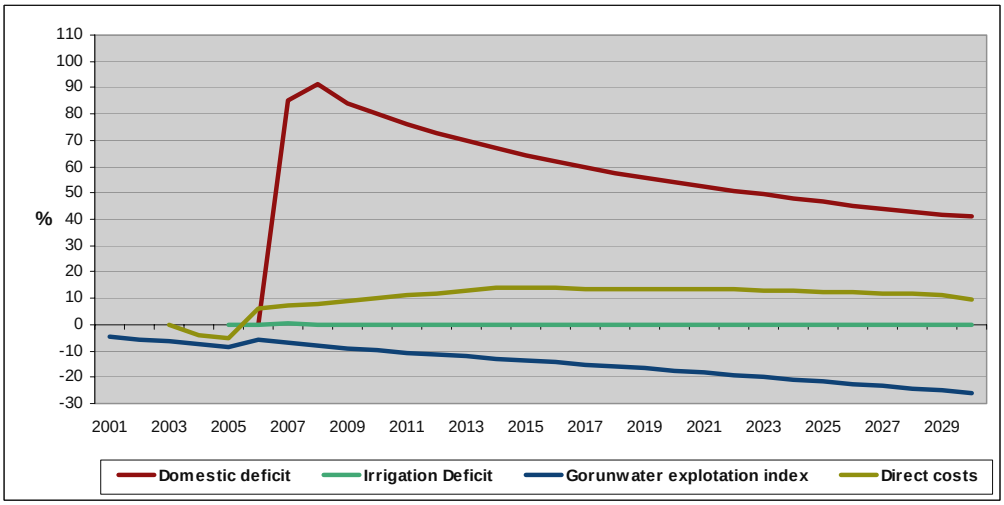

Figure 8-46. Improvement with respect to the BAU + Normal scenario

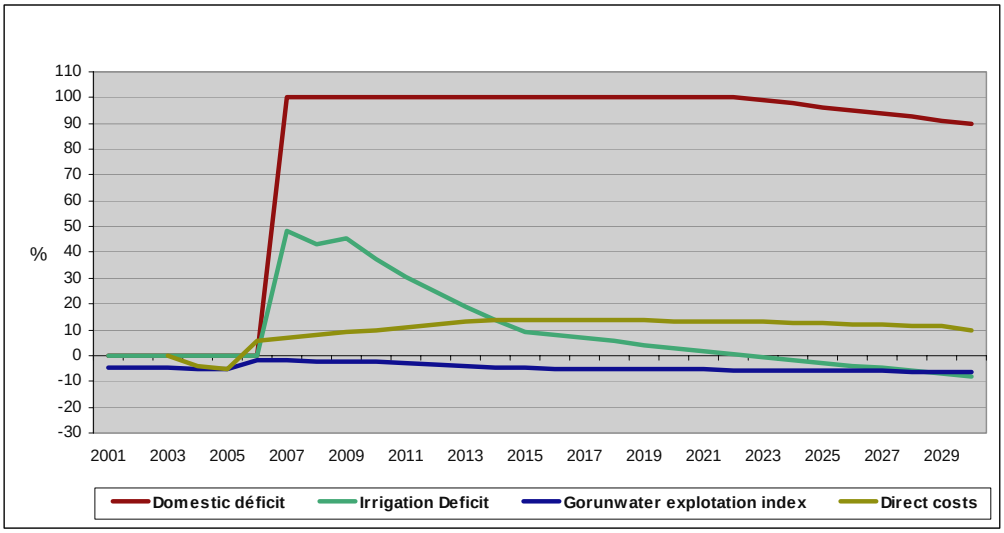

Figure 8-47. Improvement with respect to the STABILIZED + Normal scenario

The evaluation score obtained for this option under the four reference scenarios is presented in Figure 8-48. The highest score is obtained under stable (normal) availability conditions. Performance is lower under the two other scenarios, namely BAU+HD and LD+HW, endorsing the importance of this option.

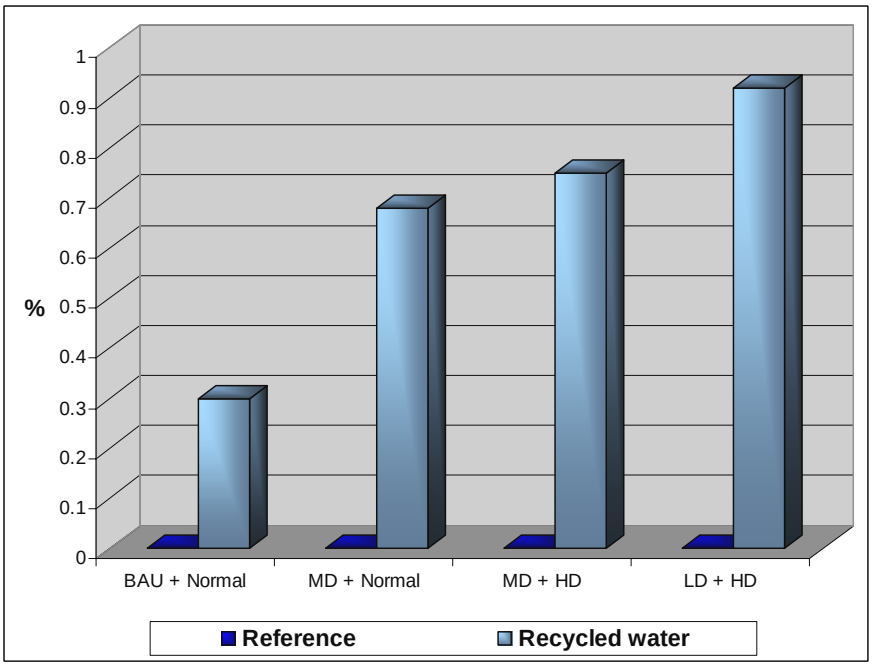

Figure 8-48. Evaluation of conservation measures under the four reference scenarios

Direct cost development for the different scenarios obligatorily involves renewal of plants as soon as they become obsolete.

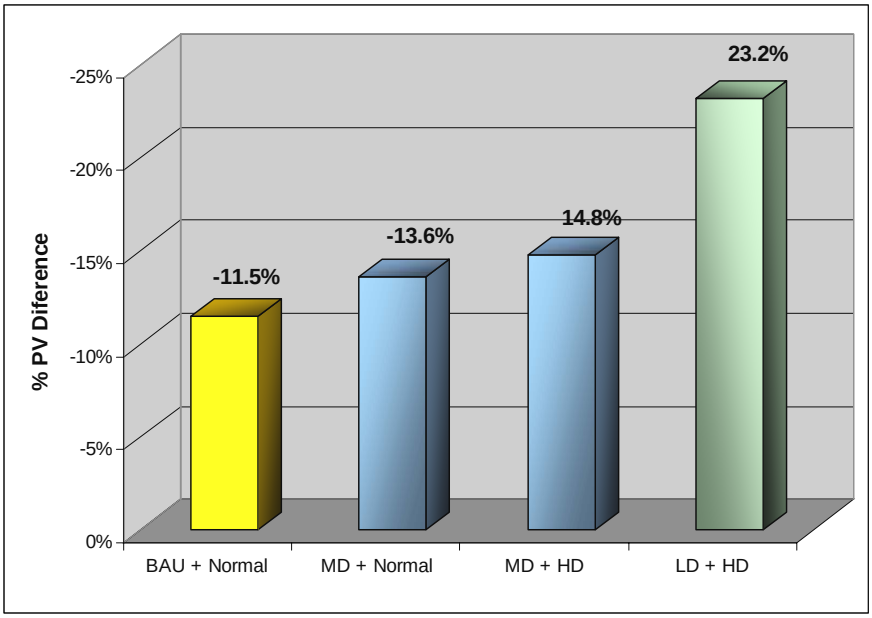

Figure 8-49. Present Value difference over the four reference scenarios (Conservation measures option)

Exploitation of Surface Water

Within the island's water balance, infiltration represents the highest input to available water, with 239 million m^3, since 606 million m^3 correspond to evapotranspiration, and surface water are of only 20 million m^3 (estimations made for an average rainfall year, with 425 mm = 865 million m^3/year).

Under these conditions, surface waters are only a marginal element within the total balance, and even in the hypothetical case of collecting them totally, it would not exceed 10% of the island's water demand, and practically inconceivable costs.

Present policy is to integrate small exploitations into more complex systems, such as valley derivations, without making specific constructions. For this reason, to show their influence in the different scenarios, surface water exploitations have been integrated in the regulatory reservoir strategy, already examined, which besides including saving benefits due to flow regulation, also consider these inputs.

8.4. Final Selection

The final selection of instruments to be further analysed during the strategy formulation phase depends on the performance of the options examined regarding the four indicators that were presented throughout the analysis. Indicators show the answer to the instrument application under the different sustainability criteria (technical, financing, environmental and socioeconomic).

For this proposal the different options have been evaluated under the analysis of four reference scenarios, through the application of the four mentioned indicators. The overall score of each option is estimated as the average of the evaluation score for each indicator under the four scenarios. Results within the most significant cases are presented: BAU + Normal scenario and STABILISED + Normal.

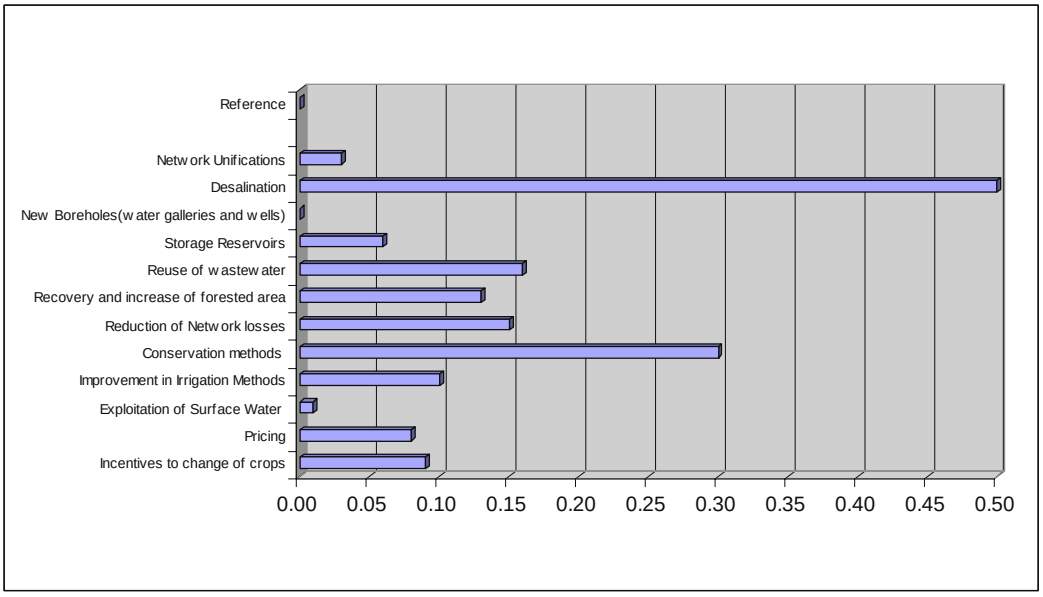

Figure 8-50. Evaluation of all options under the BAU + Normal scenario

Results are summarized in Figure 8-50 and Figure 8-51. The efficiency of each option is approached through the efficiency in meeting the primary goal of the analysis (domestic demand coverage). Environmental performance is expressed through the groundwater exploitation index, since, in the case of Tenerife, it expresses not only the effect of human water use, but also the complex effects on the environment derived from aquifer overexploitation. Cost at this stage only includes the financial (direct) cost associated with each option, while economic sustainability and equity are expressed through irrigation demand coverage since one of the goals set for the analysis is to balance the development of tourism, acceptable population growth and agricultural sectors.

In light of the two figures, showing different behaviours, it results that in both cases solutions are made up through the combination of different instruments, with different weights. Besides the fact that desalination stands out among the other instruments, it is confirmed that other ones such as network loss reduction and saving measures have an important weight.

From the analysis one also gathers which are the risks of betting on a massive structural solution such as desalination, since in a possible scenario of contention and of more appropriate and sustainable development, it stops being a general solutions and turns to be a punctual one or it is used to cover regional specific deficits. This could cause a hardly reversible technical and structural inertia within the system.

Finally, the analysis decidedly contributes to emphasise the risks derived from maintaining the last growing rates reflected in the BAU scenario, especially in a possible situation of a long water deficit, such as it happened between 1931 and 1948, a period remembered from the inhabitants of the Canary Islands as a time of emigrations and hunger.

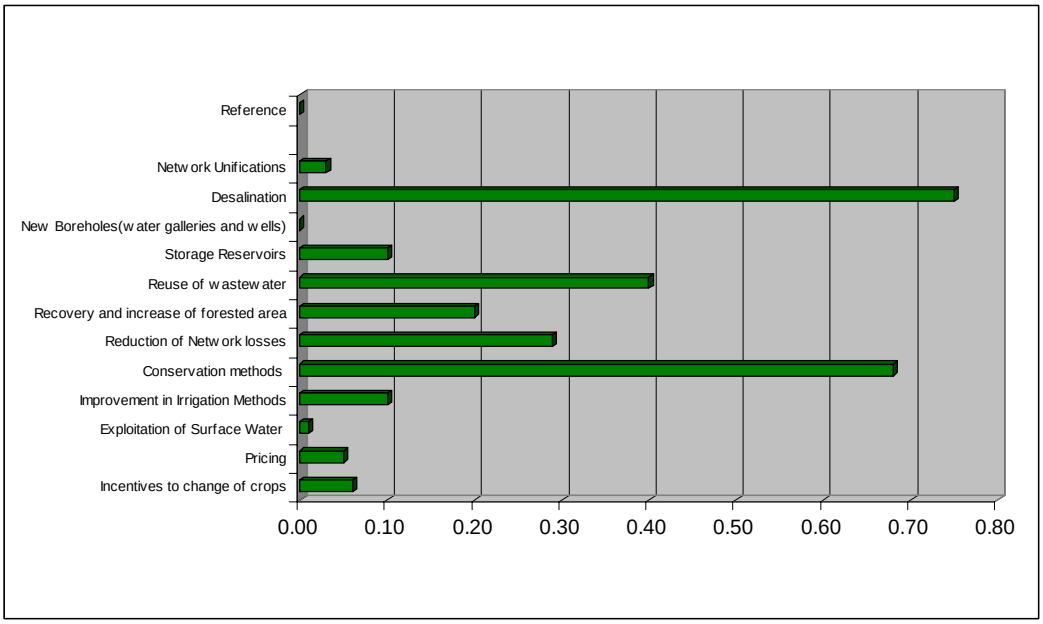

Figure 8-51. Evaluation of all options under the STABILISED + Normal scenario

9. Comprehensive Scenarios for Ribeiras do Algarve

The Ribeiras do Algarve River Basin, with an area of 3837 km^2 and including 18 Municipalities (Figure 9-1), is the most popular tourist destination in mainland Portugal and has a registered resident population, in 2001, of around 365,000 inhabitants which is increased by an average of approximately 200% on average during the summer months due to tourist population. However, that percentage increase is different for each Municipality (Figure 9-1): Albufeira = 571%, Aljezur =288%, Almodôvar = 0%, Castro Marim = 557%, Faro = 54%, Lagoa = 365%, Lagos = 227%, Loulé = 204%, Monchique = 43%, Portimão = 252%, São Brás de Alportel = 41%, Silves = 104%, Odemira = 0%, Olhão = 70%, Ourique = 0%, Tavira = 152%, Vila do Bispo = 186% and Vila Real de Santo António = 25%.

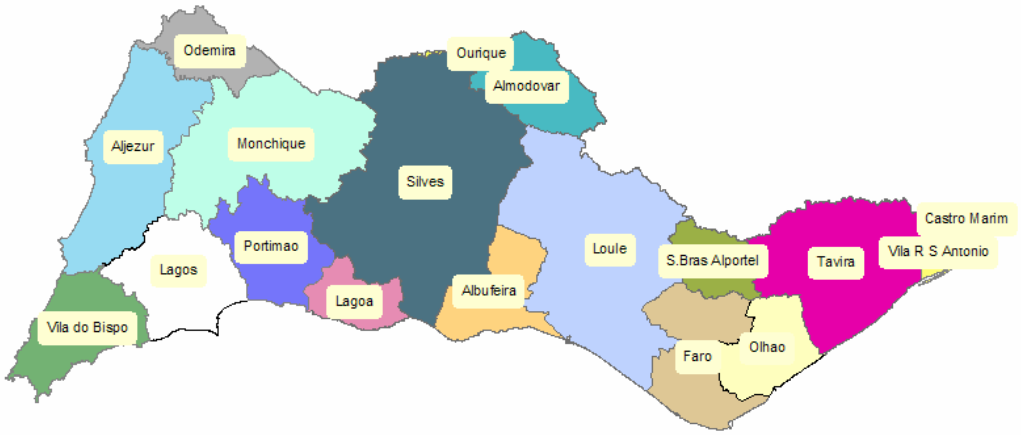

Figure 9-1. Municipalities located within the Ribeiras do Algarve River Basin

The Ribeiras do Algarve River Basin has undergone, in the last decades, deep changes in its demography, mostly due to the important development of the tourism activity creating a new reality. In the 1980s, one could identify a productive structure based on three economical activities: agriculture, fishing and tourism. Nevertheless, in recent years the backbone activities of Algarve's economy have shifted towards tourism and the associated tertiary activities. One of the most specific demographic characteristics of the River Basin is the quite unequal population distribution. Most of the inhabitants are living in the littoral zone and the inland region is undergoing a desertification process associated with a significant ageing population. That way, the pressure on water resources exerted by the seasonal population is very intense, leading to water shortage during the summer months.

Traditionally, the domestic and agricultural demands were satisfied by groundwater resources, supporting the development of tourism and irrigated cultures. However, the combination of natural processes and aquifers overexploitation led to groundwater salinisation and water quality deterioration. Therefore aquifers progressively became a non-reliable source of water supply, causing a shift from groundwater to surface water as

the major source of public water supply. This change in the supply sources enabled the recovery of the aquifers storage.

This way, from 1995 onwards, the management of the water supply has been based on surface water abstractions. Initially two Inter-municipal companies were created: one for the west part of the basin, "Águas do Barlavento Algarvio" and another one for the east part, "Águas do Sotavento Algarvio". In 2000, the two companies merged forming "Águas do Algarve, SA" Company which has the concession of the Primary Water Supply system (Figure 9-2) and guarantees the supply of the River Basin municipal secondary network systems. The two previously existing systems were connected, constituting the Primary Water Supply System as known today. The connection between the two former systems allows transferring a maximum of 7 hm^3 from one side to the other. Since 2001, this Company also has the concession for the primary network for wastewater drainage and treatment.

More specifically, the Primary Water System of Águas do Algarve is based:

- in the East part of the Ribeiras do Algarve River Basin, "Sotavento" region, on the Odeleite-Beliche system (located in the Guadiana River Basin and, considered as an importing node) and
- in the West part, "Barlavento" region, on Bravura and Funcho dams, as shown in Figure 9-2.

Figure 9-2. Supply Nodes of the Primary Water Supply System of Águas do Algarve

However, the supply nodes have limitations, dictated by agreements made with INAG during the concession period. That way, Águas do Algarve Company is limited to abstract the volumes from the existing storage reservoirs presented in Table 9-1.

Table 9-1. Volume available in the storage reservoirs for urban supply

Storage Reservoir	Volume (m^3)	
	Minimum	Maximum
Bravura	4,000,000	6,000,000
Funcho	12,000,000	23,000,000
Odeleite-Beliche		69,000,000*[1]

Nevertheless, agriculture is still the most important water sector user (about 67% in 2000) and presently both surface (SW) and groundwater (GW) are used for irrigation. According to the River Basin Plan the agricultural area represents about 32 000 ha, i.e. approximately 8% of Ribeiras do Algarve River Basin non-urbanized area. Although in agriculture groundwater is still the main supply resource, with 85% of the irrigated area using it, the overall efficiency of agriculture water use is low (about 60%). Two types of irrigation sites, public and private, exist. Public irrigation sites are mainly supplied with surface water and farmers are gathered into farmers associations to whom they pay water. Contrarily, private irrigation sites use groundwater for irrigation and are responsible for each irrigation site's maintenance. Additionally, golf courses represent an important economic activity and are mainly located by the sea. The salinisation of the aquifers necessitates finding an alternative to supply those, by re-using wastewater treatment plants effluent or by eventually using desalinised water, implying an important increase of the associated costs.

Figure 9-3 presents the different public irrigation sites considered and golf courses.

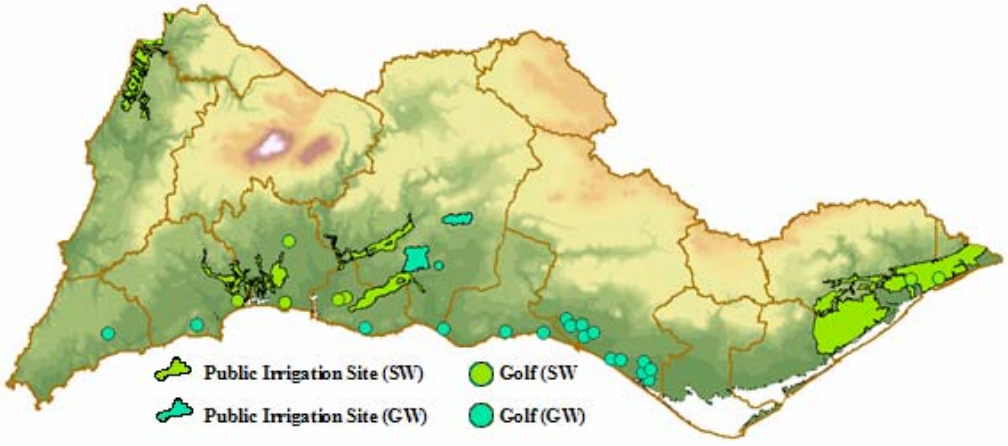

Figure 9-3. Public irrigation sites and golf courses

At Ribeiras do Algarve River Basin, conflicting interests on water resources between the tourism sector and agriculture coexist mainly during the summer months. Infrastructure deficiencies, poor groundwater quality in some areas, high values of secondary water supply network losses (16% to 61%) and inadequate irrigation methods, urge the

[1] Water volume treatment capacity of Tavira's Water Treatment Plant

implementation of management measures in order to solve and prevent conflicts between users.

Under this context and having in mind the interests of the different stakeholders, the goal of the formulation of the scenarios and strategies for Ribeiras do Algarve River Basin is to:

- Implement options which enable 95% domestic demand coverage, particularly in the West of the Ribeiras do Algarve River Basin, and solving localized deficits in irrigation.
- Promote options that prevent environmental resources degradation, namely aquifers overexploitation. These options apply particularly to aquifers by the sea where overexploitation increases salinisation risks.
- Promote options that enable to attain economic feasibility of water use through direct, environmental costs evaluation and rate of cost recovery optimization aiming at full cost recovery.

9.1. Demand and Availability Scenario Components

Given the importance of water consumption by irrigation and the growing importance of tourism, the formulation of demand scenarios for the Ribeiras do Algarve River Basin was based upon assumptions on permanent and seasonal population and irrigation growth rates.

Formulation of Domestic Demand Scenarios

Data

For permanent and seasonal population, a variety of data and data estimations have been collected and analysed from several institutions and governmental and non-governmental organisms (Table 9-2), regarding population fluctuation, consumptions, network system description, network losses, water sources (surface and groundwater), irrigation efficiencies, types of irrigated cultures, irrigation sites and costs associated with water distribution and drainage.

Table 9-2. Available information on domestic demand components

Authority	Available Information
Águas do Algarve S. A.	a) Served population with water supply and water drainage and treatment b) Consumption Fluctuation c) Costs associated to Primary Network System
National Statistical Institute (INE)	d) Permanent Population e) Seasonal Population f) Tourist Arrivals, Departures and Overnight stays
National Water Authority (INAG)	g) Permanent Population h) Overnight stays i) Consumption Fluctuation j) Served population with water supply and water drainage and treatment k) Network losses l) Rainfall data
National Tourist Institute	m) Seasonal Population

The resident population was estimated to be approximately 365,000 inhabitants by 2001. The monthly variation of seasonal population is presented in Table 9-3.

Table 9-3. Monthly variation of seasonal population in Ribeiras do Algarve River Basin

Month	Seasonal Population Fluctuation[2]
January	19%
February	26%
March	53%
April	55%
May	65%
June	66%
July	77%
August	100%
September	73%
October	55%
November	28%
December	25%

The uneven spatial distribution of tourist population per Municipality in August is presented in Figure 9-4. The littoral Municipalities (Albufeira, Aljezur, Castro Marim, Faro, Lagoa, Lagos, Loulé, Portimão, Olhão, Tavira, Vila do Bispo and Vila Real de Santo António) represent 97% of the seasonal population in August whereas the inland ones (Monchique, São Brás de Alportel and Silves) represent only 2%.

[2] Share compared to the seasonal population during August (709,756) in 2001

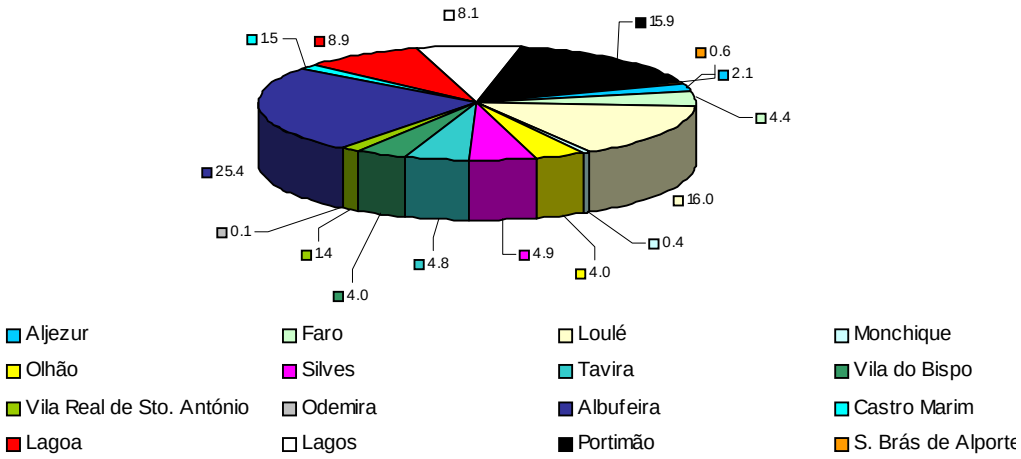

Figure 9-4. Distribution of the seasonal population in August by Municipality, in percentage (2001 data)

Nevertheless, the areas of the Municipalities belonging to the Ribeiras do Algarve River Basin differ significantly and therefore the seasonal population density (seasonal population in August divided by the area) for each Municipality (hab/km^2) may show even better the uneven distribution of tourist population. In August 2001, Castro Marim and Albufeira were the Municipalities with the highest population density value, 1314 hab/km^2 and 1280 hab/km^2 respectively (Figure 9-5). In that month, in Loulé, although seasonal population density was not one of the highest, it was 10.5 times higher than the permanent population. This observation may be justified by the fact that Loulé has, after Silves, the second highest area of all Municipalities in Ribeiras do Algarve River Basin, and the seasonal population is mainly concentrated by the sea.

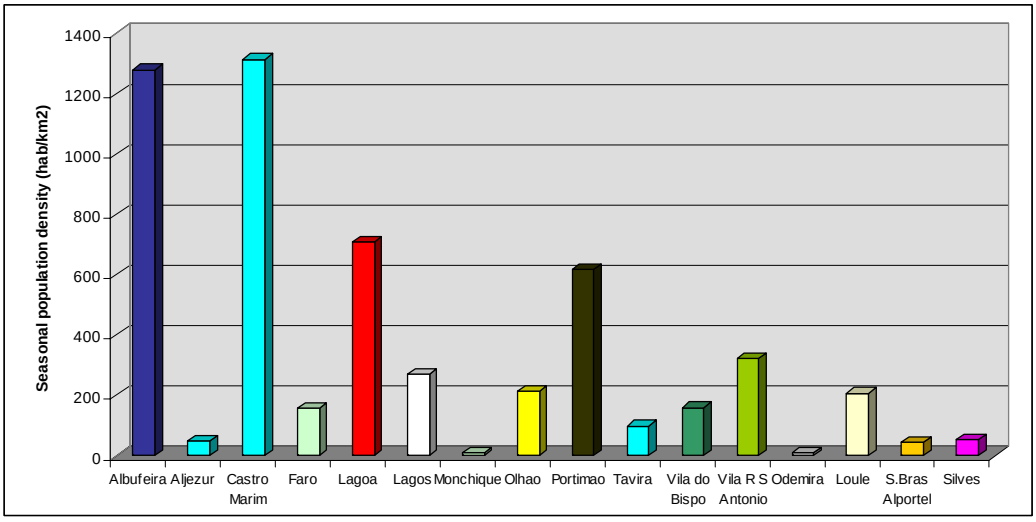

Figure 9-5. Seasonal population density (inhabitants/km^2) in August for each Municipality (2001 data)

The population in 2000 was considered to be the same as in 2001, using the results from the 2001 Census. Finally, domestic consumption rates were estimated based on the real supply delivered by Águas do Algarve Company to the different settlements in 2002.

Projections

For identifying the business as usual scenario (BAU), it was assumed that during the period examined (2000 – 2035) the permanent population will continue to increase with a steady yearly rate. Growth rates for the different Municipalities were estimated for permanent population according to the projections presented in the Ribeiras do Algarve River Basin Plan for 2000-2020. For seasonal population, the growth rate was set equal for all the Municipalities and estimated upon the projection from 2000-2020. Seasonal population growth rate is higher than the one set for permanent population (Table 9-4) and this fact is related to the seasonal population increase, the tourism development and the permanent population decrease due to a reduction in the birth rate.

The two other scenarios formulated for the analysed period assume that after a point in time the population in Ribeiras do Algarve River Basin will reach its carrying capacity regarding the development of tourism. In one of them, this is followed by stabilization of population, while a more pessimistic scenario supposes a small decrease of tourism and birth rate.

Under this context, three different potential trends have been distinguished, forming the potential scenarios for domestic demand:

I. A scenario where demand increases at a steady rate, equal to that currently observed, and corresponding to a "business as usual" situation (BAU),

II. A scenario where demand is stabilized 10 years after the reference year (Stabilized Demand, SD)

III. A scenario where the demand decreases 15 years after the reference year (Low Demand, LD).

The annual growth rates for permanent and seasonal population considered for each demand scenario were set as presented in Table 9-4. The differentiation by Municipality is considered equal for the three scenarios, "Business as Usual" (BAU), "Stabilized Demand" (SD) and "Low demand" (LD).

Table 9-4. Population trends for the three scenarios

Scenario	Period	Growth Rate (%)	
		Permanent Population	Seasonal Population
BAU	2000 – 2035	differentiated for each Municipality[3]	2.3
Stabilized Demand	2000 – 2010	differentiated for each Municipality[3]	2.3
	2011 – 2035	0.0	0.0
Low Demand	2000 – 2010	differentiated for each Municipality[3]	2.3
	2011 – 2015	0.0	0.0
	2016 – 2035	-0.5	-0.5

The demand evolution corresponding to the three scenarios is presented in Figure 9-6.

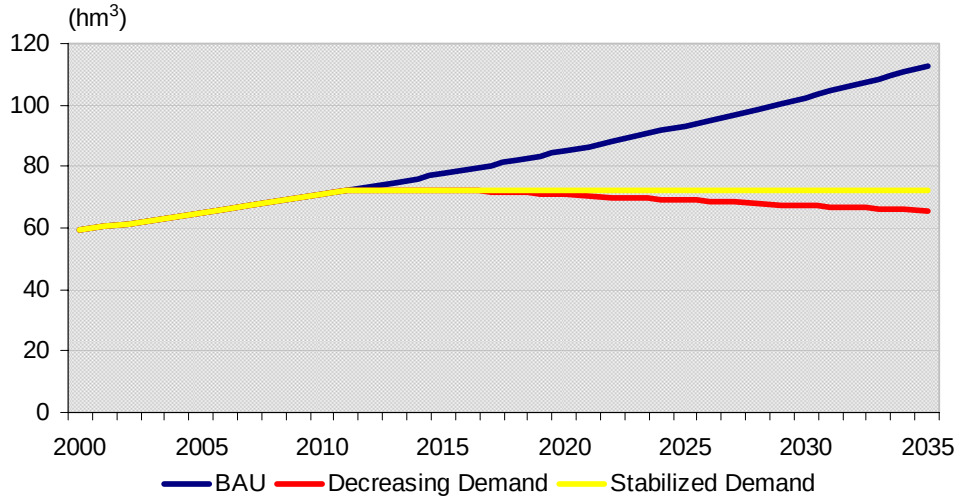

Figure 9-6. Domestic demand scenarios

It should be noted that the consumption rates for permanent and tourist population were set according to the River Basin Plan (differentiated by Municipality) and considered constant for all the period of the simulation.

Irrigation Demand Scenarios

Data

Concerning irrigation demand, it is important to note that it is very difficult to gather accurate data. In fact, the information uncertainty is major drawback. The cultivated area is estimated to be around 32,000 ha, however, the different Institutions contacted about

[3] Albufeira: 2.01%; Aljezur: 0.19%; Almodôvar: -1.59%; Castro Marim: -0.87%; Faro: 2.01%; Lagoa: 1.07%; Lagos: 1.07%; Loulé: 1.07%; Monchique: 1.59%; Odemira: 0.87%; Olhão: 0%; Ourique: -1.59; Portimão: 2.01%; São Brás de Alportel: 0.18%; Silves: 1.07%; Tavira: 0.18%; Vila do Bispo: 0.18% and Vila Real de Santo António: -0.87%.

this matter are not able to provide a consistent evaluation of the water volumes involved in this activity. The stakeholder consultation showed, as expected, the existing uncertainty regarding agriculture consumption. Nevertheless, the data introduced in the DSS results from the analysis of different sources of information, attempting to adopt a coherent and reliable approach (Table 9-5).

Table 9-5. Available information on irrigation demand components

Authority	Available Information
DGA of Algarve (Ministry of Agriculture, Rural Development and Fishing)	General Information about Irrigation Sites, Crops and Irrigation Methods
Farmer Association of Alvor	Irrigation Sites Characteristics, Crop Types and Irrigation Methods concerning the Public Irrigation Site of Alvor
Farmer Association of Silves, Lagoa and Portimão	Irrigation Sites Characteristics, Crop Types and Irrigation Methods concerning the Public Irrigation Site of Silves, Lagoa and Portimão
IDHRa (Rural Development Institute)	Irrigation Sites Characteristics, Crop Types and Irrigation Methods concerning the Public Irrigation Site of Sotavento Algarvio Irrigation Sites Characteristics, Crop Types and Irrigation Methods concerning the Public Irrigation Site of Benaciate Costs associated to Public irrigation sites
CCDR Algarve	Information of the River Basin Water Management Plan, especially on Private Irrigation Sites and groundwater exploitation (see Annex) Data on Golf Courses
Ribeiras do Algarve River Basin Plan	Irrigation sites (public and private) areas and demand Crop types and cultivated areas Costs associated to public and private irrigation sites

Projections

As for the domestic demand scenarios, according to the projections presented in the River Basin Plan for 2000-2020, the growth rates considered for public and private irrigation sites and golf courses are presented in Table 9-6.

Table 9-6. Growth rates considered for irrigation sites and golf courses

	Period	Growth Rate (%)
Private irrigation site	2000 – 2020	1.3
	2021 – 2035	0.0
Public irrigation sites	2000 – 2020	differentiated for each public irrigation site[4]
	2021 – 2035	0.0
Golf courses	2000 – 2035	0.0

Furthermore, a growth rate of 0.5% was considered for animal breeding sites until 2020 and no growth rate for industrial sites.

The demand scenarios considered hereafter, entitled the reference case, are the combination of one of the domestic demand scenarios and the irrigation and industrial demand scenarios.

Formulation of Availability Scenarios

Data

The climate in Ribeiras do Algarve River Basin is Mediterranean temperate, characterized by rainy winters and dry summers. The average temperature is 18 ºC and the average annual precipitation is around 750 mm. However, there are differences between the corresponding values of the six sub-basins identified (Figure 9-7): a maximum of 813 mm/year in the "Costa Ocidental" sub-basin and a minimum of 565 mm/year in the "Costa Sul". Those differences reflect not only spatial but also temporal different precipitation distribution (Figure 9-8).

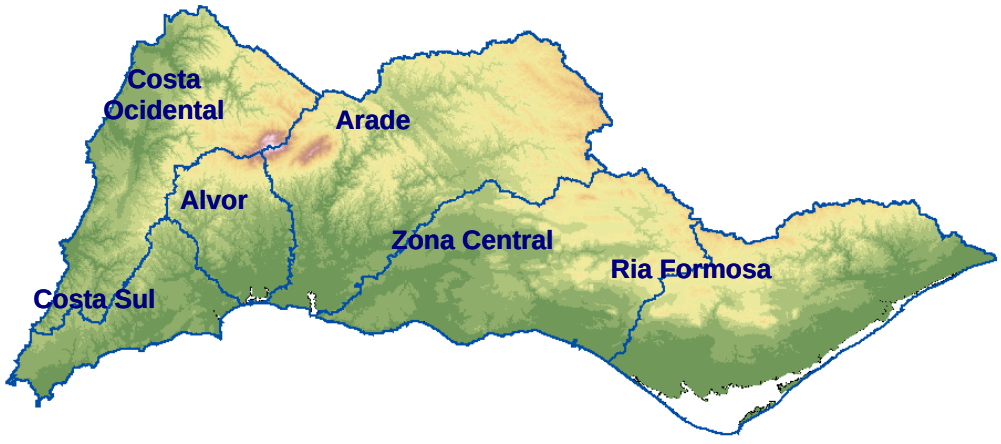

Figure 9-7. Ribeiras do Algarve sub-basins

[4] According to the River Basin Plan

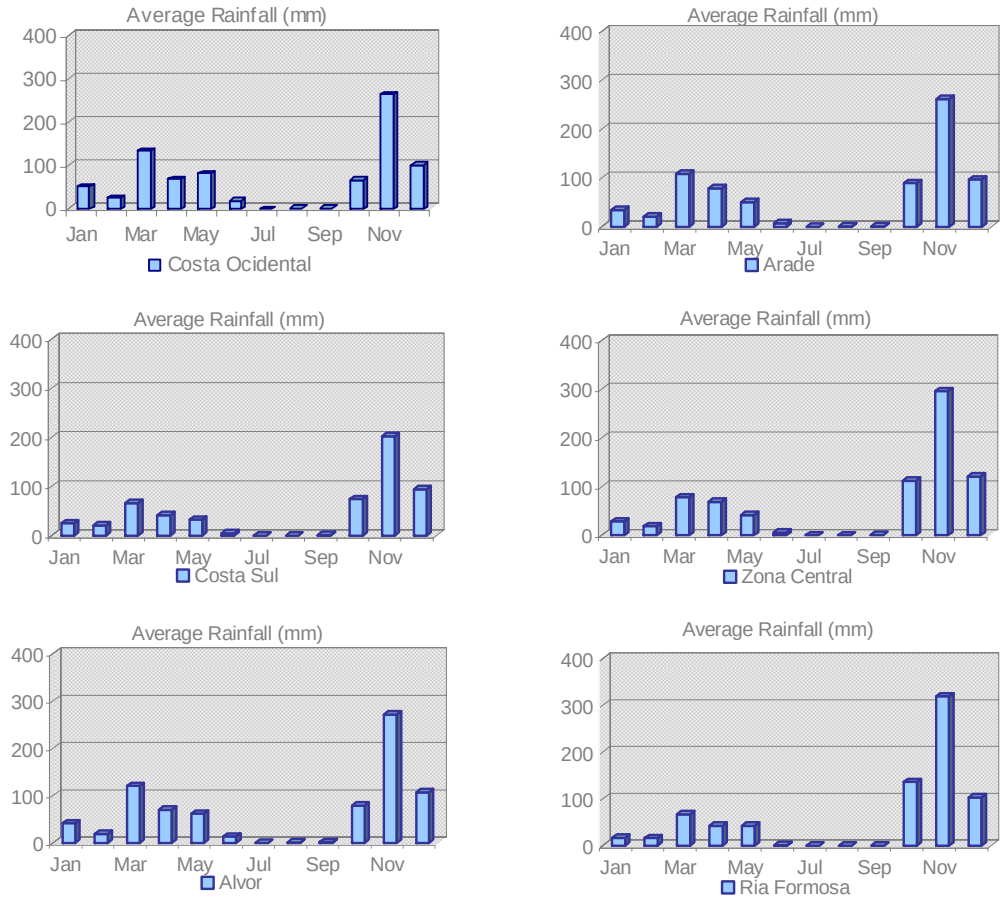

Figure 9-8. Average monthly rainfall in the different sub-basins

Scenarios

The formulation of the availability scenarios (Figure 9-9) was based on the sequence of years with respect to rainfall presented by INAG (National Water Institute) for the 13 meteorological stations considered (Table A3-2 and Figure A3-1 of the Annex). Three hydrological scenarios were considered:

a) The Normal Scenario (Normal) represents a period of 35 years defined in accordance with the historical sequence that occurred between 1970 and 2000.

b) The High Frequency of Wet Years Scenario (HW) was defined considering a 25% increase of the Normal scenario's precipitation.

c) The High Frequency of Dry Years Scenario (HD) was defined considering a 10% decrease of the Normal Scenario's precipitation.

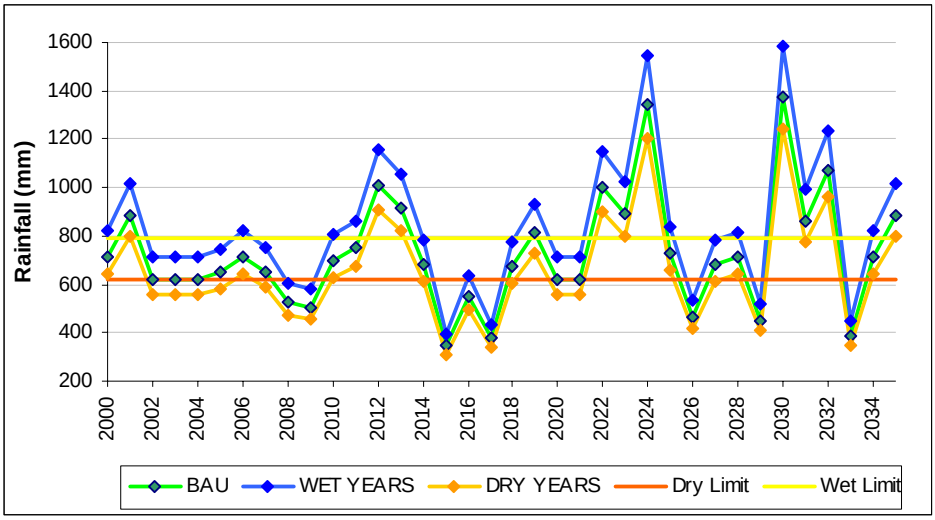

Figure 9-9. Water availability scenarios

The intra-annual rainfall variation coefficients considered (Annex, Table A3-1), in order to determine the monthly rainfall variation, were defined following the analysis of the hydrological data series provided by the National Water Institute. The three water availability scenarios presented in Figure 9-9 (BAU, Wet Years and Dry Years scenarios) were used to formulate the three water year sequences defined in the corresponding Table of the Annex (Table A3-3).

Nevertheless, research concerning this aspect is being developed under this project and the preliminary results obtained anticipate the aggravation of water deficit problems in the Ribeiras do Algarve Region by means of the simulations already developed and hereafter described.

Combination of hydrological and demand scenarios

Besides the availability scenarios defined previously, it is important to establish different scenarios to evaluate the behaviour of the overall water system. The different management options that have been evaluated are the following:

- A combination of Steady Demand Increase with a High frequency of Dry years **(BAU+HD)**, reflecting a severe scenario of water shortage, according to the River Basin Plan,
- A combination of Low Demand with a High frequency of Wet years **(LD+HW),** reflecting the best case scenario, and
- A combination of Steady Demand Increase 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.

It should be emphasized that the simulation period considered begins in 2000 as inferred from the scenarios formulation. This way, one includes the year 2000 used as reference in the National Water Plan and the Ribeiras do Algarve River Basin Plan and also follows the infrastructural evolution of the Primary Water Supply System previously described.

After defining the demand and availability scenarios, one can for instance, through the DSS, estimate the overall domestic deficit and irrigation deficit under the three chosen scenarios. Those results for the reference case (i.e., with no implementation of management options, defined in 9.3. for the three different scenarios) are presented in Figure 9-10 and Figure 9-13.

As one can observe, from Figure 9-10.a, the domestic deficit under the BAU+Normal and BAU+HD scenarios is approximately equal. As said previously, most of the Ribeiras do Algarve River Basin, namely the settlements where the permanent and seasonal population are higher, is supplied by surface water. In Sotavento, the capacity of Odeleite-Beliche system is sufficient to assure the domestic demand. However, in Barlavento, according to the agreement made with INAG (Table 9-1), the maximum volume available in Funcho storage reservoir for domestic supply is not enough to assure all the demand associated to the BAU scenario, increasing significantly the deficit observed. That way, the deficit is owed not to an insufficient recharge of the Funcho reservoir but to the limitation imposed by the agreement. Therefore, the effect extent of the sequences of dry years defined in the HD hydrological scenario on the deficit is almost nonexistent. For the LD+HW scenario, the domestic deficit is always below 5 hm^3, representing, on average, less than 4% of the domestic demand considered for this scenario. Figure 9-10.b presents the estimated domestic demand coverage under the selected demand and availability scenario combinations. As one can observe, for the BAU+Normal and BAU+HD scenarios, the domestic demand coverage drops to 75% by the end of the simulation period.

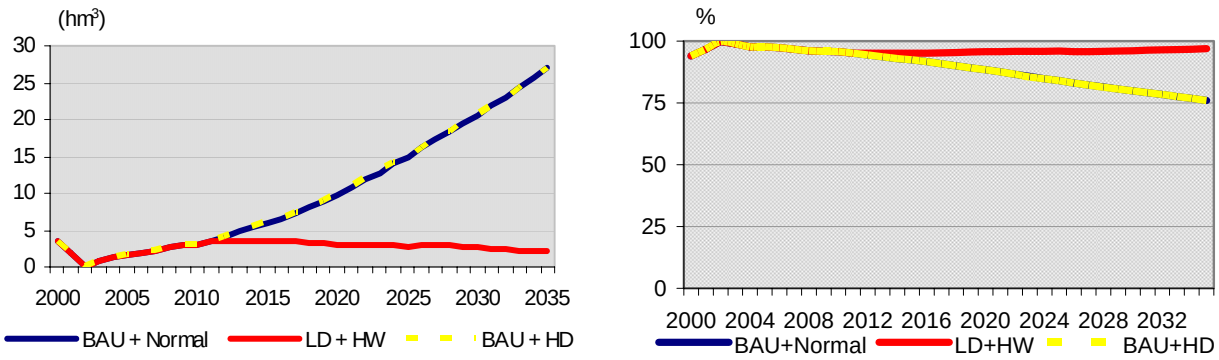

Figure 9-10. Reference case: a) Estimated domestic deficit and b) Estimated domestic demand coverage under the selected demand and availability scenario combinations

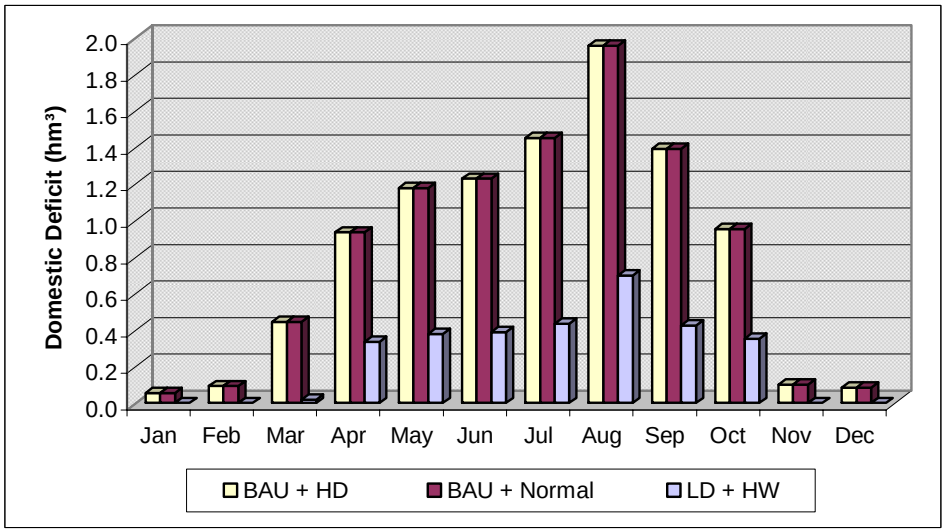

Figure 9-11. Reference case: Monthly domestic deficit (year 2020)

As previously explained, domestic supply is assured by surface and groundwater. Figure 9-12 shows the domestic deficit according to the type of supply: 99% of this deficit is due to surface water, almost all of it in Barlavento (95%).

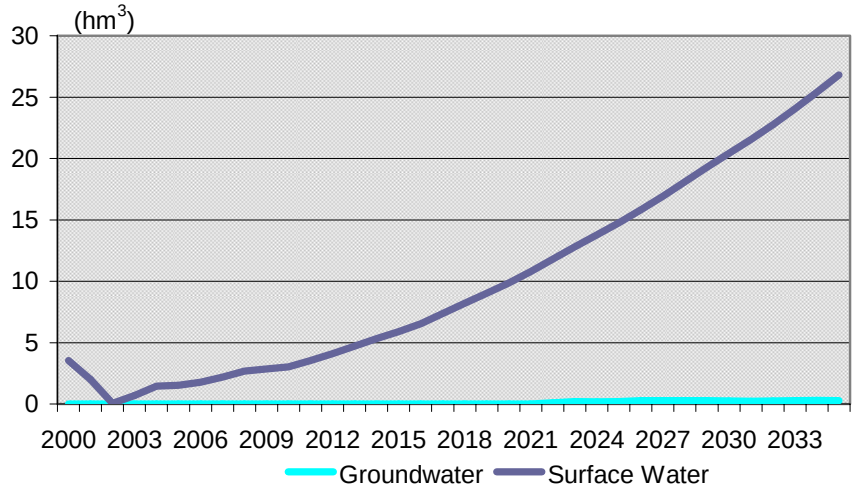

Figure 9-12. Reference case: Domestic deficit according to the type of supply (BAU+HD)

It should be noted that the domestic deficit may not only represent an effective shortage of water but may also be a consequence of inadequate pipeline diameter, because of the required flow transfer not being assured. One should stress that deficits due to pipeline diameter have been identified by Águas do Algarve and that the substitution of these pipelines is already scheduled. Moreover, the value of domestic deficit concerning urban supply by surface water from 2000 to 2003 is due to the scheduled construction of the network reservoirs.

Contrarily to settlements, most of the irrigation sites are supplied with groundwater and therefore dependant on its availability. The estimated irrigation deficit is consequently higher for the BAU+HD scenario and lower for the LD+HW scenario (Figure 9-13.a). However, for the BAU+HD scenario the peaks observed in 2010 and 2021 are due to water deficiency in the Silves, Lagoa and Portimão (SLP) Public irrigation site which is supplied by surface water from Funcho storage reservoir. The increase of the deficit occurring in the first years is due to a sequence of dry years that affect the aquifers and consequently the irrigation deficit. Figure 9-13.b presents the irrigation demand coverage under the selected demand and availability scenario combinations are in accordance with what was explained above.

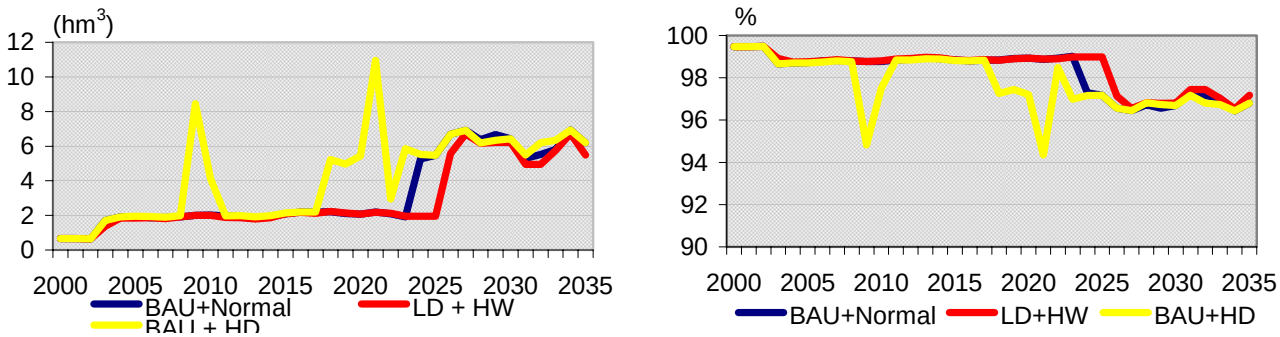

Figure 9-13. Reference case: a) Estimated irrigation deficit and b) Estimated irrigation demand coverage under the selected demand and availability scenario combinations

Figure 9-14 shows the monthly deficit existing for irrigation in 2020. As one would expect, the peaks occur during the summer months, when the crop requirements are higher.

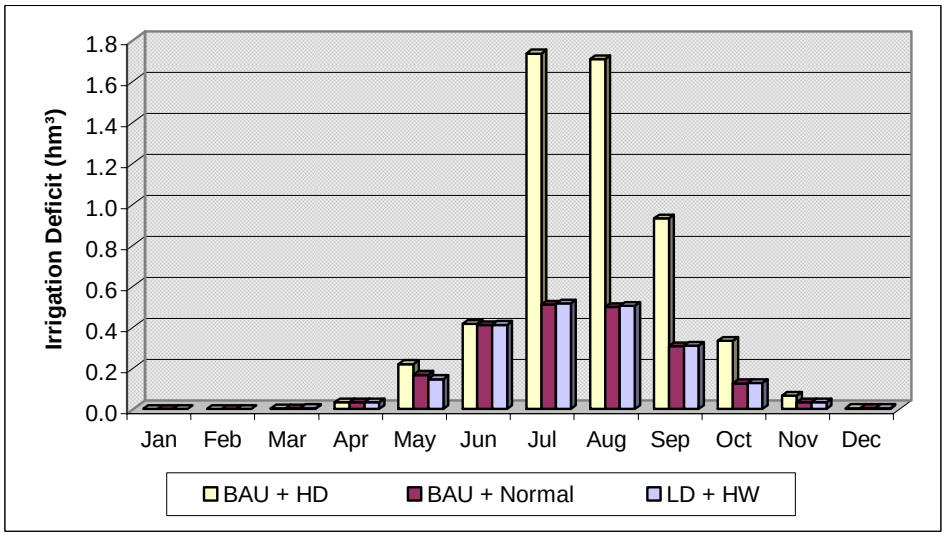

Figure 9-14. Reference case: Monthly irrigation deficit under the three scenarios (2020)

Cost Estimation

The estimation of direct costs for the Ribeiras do Algarve River Basin was based on the evaluation of:

- Amortization of capital costs associated to past and new investments, for both domestic irrigation and industrial uses,
- Operation and maintenance costs of new and existing infrastructures, for domestic, irrigation and industrial purposes.

For domestic use, the capital and specific operation and maintenance costs of the primary network system were estimated according to information of Águas do Algarve S.A. Company. Concerning secondary network systems, if the settlements were supplied with groundwater, the values were estimated according to specific bibliography of National Laboratory of Civil Engineering (Lencastre, 1994). For settlements supplied with surface water direct costs have been estimated by means of expert consultation.

Concerning revenues from water billing, there are two levels of water service supply in the Basin. On the first level, Águas do Algarve Company is responsible for the Primary Water System and charges a water price to each municipality. On a second level, each Municipality is responsible for providing water and to each settlement network. There is an exception to this scheme for Aljezur and Monchique Municipalities, entirely supplied by groundwater, where the Municipality is the unique water service provider. For all the settlements water selling prices were estimated according to information of the Water National Plan (PNA, 2000).

For irrigation use, specifically for public irrigation sites, operation and maintenance costs were set according to the River Basin Water Plan (PBHRA, 1999) and to data provided by Silves, Lagoa and Portimão (SLP) and Sotavento Algarvio farmers associations (IHERA, 2001). Revenues from water billing were calculated according to information of the National Water Plan (PNA, 2000) and farmers associations (IHERA, 2001).

For Private irrigation sites (defined as sites supplied by private boreholes), capital, operation and maintenance costs for borehole construction and irrigation method implementation were set according to the River Basin Water Plan (PBHRA, 1999), using information from experts and hydraulic infrastructure implementation companies. Although farmers owning this type of irrigation sites do not pay for water use, in terms of overall economical analysis of the Ribeiras do Algarve River Basin the water selling price was considered as being equal to private irrigation sites operation and maintenance costs (PBHRA, 1999).

For industrial use, network capital and specific operation and maintenance costs were set according to Águas do Algarve S.A. Company and expert consultation. For industrial units using groundwater the direct costs were estimated according to bibliography of National Laboratory of Civil Engineering (Lencastre, 1994). Revenues from water billing were calculated by means of the Water National Plan (PNA, 2000).

Present Values

Present values have been estimated for the period 2000 to 2035, using a discount rate for hydraulic works of 3.33% set by decree.

9.2. Selection of Management Options and indicators

All the stakeholders consulted have a different approach to water problems due to their different levels of intervention. In fact, the stakeholder consultation was made from a national to the regional and to the local levels.

At the national level, the **National Water Institute** was consulted as the responsible for water management. The main strategic objectives are related to urban water supply and economic activities, as tourism and agriculture. Solving existing lacks in water supply and to guarantee that water of good quality is delivered has been a crucial goal. In that way, the Odelouca dam may be an important step to allow a significant improvement in domestic demand coverage. Regarding demand management, emphasis is given to the achievement of irrigation guarantee percentage of 80% through better knowledge of the irrigation situation and promotion of a more efficient management of water irrigation and improvement of taxes in the public irrigation sites.

At the regional level, **Águas do Algarve S.A.** was involved in the Project since its beginning. The real turnover occurred at the beginning of the 2000s with the implementation of the Primary Water Supply System. Since then, emphasis has been given to its improvement. Presently, the domestic demand coverage is above 90%. Consequently, the major objective is the improvement of the water supply in order to achieve 95% for domestic demand coverage. This improvement relies mostly on the construction of the Odelouca dam. However, for now, there is a delay in the building of the dam putting the achievement of the goal for network coverage at steak.

On the other hand, **Farmers Associations** and **IDRHa** insist on an improvement in irrigation water supply. For example, Funcho dam, currently being used for domestic water supply, was also built for irrigation purposes. Farmers demand its reallocation to agriculture. The extensive use of groundwater for irrigation supply is an important issue since salinisation of the aquifers is a real problem in Algarve.

CCDR Algarve as the official body of coordination has an overall view concerning existing problems and the different goals of the several entities involved. Besides the objectives already referred, there is the imperative necessity to reduce losses in the secondary urban water supply network systems (at Municipality level) and in the different irrigation systems. Moreover, Municipalities still own drills that were used for urban supply before the implementation of the Águas do Algarve Primary Water Supply System but inactive (except Albufeira and Lagoa which, according to Águas do Algarve S.A., still use some of their drills to ensure a small fraction of the water supply). It appears as a necessity, according to Municipalities point of view that they should be allowed to use their drills complementing Águas do Algarve supply.

Finally, **Tourism Institutions** have overall the same objectives and expectations as the Municipalities. Supply enhancement and reduction of losses are referred as the best ways to face water shortages during the summer period.

Figure 9-15 compiles the new strategies defined based on the stakeholders consultation.

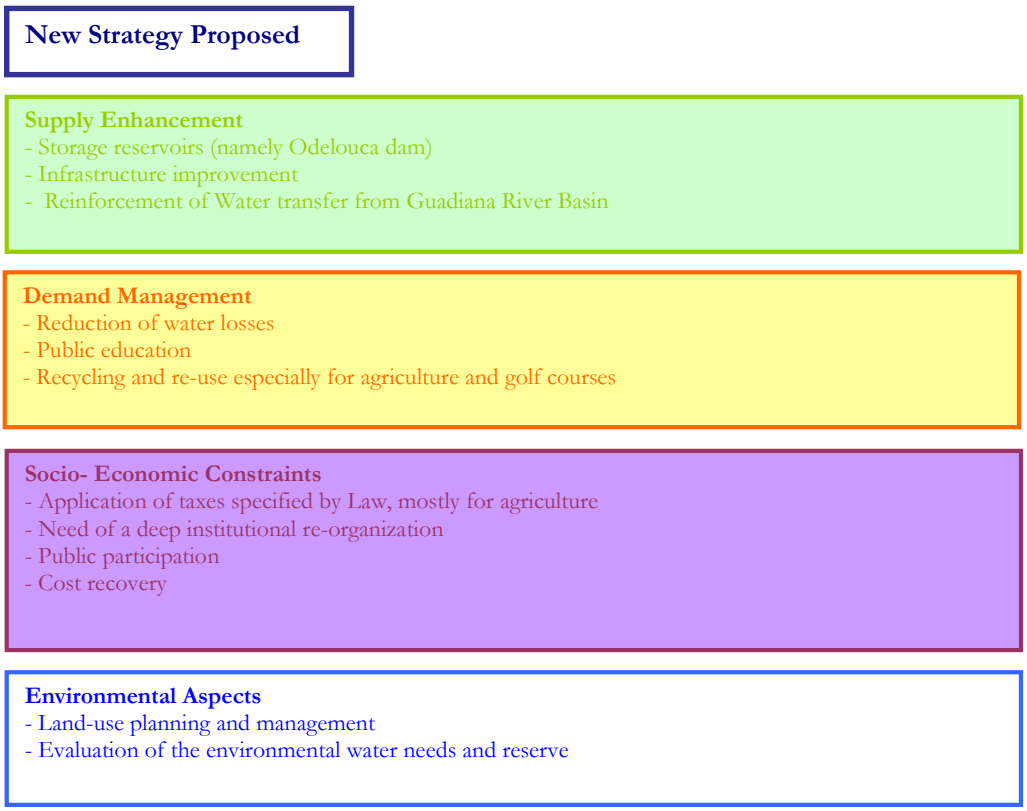

Figure 9-15. Summary of management options

Based on all management options mentioned by the stakeholders consulted, some options were analysed using the WSM-DSS:

- **Structural options** for supply enhancement, including:
  - ⇒ **Dam construction** aiming to reduce domestic demand deficit in Algarve River Basin, in the Municipalities supplied by Águas do Algarve company;
  - ⇒ **Network Enhancement** to improve domestic demand coverage by increasing the number of Municipalities supplied by the Primary Water Supply System (currently, 30 out of 51 secondary network systems are supplied by Águas do Algarve, S.A.);
  - ⇒ **Desalination unit construction,** to solve water deficit and/or water quality problems in domestic use (Aljezur Municipality) and golf courses;
  - ⇒ **Water Reuse,** through the use of treated wastewater for golf courses
- **Demand management options**, including:
  - ⇒ **Reduction of Network Losses**, through replacement of old and damaged pipes of all the Municipal secondary water supply systems (structural intervention);
  - ⇒ **Improvement in Irrigation Methods**, for better irrigation efficiency and savings in water consumption;
  - ⇒ ;
- **Socio Economic measures,** more specifically the impact of new pricing structures for irrigation and settlements.

The selection of appropriate indicators for ranking the above options reflects the perception of the local stakeholders towards economic development, social and environmental sustainability. Since it is widely acceptable that future economic growth is to rely to tourism, the analysis of options is to be formulated around **coverage of domestic needs**. For Ribeiras do Algarve River Basin this indicator expresses the efficiency of the operation of the water resource system, and to a large extent the technical sustainability. This last though is also demarcated by **irrigation demand coverage**. Although currently agriculture is not the primary economic activity, agricultural activities are a major consumer of water at Ribeiras do Algarve River Basin. Aquifer overexploitation and salinisation are among the key environmental problems that threaten not only the provision of supply but also the future resources of the Basin. That way, environmental protection is expressed through the **groundwater exploitation index** and the **non sustainable groundwater production fraction**. Finally, the cost analysis is taken into account through the consideration of the **rate of cost recovery**.

The satisfactory range of values and the weights assigned to the chosen indicators are presented in Table 9-7.

Table 9-7. Satisfactory range of values and weights for the indicators of the Ribeiras do Algarve Case Study

Indicator	Satisfactory range of values	Weight
Domestic demand coverage	95-100%	0.50
Irrigation demand coverage	80-100%	0.25
Groundwater exploitation index	0-80%	0.075
Non sustainable groundwater production fraction	0-35%	0.075
Rate of cost recovery	100-120%	0.1

9.3. Analysis of water management instruments

Structural options

Dam Construction

As said previously and considering the population growth rates presented in Table 9-4, there is always a deficit in urban supply for any range of the scenarios considered. The major deficit is due to the limitation existing in the Funcho storage reservoir that will not be able to guarantee the necessary volumes for urban water supply, in Barlavento Municipalities.

That way, it appears reasonable to consider a new supply source to provide water to the West area of Algarve, Barlavento: Odelouca dam may start operating in 2008, with a capacity of 157 hm3 and dead volume of 23 hm^3. In fact, the construction of Odelouca dam has already begun and its main goal is to assure domestic demand coverage in the Barlavento, above 95%. This construction has now been stopped, expecting developments at the financial, environmental and social sustainability level. Figure 9-16 shows the foreseen location for Odelouca dam and Table A3-4 (Annex) presents the capital costs associated to the project construction.

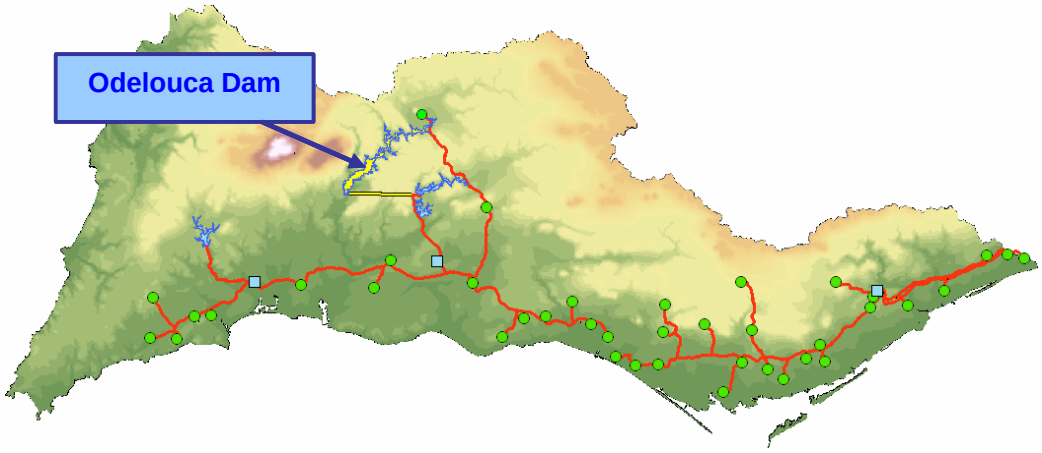

Figure 9-16. Odelouca dam location

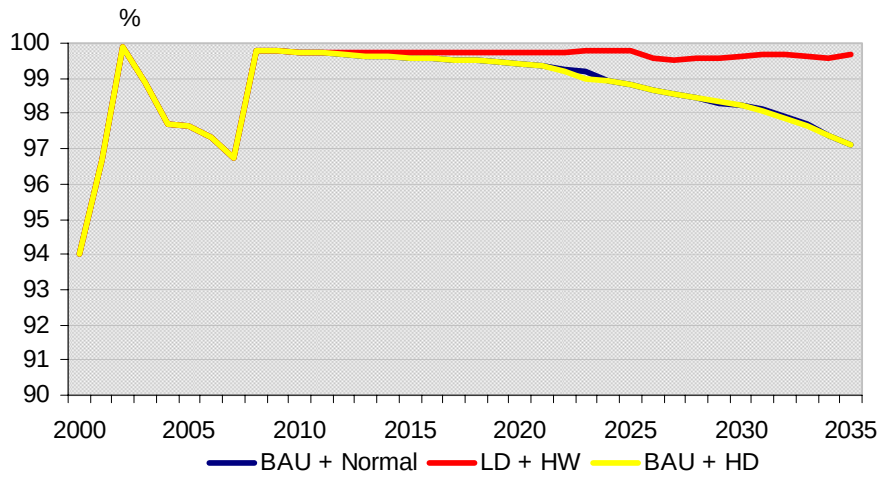

Figure 9-17. Percent demand coverage effectiveness of Odelouca dam to domestic use

Figure 9-17 shows the domestic demand coverage evolution over time, for the different scenarios analysed with the DSS.

That coverage is always above 94% but is expected to decrease between 2002 and 2008 when Odelouca dam is considered to start operating. With the introduction of this option and under the LD+HW scenario the domestic demand coverage rises to almost 100%, for all the simulation period. As expected, under the BAU+Normal and BAU+HD scenarios, the demand coverage is lower, as the water requirements in BAU demand scenario are higher. By 2022 the differences observed between the latter referred scenarios is due to unmet demand related to groundwater supply sources, namely at Monchique aquifer.

It should be noted that in Barlavento, the domestic demand coverage obtained with this option is 99% in average, showing that the goal of the Odelouca dam construction is achieved.

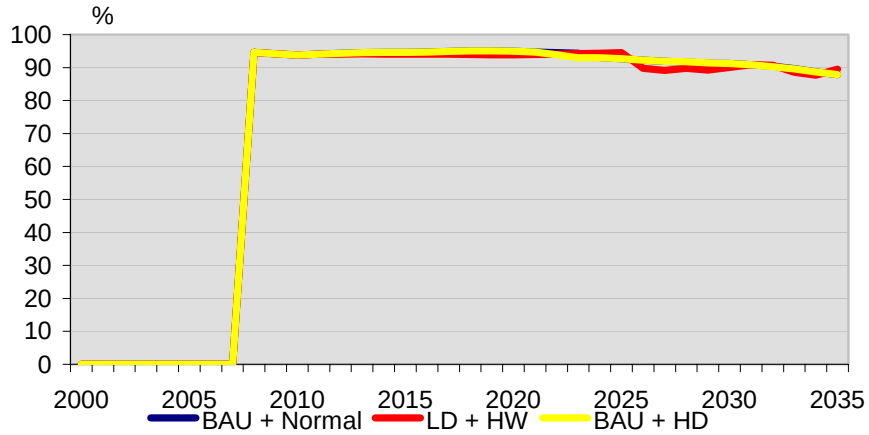

Figure 9-18. Percent improvement of deficit in domestic use with respect to the reference scenarios

As previously referred (Figure 9-12), 95% of the domestic demand deficit is related to Barlavento, the West part of the Ribeiras do Algarve River Basin. Figure 9-18 shows that the domestic deficit improvement achieved with this option is above 93%, on average, from 2008 until the end of the simulation.

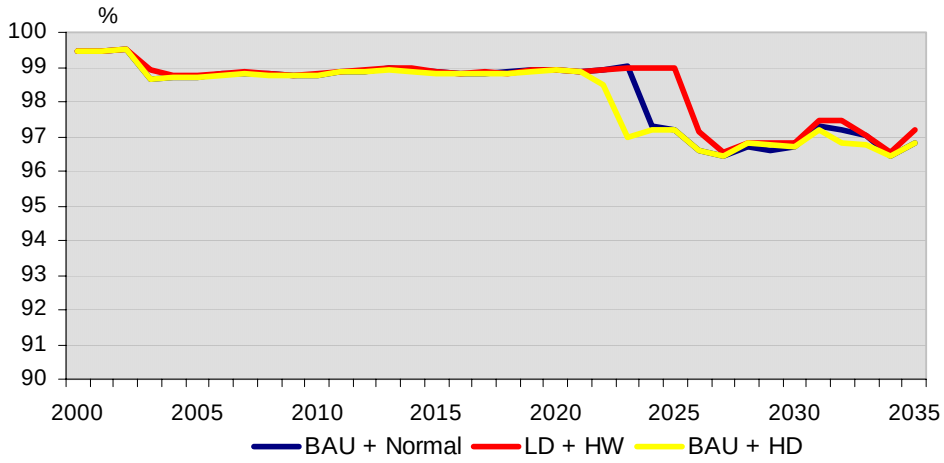

Figure 9-19. Percent demand coverage effectiveness of Odelouca dam to irrigation use

Concerning irrigation use, in the first 5 years of the period of simulation, one can observe a small reduction of the demand coverage effectiveness due to a considered sequence of dry years that affects a specific aquifer (São Bartolomeu). The introduction of the Odelouca dam has indirect influence on agriculture as, with this option, Funcho dam is re-allocated to agriculture from 2008 onwards. For the BAU+HD scenario the percent demand coverage effectiveness goes down from 2021 on due to Monchique aquifer being unable to satisfy all the abstraction needs. For the BAU+Normal scenario this failure happens in 2023 as the groundwater availability is higher. In the LD+HW scenario, it only happens in 2025 as this scenario is associated to higher groundwater availability and less demanding conditions (Figure 9-20).

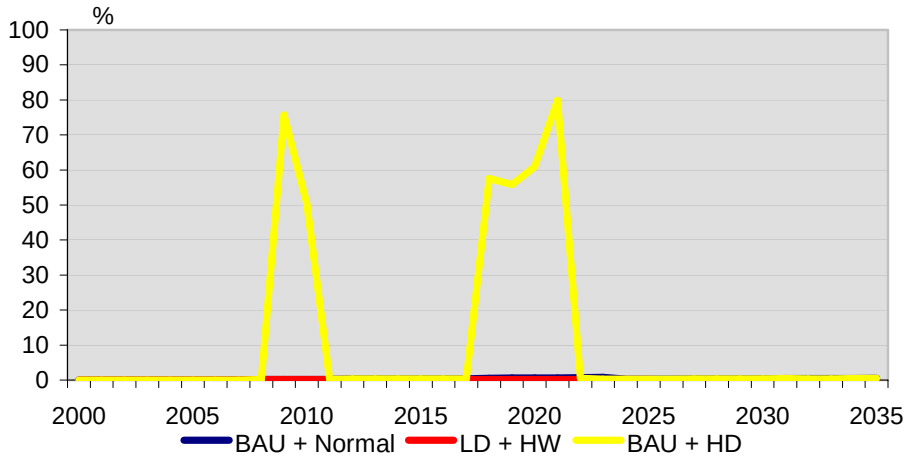

Figure 9-20. Percent improvement of deficit in irrigation use with respect to the reference scenarios

At first sight, the improvement in the irrigation deficit shown in Figure 9-20 is outstanding. The peaks observed for the BAU + HD scenario are due to the Silves, Lagoa and Portimão (SLP) public irrigation site (see Figure 9-13), currently supplied by surface water based on Funcho dam. With the introduction of Odelouca dam, Funcho dam will be consequently fully allocated to agriculture, allowing the mitigation of the BAU +HD scenario deficit.

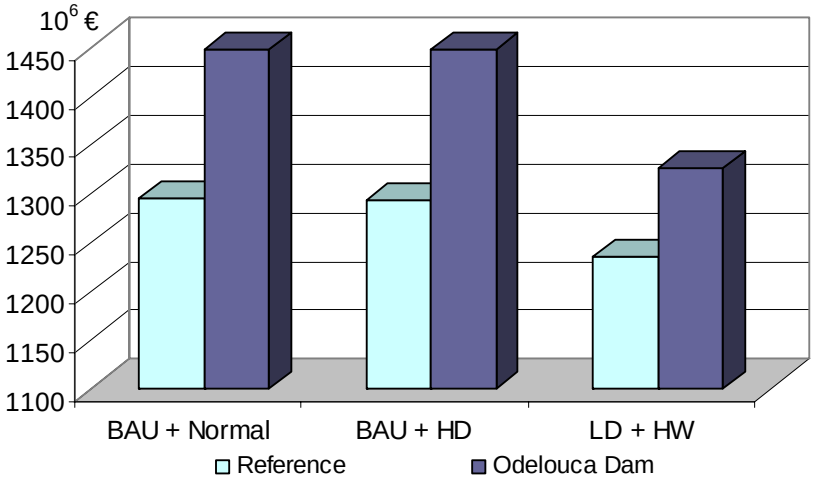

Figure 9-21. Total direct cost difference of the Odelouca dam option under the three scenarios (Present Value – Million €)

Overall the dam construction option is the most expensive of all the simulated ones, in terms of capital costs (Table A3-4 of the Annex). Nevertheless, under the BAU + Normal and BAU + HD scenarios the dam construction represents an increase in terms of present value of only 12%. Furthermore, under BAU+Normal and BAU+HD the present value differs less than 1% between them. This result reflects the importance of surface water in domestic use directly affected by this option. Water flowing within the Network System is closely dependant on the demand scenario rather than with the hydrological scenario. As a consequence, the present value increase of the option under the LD + HW is much lower (7%), since the quantity of water supplied to each consumer is lower, therefore decreasing specific operation and maintenance costs.

Network Enhancements

Águas do Algarve Company, through the concession of the Primary Water Supply System, has been committed to cover 95% of urban water supply users. Presently, this percentage is above 90%. That way, new expansions represent more important investments, as they intend to serve smaller settlements farer from the main pipeline.

As referred by the Águas do Algarve Company, two major connections are planned to be realised soon, and those will benefit two Municipalities, Aljezur and Monchique. In addition, new connections and one replacement are considered to be benefiting other Municipalities as Albufeira, Portimão, Lagos, Loulé and Tavira, increasing network coverage percentage. Figure 9-22 shows the location of the new reservoirs and pipelines.

Tables A3-5 and A3-6 of the Annex present the cost estimation associated to the system enhancement.

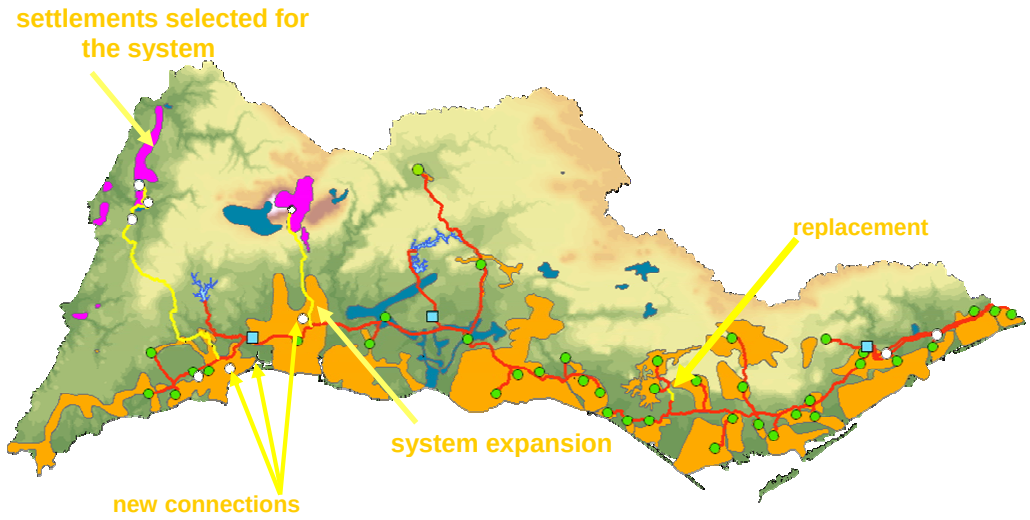

Figure 9-22. Primary Network System: expansion, enhancements and replacements

Table A3-7 of the Annex presents the new connections scheduling.

Figure 9-23 shows the demand coverage effectiveness for domestic use with the network enhancement option.

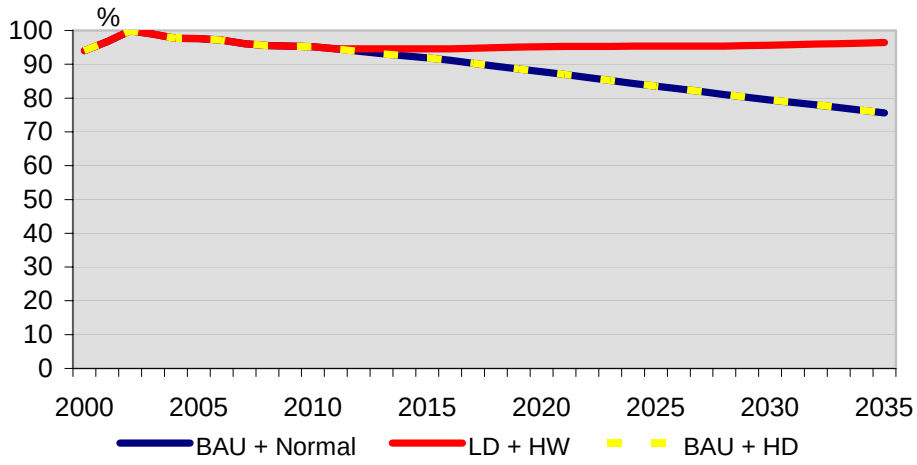

Figure 9-23. Percent demand coverage effectiveness of network enhancement to domestic use

The demand coverage effectiveness is lower than in the reference case as some settlements in Aljezur for example that were previously supplied by groundwater are now connected to the Primary Water Supply System and consequently have a deficit as the quantity available is the same and the population to supply increased (Figure 9-23).

There are no differences observed between the BAU+Normal and BAU+HD scenarios because, as explained in the "Formulation of availability scenarios", the demand coverage

variation depends on demand scenario rather than on the availability scenario. As expected, the demand coverage effectiveness is higher for the LD+HW scenario.

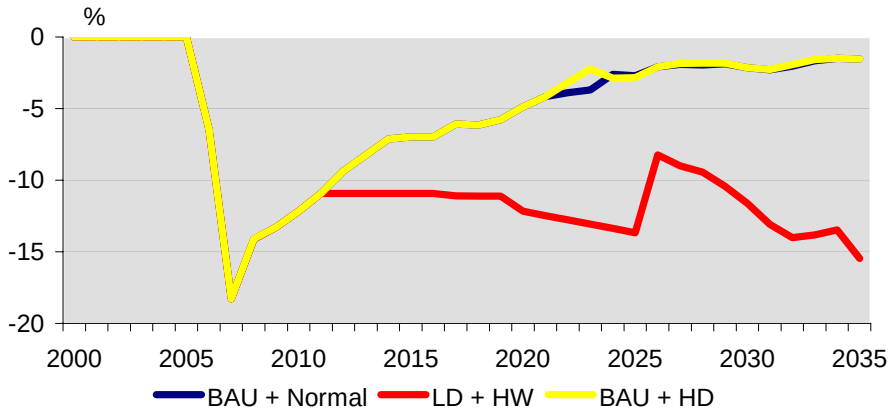

Figure 9-24. Percent improvement of deficit in domestic use with respect to the reference scenarios

With this option, more Municipalities are covered by the Primary Water Supply System, but the water quantity that is distributed is the same of the reference case. Therefore, the overall domestic deficit increases (Figure 9-24), with a maximum of almost 20% in 2006 under BAU+Normal and BAU+HD scenarios. Furthermore, 12% of the latter value is concentrated in Barlavento Algarvio, in Monchique and Aljezur Municipalities, where the new connections are implemented.

Although the differences observed between the domestic deficit before and after the option implementation under all scenarios are the same (on average 0.4 hm^3) the demand under BAU+HD and BAU+Normal scenarios is higher than under LD+HW scenario. Consequently, although negative improvements are observed for the three scenarios, under LD+HW scenario the value is lower (-12%, on average) than for the other two scenarios (-5.7%, on average).

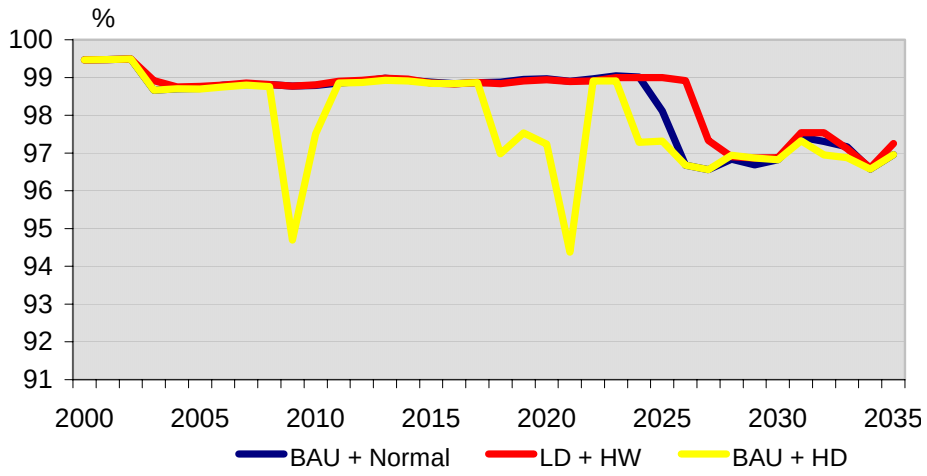

Figure 9-25. Percent demand coverage effectiveness of network enhancement to irrigation use

Regarding irrigation use, concerning demand coverage effectiveness (Figure 9-25), in 2009, the greater unmet demand percentage is observed in the BAU+HD scenario, in Silves, Lagoa and Portimão (SLP) Public irrigation site. The deficit in that irrigation site is exclusively due to Funcho storage reservoir use, with the abstractions needed for public water supply being higher as a result of the new network enhancements.

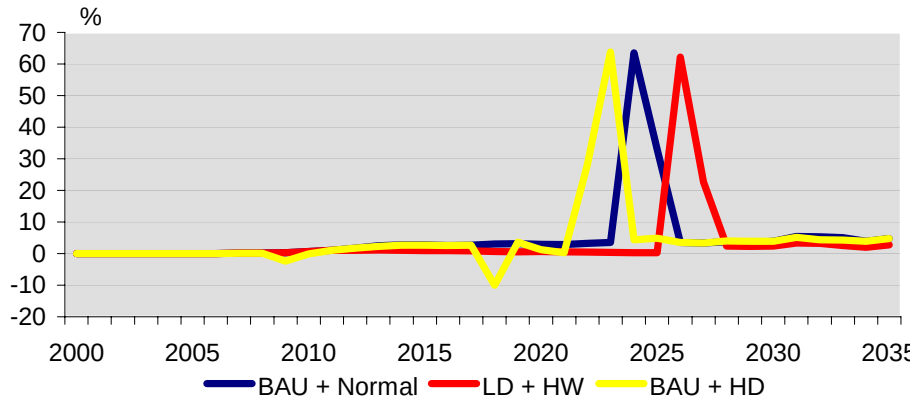

Figure 9-26. Percent improvement of deficit in irrigation use with respect to the reference scenarios

As previously stated, this option increases the water availability for this purpose as settlements that were previously supplied by groundwater, are now supplied by the Primary Water Supply System, through surface water. Therefore groundwater previously available for settlements supply is now available for irrigation use. The best example is Monchique aquifer where a major improvement of the deficit (65%) observed (Figure 9-26) for the year 2023 is observed. The deficit improvement depends on the availability scenario considered, i.e., in LD+HW where higher quantity of groundwater is available, deficit in that scenario is delayed (2023).

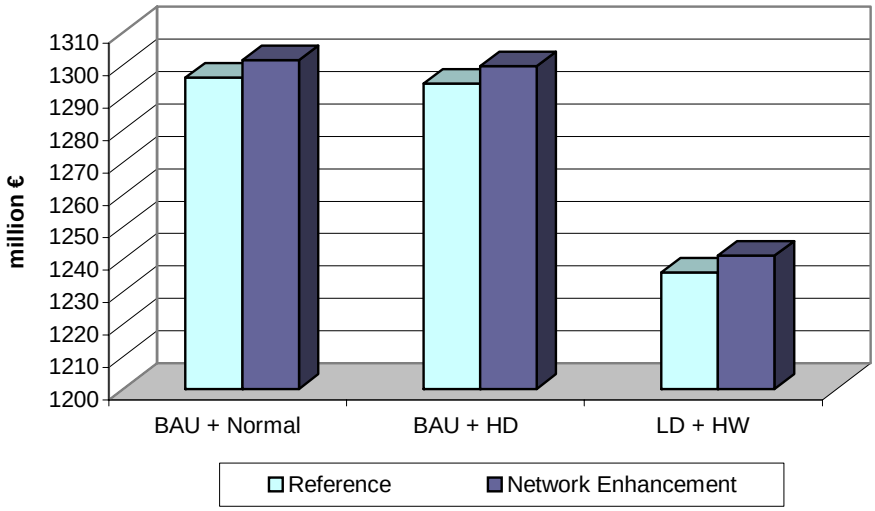

Figure 9-27. Total direct cost difference of network enhancement option under the three scenarios (Present Value – Million €)

Under all three scenarios, the additional cost incurred corresponds to the change from groundwater to surface water at Aljezur and Monchique Municipalities and the increase of network coverage at Albufeira, Portimão, Lagos, Loulé and Tavira. System expansion, replacement and new connections costs increase total direct costs by 0.5% for the whole region and up to 37% in the Aljezur and Monchique Municipalities (in terms of present value). In fact, the present value increase is mainly associated to the capital cost depreciation. By the end of depreciation period (2032) the specific operation and maintenance costs, at the Municipalities of Aljezur and Monchique, are shown to be 65% lower than when those Municipalities were supplied by groundwater.

Desalination

Desalination is a water supply enhancement option that has still not been used in the Ribeiras do Algarve River Basin. Two kinds of desalination units were considered for this option, with different purposes and characteristics:

- Aljezur Municipality, currently supplied with groundwater, was chosen as a site to construct a desalination plant (Figure 9-28), in 2006, using seawater, because the Aljezur aquifer presents quality problems such as high concentration of chlorides. This desalination plant will produce 0.45hm^3 in 2006, 0.55hm^3 in 2020 and 0.71hm^3 in 2035. This unit aims to solve water quality problems, particularly in Aljezur, Bordeira, Carrapateira, Vale da Telha/Arrifana, Monte Clérigo/Espartal settlements.

Also, the construction of desalination units for golf courses irrigation would allow abstracting groundwater from Campina de Faro aquifer, which presents high concentrations of nitrates and chlorides. Thus, another unit, processing brackish water, will be located in Loulé Municipality (Figure 9-28) and start operating by 2006. The water treated in this unit will be used for irrigation purposes in four golf courses (Quinta do Lago, Quinta do Lago - São Lourenzo, Quinta do Lago - Ria Formosa and Quinta do

Lago - Pinheiros Altos) and its capacity will be 11500 m^3/day in 2006. For Quinta do Lago - São Lourenzo and Quinta do Lago - Ria Formosa golf courses, the connection to a wastewater treatment plant will be substituted by the connection to the desalination unit. Moreover, Table A3-8 of the Annex presents the desalination associated costs.

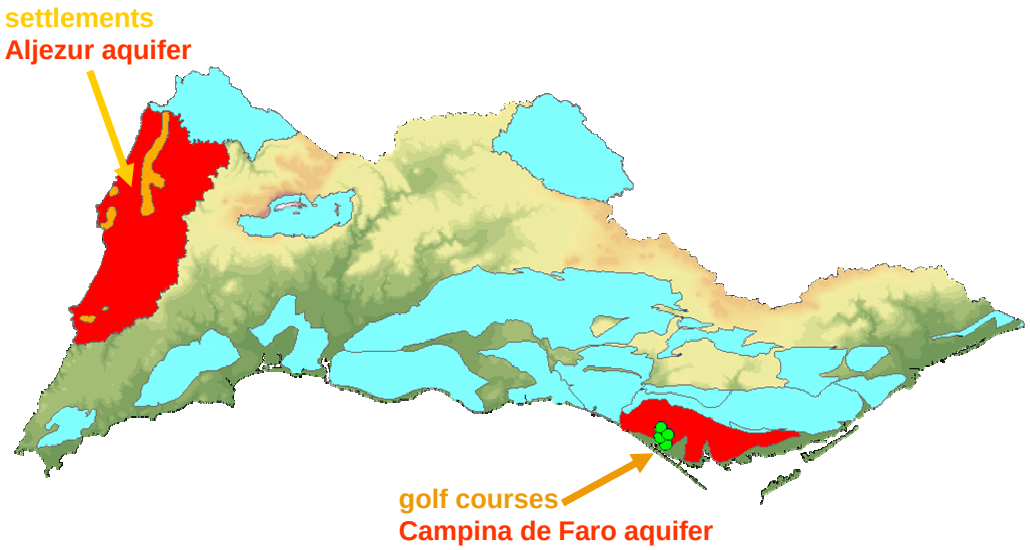

Figure 9-28. Location of the two desalination plants considered

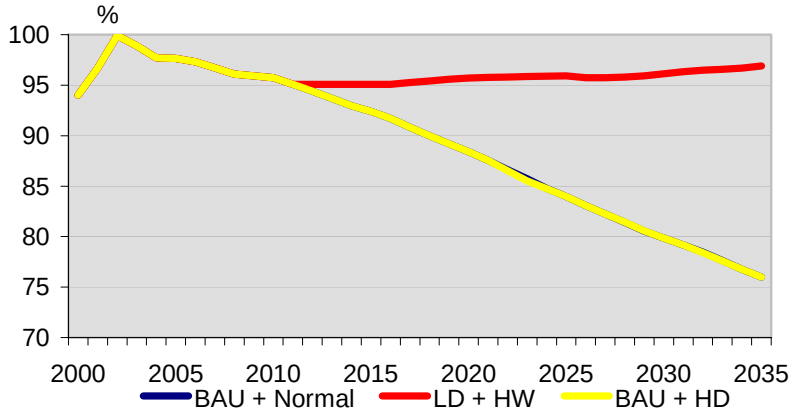

Figure 9-29. Percent demand coverage effectiveness of desalination to domestic use

Concerning the domestic use, the desalination unit was designed in order to supply Aljezur Municipality population with better water quality giving up abstractions for domestic water supply, from Aljezur aquifer. As the desalination unit was foreseen to provide the same quantity of water as the Aljezur aquifer and there was no domestic deficit in the reference case, no graph for domestic deficit improvement, which is inexistent, is provided.

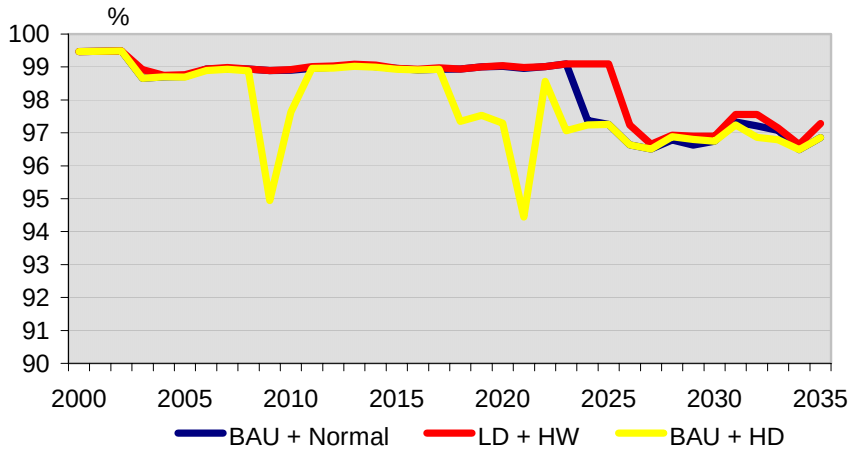

Figure 9-30. Percent demand coverage effectiveness of desalination to irrigation use

There are little differences in irrigation coverage between the reference case and the introduction of the desalination units as one of the desalination plants is for golf courses. This option eliminates the existent deficit (on average 42%) in Quinta do Lago – Ria Formosa golf course, which resulted from the link to Quinta do Lago wastewater treatment plant (Figure 9-30).

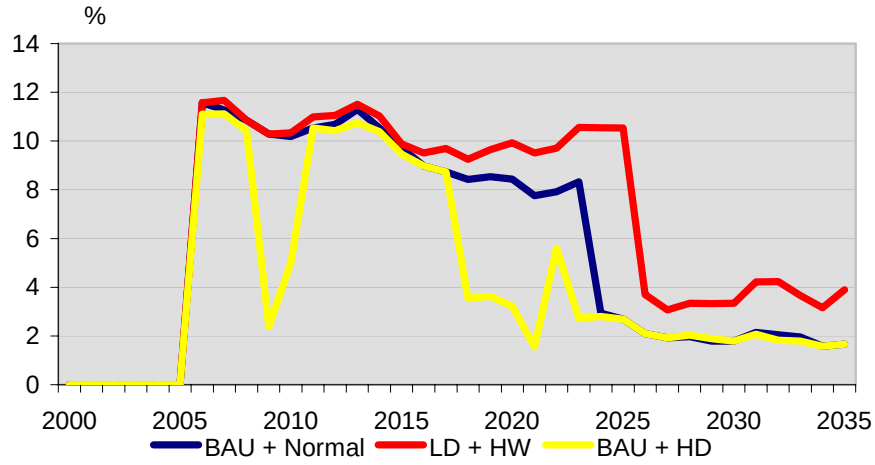

Figure 9-31. Percent improvement of deficit in irrigation use with respect to the reference scenarios (desalination option)

Under all scenarios, this option represents approximately an improvement of only 0.1% in irrigation coverage for the entire Ribeiras do Algarve Basin (Figure 9-31).

On average, the implementation of the desalination unit for the irrigation of golf courses causes a deficit improvement in the golf courses of 8% under LD+HW (the scenario where more water is available), 7% under BAU + Normal and 5% under BAU + HD scenarios (Figure 9-31).

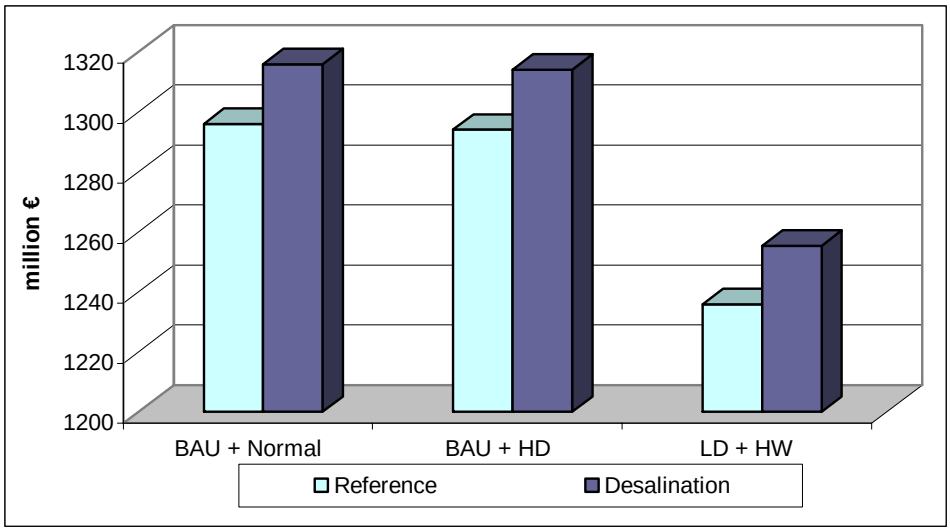

Figure 9-32. Total direct cost difference of the desalination option under the three scenarios (Present Value – Million €)

Figure 9-32 compares the present value of total direct cost of the three scenarios that were studied. In all three cases the construction of the two desalination plants to supply the Aljezur Municipality settlements and golf courses in Quinta do Lago only represent a 1.5% increase of costs for the three scenarios. In fact, the construction of desalination plants are localized measures and the overall increase of direct costs when considering the whole basin is small.

Though, focussing only the Aljezur Municipality settlements and the golf courses supplied by the desalination units, the present value presents a 250% increase when comparing the BAU + Normal scenario with the implementation of desalination units for the same scenario.

Water Reuse

Nowadays, Quinta do Lago - São Lourenzo and Quinta do Lago - Ria Formosa golf courses are using treated water from wastewater treatment plant. The Algarve Commission of Coordination and Regional Development has delimited a critical area (Figure 9-33) where aquifers, as a result of the proximity of the sea, are subjected to salinisation unless protected and where new water boreholes are not allowed except if employed for domestic use.

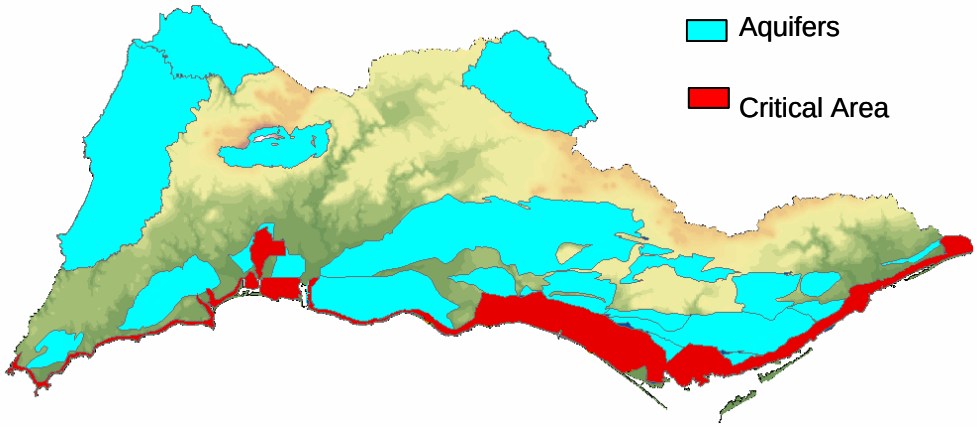

Figure 9-33. Critical area location

In this option, golf courses situated within the critical area were connected to a wastewater treatment plant, WWTP, at a distance of less than 2000 m from the golf course to be supplied. The WWTP holds secondary treatment and therefore tertiary treatment will be implemented and capital costs supported by each golf course benefited with this option.

In 2006, six golf courses were selected to adopt this type of water supply. In Loulé Municipality: Vilamoura – Millennium, Vilamoura – Laguna Course, Vale do Lobo – Ocean Golf Course and in Albufeira Municipality: Balaia Village, Herdade dos Salgados and Pine Cliffs. Table A3-10 of the Annex presents the yield and construction costs for water reuse.

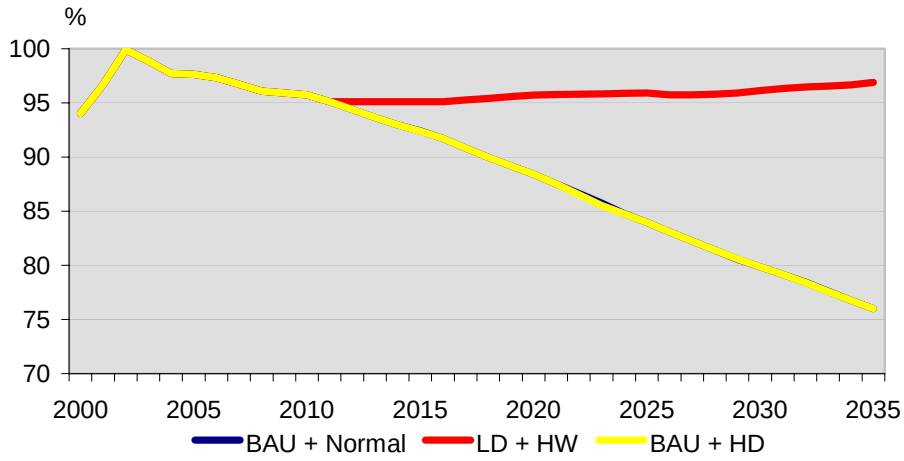

Figure 9-34. Percent demand coverage effectiveness of water reuse to domestic use

The reuse option only deals with golf courses in Municipalities where settlements are supplied with surface water. Therefore, domestic effectiveness presents no differences before and after the option implementation (Figure 9-34) and no domestic deficit improvement is observed.

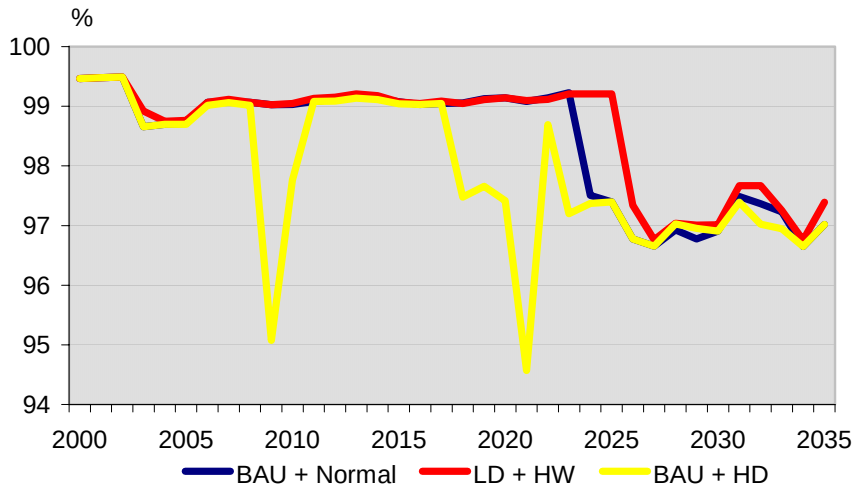

Figure 9-35. Percent demand coverage effectiveness of water reuse to irrigation use

The differences in irrigation demand coverage for the whole Ribeiras do Algarve River Basin, between all three scenarios and the base case, are on average 0.26%, i.e. there is almost no distinction between the data presented in Figure 9-35 and the percent demand coverage effectiveness to irrigation use in the base case. Similarly, in Loulé and Albufeira Municipalities where water reuse is carried out, the differences in irrigation demand coverage, between all scenarios and base case, are on average 2%. As stated before, the peaks in percent demand coverage effectiveness for irrigation under BAU + HD scenario are due to water deficit at Arade dam. Implementing this option implied just a shift from groundwater supply to water reuse in golf courses and a decrease in the groundwater volume exploited in the critical area.

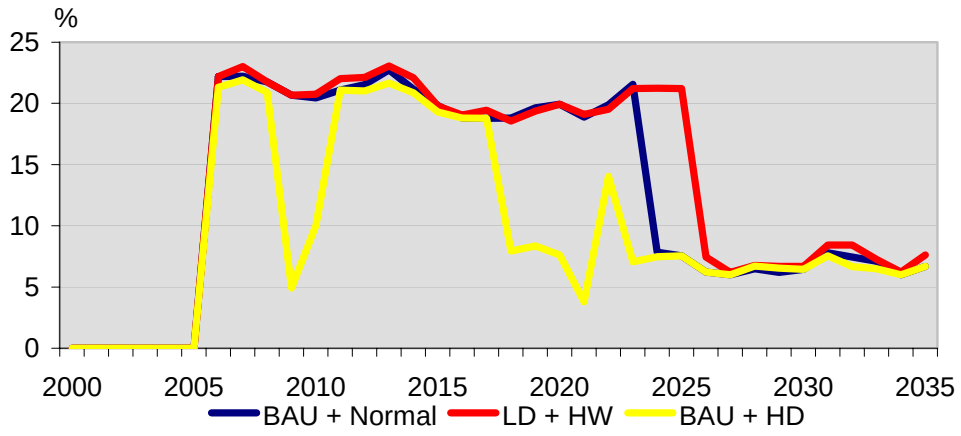

Figure 9-36. Percent improvement of deficit in irrigation use with respect to the reference scenarios (water reuse)

The improvement of the irrigation deficit is only observed in Herdade dos Salgados golf course where the deficit, which was 415 m^3 in 2005, becomes inexistent after 2006. The

small fluctuations observed are caused by the sequence of hydrologic years selected for each scenario (Figure 9-36).

Demand management options

Reduction of Network Losses

The current estimated level of network losses, in the Ribeiras do Algarve River Basin settlements, ranges from 16 to 61% for the total domestic water supply. The option that was explored was a gradual reduction of losses of 15% in 15 years for each Municipality (Table A3-9 of the Annex). These losses reductions will be achieved through successive network interventions (upgrade, replacements, maintenance). The application of this option was made on the assumption that internal network interventions will be implemented in different Municipalities, in three phases: from 2005 onwards at a 5% rate until 2010, 5% from 2010 to 2015 and 5% from 2015 to 2020.

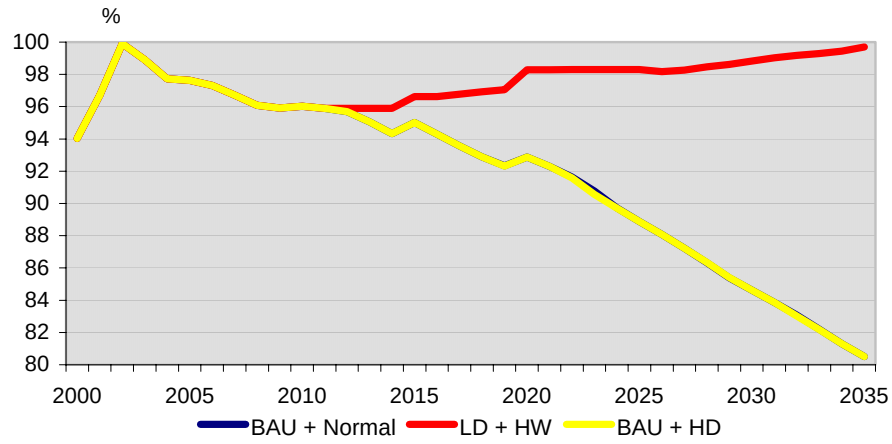

Figure 9-37. Percent demand coverage effectiveness of losses reduction to domestic use

Analyzing Figure 9-37, one can observe that the domestic demand coverage for LD+HW scenario, after the year 2015, is always above 96%, almost reaching 100% for the last year of the simulation period.

For the other scenarios (BAU+Normal and BAU+HD), the domestic demand coverage decreases to values under 90% in 2024, mostly due to Barlavento. The deficit in Barlavento represents 95% of the total existent deficit in the Algarve mainly as a result of Funcho dam surface water abstraction limit of 23 hm^3.

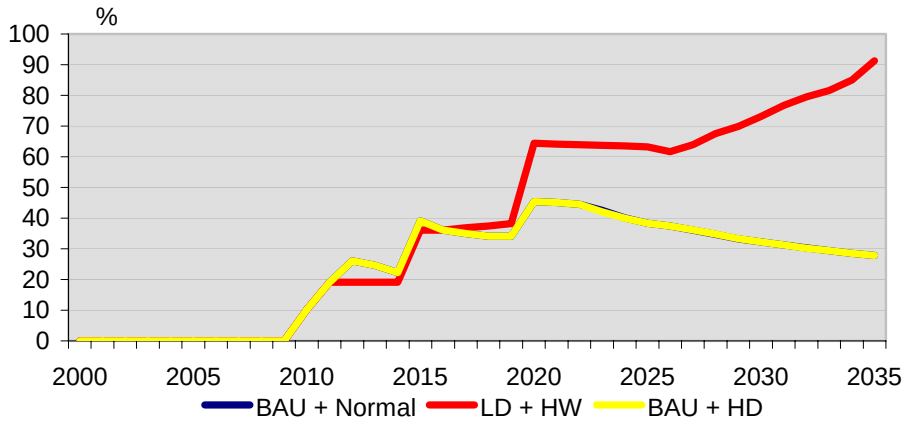

Figure 9-38. Percent improvement of deficit in domestic use with respect to the reference scenarios (losses reduction)

In terms of domestic deficit, the LD+HW scenario performs better for the analyzed option, presenting an improvement of 54% on average, for the period of simulation, reaching 97% in the last year. An average improvement of 33% of the water deficit, after 2010 and a maximum value of the improvement (45%) in 2020 are observed under the BAU+Normal and BAU+HD scenarios. In those scenarios, as the reduction of losses ends in 2020, the decreasing of the domestic use deficit improvement is due to the continuous increasing of demand (Figure 9-38).

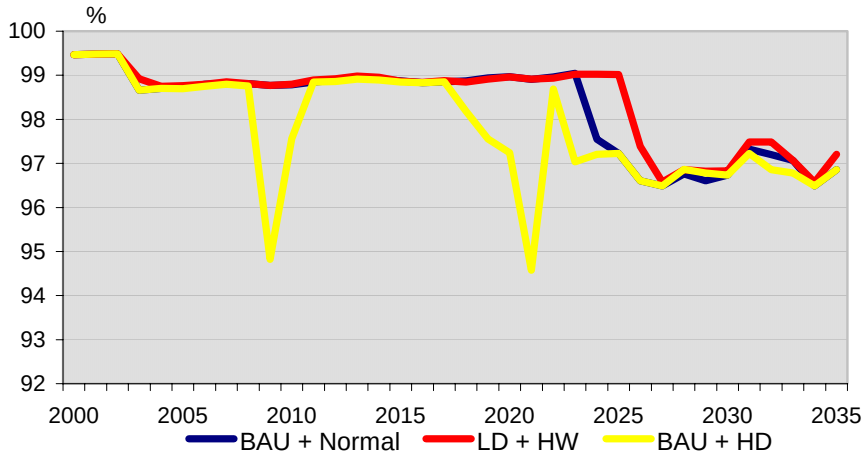

Figure 9-39. Percent demand coverage effectiveness of losses reduction to irrigation use

For the worst case scenario, BAU+HD, and although the irrigation coverage is on average 98% along the simulation period, this parameter presents values of 94.8% and 94.6% in 2009 and 2021 respectively (Figure 9-39). The major share comes from Silves, Lagoa and Portimão public irrigation site, which achieves irrigation coverage values of 41% in 2009 and 26 % in 2021, because of severe water shortage in Funcho dam. The Monchique private irrigation site is particularly affected, showing a deficit of 62% under BAU+Normal and LD+HW scenarios by 2024 and 2026.

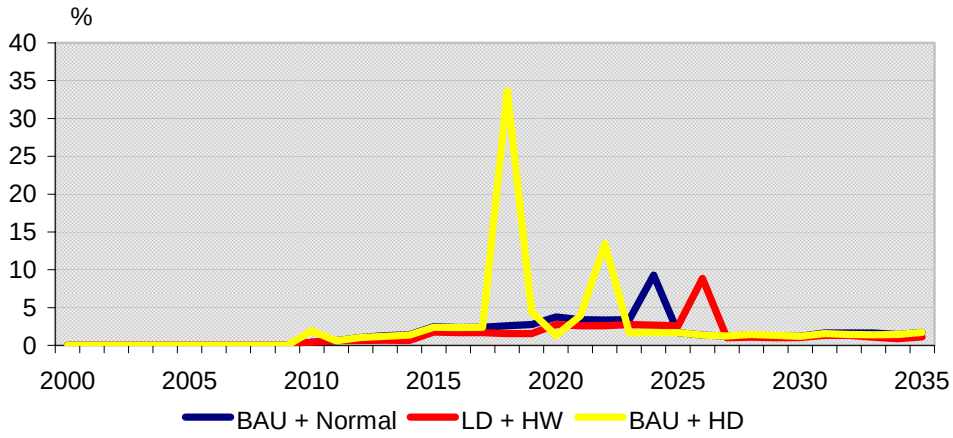

Figure 9-40. Percent of improvement of deficit in irrigation use with respect to the reference scenarios (losses reduction)

Although this option is directed towards the domestic supply network systems, it also influences agriculture indirectly, namely public irrigation sites supplied by surface water. As stated before, domestic use and Silves, Lagoa and Portimão public irrigation site, are mostly supplied by surface water from Funcho dam. Thus, the option considered affects significantly the latter irrigation site particularly under the BAU+HD scenario (Figure 9-40).

Under the BAU+Normal and LD+HW scenarios, the overall deficit improvement, after the option is implemented, is 2%. Specifically, under LD+HW scenario the irrigation deficit decreases 9.3% in 2024 and 8.3% in 2026 (Figure 9-40).

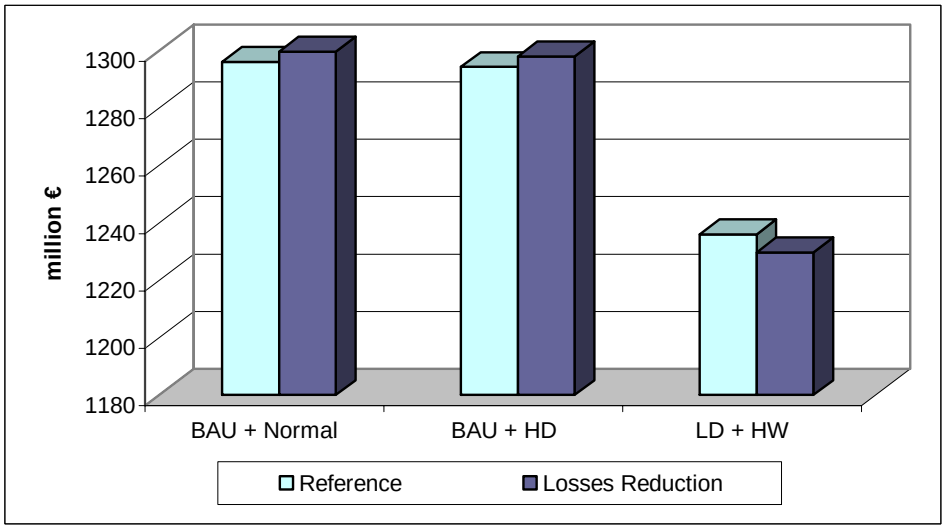

Figure 9-41. Total direct cost difference of the losses reduction option under the three scenarios (Present Value – Million €)

This option presents the lower present value among all options. Under BAU+Normal and BAU+HD scenarios, losses reduction causes domestic deficit decrease consequently, the volume of water supplied increases and specific operation and maintenance costs

increase. Contrarily, under the LD+HW scenario present value decreases after the scheduled network interventions. Under this scenario the domestic unmet demand is lower; losses reduction decrease the volume of water delivered to domestic users and operational costs are lower.

Improvement in Irrigation Methods

Agriculture represents the most important water consumer in the Algarve. The irrigation sites represent 123.7 hm^3 (approximately 67%) of the total water consumption at the Ribeiras do Algarve River Basin. From this volume, 96.9 hm^3 correspond to groundwater consumption. The irrigated area growth rate varies either for public and private irrigation sites, causing an increase in water need and therefore enhancing irrigation water deficit. Moreover, it is predicted that an area of 10 650 ha of public irrigation sites is to be implemented by 2006.

In order to diminish losses in agriculture, which represented a maximum of about 27 hm^3 (22% of the supply volume used for irrigation) for BAU+Normal scenario in 2000, alterations in irrigation methods (furrow and sprinkler) were implemented both in public and private irrigation sites. Hence, furrow irrigation method implementation area percentage will be decreased whereas, sprinkler irrigation method implementation area percentage will consequently increase.

Table 9-8 presents the application percentage (% area) change from furrow to sprinkler irrigation method for public and private irrigation sites.

Table 9-8. a) Irrigation methods application extent (% area), for public irrigation sites

	2005		2006	
Public irrigation sites	Furrow	Sprinkler	Furrow	Sprinkler
Silves, Lagoa and Portimão	100%	0%	0	100%
Mira	100%	0%	0	100%
Alvor	100%	0%	100%	0%
Vale da Vila*[5]	-	-	0	100%
Alcantarilha*	-	-	0	100%

b) Irrigation methods application extent (% area), for private irrigation sites

	2006		2012		2020	
	Furrow	**Sprinkler**	**Furrow**	**Sprinkler**	**Furrow**	**Sprinkler**
Private irrigation sites	20%	80%	15%	85%	10%	90%

As part of the option, the efficiency of furrow and sprinkler irrigation methods will be enhanced (Table 9-9), for example by means of repairing.

[5] operation start 2006

Table 9-9. a) Irrigation methods efficiency improvement, for public irrigation sites

	2006		2012		2020	
	Furrow	Sprinkler	Furrow	Sprinkler	Furrow	Sprinkler
Public irrigation sites	65%	85%	65%	85%	70%	85%

b) Irrigation methods efficiency improvement, for private irrigation sites*[6]

Regadio privado	2006		2012		2020	
	Furrow	Sprinkler	Furrow	Sprinkler	Furrow	Sprinkler
de Aljezur	65%	85%	65%	85%	70%	85%
de Almodôvar	65%	85%	65%	85%	70%	85%
de Lagoa	65%	85%	65%	85%	70%	85%
de Monchique	-	-	65%	85%	70%	85%
de Odemira	65%	85%	65%	85%	70%	85%
de Ourique	65%	85%	65%	85%	70%	85%
de S. Brás Alportel	-	-	65%	85%	70%	85%
de Vila do Bispo	65%	85%	65%	85%	70%	85%

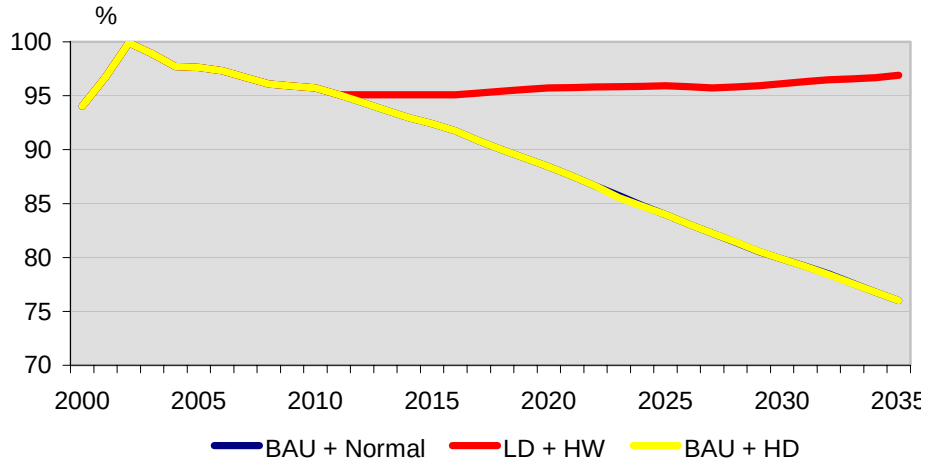

Figure 9-42. Percent demand coverage effectiveness of Improvement in Irrigation methods to domestic use

From Figure 9-42, under the LD+HW scenario, the domestic coverage is always higher than 95%. For the other scenarios, the domestic coverage presents a decreasing trend, reaching values lower than 80% from 2030 onwards. Consequently, no changes are observed.

[6] For the remaining private irrigation sites no other than these modifications in efficiency were implemented

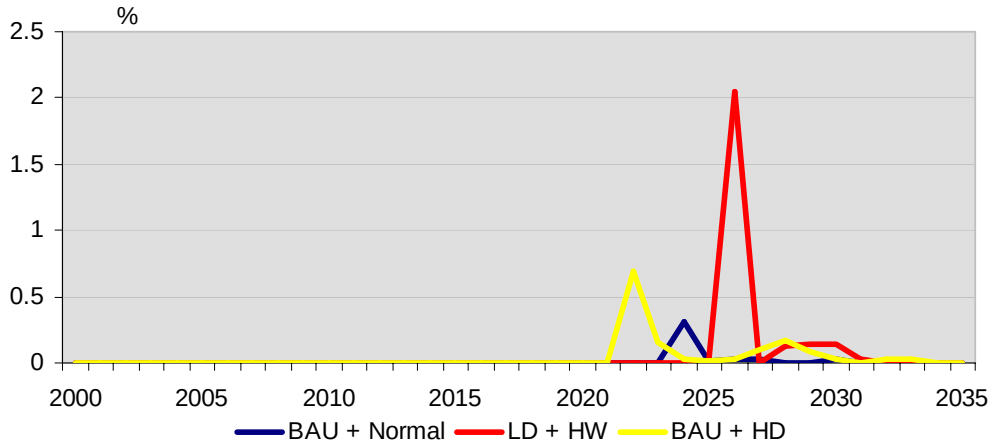

Figure 9-43. Percent improvement of deficit in domestic use with respect to the reference scenarios (improvement in irrigation methods

The observed domestic deficit improvement is indirectly related to the change from furrow to sprinkler method. Under BAU+HD scenario, the deficit observed in settlements supplied with groundwater abstracted from S. Bartolomeu in 2021 and Monchique in 2023 aquifers decreases.

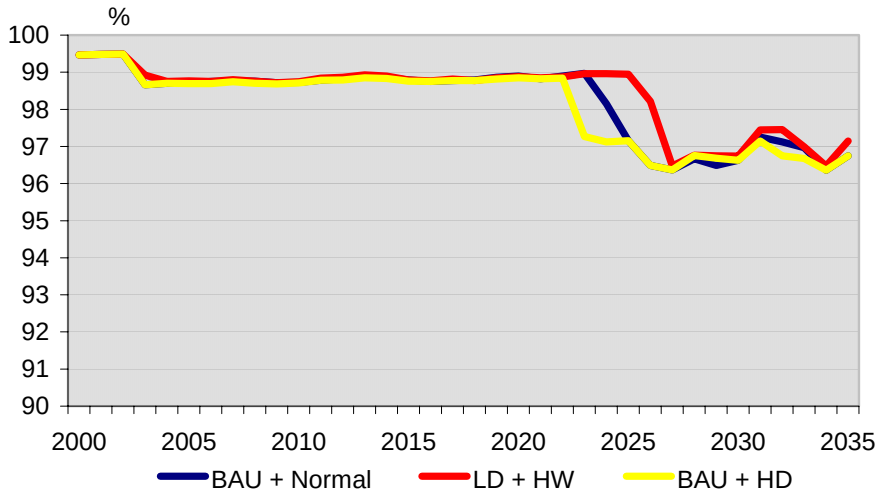

Figure 9-44. Percent demand coverage effectiveness of improvement in irrigation methods to irrigation use

For the BAU+HD scenario the percent demand coverage effectiveness decreases from 2021 due to Monchique aquifer being unable to satisfy all the necessary abstractions. For the BAU+Normal and LD+HW scenarios this failure happens in 2023 and 2025 respectively as these two scenarios are associated to less demanding conditions (Figure 9-44).

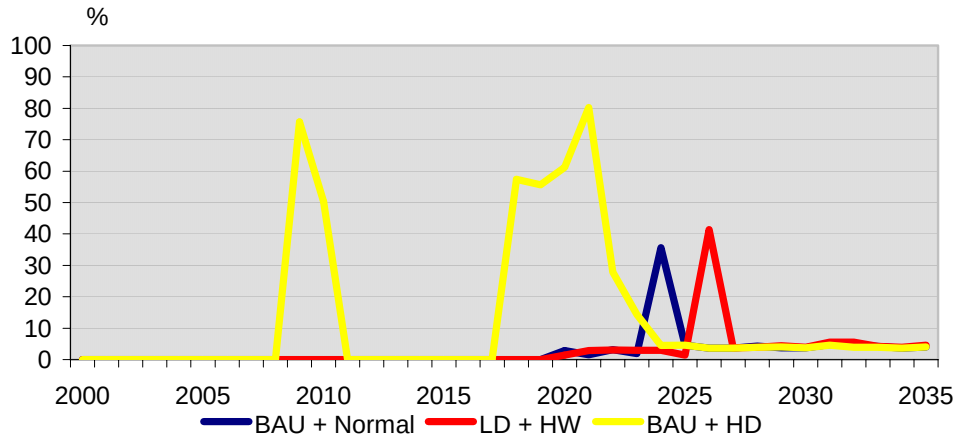

Figure 9-45. Percent improvement of deficit in irrigation use with respect to the reference scenarios (improvement in irrigation methods)

Under BAU+HD scenario there is an irrigation deficit improvement which reaches almost 80%, from 2009 to 2011 and from 2017 to 2021 (Figure 9-45). The latter is due to the mitigation of the unmet demand in Silves, Lagoa and Portimão public irrigation sites. There is also a deficit improvement observed in 2024 under BAU+Normal and in 2025 under LD+HW which is due to the overexploitation of S. Bartolomeu and Monchique aquifers.

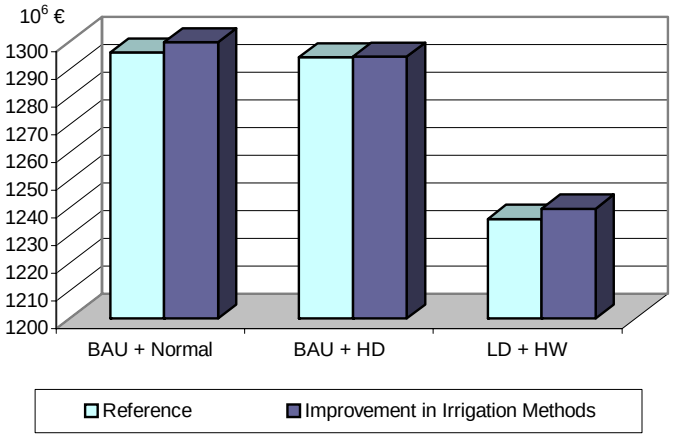

Figure 9-46. Total direct cost difference of the improvement in irrigation methods option under the three scenarios (Present Value – Million €)

Only costs at public irrigation sites were considered because, at this stage, only data concerning these types of irrigation sites was available. Consequently, the increase in terms of present value reflects the capital costs associated to the implementation of new irrigation methods at public irrigation sites. Therefore, although the irrigation deficit decreases (Figure 9-46) at private and public irrigation sites, the specific operation and maintenance costs increase are associated to public irrigation sites.

9.4. Final Selection

The final selection of instruments to be further analysed depend on the performance of the options explored regarding the indicators that were presented throughout the analysis.

Results are summarized in Table 9-11. The effectiveness of each option is approached through the evaluation score obtained by the WSM-DSS, from the behaviour with respect to domestic and irrigation demand coverage, assuming a weight of 0.5 and 0.25 respectively.

Environmental sustainability is expressed through the performance with respect to Non Sustainable Water Production Fraction and Groundwater Exploitation Index, assuming weight of 0.075 for each indicator.

Economic Efficiency is expressed through the evaluation score obtained by the WSM DSS, from the performance with respect to rate of cost recovery, assuming weight 0.10 and through total direct cost, expressed in present value terms.

Table 9-10. Final evaluation of instruments

Option	Effectiveness (Relative Performance Index for Demand Coverage)	Economic Efficiency		Environmental Resources (Relative Performance Index for Environment Resources)
		Rate of Cost Recovery Index	(Direct Cost – PV-million €)	
Base Case (BAU+Normal)	0.250	0	1296	0
Dam Construction	0.524	0	1448	0
Network Enhancement	0.250	0	1301	0.15
Desalination Unit Construction	0.250	0	1315	0.075
Reduction of Network Losses	0.251	0	1230	0
Improvement in Irrigation Methods	0.250	0	1300	0.15
Water Reuse	0.250	0	No data	0.075

All the rate of cost recovery values are zero (Table 9-11) because at any time throughout the simulation period the index value is higher then the lower limit (100%). Nevertheless, the option that presents higher average rate of cost recovery values is the dam construction, since a higher quantity of water is sold. A pricing measure is therefore needed in order to achieve this objective.

The normalisation of the results obtained in Table 9-11 under a scale ranging from 0 to 5 yields the results presented in Table 9-11.

Table 9-11. Normalised option performance matrix

Option	Effectiveness (Relative Performance Index for Demand Coverage)	Economic Efficiency		Environmental Sustainability (Relative Performance Index for Environment Resources)
		Rate of Cost Recovery	(Direct Cost – PV-million €)	
Base Case (BAU + Normal)	-	-	***	-
Dam Construction	*****	-	-	-
Network Enhancement	-	-	***	*****
Desalination Unit Construction	-	-	***	***
Reduction of Network Losses	-	-	*****	-
Improvement in Irrigation Methods	-	-	***	*****
Water reuse	-	-	No data	***

From the normalized matrix presented in Table 9-11 it could be inferred that the application of one option by itself is unsatisfactory since it cannot simultaneously fulfil the criteria of effectiveness, economic efficiency and environmental sustainability. A hard option such as dam construction occupies an advantageous position in terms of effectiveness, occupying an unsatisfactory rank in terms economic efficiency and environmental sustainability. If a strategy is developed these options should incorporate other options to improve economic and environmental performance, like hard options such as network enhancement or softer ones like improvement in irrigation methods.

Due to the complexity and size of the Ribeiras do Algarve River Basin, it is often difficult to observe some clear differences in the indicators when a management option is only applied locally to a specific Municipality or Settlement of the Basin. This situation applies to Aljezur where, for example, the effect of introducing desalination plant is not distinguished in the evaluation total score.

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10.Concluding remarks

10.1. Scenario analysis and Strategy development

The analysis of comprehensive scenarios for each Case Study Region, as stated in the introductory section of this Deliverable, aims to identify water management options that can be **combined** in the Strategy Formulation Process out of a set proposed by different stakeholders. The developed strategies should target the mitigation of water stress conditions in the regional context of the Case Study -up to a certain point- without compromising the goals of environmental sustainability (options should assist at the minimization of environmental impacts) and economic sustainability (avoiding disproportionate costs and ensuring adequate cost recovery levels).

For this purpose, the objectives of the comprehensive scenario analysis undertaken, assessing single water management options under different availability and demand scenario components, were to:

- Define the extent for the application of each option, and the level at which this option can assist in mitigating water stress;
- Estimate the range of direct costs for each option, in order to assist in the selection of least-cost measures, and decide whether application costs may prove to be disproportionate;
- Estimate the environmental impacts and/or costs associated with each option, in order to select those that can contribute to a more environmentally sustainable management of water resources in each region.

The role of scenario analysis as a component of the overall methodology in Strategy Development in the framework of the WaterStrategyMan project is depicted in Figure 10-1.

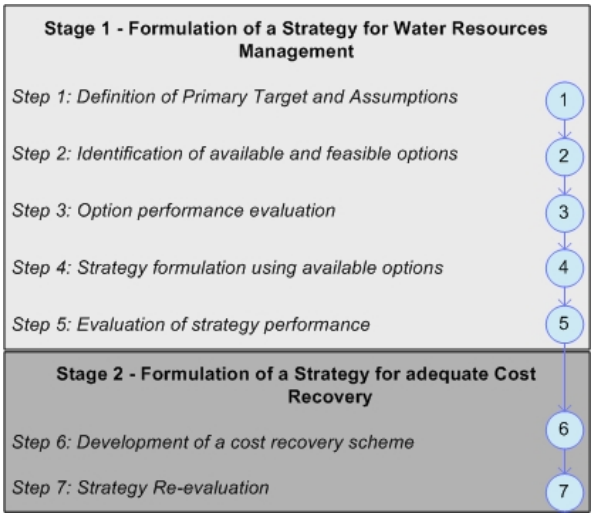

Figure 10-1. The process of Strategy Development

Under this context, the outcomes of comprehensive scenario development and evaluation should be regarded as a milestone in the overall WSM methodology towards the development of improved and, most importantly, integrated water management strategies, aiming to depict potential barriers in the application of options and impacts associated with both current and future practices. The outcomes for each case study from the scenario analysis are summarized in the following paragraph.

10.2. Summary of outcomes from Scenario Analysis

Throughout the process of scenario formulation, and as presented in the respective Case Study chapters, a variety of options, both structural and non-structural, have been examined. The comprehensive list of options includes technical measures for the enhancement of supply, demand management options, and water saving technologies. Institutional/legislative measures or reform, and capacity-building, as well as instruments and measures aiming to increase public awareness on water scarcity have not been examined at this stage, as they aim to support the formulation of an enabling environment for the application of the above measures.

Table 10-1 presents the overall evaluation for each option and each Case Study, ranking the examined options as to their applicability in the development of integrated WM strategies. The respective detailed performance matrices are presented in each case study chapter, under the Final Selection paragraph.

In general, for each region, the following can be summarized:

Options examined for **Paros Island, Greece** (**Typology Type II, Insular**), included network unifications and enhancements, desalination, groundwater exploitation, storage reservoir construction, reduction of network losses, cistern construction, improvement in irrigation methods, conservation measures in domestic use and pricing for irrigation and domestic users. The evaluation of each was conducted under three different scenario combinations, a business-as-usual state, a high shortage state (high demand-low availability), and a low shortage state (low demand-high availability), and was based on effectiveness improvements with respect to each reference scenario for irrigation and domestic demand coverage, direct costs and environmental costs. The main outcome of the scenario analysis was that strategy development cannot rely on the application of a few options only. Although desalination seems to occupy an advantageous position in terms of technical, economic and environmental sustainability, very high costs indicate that the measure should be combined with other interventions, such as smaller structural solutions, (interception dam, network unifications, network loss reduction through replacements), as well as "softer" interventions, aimed to management of demand (domestic conservation, irrigation method improvements). Although irrigation pricing appears to be one of the most effective options, given the current institutional framework it is highly unlikely that such an option can be actually realised to the extent that it is presented in the current assessment.

Scenario analysis for **Belice Basin, Sicily, Italy (Typology Type III)**, involved the examination of two supply enhancement methods (i.e. exploitation of Belice river, and

wastewater treatment and reuse), two conservation methods (irrigation method improvements, reduction of distribution losses), and domestic pricing. Options were evaluated under three different combinations of demand and availability scenarios, depicting a normal state, a high shortage state and a low shortage state. Indicators used concerned effectiveness, with particular emphasis to irrigation, which is the main target of the assessment, and improvement with respect to each reference scenario, direct costs and environmental costs. The main outcome of the analysis was that water reuse takes an advantageous position in terms of effectiveness and economic efficiency; however softer instruments, such as water pricing and network loss reduction should be integrated with structural options in order to ensure adequate coverage of water needs for both urban and irrigation demand at the **whole** of Belice Basin area.

Options examined for the **Limassol Region in Cyprus (Typology Type II, Regional)** included water reuse, expansion of the existing water treatment plant of Limassol, wastewater treatment expansion, measures aiming to reduce network losses, conservation measures to domestic use and application of domestic and irrigation pricing schemes. The options were evaluated under three different combinations of demand and availability scenarios according to their relative performance with respect to demand coverage, the benefit/cost ratio and the incurred environmental costs. Results indicate that pricing reforms can have a significant effect in the overall water balance, an effect which is much stronger when pricing is oriented to irrigation water. However, the expansion of the water treatment plant is also necessary, presumably at a lesser extent if combined with other more "soft" interventions. This is one of the issues that remain to be examined in the Strategy Formulation phase.

A variety of water management methods was examined in the case study of **Tenerife, Canary Islands, Spain** (**Typology Type II, Insular**), under two different demand scenarios. The analysis included structural, both small and large-scale interventions (network enhancements and unifications, storage reservoirs, groundwater exploitation, wastewater reuse, reduction of network losses), and non-structural measures (recovery and increase of forested area, rainfall harvesting systems, and conservation measures for domestic users). Under both scenarios examined, solutions can be found through the combination of different instruments, with different weights. Other than the fact that desalination stands out among the other options, it is confirmed that other interventions such as network loss reduction and saving measures can have an important weight. From the analysis undertaken the risks of betting on a massive structural solution, such as desalination, are also evident. Under a possible scenario of contention and of more appropriate and sustainable development, desalination stops being seen as a panacea and becomes a more targeted solution. This could cause a technical and structural inertia within the system difficult to reverse. Finally, the analysis emphasises the risks derived from maintaining the prevailing assumptions on growth rates, especially in a possible situation of long-lasting water deficit.

Options were examined for **Tel Aviv region in Israel** (**Typology Type I**) under two different availability scenarios, normal (average) water availability, and cyclic (defined as a

sequence of years where three consecutive years with average supply are followed by three consecutive dry years with a supply that is 30% lower than the average). Criteria used for evaluation included social and private welfare surplus, environmental costs and direct costs. Four options were evaluated: (a) increase of recycling of treated wastewater, (b) desalination (c) increase of groundwater abstractions (overpumping), and (d) conservation measures, aiming to reduce gross domestic demand.

From a social and environmental point of view and under both availability scenarios, increased supply of recycled water is one of the best options examined, as it results to both increased social welfare surplus, and negligible environmental costs (best option under the normal scenario and second best under the cyclic scenario). On the other hand, this is the only management option under which agricultural supply is not fully met during all the years of the time horizon; this results in a lower value for private welfare surplus, that may result in opposition by the agricultural lobby. The effect is stronger in the case of the cyclic weather scenario, where private welfare surpluses and improvements with respect to the reference scenario are the lowest among all options examined. Measures aiming to reduce gross domestic demand also yield high social surplus and zero values for environmental costs. Domestic conservation has the additional advantage of augmenting private welfare surplus, as the demand reduction results in higher supply available for all uses. With respect to the increase of groundwater overabstractions, the measure results in increased supply for all uses, thus incurring a high private welfare surplus and increased efficiency. However, the high values for environmental costs as well as the low values for social welfare surplus should discourage the application of the option from a social and environmental point of view under all cases.

Integrated strategy development for the Tel-Aviv region should therefore focus on the examination of both structural and non-structural options, as supply enhancement through recycling and desalination, and domestic demand reduction through the promotion of conservation measures. Additional options to be evaluated include also the option of creating a partial institutional and economic separation of Tel-Aviv's water resources from the national water system and operating it as a balanced economic entity with respect to the industrial and domestic sectors.

The analysis for the **Ribeiras do Algarve** region, Portugal (**Typology Type II, Regional**) focused on the examination of six options under three different scenario combinations of demand and availability scenarios. The options, which include dam construction, expansion of the primary water supply system, desalination, water reuse, reduction of network losses, and improvement of irrigation methods, were ranked according to their effectiveness in meeting domestic and irrigation water needs, direct cost and rate of cost recovery, and environmental impact, expressed in terms of groundwater exploitation index and non-sustainable groundwater production. One important conclusion that was drawn from the analysis is that structural solutions, as dam construction, although occupying an advantageous position in terms of effectiveness, can be characterised neither as economically efficient, nor as

environmentally sustainable. Economic and environmental performance can be improved through combinations of options, as system expansion, or demand management in the form of increased irrigation efficiency (improvement in irrigation methods). Due to the complexity of the water system, a variety of water management problems (small localised deficits or overexploitation problems) can be solved through the application of small scale, structural solutions (local application in a municipality, river basin or sub-basin), without necessarily requiring large scale structural interventions.

Table 10-1. Applicability of different management options for the identified Paradigms, under the concept of Strategy Development

Paradigm Type	I	II				III
		Insular		Regional		
Management Option / Region	Tel-Aviv	Paros	Tenerife	Limassol	Algarve	Belice Basin
Network unifications and system expansion	-	***	***	**	*****	-
Storage Reservoirs	-	**	***	-	**	-
Loss Reduction	-	****	****	**		**
Irrigation Improvement	-	****	***	-	***	*
Irrigation Pricing	-	****	**	****	-	-
Domestic Pricing	-	***	**	***	-	***
Desalination	***	*****	*****	-	***	-
Conservation	*****	*****	****	**		-
Cisterns	-	*	-	-	-	-
GW Exploitation	**	*	*	-	-	
Surface water exploitation[1]	-	-	**	-	-	***
Wastewater recycling and reuse	***	-	***	*	**	****
Increase of forested area	-	-	***	-	-	-

Legend:

(*) – least applicable (*****) – highly applicable

-: not examined/not applicable

[1] Includes exploitation plans for the Belice river for the Belice Case Study (diversions and enhancement of current system) and rainfall harvesting systems for Tenerife

ANNEX

SCENARIO DATA

A1. Paros Island, Greece

Hydrological sequences

Table A1-1. Intra-annual rainfall variation

Year Type	Factor Relative To Normal Year											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Dry Year	0.7	0.7	0.7	0.7	0.7	0.7	1.0	1.0	0.7	0.7	0.7	0.7
Wet Year	1.3	1.3	1.3	1.3	1.3	1.3	1.0	1.0	1.3	1.3	1.3	1.3

Table A1-2. Dry and Wet availability scenarios (figures in mm)

Year	DRY		WET	
2000	282.3	NORMAL	362.9	NORMAL
2001	324.0	NORMAL	450.5	NORMAL
2002	556.4	WET	341.3	NORMAL
2003	230.1	DRY	450.6	NORMAL
2004	426.7	NORMAL	450.2	NORMAL
2005	357.1	NORMAL	311.2	NORMAL
2006	364.3	NORMAL	269.3	DRY
2007	434.6	NORMAL	215.2	DRY
2008	360.1	NORMAL	584.9	WET
2009	220.9	DRY	605.9	WET
2010	427.7	NORMAL	189.9	DRY
2011	259.6	DRY	534.1	WET
2012	246.9	DRY	417.1	NORMAL
2013	319.1	NORMAL	581.1	WET
2014	142.2	DRY	375.1	NORMAL
2015	642.8	WET	486.6	NORMAL
2016	377.7	NORMAL	268.8	DRY
2017	384.0	NORMAL	432.0	NORMAL
2018	439.2	NORMAL	700.0	WET
2019	346.8	NORMAL	437.1	NORMAL
2020	384.3	NORMAL	522.0	WET
2021	229.0	DRY	526.1	WET
2022	336.8	NORMAL	478.2	NORMAL
2023	234.0	DRY	407.4	NORMAL
2024	108.5	DRY	396.7	NORMAL
2025	359.9	NORMAL	404.9	NORMAL
2026	150.0	DRY	518.8	NORMAL
2027	402.2	NORMAL	306.9	NORMAL
2028	453.0	NORMAL	541.4	WET
2029	490.1	NORMAL	395.1	NORMAL
2030	396.9	NORMAL	617.4	WET
2031	643.5	WET	384.2	NORMAL

Year	DRY		WET	
2032	339.1	NORMAL	213.2	DRY
2033	327.6	NORMAL	465.0	NORMAL

Network unifications parameters

Table A1-3. Construction years for network unifications

Connection	Year		
	BAU + Normal	BAU + HD	LD + HW
Agairia – Kampos	2005	2005	2005
Dryos – Marpissa	2005	2005	2005
Naoussa – suburbs	2005	2005	2005
Kostos – Naoussa	2028	2021	-

Desalination parameters

Table A1-4. Capacity and construction cost for the BAU+Normal scenario

Unit	Capacity (m^3/d)		Construction Cost (€)	
	2005	2021	2005	2021
Paroikia	800	1,100	790,000	1,050,000
Naoussa suburbs	450	850	480,000	830,000
Marpissa	1,400	1,500	1290000	1,365,000
Parasporos[1]	-	500	-	523,000
Total	2,650	3,950	2,560,000	3,768,000

Table A1-5. Capacity and construction cost for the BAU+HD scenario

Unit	Capacity (m^3/d)		Construction Cost (€)	
	2005	2021	2005	2021
Paroikia	900	1200	873,000	1,123,000
Naoussa suburbs	450	1100	480,000	1,041,000
Marpissa	1,400	1,500	1,290,000	1,365,000
Parasporos	-	600	-	612,000
Total	2,750	4,400	2,643,000	4,141,000

[1] The Parasporos unit in the BAU + Normal scenario is constructed in 2026 and supplies the southern part of the municipal department of Paroikia and a part of the tourist facilities of the settlement

Table A1-6. Capacity and construction cost for the LD+HW scenario

Unit	Capacity (m^3/d)		Construction Cost (€)	
	2005	2021	2005	2021
Paroikia	850	850	830,000	830,000
Naoussa suburbs	250	250	285,000	285,000
Marpissa	1,200	1,200	1,123,000	1,123,000
Parasporos	-	-	-	-
Total	2,300	2,300	2,238,000	2,238,000

Groundwater Exploitation

Table A1-7. Construction years for the new boreholes for the three scenarios

Borehole	Construction Year		
	BAU – Normal	BAU – HD	LD – HW
Arhilohos	2006	2006	2007
Glysidia	2005	2005	2005
Kostos 1	2005	2006	2006
Kostos 2	2011	2007	2007

Reduction of network losses

Table A1-8. Scheduling of network replacements

Municipal Department	BAU + Normal	BAU + HD	LD + HW
Paroikia	2005-2008	2005-2008	2005-2007, 2009
Naoussa	2005-2008	2005-2008	2005-2008
Marpissa	2005-2007	2005-2007	2005-2007
Kostos	2006, 2007, 2009	2006, 2007, 2009	2006, 2007, 2009
Arhilohos Lefkes Agairia	2006, 2009, 2012	2006, 2009, 2010	2006, 2007, 2015

Cisterns

Table A1-9. Construction and expansion years for cisterns

Municipal Department	Construction Year[2]		
	BAU + Normal	BAU + HD	LD + HW
Paroikia	2005 (2010)	2005 (2010)	2005 (2010)
Marpissa	2005 (2010)	2005 (2010)	2005 (2010)
Naoussa	2022 (2026)	2021 (2026)	2022 (--)
Kostos	2006 (2011)	2005 (2010)	2006 (2011)
Arhilohos	2007 (2026)	2006 (2011)	2006 (2011)

[2] Capacity expansion years are presented in the brackets

Table A1-10. Parameters for the cistern expansion scheme

Municipal Department	Number of Cisterns	Capacity (m^3)	Capital Cost (thousand €)
Paroikia	187	4,030	413
Marpissa	30	680	70
Naoussa	100	2,100	215
Kostos	12	260	27
Arhilohos	30	630	65
Total	*172*	*3670*	*377*

Irrigation method improvement parameters

Table A1-11. Total penetration of drip irrigation per municipal department

Municipal Department	Maximum Penetration (%)
Paroikia	65%
Marpissa	77%
Naoussa	68%
Kostos	43%
Arhilohos	64%
Agairia	46%

Table A1-12. Scheduling of irrigation method improvements

Municipal Department	BAU + Normal	BAU + HD	LD + HW
Paroikia	2005,2007,2009,2011		
Marpissa			
Naoussa			
Kostos			
Arhilohos			
Agairia	2005,2007,2018,2028	2005,2007,2009,2011	2005,2007,2015,2017

A2. Belice Basin data

Hydrological sequences

Table A2-1. Normal, Dry and Wet rainfall scenarios (figures in mm)

Year	NORMAL	DRY	WET
2001	512.70	545.29	407.00
2002	505.26	384.61	515.07
2003	497.82	427.24	551.44
2004	490.38	678.64	448.63
2005	482.94	286.61	493.86
2006	475.50	509.12	453.23
2007	468.06	456.94	457.33
2008	460.62	443.73	439.31
2009	453.18	437.25	305.49
2010	445.75	336.94	424.85
2011	438.31	739.49	476.90
2012	430.87	201.36	429.55
2013	423.43	435.61	436.92
2014	415.99	395.94	459.52
2015	408.55	327.21	325.60
2016	401.11	246.79	331.39
2017	393.67	438.52	604.37
2018	386.23	426.36	224.66
2019	378.79	315.33	425.33
2020	371.35	341.54	377.02

Table A2-2. Normal, Dry and Wet rainfall scenarios (figures in mm)

Meteorological data	Historic Period Selected	
	20 Years Wet/Cold	20 Years Dry/Hot
Rainfall	1953 -> 1972	1966 -> 1985
Temperature	1962 -> 1981	1955 -> 1974

Belice Exploitation parameters

Table A2-3. Exploitation of surface water of Belice River

Option	Yearly Volume abstracted (hm^3)	Conveyance factor of pipelines to Garcia	Construction Cost (Million €)	Purpose
Pumping from right branch of Belice	6	0.05	22.9	Integration to all water use
Expansion existing station on Belice	7	0.05	25	Integration to irrigation

Table A2-4. Implementation year for Belice Exploitation

Options	Year		
	BAU	BEST	WORST
Pumping from right branch of Belice	2004	2004	2001
Expansion existing station on Belice	2004	2004	2001

Distribution network replacement parameters

Table A2-5. Replacements of Montescuro

Construction Years	Initial average efficiency	After replacement	Cost (Million €)
2004-2006	40 %	21 %	61.4

Irrigation Methods improvement parameters

Table A2-6. Improvement of Irrigation Methods

Implementation Years	Districts involved	Yearly increment of drip over sprinkler	% at 2020	Cost (€/m^2)
2005-2020	Menfi, Sciacca, Sambuca di Sicilia	+ 2%	Sprinkler – 28% Drip – 72%	~0.1 (indicative cost)

Waste Water Re-use parameters

Table A2-7. Wastewater Reuse for Irrigation

Implementation Years	Plants	Total Capacity (m^3/d)	Effluent Price (€/m^3)	Cost (Million €)
2004-2006	Menfi, Castelvetrano, Sambuca di Sicilia	12,497	0.092	118.8

Water Pricing parameters

Table A2-8. Water Pricing Variation for Domestic & Tourist

Implementation Years	Demand elasticity for domestic & tourist		Yearly increment of selling price	Variation of price 2001 - 2020 (€/m3)
	Permanent	Seasonal		
2001 – 2020	0.2	0.35	+ 1.87%	0.8 -> 1.1

A3. Ribeiras do Algarve data

Hydrological sequences

Table A3-1. Intra-annual rainfall variation

Water Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Dry	0.9	0.8	0.8	0.8	0.6	0.6	0.7	0.6	0.6	0.7	0.8	0.8
Normal	1	1	1	1	1	1	1	1	1	1	1	1
Very Dry	0.7	0.7	0.7	0.7	0.6	0.5	0.6	0.4	0.5	0.6	0.7	0.6
Very Wet	1.6	1.6	1.4	1.3	1.7	2	4.9	5.6	2.1	1.6	1.5	1.7
Wet	1.1	1.1	1.2	1.1	1.3	1.2	1.7	2	1.2	1.3	1.2	1.2

Table A3-2. Meteorological stations considered

Station Number	Name
30E/01	Aljezur
30E/02	Marmelete
30E/03	Barragem da Bravura
30F/05	Vidigal
30G/01	Alferce
30G/03	Barragem do Arade
30H/03	São Bartolomeu de Messines
30H/05	Paderne
30L/03	Faz-Fato
31I/01	Loulé
31J/01	São Brás de Alportel
31K/01	Santa Catarina/Tavira
31E/01	Lagos

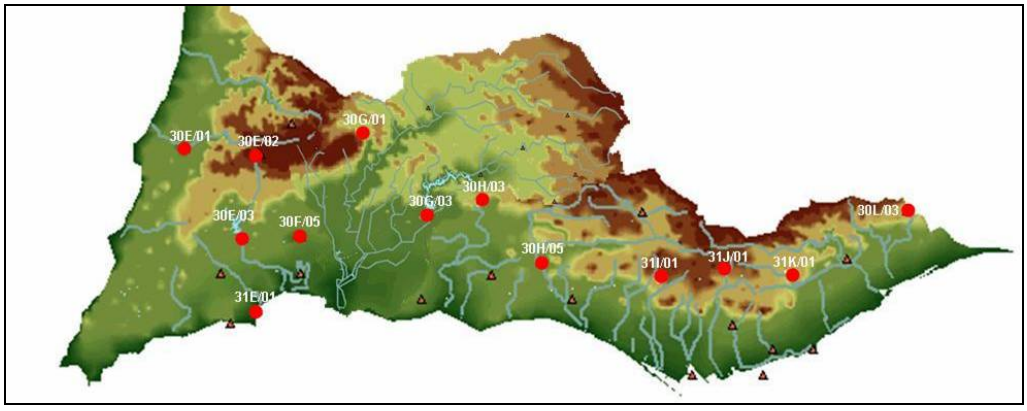

Figure A3-1. Map of the meteorological stations considered

Table A3-3. Dry, Normal and Wet availability scenarios

	Dry	Normal	Wet
2000	normal	wet	normal
2001	wet	very wet	wet
2002	dry	normal	dry
2003	dry	normal	dry
2004	dry	normal	dry
2005	normal	normal	dry
2006	normal	wet	normal
2007	normal	normal	dry
2008	dry	dry	very dry
2009	dry	dry	very dry
2010	normal	wet	normal
2011	normal	wet	normal
2012	very wet	very wet	wet
2013	wet	very wet	wet
2014	normal	normal	dry
2015	very dry	very dry	very dry
2016	dry	normal	dry
2017	very dry	very dry	very dry
2018	normal	normal	dry
2019	wet	wet	normal
2020	dry	normal	dry
2021	normal	normal	dry
2022	very wet	very wet	wet
2023	wet	very wet	wet
2024	very wet	very wet	very wet
2025	normal	wet	normal
2026	very dry	dry	very dry
2027	normal	normal	dry
2028	normal	Wet	normal
2029	very dry	dry	very dry
2030	very wet	very wet	very wet
2031	wet	very wet	normal
2032	very wet	very wet	wet
2033	very dry	very dry	very dry
2034	normal	wet	normal
2035	wet	very wet	wet

Dam construction parameters

Table A3-4. Cost Estimation for Odelouca dam project

Cost Component	Cost (million €)
Dam and accessibilities	39.8
Tunnel	25.8
Land Expropriations	4.3
Total	**69.9**

Network enhancement parameters

Table A3-5. Pipeline connection construction costs (connections)

Cost Component	Cost (€)
Aljezur	
Ocidental R3	2,747,073.45
Ocidental R2	480,384.72
Ocidental R1	462,413.48
Portimão	
Ocidental Morgado dos Reguengos/Monchique-Ginjeira	163,591.62
Ocidental Morgado dos Reguengos	94,661.30
Albufeira	
Oriental Cerro de Ouro	2,359,256.90
Monchique	
Ocidental Monchique-Ginjeira	2,110,868.39
Lagos	
Ocidental Final RXVI	141,774.14
Ocidental Final RVII	214,917.39
Loulé	
Oriental Quintinhas	56,656.91
Tavira	
Nascente Cumeada	40,128.17
Nascente Santa Margarida	48,846.75
Total	**8,920,573.22**

Table A3-6. New network cost estimation for the system enhancement (reservoirs)

Cost Component	Cost (€)
Aljezur	
R3	6,679.00
R2	6,451.00
R1	37,768.00
Portimão	
Morgado dos Reguengos	5,444.00
Albufeira	
Cerro de Ouro	354,525.00
Monchique	
Monchique-Ginjeira	11,273.00
Loulé	
Oriental Quintinhas	7,977
Tavira	
Cumeada	134,611.00
Total	564,728.00

Table A3-7. Construction years for network unifications

Municipality	Reservoir	Settlement	Year
Aljezur	R1	Aljezur (sistema norte)	2006
	R2	Vale da Telha/Arrifana	2006
		Monte Clérigo/Espartal	
	R3	Bordeira	2006
		Carrapateira	
Monchique	Monchique-Ginjeira	Monchique	2007
		Caldas de Monchique	
Albufeira	Cerro de Ouro	Albufeira	2006
Portimão	Morgado dos Reguengos	Portimão	2006
Lagos	RVII	Lagos/Luz	2006
	RXVI		
	Sargaçal		
Loulé	Quintinhas	Vilamoura	2006
Tavira	Cumeada	Conceição	2006
	Santa Margarida	St.º Estevão	2006

Desalination parameters

Table A3-8. Capacity and construction cost for the all scenarios

	Type	Capacity (m3/day)	Capital cost (€)	O&M costs (€/m^3)
Aljezur	Seawater	6000	4 595 005	0.55
Quinta do Lago	Brackish water	11500	5 413 165	0.37

Reduction of network losses

Table A3-9. Scheduling of network replacements

Municipalities	Current Losses (%)	Reductions %			Losses in 2020 (%)
		2010	2015	2020	
Aljezur	30	5	5	5	15
Almodôvar	30	5	5	5	15
Castro Marim	30	5	5	5	15
Faro	30	5	5	5	15
Lagoa	30	5	5	5	15
Loulé	32	5	5	5	15
Monchique	30	5	5	5	15
Odemira	30	5	5	5	15
Portimão	30	5	5	5	15
Tavira	30	5	5	5	15
Vila Real St.º António	28	5	5	5	15
Lagos	60	5	5	5	45
Olhão	61	5	5	5	45
S. Brás de Alportel	56	5	5	5	45
Silves	59	5	5	5	45
Albufeira	16	5	5	5	1
Vila do Bispo	43	5	5	5	28

Table A3-10. Yield and construction costs for water re-use

Golf course	WWTP	Demand (2006) (10^3 m3)	Tertiary treatment capital cost (10^3 €)
Balaia Village	Vale Faro – Zona Nascente	294	60.3
Herdade dos Salgados	Galé	458	93.9
Pine Cliffs	Pinhal do Concelho	150	30.7
Vilamoura Millennium	Vilamoura	406	83.2
Vilamoura – Laguna Course	Vilamoura	406	83.2
Vale do Lobo – Ocean Golf Course	Vale do Lobo	353	72.4

Groundwater

Considering the difficulties in getting data for the aquifers in the Ribeiras do Algarve River Basin due to lack of research in this area, a criterion has been developed in order to estimate the Yield Factor and NonSustainable Groundwater Production Fraction of each aquifer. Firstly, the capacity of each aquifer was calculated, based on its area, saturated area and storage coefficient. All these parameters have already been defined in River Basin Plan.

Capacity of aquifer (m^3) = Area (m^2) x Saturated Height (m) x Storage Coefficient

Following that, the Yield Factor was defined as:

Yield Factor= Available volume / Groundwater availability volume

with

Available Volume = Water Available (m^3/year/km^2) x area (km^2)

The "available volume" is the groundwater volume that is available for abstraction, being smaller than the volume stored in aquifers. Furthermore it is necessary to preserve the aquifers sustainability assuring that the necessary quantity for its protection is maintained.

It was assumed that the Yield Factor was equal to 1 (100%), allowing the total aquifers storage volume to be abstracted. The aquifers sustainability is therefore preserved by setting a fraction of recharge that limits the volume that can be abstracted.

In this way, the Sustainable Factor was defined as:

Sustainable Factor = DHS / Recharge (per aquifer per year)

The DHS, is the groundwater sustainable volume as defined by the Water National Plan, i.e, the groundwater volume associated to the recharge, which is available in the aquifer. However improvements in the determination methodology of this parameter are being made.