Guidelines for Integrated Water Management

Regional Experiences and Management Methods Applicable to Water Stressed Regions

Preface

The present document provides Guidelines for Water Management methods and options examined in the process of development of suitable water management strategies for water deficient regions. These guidelines have been developed within the framework of the WaterStrategyMan Project (*Developing Strategies for Regulating and Managing Water Resources and Demand in Water Deficient Regions*, Contract no. EVK1-CT-2001-00098) , a project supported by the European Commission under the Fifth Framework Programme, contributing to the implementation of the Key Action *Sustainable Management and Quality of Water within the Energy, Environment and Sustainable Development*.

The purpose of the document was to develop Strategy Guidelines, a set of instructions that analyze a given strategy into actions required within the selected water management options, set within a suitable but flexible time framework. The document aims at enabling the dissemination of the Project results, by providing a step-by-step analysis of the specific options to be used within the framework of a strategy and their specifications (relative costs, duration, and project lifetime). Case Study regional experiences in the application of these options have been included, in order to provide input based on hands-on experience.

The document is structured in 11 chapters. The first (introductory) chapter provides a summary of the work undertaken for the WaterStrategyMan project, setting the methodological framework for the analysis of management options presented in the subsequent chapters.

Chapters 2 to 9 each reflect a major management option or method that is used in the Strategies developed for the Case Studies. These are:

- *Desalination*, which is an option widely used in regions facing severe scarcity,
- *Recycling and reuse,* concerning the use of treated and untreated wastewaters,
- *Groundwater Exploitation*, including the drilling of boreholes as well as the use of groundwater enhancement methods that enable the sustainable exploitation of both surface and groundwater.
- *Storage Reservoirs and Dams*, constructed for water storage and aquifer enhancement,
- *Conservation measures in domestic use*, including the use of cisterns, low-flow devices, as well as behavioural modifications for the reduction of water waste,
- *Irrigation Method Improvements and Crop changes*, including shifts of irrigation practices and methods, as well as crop substitution and rotation,
- *Network improvements and enhancements*, including new connections for improving efficiency as well as replacements of old components to reduce losses, and
- *Pricing*, used as a tool and/or incentive for demand management in the domestic and agricultural sectors.

Each chapter includes a brief literature presentation of each of the selected options and an empirical part based on the WaterStrategyMan Project Partners’ experiences, gathered through the Case Studies undertaken.

Chapter 10, *Discussion*, includes combined analysis of the Case Study experiences and interpretation of the options application outcomes in the selected study areas. In this respect, the discussion chapter is aimed at forming suggestions on preferable options for each area of question or for areas with similarities to those selected for the Case Studies in relation to their specific characteristics and water availability issues.

Finally, Chapter 11 provides an overview of the literature information on each option, which includes general information on the overall description of the methods applied, experiences from option implementation, relative costs and lifetime, and advantages and disadvantages of the option with respect to applicability, efficiency, costs and impacts. Information is provided in the form of comprehensive tables, and wherever applicable, the overviews were extended to include further information on specific technologies, their maturity and constraints and research and technology advances. The content falling under these headings is adapted in each table to suit the most appropriate presentation of the examined option.

The WaterStrategyMan Project partners have all been actively and directly involved in the development of the Guidelines for Integrated Water Resources Management: the National Technical University of Athens, the Ruhr-University Bochum, ProGEA S.r.l., the Office International de l'Eau, the Hebrew University of Jerusalem, the Water Development Department (Governmental Department – Cyprus), INSULA (International Scientific Council for Island Development), Aeoliki Ltd, and the Faculdade de Engenharia da Universidade do Porto. They are all gratefully acknowledged.

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Chapter 1 Methodological Framework

Integrated water management is often seen as a potential answer to the water availability problems in areas facing serious water shortage, either periodically or throughout the year. Apart from being a major issue in the Mediterranean region, water shortage also has a social dimension, as it is can be associated with the socially disadvantaged areas which lack infrastructure.

This document examines the applicability of different technological water management options under different geological, climatic and socio-economic conditions, and provides an outline of the existing water management issues in selected Case Study areas. The document is additionally aimed at informing policy makers on the practicality of the different water management options and can be used as guidance for strategic planning dealing with water availability issues. It can also set the basis for future research on water management issues in regions facing similar problems and make suggestions on the most appropriate approach and the implications this may have on the individuals and the groups affected.

Methodological approach to regional experiences

The main objective of the WaterStrategyMan Project was the formulation of suitable, integrated strategies for regulating and managing water resources and demand in water deficient regions. To that end, one of the objectives of the work undertaken was the definition of the extent of the applicability, both in terms of effect and cost, of different management options under a variety of water availability and demand conditions. This, combined with the actual experiences on the applicability of management methods to the Case Studies of the project, aimed to provide a a stepping stone in the process of Strategy formulation appropriate for the identified water management paradigms.

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 to follow the currently observed and forecasted trends. 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”.

For the purposes of the Case Studies, the scenarios were evaluated for a long time horizon, from 20 to 30 years, using the GIS-based Decision Support System (WSM DSS) that has been developed in the Project.

The present document analyses the outcomes of this analysis for the Case Study Regions of the project, briefly analysed in this chapter. Regional experiences are presented both from the actual application of different management methods, as well as from the scenario analysis, as defined above. For each option, the concluding remarks on impact – social, environmental and economic – as well as costs, defining its cost effectiveness, are outlined. The overall aim is to provide insight to problems that frequently arise in the application of different management methods under different regional and water management conditions.

Description of the WSM Case Studies

Out of a total of 15 regions originally analysed in terms of water management practices in six countries (Cyprus, Greece, Israel, Italy, Portugal, and Spain), six Case Studies, one for each country, were selected. The basic criteria for the selection of the specific Case Study regions were:

- The existence of Natural Aridity in the areas,
- The existence of Water Shortages on a permanent or seasonal basis due to natural or anthropogenic reasons, or the recurrence of drought and/or flood cycles,
- The insufficiency of water resources management efforts in the areas,
- The lack of proper administrative or institutional framework for the effective water resources management,
- The existence of socioeconomic conditions affecting the management of water resources.

The six Case Studies that have been selected for the evaluation of the integrated water resources management strategies under development are described below.

1) Paros Island in the Cyclades complex, Greece. The period of peak water demand, and respectively the major water stress season in Paros, occurs during the summer months due to the high tourist influx onto the island. During that period the existing infrastructure capacity is stretched, and is often insufficient to cover demand at peak times, resultint in temporary shortages, which in return affect tourism.

- **Typology:** Predominantly tourist (Type II), insular.
- **Dominant water management 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 region, 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 water management 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 incorporates 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. Consequently, new interventions are needed to satisfy the local irrigation demands.

- **Typology:** Predominantly agricultural (Type III).

- **Dominant water management 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 and the Arava region, Israel. There are conflicts arising between the provision of water for urban water supply and that 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 of Tel-Aviv is characterized by relatively high domestic and industrial consumption, and relatively low agricultural consumption, whereas Arava is sparsely populated, except for the tourist city of Eilat at the southern tip, but its domestic per capita consumption region is particularly high due to the dry climate and the high garden irrigation demands.

- **Typology:** Tel-Aviv - Predominantly urban (Type I), Arava - Predominantly agricultural (Type III).
- **Dominant water management Paradigm:** The water used for the two regions originates 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 Arava region receives water from local sources only. The Dominant Paradigm in the two regions 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 water management 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 existing 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, constituting research on alternative means of supply both necessary and urgent.

- **Typology:** Predominantly tourist (Type II), regional.
- **Dominant water management 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.

Management Options and Methods

A variety of options and methods have thus far been integrated in the water management system of the Case Study regions, and in arid and semi-arid areas facing similar problems. Options and methods that represent the core of options and instruments analysed in the present document are outlined in Table 1, and are generally grouped under four major 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, economic incentives etc.

Table 1 Management options examined in the course of Case Study analyses

Management option	Description
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.
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.
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.
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.
Pricing	Control of the elastic water demand through the application of varying pricing levels.
Environmental Policies	Penalties and fines, Impact and risk assessment.

Chapter 2 Desalination

Overview

Desalination is a treatment process that removes salts from water. Saline solutions, other than sea water, are typically described as brackish water with a salt concentration between 1,000 ppm and 11,000 ppm TDS. Normal sea water has a salinity of 35,000 ppm TDS or more.

Desalination can provide:

- New primary water sources,
- Water "insurance",
- Drought proofing,
- Water independence,
- A means to resolve conflicting urban/agricultural needs.

A typical desalination plant consists of a water pre-treatment system, the desalination unit, and a post-treatment system.

Several desalination processes have been developed but not all of them are reliable and in commercial use. The most important processes are divided into two main categories: phase-change (such as distillation processes), and single-phase processes (membrane processes). The quality of the produced water and the consumed energy are the two most critical parameters of the desalination processes.

Desalination is an energy intensive technology. The energy input to the plant may be thermal, (defined in terms of water produced per unit of steam or per 2,500 kJ used) mechanical or electricity (expressed in kWh/m^3 produced).

Seven basic techniques can be used to remove salt and other dissolved solids from water: Multiple-Effect Distillation-MED; Multi-Stage Flash Distillation-MSF; Solar Distillation, Reverse Osmosis (RO), Electrodialysis (ED), Ion Exchange (IX), and Freeze desalination. Distillation processes (MED, MSF and Solar) and Freezing involve removing pure water, in the form of water vapour or ice, from salty brine. RO and ED use membranes to separate dissolved salts and minerals from water. IX involves an exchange of dissolved mineral ions in the water for other, more desirable dissolved ions as the water passes through chemical resins.

In addition to removing salts and other dissolved solids from water, some of these desalination techniques also remove suspended material, organic matter, bacteria and viruses. These techniques were originally developed for treating large quantities of water at a central location, but some of them, especially RO., have also been adapted for small scale use in houses (U.S. Congress, 1988).

The selection of the appropriate technique is based on several parameters, such as site conditions, local circumstances, energy availability, product quality, product quantity adequate to cover the needs of the area, and cost efficiency (CRES, 1998a).

Further information on desalination and desalination technologies is provided in the respective sections of Chapter 11.

Regional Experiences from Paros Island, Greece

Experiences from current practices

Desalination is a water supply enhancement option of increasing popularity in the Greek islands. During the last few years a considerable number of desalination units have been constructed for supplying water to popular tourist destinations.

A small brackish desalination plant already exists in Paros, supplying only the settlement of Naoussa. The unit desalinates the brackish water of the Naoussa spring (stable water supply of approximately 2,000 m^3/d) and can produce up to 1,450 m^3/d of potable water. During low consumption periods (winter and autumn months), surplus water is mixed with the brackish water pumped from the Naoussa aquifer and is provided to the local farmers for irrigation.

Since the full operation of the unit started in 2002, domestic water deficits in the traditional settlement of Naoussa have been considerably alleviated, and the quality of water supplied to the tourist sector has substantially improved. In view of these results, the Municipal Office for Water Supply is considering the construction of other units in the tourist areas of the island. The fact that during the off-peak season a small amount of water is supplied to irrigation had a significant effect in the resolution of social conflicts between the farmers of the area and the hotel owners. The majority of local stakeholders are favourable towards the construction of additional plants to supply tourist areas.

The operation of the unit has had a considerable effect on the water balance of the Naoussa-Ksiropotamos aquifer, which faces a serious overabstraction problem and in fact has been, due to the previous exploitation patterns, sea-intruded.

The construction of the desalination plant was financed by the Ministry of Development and its operation falls under the authority of the Municipality of Paros. In 2002 the construction cost of the unit was equal to 440,000 €. Data for the operating, maintenance and energy costs of the plant are not available by the local authorities, but are expected to be typical of brackish water desalination plants.

Experiences from the scenario analysis

The option that was examined was the construction of four additional desalination units, mainly aimed to supply tourist areas. The total required capacity can range from 2,750 m^3/d in 2005 to 4,000 m^3/d in 2021.

Desalination is the structural solution that performs the best among all those that have been examined. Units were designed to meet 95% of the observed domestic deficits, under all availability conditions. Under this assumption, the evaluation of the option depicted that at throughout the examined horizon (period 2005-2030) the improvement of domestic demand coverage can even reach 85% with respect to the BAU (Business as usual) scenario. The lower dependence of domestic use to groundwater resources results in higher volumes of water available for irrigation, thus improving irrigation demand coverage up to 25%.

For Paros island, the main component of environmental cost is related to groundwater depletion due to overabstraction for meeting irrigation and domestic needs. With the application of extensive desalination schemes, the dependence of domestic use from groundwater resources is significantly lowered. However the overall performance concerning groundwater exploitation shows minor improvements, ranging from 7 to 10%. This is attributed to the fact that no additional regulatory measures are imposed to irrigation, which still solely relies on groundwater resources.

Despite the observed improvement and in spite of recent technological advances, which lower the energy cost, desalination remains a very expensive solution. A 30% increase of costs (expressed in present value terms) is anticipated if a water management strategy predominantly relies on desalination. A combination of this option with others, mostly non-structural solutions should be therefore preferred in an effort to limit the required capacity, and avoid incurring very high additional costs to consumers.

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

The semi-arid climate and the already intensively utilized water resources cause water scarcity problems due to structural and temporary water shortages. The high level of utilization of the natural water resources and the continuing increase of water demand coupled with the decrease of water availability due to repeated droughts, led the Government of Cyprus to the decision of introducing sea water desalination for meeting a major part of the domestic supply. It should be noted that for the ten years prior to the winter of 2003 – 04, the available water from the Government projects and from other sources was very limited which led to supply cuts up to 30% of normal demand in the domestic sector and up to 70% of the normal demand in the agricultural sector. These had serious adverse effects on the social and economic activities and a negative impact on the environment.

Currently in Cyprus, two desalination plants are in operation: the Dhekelia Desalination Plant, since 1997, east of Larnaka, and the Larnaka Desalination Plant, since 2001, west of Larnaka, near the airport, both on the southern shore of the island, near the Dhekelia Power Station, from which they draw their power. These plants have a nominal capacity of 40,000 and 51,667 m^3/d respectively.

Both plants use the reverse osmosis process with a recovery of 50%. Energy is supplied from the electric grid, while energy recovery turbines operate on the outlet. Both plants are supplied through an open sea intake and water is undergoing a pretreatment for reducing the Silt Density Index and the pH for the protection of the membranes. The desalinated water is post-treated for achieving an acceptable quality complying with the Cyprus and European drinking water quality standards.

Brine is discharged to the sea at a depth of at least 15m and at a distance of at least 1 km from the shore. The sea environment around the brine disposal point is monitored on a continuous basis and the results so far are within acceptable levels. In all cases environmental impact assessment studies were carried out before construction and mitigation measures were imposed on the contractors for minimizing adverse environmental effects.

Seawater desalination comes at a high price, one that is above the cost of simply supplying the water. Desalination consumes vast quantities of power that are produced by the thermal power plants of Cyprus. There are considerable negative environmental externalities imposed by these plants, and in general, these externalities are not internalized in prices charged to the water user. In the case of desalination in Cyprus, there are no extra costs imposed to include these externalities, which are mostly in the form of air pollution such as carbon dioxide emmissions etc.

With sea water desalination a steady supply of good quality water has been secured for the urban areas and the major economy sector of tourism. Thus domestic supply has been freed from the uncertainty of weather conditions. Desalination is one of Cyprus last resorts in terms of water resources, and creates, in theory, an unlimited supply. However there are also certain risks other than just the environmental ones in this type of water supply. Since all electricity on the island is generated by fossil fuels, water prices and drinking water availability are influenced from fossil fuel prices, which in turn define the energy costs for desalination.

The exceptionally wet winter of 2003 – 2004 after a ten year sequence of dry years has filled all the reservoirs in the island. Therefore, theoretically there is no present need for continuing the desalination, and protests have been raised to that effect. Nevertheless, this is one of the inherent disadvantages of the BOOT type system that was used for desalination financing. Desalination supply continues at a reduced rate, in accordance to the original agreement.

As stated above, both existing plants were commissioned on the basis of a BOOT (Build-Own-Operate-Transfer) contract, with the units being transferred at the Government at the 10th year of their operation.

The Dhekelia Plant is contracted to supply water at a cost of 0.55 CY£/m^3, and the new plant in Larnaka supplies water at a cost of 0.42 CY£/m^3.

In 2001 to 2002 plans were under way for a third plant in the Limassol area of a capacity between 20,000 and 40,000 m^3/d, which was expected to start operation by 2004. Surplus water that would arise from the operation of this plant would have allowed a better coverage of the agricultural demand and would have also allowed the built up of strategic reserves in groundwater aquifers, which are at a very low level. Similarly, the new plant was to be built under a BOOT contract. Options were given for any process or a combination of known processes with incentives for low energy consumption and especially for exploitation of renewable energy sources. However, these plans, are at present of reduced priority, as a result of the very wet season of 2003-2004 and their implementation is unlikely for the immediate future.

Since at present the construction of additional desalination plants is not in the immediate plans of the Government, the desalination option was not tried out.

Regional Experiences from Belice Basin, Italy

Experiences from current practices

Desalination is not practiced in the territory of the Garcia-Arancio irrigated districts, although their geographic location, extending along the South coast of Sicily, would permit seawater exploitation. Unlike neighbouring districts, which are using desalination for domestic supply, in order to compensate for the inadequate spring groundwater extraction, the analysed districts can rely on the available surface resources of the Belice Basin, and in particular on the Garcia Lake. At the time being, water management plans do not include desalination programs, at least in short-term planning.

Under this context, desalination was not examined for the irrigation territory of Garcia-Arancio.

Regional Experiences from Tel-Aviv and Arava regions, Israel

Experiences from current practices

Israel has access to limited quantities of relatively low quality water. Increases in population, industry and agricultural activities over the last three decades, coupled with a given water development policy, had led to gradual salinization, and consequent increasing scarcity of good quality (fresh) water. Attention in Israel is being increasingly focused on the development of so-called “marginal” resources, mainly sewage effluents, and on seawater desalination.

The approach that has guided the water supply sector for decades has been one of brinkmanship, including deferment of desalination to as late as possible. Indeed, **currently the commercial supply of desalinated water in Israel is marginal.** The largest (and almost single) seawater desalinated plant is operated (via reverse osmosis technology) in the city of Eilat, in the Arava region. Currently its capacity is about 6 hm^3/yr. The approach of brinkmanship is guided by short-term economic considerations, according to which maximum storage capacity must be ensured for potential large natural replenishment occurrences, in an effort to prevent overflows and discharge to the sea. This approach was recently abandoned by the Israeli Water Commission in favour of one that will prevent shortfalls in water supply in order to ensure stabilization of the country's water supply system in the future. Based on the recommendation of the Water Commission, in March 2002 the Government of Israel approved the construction of seawater desalination plants with a total capacity of 400 hm^3/yr (while an additional 50-100 hm^3/yr will be imported from Turkey). Of this amount, 90 hm^3/yr, are planned to be installed in the region of Tel Aviv. The plants will at best commence operation in the second half of 2005, and will be completed before 2010. This quantity of desalinated water is required to close the gap in the water balance that was created as a result of combination of factors:

1. Successive drought years,
2. Continued exploitation of natural water resources, causing their depletion,
3. Delay in introducing desalination,
4. Delay in adjusting institutions and water prices to the desalination era, and
5. Fulfillment of obligations for supplying water, as required by international agreements with Jordan and the Palestinian Authority.

The decision on the quantity to be desalinated was based on a comprehensive research of the Planning Division of the Water Commission and included prediction of agricultural, urban and industrial demands (a minimum amount of 530 hm^3/yr of fresh water should be conserved for agricultural use), various scenarios of natural water replenishments (based on historical data for the years 1932-1993), the probability for a series of dry years, and more. Desalination of 400 hm^3/yr before the end of the century, with subsequent development of 20 hm^3/yr, in accordance with the actual replenishment and the conditions of the reservoirs during the course of the current and next decades, are expected to increase the supply reliability of the national system to a maximum extent and ensure sustainability; even if it turns out that water utilization potential from natural resources has decreased to 90% of the historical amount and even if limited implementation capacity causes delays in development. If unusually rainy periods occur and/or water conservation efforts prove to be more successful than expected, it will be possible to reduce accordingly (or even cancel) the planned annual supplement (20 hm^3/yr).

The cost as per the latest tender for desalinated seawater is 0.53 US\$/m^3 at the gate of the plant. Connection to the national water system and transportation add 0.15 US\$/m^3, implying desalination costs of about 0.70 US\$/m^3.

The total planned investment in seawater desalination in the current decade (2000-2010) is about 1,147 million US$, 82% by the private sector and the remaining 18% by the national water company, Mekorot. The high share of planned investment in desalination from total planned investment in the Israeli water sector in the current decade, 25%, illustrates the crucial role that desalination will soon play in the water economy of Israel.

The forthcoming entry into the desalination era in Israel has a significant impact in several areas:

a. Water Transfer

Until now a significant amount of Israel's fresh water (about 350-400 hm^3/yr) was transferred from Lake Kinneret (Sea of Galilee) in the north to the center and to the south via the National Water Carrier (NWC). In the desalination era, a large amount of desalinated seawater will be transferred from the south-west (the Mediterranean) to the east and the center (including the region of Tel Aviv), where most of the urban population reside.

b. Water Supply Sources

Currently, total water supply in Israel is composed of about 75% natural fresh water (from all sources), 10% water from saline resources, and 15% recycled waste water. The amount of desalinated seawater is negligible. This mix will change significantly in the desalination era, with the rapid development of unconventional water resources – desalinated seawater and recycled effluents (see below). The planning department of the Water Commission predicts that the percentage of natural fresh water in 2010 will decline from 75% to about 60%, while the percentage of recycled effluents and of desalinated seawater will increase from its current levels of 15% and 0% to 20% and 19%, respectively.

c. Water Quality

Israel has experienced a long trend of increasing salinity in most of its natural water sources. This process is the result of several factors:

1. Reduction of natural drainage and natural salt leaching to the sea, due to the very intensive exploitation of Israel's water sources,
2. Intrusion of seawater in some locations along the coastal plain,
3. Transfer of chlorides with irrigation water from Lake Kinneret to the regions served by the NWC, and
4. Irrigation with treated wastewater which is more saline (by about 100 mg chlorides per litre) than fresh water.

Adding a large quantity of desalinated sea water, of very low salinity, to the water system, is expected to decelerate the salinization process significantly. Specifically, the long term over-pumping from the groundwater aquifer with its associated intrusion of seawater will stop, and the salinity of the recycled effluent "supplied" for irrigation by the urban and industrial sectors, the consumers of the desalinated seawater, will be reduced significantly.

d. Water Pricing and Water Institutions

The marginal value of water (MVW) to a user is the maximum utility (for urban consumers) or benefits (for agricultural producers) generated by the last water unit in use.

Water allocation that maximizes total benefits derived from a given amount of water supply must equate the marginal values of water across all users. Economists call such an allocation **efficient**. Some decision makers claim that in the desalination era, efficient allocation of water requires that the price of fresh water (from all sources) to all (urban, industrial and agricultural) users should be increased and equated to the marginal costs of desalinated water, which is about 0.60 €/m^3. At first glance, this claim makes economic sense, but this is not really so. Since the average cost per m^3 of fresh water (i.e., the total costs of producing and supply fresh water divided by the sum of fresh water from natural resources and of desalinated seawater) is much lower than the marginal cost of recycled water, the total revenues of the water suppliers (including the national water company Mekorot, which supplies about 60% of the total amount of fresh water) will exceed by far the total costs, i.e., the water suppliers will accumulate excessive financial surpluses.

In contrast to domestic and industrial demand, agricultural demand is quite sensitive to the price of water. It is quite probable that at a price of 0.60 €/m^3, agricultural demand for fresh water in Israel will be reduced significantly and farmers will stop cultivating a substantial portion of their previously irrigated land. In such a case there will be no need to desalinate seawater, and some economists claim that the desalination era can be postponed for more than 10 years.

Some of the planned desalination plants are expected to be operated by private companies. The new forthcoming partial privatization of water supply is a potential source of conflict between the government-owned company, Mekorot, and private entrepreneurs on two issues:

- The control of the supply of newly developed water resources (mostly desalinated sea water), and
- The responsibility for the operation of the intra-cities water systems (currently operated by the cities themselves).

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.

e. Water Reliability

As mentioned above, the approach that has guided the water supply sector for decades has been one of brinkmanship, including deferment of desalination to as late as possible.

The forthcoming massive supply of desalinated seawater is expected to increase the supply reliability of the national system to a maximum level and ensure sustainability; even if it turns out that water utilization potential from natural resources has decreased to 90 % of the historical amount and even if limited implementation capacity causes delays in development. The economic contribution of the increased reliability is important: long-run planning and operating of agricultural activities is very difficult and is sub-optimal under conditions of uncertain water supply.

Experiences from the scenario analysis

The option to increase the supply of fresh water for the region of Tel-Aviv via seawater desalination was examined under two reference, or business as usual (BAU), scenarios. The BAU scenarios represent the current demand and supply conditions under the two assumed water availability conditions:

- 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
- 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).

We assumed the establishment of one desalination plant, capable of desalinating 50 hm^3 of sea water annually, in the third year of the time horizon, and then the establishment of an identical desalination plant in the seventh year of the planning period. The plants are operated only in periods of freshwater shortage.

Under **normal weather conditions**, only one of the two desalination plants is operated to fully meet the deficit in the agricultural sector. Relative to the reference scenario BauN, the improvement in agricultural deficit after the fourth year of the time horizon is very significant and equal to 100% for all the remaining years of the planning period. Desalination also eliminates the environmental costs associated with the reduction in the area of cultivated agricultural land. The welfare indicator in our analysis is represented by the net present value of the Social Welfare Surplus associated with the regional water economy, and is denoted by NPV(SWS). We found that the value of NPV(SWS) associated with the desalination scenario is lower by about 28 million € than the one obtained under the reference, BauN, scenario. The reduction in Social Welfare Surplus is attributed to the utilization of costly desalinated water to overcome the water deficit in the agricultural sector. Thus, it can be concluded that under normal weather conditions, meeting all unmet demands via the establishment of desalination plants is socially undesirable in the region of Tel Aviv.

Under **the cyclical weather conditions**, both desalination plants are operated. The unmet demand under the reference scenario BauC is not limited to the agricultural sector and water deficits for all sectors are quite large during the dry periods. Desalination results in substantial reduction of deficits. However, 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. Almost all water cuts are imposed on the agricultural sector; nevertheless, the industrial and the domestic sectors suffered some minor water cuts as well. Desalination also results in a significant decrease in environmental costs associated with the reduction in the area of cultivated land. As for the welfare indicator, we found that the values of NPV(SWS) associated with the desalination scenario is lower by about 20 million € than the respective value under the reference, BauC, scenario. This implies that **the option to reduce water deficits via (expensive) desalination is socially undesirable in the region of Tel Aviv.**

Regional Experiences from Tenerife, Spain

Experiences from current practices

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 different commercial technologies have been implemented to desalinate both groundwater and seawater: Vapour Compression, Multi-Stage-Flash, Multi-Effect-Distillation, Electrodialysis Reversal process, and, finally, Reverse Osmosis (RO). The Eastern Islands of the archipelago have accumulated more experience because, due to their extreme aridity, their only means to face population and tourism growth was through seawater desalination. Large-scale desalination on Tenerife started later, since water shortage only appeared at the beginning of the 1990s, after the tourist boom in the southern, dry part of the island started at the end of the 1970s.

Nevertheless, the first units were constructed in 1976, and the volume of water treated has been increasing to reach 18 hm^3 at 2002[1], which is 9% of the total island water demand. Desalination has been practically the main response to water demand increase and aquifer overexploitation, as well as a means to resolve the problem of water quality decline in overexploited areas. The accumulated increase in desalinated water production has been 12%/year. Table 2 shows the main seawater desalination units operating at present.

All these are actually operational units (46,000 m^3/day capacity) among which the two bigger plants, built by public initiative, stand out with a capacity of 20,000 m^3/day: Santa Cruz (Metropolitan area) and Adeje-Arona (largest tourist area in the south of the island). In addition, the two main industryies of the island, the power station (UNELCO) and oil refinery (CEPSA) are completely autonomous with regard to water supply, increasing the availability

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[1] Data obtained from the Canary Islands Water Centre (Manuel Hernández Suárez, 2002).

of good quality water for domestic use. The table also includes the small desalinating plants of the hotel sector in the south of the island, which sum up 500 m^3/d as a whole. Finally there is a small production of 14 m^3/d at the ITER, which is the first experimental action non grid-connected plant that directly combines desalination and wind power. Direct energy supply from renewable sources in desalinated water production is targeted to reach 10% in the next years.

Table 2 Main Desalination Units (2002)

Construction Year	Name & Location	Capacity (m^3/day)	Desalination Process	Operator	Use
1986	Unelco, Caletillas	500	VC	Unelco	Industrial
1992	Unelco, Caletillas	600	VC	Unelco	Industrial
1994	COTESA, Santa Cruz	3,600	MED	COTESA	Domestic
1994	I.T.E.R. Cabildo, Granadilla	14	RO	Tedagua	Domestic
2002	Adeje-Arona	20,000	RO	Ionics	Domestic
2000	Unelco, Granadilla	500	VC	Unelco	Domestic
2001	Santa Cruz	20,000	RO	Cadagua-Pridesa	Domestic
	CEPSA, Santa Cruz	1,000	M.E.D.	CEPSA	Industrial
	21 Hoteles Los Cristianos Las Américas, Los Cristianos	500	RO	ND	Domestic

An increasing part of groundwater extracted in Tenerife has a quality lower than the one that can be accepted by most agricultural crops. The problem worsens if we consider that reclaimed urban wastewaters do not comply with water quality requirements for most cultivations. The Hydrological Plan of the island set up several measures to solve this problem of poor water quality, such as the construction of several brackish water desalination (Table 3), which can treat 64,000 m^3/day.

Table 3 Brackish water deslination units (2002)

Construction Year	Name & Location	Capacity (m^3/day)	Desalination Process	Operator	Use
1996	Aripe (Fase I), Guia de Isora	2,000	EDR	Ionics	Domestic
1997	Aripe (Fase II), Guia de Isora	2,000	EDR	Ionics	Domestic
1999	Aripe (Fase III), Guia de Isora	4,000	EDR	Ionics	Domestic
2000	Aripe (Fase IV), Guia de Isora	4,000	EDR	Ionics	Domestic
1994	Buenaventura Bencomo	420	OI	Tedagua	Irrigation
1996	Cdad. Bienes Ros Martin	950	OI	Tedagua	Irrigation
	Cooperativa La Monja	1,200		La Monja	Irrigation
1997	Costa Tejina, Tejina	1,400	EDR	Ionics	Irrigation
	Finca El Viento	2,200		El Viento	Irrigation

Construction Year	Name & Location	Capacity (m^3/day)	Desalination Process	Operator	Use
	Geranios Tenerife S.A.	420		Geranios de TF	
1995	Geranios Tenerife, S.A.	200	OI	Geranios de TF	Irrigation
1999	Hielos Nevada S.L., Santa Cruz	24	OI	Hielos Nevada S.L.	Domestic
1994	Icod I (Fase I), Icod de los Vinos	1,200	EDR	Ionics	Domestic
2001	Icod I (Fase II), Icod de los Vinos	2,100	EDR	Ionics	Domestic
2003	Icod II, Icod de los Vinos	4,000	EDR	Ionics	Domestic
1995	La Guancha (Fase I)	1,900	EDR	Ionics	Irrigation
2000	La Guancha (Fase II)	4,000	EDR	Ionics	Irrigation
	Manuel Pérez Yánez	3,500		Manuel Pérez	
1997	Pozos Costa Tejina, Guia de Isora	1,400	EDR	Ionics	Irrigation
1994	Pozos de Chío, Guia de Isora	2,100	EDR	Ionics	Irrigation
1994	Pozos de Chio, Guia de Isora	3,000	RO	Tedagua	Irrigation
1995	Promotora Punta Larga, Punta Larga	420	RO	Tedagua	Irrigation
1998	Promotora Punta Larga S.A. , Punta Larga	550	RO	Tedagua	Irrigation
	Regantes	275	RO	Regantes	Irrigation
2003	Tamaimo, Arona	2,100	RO	Ionics	Irrigation
2002	Terciario de Adeje - Arona	4,000	EDR	Ionics	Irrigation
2002	Terciario de Santa Cruz, Santa Cruz de Tenerife	2,200	EDR	Canaragua	Irrigation
1996	Valle de San Lorenzo Fase I), Parque La Reina, Arona	4,000	EDR	Ionics	Irrigation
1998	Valle de San Lorenzo (Fase III), Parque La Reina, Arona	4,000	EDR	Ionics	Irrigation
2002	Valle de San Lorenzo (Fase II), Parque La Reina, Arona	4,000	EDR	Ionics	Irrigation
	Vilbazo	360	RO	Vilbazo	Irrigation

Source: Canary Islands Water Centre

Finally, between 2003 and 2006 a number of new desalinating plants will start functioning, increasing total capacity of more than 30%. The listed units of Table 4 have been approved and/or are being built.

Table 4 Planned desalinating plants for domestic supply

NAME	Capacity (m^3/day)	Year
SANTA CRUZ (DAM0102) 2nd phase	20,000	2006
CEPSA (DAS0109) 2nd phase	3,800	2006
GRANADILLA (DAM0803) 2nd phase	5,000	2006
ICOD-III	4,000	2004

The main environmental impact of desalination units and desalinated water production is essentially due to the discharge to the sea of the large quantities of brine produced, in average 55% of seawater used. Reducing the quantity of brine discharged would reduce membrane lifetime, since they would be working in stricter conditions.

In spite of the beneficial conditions of the Canary Island coasts (small platform, acceptable depth at short distance from the coastline and plenty of undercurrents) it is doubtless that brine discharge affects an ensemble of habitats and situations, such as beds of marine phanerogams. For this reason, all operative units must comply with a number of criteria established by environmental authorities to regulate brine discharge outfalls. Most difficulties are related to the widespread smaller units that do not have infrastructural capacity to set up appropriate discharge pipelines.

Figure 1 and Figure 2 show brine discharge simulation, and its lower impact compared to other types of discharges, such as wastewater.

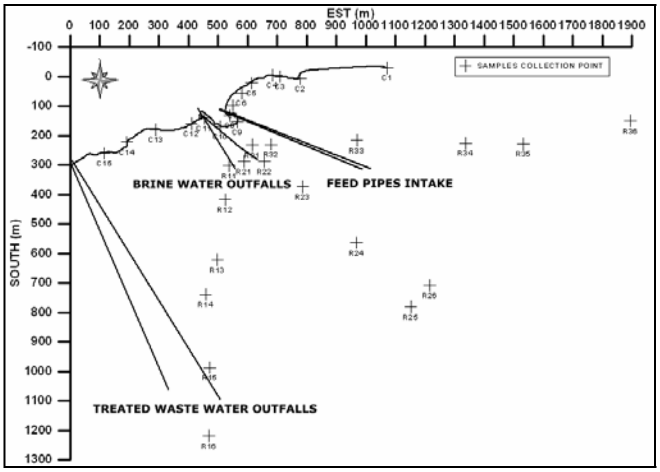

Figure 1 Sampling around the brine outfall (Perez-Talavera and Quesada-Ruiz, 2001)

In addition to the increased salinity effects, other side effects such as turbidity, extremely important in area of high biological productivity, have to be considered, obliging to lead pipe outfalls at a distance from the coast (Figure 3).

Same considerations apply to groundwater desalination units that also discharge to the sea but with lower salt concentrations.

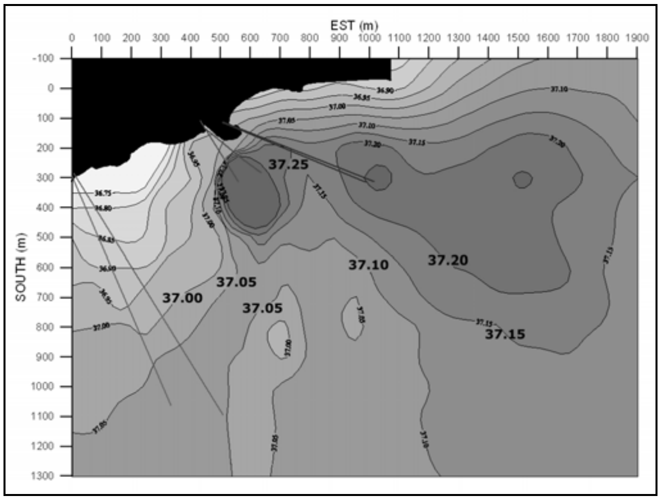

Figure 2 Salinity around the brine outfall (Perez-Talavera and Quesada-Ruiz, 2001)

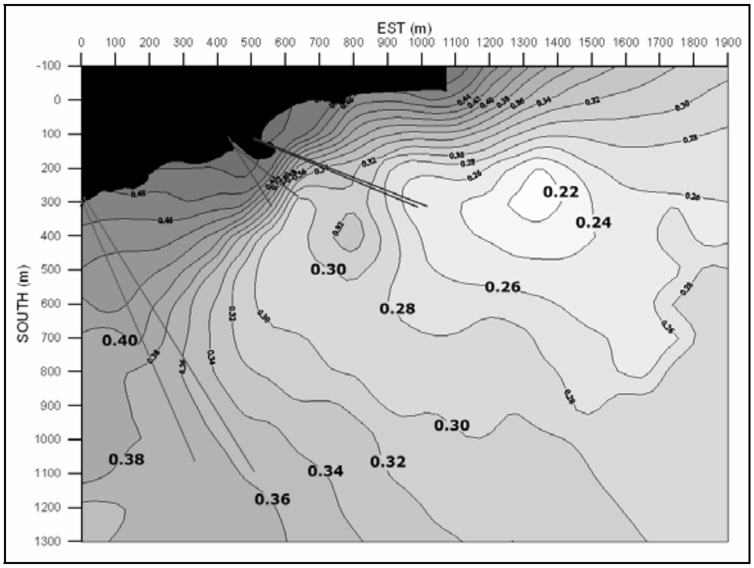

Figure 3 Turbidity around the brine outfall (Perez-Talavera and Quesada-Ruiz, 2001)

Other important impacts to be considered in desalinated water production lie in the increase in electricity consumption and in the industrial occupation of lands in coastal areas. With regard to the first one, extreme island dependence on fossil fuels multiplies the impact through new demands to increase energy potency and infrastructures. The Tenerife strategy is to increase the share of renewable energies (mainly wind power) to respond to these new demands until maximum penetration to the grid is achieved, taking into account that desalination works as a vector of energy storage for renewable energy sources.

Application of energy saving methods to new units, added to the increasing RO efficiency, lead to a big reduction of prices, making desalinated water competitive even for agricultural uses. Application of these energy saving methods and other ones (reverse osmosis with energy recovery devices, two step 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 reality, automatic devices also achieved a notable reduction of operational and maintenance costs, achieving water production prices of **0.56 €/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 5 Desalination costs in medium and large plants on Tenerife

Cost component	Cost (€/m^3)
Water pumping to plant (50m)	0.026
Energy 3.1 Kwh/m3	0.225
Pre-treatment (sodium bisulphite, anti-incrustation)	0.006
Post-treatment	0.008
Personnel	0.066
Membrane replacement	0.006
Filter replacement	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**

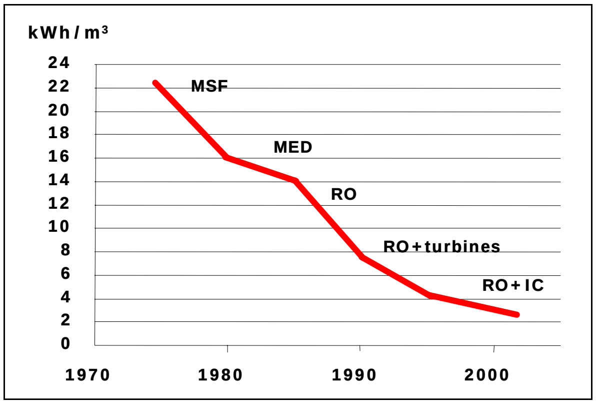

Figure 4 Evolution of energy consumption per m^3 of desalinated seawater.

Experiences from the scenario analysis

The increase in desalination in the scenario analysis involves doubling present-day desalinating capacity, with an increase rate similar to the one produced in the last years (18 hm^3/year). Approved enlargements involve an increase of 10.9 hm^3 in 2006-2007, assuming full working performance of the installed capacity. The remainder (7 hm^3/year) will be progressibely implemented until 2015.

Growths considered by scenarios are basically related to the increase in seawater desalination, since brackish groundwater exploitation has reached its maximum and is a conjunctural and not long term solution.

Desalination is the structural solution that performs the best among all those that have been examined. It is a complementary solution to meet the increasing domestic deficit, although it displays different behaviours under different scenarios. Under a business-as-usual scenario, the maximum foreseen increase in desalination would only cover the deficit, but is not enough to substantially improve aquifer overexploitation. This situation changes under a demand stabilisation scenario, which shows an improvement in the groundwater exploitation rate, the main environmental impact of water management on the island.

Increasing desalination as a unique solution to cover deficit has an evident risk in the scenario that tends to low consumption. This case, leading to a stabilised demand that starts to decrease to reach previous years' levels, could result in oversized desalination and energy infrastructures.

In large desalination units, which basically support the productions set in the scenarios examined, advanced RO installation costs are decreasing, by estimation, in a first stage, until reaching 510 €/m^3 of installed desalination capacity. That involves a total investment of 15 M€ until 2007 and 23 M€ until 2015.

Reduction of installed capacity costs, jointly with new energy efficiency improvements and low maintenance costs derived from the scale of installations, would allow reducing the cost of produced desalinated water up to **0.4 €/m^3** (at present the cost equals 0.56 €/m^3), taking into account all variables. Under these conditions, the achieved unit cost would be more competitive than that of water pumped from the deepest wells, and that of water transferred from distant areas, as practiced at present.

Regional Experiences from Ribeiras do Algarve, Portugal

Experiences from current practices

Golf courses in the Algarve region make an important contribution to the development of tourism, having generated 350 million € in 2002, which corresponds to approximately 11% of the revenues from tourism.

Most of them are located in a coastal zone classified by the Commission of Coordination and Regional Development (CCDR Algarve) as a **"critical area"**, where aquifers are subjected to overexploitation and salinisation and therefore no extra borehole construction is allowed except for domestic use. In that critical area, many new boreholes, mainly for new golf courses, are subjected to licensing restrictions, to protect the quality of aquifers.

The construction of desalination units is not very common in this region. Nevertheless, there is already a case of a desalination unit treating groundwater for irrigation purposes for golf courses: in Ferragudo Albufeira aquifer, supplying the Vale do Milho (Lagoa) golf course. This unit was installed in 2004 and has a treatment capacity of 115 m^3/d.

No data have been made available on impacts and costs.

Experiences from the scenario analysis

The construction of new desalination plants will allow the implementation of new golf courses. The option that was examined was the construction of two desalination units: one unit is implemented in the Aljezur Municipality, processing seawater, and producing 0.45 hm^3 in 2006, 0.55 hm^3 in 2020 and 0.71 hm^3 in 2035 (maximum 6,000 m^3/day).

The other unit is located in the Quinta do Lago settlement, preventing further water quality degradation of the Campina de Faro aquifer; the area is already presenting high concentrations of nitrates, sulphates and chlorides. The water treated in this unit will be used for the irrigation of the following golf courses: Quinta do Lago - São Lourenzo, Quinta do Lago, Quinta do Lago - Ria Formosa (the latter currently deficiently supplied by a wastewater treatment plant) and Quinta do Lago - Pinheiros Altos. Its capacity is estimated to be 11500m^3/day in 2006 in order to satisfy the increase in golf courses irrigation demand (1.6 hm^3 in 2000).

This option is aimed at improving groundwater quality supply in the Aljezur Municipality and eliminating the current golf course unmet demand in the Quinta do Lago settlement. The construction of a desalination unit enables a decrease of 0.22 hm^3 (11%) at the overall irrigation unmet demand at Ribeiras do Algarve River Basin. The problem of the water deficit that existed in Quinta do Lago - Ria Formosa Course, which was supplied inefficiently by a wastewater treatment plant, could be solved.

The total capital cost of the Aljezur desalination unit is 4.595.005 €, including maintenance and operation costs of 0.55 €/m^3. The other desalination unit (Quinta do Lago) has a total capital cost of 5.413.165 € and specific maintenance and operation costs of 0.37 €/m^3.

The construction of the two desalination plants, one to supply the Aljezur Municipality settlements and the other to supply golf courses in Quinta do Lago, only represent a 1.5% increase of costs (in terms of present value). Nevertheless, focusing only in the Aljezur Municipality and the golf courses supplied by the desalination units, there is a 250 % increase in the direct costs (in terms of present value) relatively to the worst-case scenario. In fact, the construction of desalination plants are localized measures and the overall increase of direct costs when considering the whole basin is small.

Chapter 3 Recycling and reuse

Overview

The broad category of recycling and reuse includes several methods and practices for reusing water that has already been allocated to and utilised by a previous use. Recycling implies the use of wastewater, with minor (such as cooling) or no treatment, usually for industrial or domestic purposes. In the domestic sector, water recycling includes the use of wastewater, instead of clean water, for activities such as flushing toilets, washing the car, and even watering household gardens and plants. Reuse on the other hand tends to entail a certain level of treatment of wastewater, which is then used in irrigation, mostly of green areas, non-food crops or orchards, or industrial processes.

Advanced wastewater treatment processes aimed at producing water for domestic and industrial reuse include practices such as:

- **Nitrification**. It is the term used to describe any wastewater treatment process, which biologically converts ammonia nitrogen sequentially to nitrite nitrogen and nitrate nitrogen. Nitrification does not remove significant amounts of nitrogen from the effluent; it only converts it to another chemical form.
- **Denitrification**. It completely removes total nitrogen. As with ammonia removal, denitrification is usually best done biologically, in which case it must be preceded by nitrification.
- **Phosphorus Removal**. Phosphorus can be removed from wastewater by either chemical or biological methods, or a combination of the two. The choice of methods will depend on site specific conditions, including the amount of phosphorus to be removed and the addition of iron, aluminium or calcium salts.
- **Coagulation – Sedimentation**. Chemical coagulation with lime, alum, or ferric chloride followed by sedimentation removes Suspended Solids, heavy metals, trace substances, phosphorus, and reduces turbidity.
- **Carbon Adsorption**. One of the most effective advanced wastewater treatment processes for removing biodegradable and refractory organic constituents is granular activated carbon. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption can reduce levels of synthetic organic chemicals in secondary effluent by 75 to 85 %.
- **Other Processes**. Other advanced wastewater treatment processes of constituent removal include ammonia stripping, breakpoint chlorination for ammonia removal, selective ion-exchange for nitrogen removal, and reverse osmosis for Total Dissolved Solids reduction and removal of inorganic and organic constituents.

Regional Experiences from Paros Island, Greece

Experiences from current practices

Water recycling and reuse is still very limited in Greece. Especially in some Aegean islands, where there are problems with the successful construction and operation of wastewater treatment plants, there is little consideration for the use of treated effluents for crop or landscape irrigation. For Paros, water reuse has been proposed in 1996 for the irrigation of a small landscaped area at the northeastern part of the island, near a medium-sized wastewater treatment plant. The total construction cost for the irrigation network has been estimated at 180,000 €. However, problems associated with the operation of the wastewater treatment plant have inhibited the realisation of the project.

The option of water recycling and reuse **was not examined** for Paros, due to:

- The **strong social opposition** that the application of the option would face. Water reuse is not widespread in Greece and both farmers and consumers are very reluctant towards the irrigation of crops and landscape with treated effluents.
- The **costs** associated with the implementation of the option. All wastewater treatment plants are located far from irrigated areas, and network construction costs are expected to be prohibitive. However, with the aforementioned exception, no studies have been conducted.

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

In the large urban areas a long term plan has been established to proceed with central sewerage schemes and treatment plants. The Nicosia Scheme is in operation since 1980 with its treated wastewater being discharged in the Pedhieos River, which is dry most of the year. The Limassol – Amathus, the Larnaca and the Paphos Schemes have recently been put into operation. A number of smaller centralised schemes are also in operation as well as those at the tourist resorts of Agia Napa and Paralimni. Due to the rapid development observed in Cyprus in recent years, the need for the implementation of central sewerage schemes and the need to treat and re-use the effluent on land in order to prevent the pollution of bathing waters and aquifers and to protect the environment generally have become even more acute.

At present there are 24 wastewater collection and wastewater treatment plants with a total capacity amounting to 20 hm^3/yr, with an average annual production of treated effluents of 11 hm^3.

The treated effluent is either diverted to the riverbeds (in 2 cases) or used for landscaping (in 5 cases), and the remainder is used or intended to be used for irrigation. The treatment is at secondary level in 6 cases, and at tertiary level for the remaining cases. In total, the existing plants are destined to deliver 10 hm^3 for irrigation, 4 hm^3 for landscaping and 4 hm^3 for riverbed recharge. The expected reuse within the next ten years is expected to increase to 40 hm^3or 20% of the water demand for irrigated agriculture.

Policies are needed to strengthen the role of treated effluent reuse in enhancing the urban and rural environment (green areas, parks, forestation), in backing up agricultural water needs and in recharging groundwater reserves. Policies should probably discourage the use of recycled water for expanding an already subsidized agriculture.

Impacts of water recycling are positive, since an increase of water availability at high reliability is achieved. At the same time, the environmentally sensitive area of bathing waters in important tourist areas are protected from pollution. Water saved from conventional sources that was used for irrigation and replaced by tertiary treated effluent is diverted for domestic purposes.

Within the case study area of Limassol, the annual production of the Limassol – Amathous Sewage Treatment Plant is about 3.5 hm^3. About 1 hm^3 is used in the eastern parts of the region at Moni, Pyrgos Pareklisha, Agios Georgios and Mari areas. This quantity is used for the irrigation of olives, deciduous trees and some vegetables. However the largest quantity is used for the Vasilikos cement factory.

About 2 hm^3 are diverted to the Polemidhia dam and part in the Ypsonas reservoir, and is used for the irrigation of table grapes and citrus trees in the Akrotiri area. A small quantity is being used for landscape irrigation at major hotels in the area.

Sewage collection, secondary treatment and tertiary treatment for reuse purposes require high capital investments, as well as high costs for operation and maintenance of such schemes. Cyprus has prepared and adopted a program for sewage collection and treatment in harmonisation with the Urban Waste Water Directive. For this purpose, in the next ten years all communities or clusters of communities with population exceeding 2,000 people, and communities situated in environmentally sensitive areas will be provided with a sewage collection and treatment plant.

For water reuse, the Government undertakes all the costs concerning the construction and operation of the tertiary treatment facilities, as well as the conveyance of the treated effluent to the farms. Reuse depends upon the readiness of the farmers to accept it. A campaign to convince farmers to accept treated sewage effluent is an ongoing process, and was supported by initially supplying treated effluents free of charge; interest in reusing this water is currently gathering momentum.

The cost of recycled water includes the capital cost of the tertiary treatment plants and the operation and maintenance cost of the tertiary plant. The polluters, i.e. the domestic water consumers, cover the primary and secondary treatment costs. The costs are given over a range to cover different plants constructed at different times and with different technologies. The cost of domestic treated effluent is in the range of 0.10 to 0.60 US$/m^3 depending on the output of the plant. The price of the recycled water is comparatively low, currently about 0.04 C£/m^3, representing only the cost of tertiary treatment.

Experiences from the scenario analysis

The option of water recycling and reuse for irrigation purposes was examined, with the following technical details:

- Year of implementation: 2008.
- Recycled water during the winter months (when the irrigation demand is minimal) will be stored in Polemidhia dam and/or will recharge the Kouris Delta aquifer.
- The pipeline from the WWTP will be connected to the existing network to transfer water to Zakaki Ext., Ag. Nikolaos, Lanitis and Fassouri farms(Figure 5).
- 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 €.
- 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 million €.

Under a scenario with a high sequence of dry years, this option results in substantial reductions in irrigation deficit, with a subsequent reduction in groundwater abstractions. It also has positive effects in domestic demand coverage since as a result from the reduction of the groundwater abstractions for irrigation purposes, there are quantities of fresh water available to cover domestic purposes.

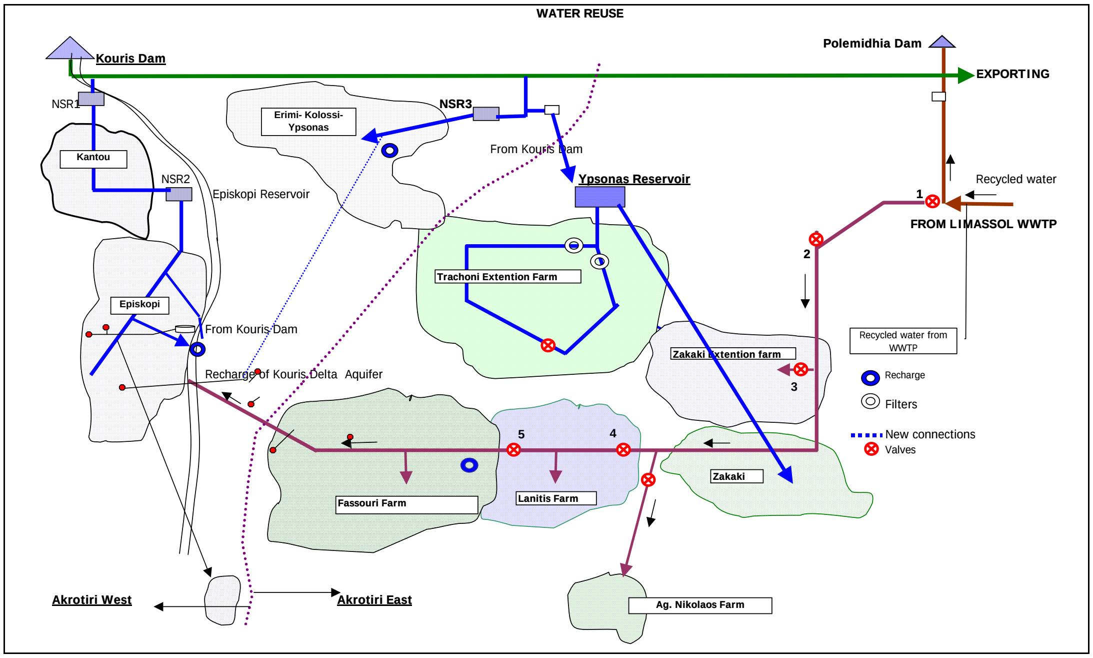

Figure 5 Water Reuse –Cyprus

Regional Experiences from Belice Basin, Italy

Experiences from current practices

A few projects are being implemented for using the effluents of treatment plants to supply irrigation sites in the Case Study area, mostly served by the artificial reservoirs of Garcia and Arancio. They involve secondary treatment plants of the municipalities of Castelvetrano, Menfi and Sambuca di Sicilia, which are being connected to the internal irrigation networks of the respective agricultural districts in order to directly supply water during the summer, when high peaks of water demand arise. In addition, effluent flows can be carried to the system of pipelines connecting the Belice River with Arancio Lake in order to recharge it during the winter. The total additional volume of treated water for the three districts is about 12,500 m^3/day.

In recent years, the local Land Reclamation Agency of Garcia-Arancio districts has started considering wastewater reuse as an effective potential water management option. This solution is of a certain importance, since it only influences irrigation demand, thus bringing advantages that are not shared with the domestic sector. Moreover, the additional amount of water supply from treated water partially alleviates domestic water supply constraints on the Garcia Lake supplies, that should be respected by the Agency (Consortium N^{o} 3-Agrigento).

Both domestic and agricultural users can rely annually on a fixed-by-law percentage of the Garcia storage volume to be exploited to satisfy the respective demands. However, in case of water scarcity, urban water use has higher priority than agriculture over the Garcia Lake supply. Therefore, it is evident that waste water reuse makes the coverage of irrigation requirements more independent of the actual traditional sources.

Financial costs for the three projects are equal to 118.8 million €, including investment costs for connecting the plants to the distribution networks of the irrigation sites, and the costs of construction or completion of the new and existing plants. Since detailed information on running costs for treated water supply is not yet available from the local Agency for Land Reclamation, an additional cost of 0.5 €/m^3 of water distributed can be considered.

Experiences from the scenario analysis

The option of waste water reuse has been analysed under the context of coherent water management scenarios.

At the beginning, interventions were scheduled to operate from year 2006, within a simulation horizon of 20 years from 2001 to 2020, but it was later preferred to apply it from 2001, to see the effect from the beginning of the simulation period, when water from Garcia Lake is still available for agricultural use (available supply decreases over the years due to the higher priority for domestic abstractions).

The effect of wastewater reuse on irrigation deficits is positive. In particular, the three districts can count on additional, augmenting water supplies, and unmet demand reduces by 10 %. Domestic coverage and deficit are not significantly influenced, since this option is tailored exclusively for meeting irrigation requirements. Under the worst circumstances of a dry climatic scenario, and a maximum domestic demand growth, the effect of the option is lower. However, even under this case, improvements in irrigation demand coverage are present.

Additional financial costs due to the option implementation is about 2.3-2.4 %. The environmental cost, associated with the sustainable amount of water abstracted from the vulnerable and shared resource of Garcia Lake increases only by 0.5 %.

Regional Experiences from Tel-Aviv and Arava regions, Israel

Experiences from current practices

The expected large scale transition to utilization of recycled water raises a few conflicts in the water economy of Israel, like:

- **Competition between agricultural and ecological utilization of recycled wastewater.** Most of the urban and industrial sewage is “produced” in the coastal plain at the center of the country (including the Tel Aviv region), while most of the irrigated areas are located in the periphery. The costs of constructing new networks to transfer the recycled water and ensure that it will not be mixed with freshwater, and the costs required to prepare new facilities to store excess treated water from winter to summer, are of major importance. The spatial distribution of aquifers and the environmental costs associated with irrigation above them, which may pollute the underlying groundwater, should also be considered.
- **Conflict between the agricultural and the urban sectors regarding purification standards for disposal set for the cities by the government.** Another conflict arises in the allocation of the costs and the benefits associated with recycling between the generators of sewage (the municipalities) and the agricultural users. An additional conflict is the issue of assurance for the municipalities that the farmers will not reduce usage suddenly (due to an economic crisis for example) and leave the cities with treated water that cannot be disposed of.

The supply of reclaimed sewage in Israel is expected to grow substantially due to increased water supply for the growing domestic and industrial sectors, and the expansion of irrigation with recycled effluents. It is assumed that between 50 to 60 % of household water can be recycled and reused in Israel, if there is sufficient demand for its use. 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, from about 300 hm^3/yr now to about 500 hm^3/year in 2010, requires the development of many more environmentally safe water treatment plants, reservoirs and conveyance systems.

The use of treated wastewater in agriculture involves strict environmental rules, with a double aim:

- preservation of groundwater when irrigation takes place above unconfined aquifers, and
- public health considerations aimed at preventing the spread of bacteria, viruses, carcinogenic materials, etc.

Strict restrictions on the use of treated wastewater in irrigation have been introduced; the issue of gradual contamination of groundwater by chemicals is being studied.

Available observations suggest that the chloride content of reclaimed sewage is higher by about 100 ppm Cl than the incoming fresh water supplied to urban consumers. Whereas the current chloride content of the water supply by the NWC is about 220 ppm, the chloride content of reclaimed sewage without underground mixing will be 320 ppm, and after open-pond storage may reach the level of 450 ppm Cl or even more. Such a level is considered harmful for sensitive crops such as citrus, avocado, and mango.

With the current technology, highly treated wastewater meets all the objective standards of drinking water, yet dual-supply systems are developed in order to avoid any unforeseeable hazards. Could highly treated wastewater serve as an emergency source for households under conditions of severe drought and severe water scarcity? It seems that the answer in Israel is “no”.

The steady and continuous increase in the utilization of recycled effluents by the agricultural (and, in the future, the environmental) sector has significant impact in several areas:

a. Large-scale water projects

The pressing need to find alternative sources of water, together with the critical condition of the environment, led the Water Commission to set up the Shafdan plant. This is a large-scale project for processing sewage to produce purified water, operated by Mekorot. The procedure results in two major benefits: a) A nearby aquifer serves as an underground reservoir for the recharged water, preventing losses by evaporation. Water is pumped as needed, mainly in summer. b) Percolation of the water through soil layers provides an additional cleaning phase. About 120 hm^3 of this purified water is transported annually via a separate pipeline called the “Third Negev Pipeline” to the western Negev for irrigation. Due to the high degree of purification, the treated water can be used for all crops without any health risks. Additional sewage water purification plants are already operative, under construction or on the planning boards. Smaller-scale plants located in the Negev itself provide treated sewage water for the irrigation of fields close to the source of the effluent. Treatment is minimal, and use of the treated water is restricted to crops such as cotton. These small projects are reported to be highly cost-effective.

b. Agricultural water supply sources

In 2002, the total amount of water consumed by the agricultural sector in Israel (1,010 hm^3) was composed of 57% fresh water from natural resources, 30% recycled effluent, and 13% brackish, saline water. It is expected that in 2010 the share of recycled water allocated to agriculture will increase to about 45%, whereas the shares of fresh and brackish water are expected to be 47% and 8%, respectively. The high-quality fresh water removed from agricultural production will be allocated to domestic use.

c. Health and Environmental Considerations

Pollution and water quality problems are central to the utilization of recycled effluent for agricultural and environmental consumption. As mentioned above, treated effluents are saltier than the background water (water used in the households and industries from which the sewage was collected), and even after treatment, the water may be polluted with other undesirable chemical and biological impurities. The use of recycled water for irrigation and river rehabilitation, depending on the degree of treatment, is therefore limited to non-sensitive crops. In addition, irrigation above aquifers may pollute the underlying reservoirs, rendering their water unsuitable for home use and, in the long-run, also for agriculture. The Israeli water law empowers the Water Commissioner to act in preventing pollution, but strict regulations have not been enacted yet. It seems as if the regulator (and the regulator's advisers) is seeking a compromise between the need for sustainable aquifers and rivers, and policies that the farmers, and, to some degree the environmentalists, can live with.

d. Pricing and Cost Sharing

The more recycling performed, the more important economically is the question of how the cost of recycling should be allocated between the generators of effluent, i.e. the cities and industries, and the users of the recycled products. In Israel, most policy makers have adopted the *"polluter pays principle"* as a guide for cost allocation. Accordingly, the Government should set purification standards for discharge, and the city should pay the full process costs. Where the option for use as irrigation or river rehabilitation exists, the city should purify the water anyway, to the level that it would have done if this option did not exist. This is called the *"zero alternative"*. The farmers should receive the purified water at the city gate for free. They should then pay only for transporting the water to their fields, and for any purification over and above the level required for the city. In many situations, this rule is not economically efficient. At first, effluents are merely a pollutant. But, once effluent is recycled, it suddenly becomes a useful input. Hence, the polluter is no longer just a polluter, and therefore should not necessarily be burdened with the entire cost of disposal. If the recycled water contributes positively to agricultural production, farmers should pay for this water.

Currently, the prices charged to farmers who utilize water from relatively large scale recycling plants operated by the national water company Mekorot are set administratively by the government at 0.10 to 0.15 US$/m^3. The government also allocates usage quotas. For other locations, with relatively small and privately operated treatment plants, the accepted doctrine is to encourage local solutions. In most cases, regional cooperatives take the recycled water from nearby, and the price paid by the farmer is determined through bargaining. In some places, recycled water is supplied free of charge.

Local solutions to the sewage problem raise difficult economic questions, such as how can the cities be assured that farmers will not reduce usage one day and leave the municipalities with treated water which they cannot dispose of.

e. Necessary Reservoirs and Related Infrastructure

While the supply of effluents by the cities is stable over the year, most of the agricultural demand is limited to the dry summer period. This necessitates the allocation of large land areas for the construction of environmentaly friendly, expensive reservoirs, to store the treated wastewater from winter to summer. Moreover, since treated wastewater cannot be mixed with fresh water, even if used for irrigation, significant investments in separate conveyance systems are necessary. Essentially, most of the initial capital outlay for the significant required investments is covered by public funds via subsidies, and this will continue in the future. In the Israeli capital market, farmers and their regional cooperatives cannot mobilize on their own the amounts needed for these projects.

Costs

Costs vary greatly according to type and size of the facility. Due to economy of scale, larger facilities have cost advantages.

Table 6 Wastewater treatment costs in Israel

Wastewater Treatment Costs	US dollars/m^3 wastewater
Secondary treatment:	0.39
Upgrade to tertiary	0.08
Upgrade to wastewater extraction: (Desalination from 400mg to 50mg chlorine)	0.15
TOTAL cost of recycling water for broad agriculture & ecological use	0.62
Pooling and conveyance of recycled water for agricultural consumption	
Regional facilities (including land)	0.26
Large scale facilities (e.g. Shafdan)	0.35

The total planned investment in reclamation plants and in upgrading effluents in the current decade (2000-2010) is about 1,000 million US$, 52% of which by the private sector and 48% by the national water company, Mekorot. The high share of the planned investment in desalination from the overall planned investment in the Israeli water sector during the current decade, 22%, illustrates the crucial role that utilization of recycled effluents play in the water economy of Israel.

The Government supports the sewage sector via subsidies at two levels. At the first level, the government finances investment in sewage and recycling projects in municipalities. This line of support from the State to the local authorities grew markedly in the 1990s when it was recognized that the law requiring municipalities to collect and treat their sewage could not be enforced. City councils found it much easier to let the waste flow into the nearest riverbed rather than to build expensive treatment systems. At the second level, the Government supports investment in the adaptation of irrigation to recycled water. As mentioned above, the cost of adaptation is not negligible and requires preparation of storage systems to keep treated water from winter to summer, as well as new networks to ensure that recycled sewage will not be mixed with fresh water.

Experiences from the scenario analysis

The option to increase the supply of recycled water for the region of Tel-Aviv was examined under two reference scenarios described in the Desalination option analysis, BauN and BauC.

Specifically, the establishment of additional treatment facilities was assumed, 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 hm^3/yr. Thus, in this scenario, the supply of recycled water is limited to 28 hm^3/yr 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 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 hm^3/yr, which is equal to the total agricultural demand for recycled water.

Under **normal weather conditions**, comparison of the recycling scenario with the reference scenario BauN shows that the period under which agricultural demand for 74 hm^3/yr is a fully satisfied increase from 4 to 10 years. Moreover, relative to the reference scenario, the level of unmet demand reduced significantly (e.g. from about 40 hm^3/yr to about 9 hm^3/yr in the last year of the planning horizon). 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 remaining years. As for the welfare indicator, we found that the values of NPV (SWS) associated with the recycling scenario 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 desirable**. Due to the relatively small water shortage for the agricultural sector under the recycling scenario, its associated environmental costs are negligible (1.3 million €). Therefore, **under normal weather conditions, the recycling scenario will be preferred by a social planner over all other management options, since it yields the highest value of SWS.** The environmental costs associated with this scenario are negligible, so a fierce opposition of environmentalists (or green lobbies) 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. On this ground, this option may be opposed by the (strong and effective) agricultural lobby.

Under **cyclical weather conditions**, the recycling scenario yields a reduction in the water deficits for all sectors, and especially for agriculture. Since unmet demand under the reference scenario is similar to the one under the recycling 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 %). The values of NPV(SWS) associated with the recycling scenario 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.** Due to the relatively small water shortage for the agricultural sector under the recycling scenario, the environmental cost decreases by almost 17 % relative to the reference scenario (35.1 million €). **From the social point of view, under cyclic weather conditions, the recycling option is the second-best one, dominated by the option of water conservation in the domestic sector.** The environmental costs associated with water conservation are lower than those associated with recycling so environmentalists will probably also prefer conservation (analysed below) to recycling.

Regional Experiences from Tenerife, Spain

Experiences from current practices

The efficiency and capacity of water recycling and reuse has been related with the size of the sewerage system and appropriate management of wastewater treatment plants. In the first case, the fast population growth of the last decades, which has sometimes been accompanied by a provisional, or even illegal construction framework, has increased the problem of sewerage network coverage.

National Housing Census statistics of 2001 give some really alarming results in comparison with Spanish averages. Only 199,981 (54 %) out of 365,041 dwellings on the island of Tenerife are connected to the sewerage network. This represents a serious environmental handicap and an important loss in the capacity of wastewater recycling. Figure 6 shows the percentages of dwellings connected to the sewerage network in each municipality of the island.

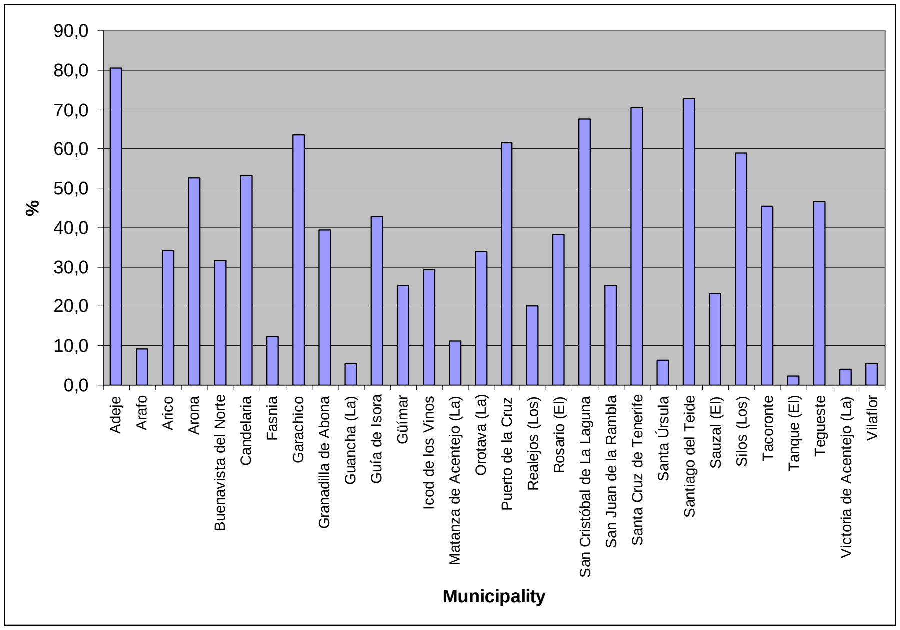

Figure 6 Percentages of dwellings connected to the sewerage network per municipality.

Low percentages are understandable in the cases of mostly rural municipalities, such as Vilaflor or El Tanque, but not in the rest. A percentage of 67% in a municipality within the metropolitan area, such as La Laguna, is actually low. Highest percentages of connection to the sewerage system are found in the municipalities that host new tourist developments.

In spite of these data, Tenerife has been a pioneer in wastewater reuse, since the 1970s when an ambitious project was initiated to treat the wastewaters of the metropolitan area, to produce water for garden irrigation. This project also included transfer of surpluses to the drier southern of the island, for gardening and agricultural use, therefore reducing the deficit of that area. This programme was consolidated in the 1980s under the name of *"Programme for the re-use in Valle de San Lorenzo of treated wastewaters from the Cities of Santa Cruz and La Laguna"*. In the coastal area of Valle de San Lorenzo, located in the southern tip of the island, an important agricultural activity has been developed, with 775 ha cultivated land (corresponding to 250 parcels), 95% of which are banana plantations. Taking into account the irrigation needs of each area, potential substitution of groundwater with treated water, required investments, wastewater treatment costs and water prices in each area, it was decided that the most advantageous option was to reuse treated urban wastewater of Santa Cruz in the Valle de San Lorenzo area. The global system of this pilot experience is made up of regulatory reservoirs, pumping stations, electrodialysis plant and pipelines.

Starting from these experiences and from the need to respond to the present-day situation, the Hydrological Plan of the island outlined the objectives of a first phase:

- 11 wastewater treatment plants with a total 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, which can be reused.

Table 7 depicts the present situation of wastewater treatment on the island of Tenerife.

Table 7 Production, discharge and re-use of wastewater (2001)

Production, Discharge and reuse of wastewater	
Domestic, tourist and industry water consumption (hm^3/year)	67.9
Total wastewater production (hm^3/year)	56.2
% of W.W. going to septic tank or directly to sea or aquifer	37%
W.W. collected through wastewater network (hm^3/year)	35.4
Loss of W.W. in wastewater network (%)	20%
Urban W.W. available for treatment (Mm3/year)	28.3
Treated urban W.W. (hm^3/year)	14.2
% of treated water on total W.W. production	25%
% of treated water on available urban W.W.	50%
Reused urban W.W. (Mm3/year)	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 (Mm3/year)	6.2
N. of operative urban wastewater treatment	11.0

Source: Manuel Fernández (CCA)

A sample of the possibilities for water recycling and reuse on the island can be found within the results of the integrated project for the tourist centres of the south of the island (CIAFTE). This project has been developed at Adeje and shows the excellent combination between water desalination, treatment and reuse (Table 8). Data relative to this integrated experience of the south of Tenerife, characterised by production at competitive prices, express an increasing efficiency:

Table 8 Adeje's Integrated System (Tourist Centres of the South). Data in m^3/year

	1998	1999	2000
DESALINATION	1,882,108	3,835,848	5,025,259
APPROPRIATE TREATMENT	1,977,308	8,468,315	9,033,483
BIOLOGICAL TREATMENT	784,131	2,621,610	13,090,625
RE-USE	430,325	1,555,032	2,006,760

With regard to experiences in wastewater treatment, it is important to point out that wastewater management and treatment plants suffer from small and medium municipalities' lack of management capacity, which led to the paralysation of the large infrastructures built. At present, there is a tendency to have an overall integrated island view of this part of water cycle.

Firstly, the fact that practically half of the island dwellings are not connected to the sewerage system is one of the most important, and at the same time least obvious, environmental impacts on the whole island, where aquifer contamination records at low altitude of most populated areas are really alarming and make further possible exploitation useless.

As a positive impact, the experiences carried out in water recycling and reuse allow at present covering an important share of water demand for gardening (both in the south and the metropolitan area), golf courses and a few agricultural areas, leaving better quality water for domestic consumption.

The case of Santa Cruz de Tenerife, the metropolitan area that has been managing and exporting recycled water for longer time, has been taken as reference for cost estimation. Total yearly costs (fixed and variable costs) of collection and treatment of Santa Cruz de Tenerife, budgeted for 2001, were calculated at 1,510,490.86 €, the total yearly volume collected and treated being 14,099,220 m^3, obtaining an average cost of 0.11 €/m^3. Fixed costs represent 61.38% of total cost.

This cost involves only water treatment. The total cost for 2001 was equal to 0.37 €/m^3. The total cost is the result of 25% corresponding to treated water and energy used for pumping, 35 % corresponding to chemical quality improvement (white water and desalinated water), while the rest is attributed to infrastructure maintenance, technical follow-up, personnel, etc.

Water treatment has more competitive costs than desalination, although not guaranteeing the same water quality. Nevertheless one of the limitations to price decrease is not due to the treatment process itself, but to the poor state of the general sewerage infrastructures that would need a big investment to improve the average standard in Spain. To achieve acceptable levels with regard to the sewerage network, the Hydrological Plan established investments of 113 M€ for 37 actions, that up to now have been partially carried out.

Experiences from the scenario analysis

The scenarios analysed plan to achieve a reused water volume of at least 21% of the total wastewater collected, bringing into operation those treatment units that are at present inoperable due to administrative competency or municipal problems. The rate of reused water is fixed, but the volume varies as it is correlated with population growth and domestic demand.

The established rate is a realistic percentage in the medium term, taking into account in the projections of island hydrological planning.

Within the scenario analysis, this measure involves a considerable reduction of the agricultural water deficit, as well of the deficit related to gardening and golf courses. Nevertheless, only under a stabilised demand scenario there is a positive effect recorded for groundwater exploitation, with values being within the limits of renewability. On the other hand, in a Business-As-Usual demand scenario, the application of this measure alone does not succeed to prevent aquifer overexploitation.Under favourable conditions the possibility to transfer good quality waters to the domestic use is verified.

With regard to environmental impact, the beneficial effect of the decrease in pollutant loads is observed although serious problems are still found in 12 submarine outfalls (the number of main submarine outfalls of the island is 21), with important repercussions for marine life and even for traditional fisheries that only operate within a narrow littoral area.

Owing to scale factors and technological improvements, as well as lower energy consumption due to the operational start of treatment units closer to consumption centres, recorded initial costs are of 0.37 €/m^3, and they are gradually reduced until reaching 0.25 €/m^3. Of course, technological improvements give as a result a higher quality level of treated water.

Repercussions of infrastructural costs derived from building secondary networks for water reuse distort water reuse strategy costs, which on the contrary would occupy a very advantageous position. At present, the only reuse infrastructures actually built are the metropolitan transfer of reused wastewater to the tourist south of the island, and a network within the southern municipalities (Adeje-Arona).

Costs deriving from the sewerage network completion (normally attributed to urban improvement programmes such as the URBAN) and from the improvement of submarine outfalls, which have not been taken into account, should also be considered.

Regional Experiences from Ribeiras do Algarve, Portugal

Experiences from current practices

In order to face an increase in water demand, water reuse is an important contribution to minimize the irrigation methods impact created by inefficient water use. Golf courses can contribute to that minimization by recycling water from wastewater treatment plants for irrigation purposes. In the Algarve region there are already three golf courses using this type of irrigation process: Salgados golf course, Quinta do Lago – Ria Formosa Course and Quinta do Lago São Lourenzo golf course. Furthermore, water reuse is generally well accepted by the public.

In year 2000, irrigation water consumption in Ribeiras do Algarve was 123.7 hm^3, while the total water production from wastewater treatment plants was about 23.6 hm^3. In that same year, only 0.5 hm^3 of treated wastewater was used for golf course irrigation, compared to a total consumption of 10 hm^3.

The effluent from wastewater treatment plants can be used for the irrigation of golf courses provided that tertiary treatment is implemented. This is also expected to prevent the overexploitation of aquifers.

Golf course owners are in favour of tertiary treatment in wastewater treatment plants. Capital costs, as well as operation and maintenance costs, and costs associated with analytical control are considered to be totally supported by the golf courses, in areas where this method is implemented.

Experiences from the scenario analysis

The option considered was the connection of golf courses that are at distance of less than 2000 m from a WWTP and situated in the “critical area” previously defined in the analysis of the desalination option.

In 2006, 6 golf courses will adopt this kind 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. The demand for these golf courses is 2.1 hm^3.

Water reuse can solve some problems by decreasing unmet demand (66% in 2035), protect aquifers from overexploitation, abandon poor groundwater quality supply and enable sustainable development of golf courses. These improvements are mainly observed in Herdade do Salgados golf course, which, in this option, has been connected to another WWTP in order to eliminate previous supply deficiencies.

Similarly to current practice, capital costs, operation and maintenance costs and analytical control are considered to be totally supported by the golf courses that implement this method. Nevertheless, data have not yet been evaluated.

Chapter 4 Groundwater Exploitation

Overview

Groundwater serves as a large subsurface water reservoir. Of the total freshwater on the planet, an estimated 75 % is stored in polar ice and glaciers, and about 25 % as ground water. Freshwater stored in rivers, lakes, and as soil moisture amounts to less than 1 %of the world's freshwater (USGS, 1999). The reservoir aspect of some large groundwater systems can be a key factor in the development of these systems. The source of water of best quality available should always be reserved for potable water supplies in order to avoid or to minimize the need for treatment. The primary objective must be to provide safe drinking-water, but if other needs can be met by the same source, then provision to do so may be made. Groundwater is the preferred source of water, provided the topography is suitable (WHO, 1982).

Groundwater resources include deep and shallow aquifers as well as non-rechargeable (fossil) groundwater resources that have been created during different climatic periods in the past (e.g. during the last Ice Age).

The large ratio of total groundwater storage to the groundwater withdrawn by pumping or to the water that constitutes natural discharge is one of the potentially useful characteristics of a ground-water system and enables water supplies to be maintained through long periods of drought. On the other hand, overabstraction of ground-water (occuring when the abstraction rate exceeds the rate of recharge) sometimes causes widespread declines in groundwater levels and a significant decrease in storage in the groundwater reservoir as well as resulting problems of overexploitation such as sea water intrusion (in coastal areas), subsidence and a deterioration of water quality.

Groundwater is retrieved from springs, wells and galleries. **Spring water** is acquired without pumping, however the year-round adequacy of the spring flow and the quality of the water must be ensured. The infrastructure which is used for the abstraction of water from ground-water bearing systems or springs may be classified into vertical (wells), horizontal or combined works. The **horizontal works** are further classified into **a) galleries** and **b) horizontal pipes** whereas the **vertical works (wells)**, are roughly classified into **a) shallow** and **b) deep wells**. Protection of the aquifer from pollution is necessary (especially in fissured rock aquifers and karstic soils).

Wells and boreholes require pumping but the provision of power for pumping will ease the problems of treatment, especially disinfection. Wells are less vulnerable to pollution since the deeper the water is situated, the less oxygen is available for microbial populations to thrive and the more difficult it is for contaminants released at the surface to reach it. Nevertheless, quality will depend on the geology, so treatment may be necessary to remove iron, manganese, sulphur, methane and ammonia. Furthermore salinity and high amounts of dissolved solids may impair the quality.

Table 9 presents a comparative overview of methods for groundwater well construction. Additional details on groundwater exploitation methods and associated impacts can be found in Chapter 11.

Table 9 Methods of groundwater well construction
(U.S. Soil Conservation Service, 1969; Modified and extended by Kallergis, 1999)

Method	Application (Materials)	Groundwater table elevation for optimum operation (m)	Common maximum depth (m)	Well diameter (cm)	Common Use	Yield (m^3/h)	Comments
Manual Auger	Clay, Silt Sand, Gravel < 2 cm	2-9	10	5-20	Household, Drainage	0.5-10	Temporary casing is need for loose materials
Mechanical Auger	Clay, Silt Sand, Gravel < 5 cm	2-15	25	15-90	Household, Irrigation, Drainage	0.5-20	Temporary casing is need for loose materials
Driven Wells	Silt Sand, Gravel < 5 cm	2-5	15	3-10	Household, Drainage	0.5-8	Used only for shallow groundwater tables
Jetted Wells	Silt Sand, Gravel < 2 cm	2-5	15	4-8	Household, Drainage	0.5-5	Used only for shallow groundwater tables
Cable Tool Percussion Drilling	Loose and whichever cohesive rock	Any	450	8-60	All uses	0.5-650	Temporary casing for loose materials. Slow Method
Rotary Drilling	Silt Sand, Gravel < 2 cm Cohesive soft to hard rock	Any	450	8-45	All uses	0.5-650	The fastest drilling method apart from hard rock.
Reverse Circulation Rotary Method	Silt Sand, Gravel	2-30	60	40-120	All uses	100-850	Appropriate for large diameters in loose materials. High amount of water needed
Rotary Percussion Drilling	Silt Sand, Gravel < 5 cm Cohesive soft to hard rock	Any	600	30-50	All uses	100-650	Very fast drilling, economically favorable for deep wells.

Regional Experiences from Paros Island, Greece

Experiences from current practices

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.

In 2001, total metered abstracted volumes for domestic use were equal to 1,671,325 m^3, with daily withdrawals of 5,500 m^3 in the winter and 24,500 m^3 in the summer. In 2002 and 2003, this volume reached 1,702,825 m^3 and constituted 88 % and 86 % of the total supplied volumes. The rest was provided by a brackish desalination plant. Groundwater exploitation, through private boreholes and drillings is the only irrigation supply source; however most boreholes are private and abstractions are not metered.

During the last few years a number of small interception dams have been proposed and constructed on the main streams of the island, in an effort to enhance groundwater supplies.

The uncontrolled abstractions of the previous decades for both irrigation and domestic consumption have had a severe environmental impact on the water quality of the most significant aquifers of Paros. Additionally, during the last 20 years and due to the intense exploitation of groundwater resources, especially during the summer months, a lot of wells and springs have dried out. As expected, the areas facing water deficiency and overexploitation are those that concentrate the main tourist and irrigation activities of Paros.

Construction of groundwater drillings in the Aegean Islands cannot be financed by the State. However, the costs associated with groundwater exploitation remain low as compared to other supply enhancement options, and the solution is preferred by the majority of local authorities. Licensing by the Regional Authorities is required. Average abstraction cost in Paros, where the depth of the most productive public boreholes ranges from 100 to 210 m, is about 0.15 €/m^3, while construction costs are typically equal to 30,000 €.

Experiences from the scenario analysis

The additional use of 4 boreholes for sustainable abstraction in selected sites proposed by the hydrogeological study of Paros (Bezes, 1996) was examined, for the augmentation of the available water supply in the months following the summer peak. The total yield of the new boreholes was equal to 204,000 m^3/yr[2] and they were mainly intended to supply the important tourist areas and some small villages.

Additional groundwater exploitation is the option that has the worst performance among the examined structural interventions. Although it may assist in meeting some domestic requirements, this effect is almost diminished in cases of drought and increasing demands. Another impact is strongly related to the aggravation of irrigation deficits; more intensive abstraction for domestic use leaves fewer quantities available for irrigation consumption. Consequently, the irrigation deficit can increase by as much as 20% with respect to a normal water shortage scenario.

The generally low financial cost of groundwater exploitation is reflected also in the scenario analysis. Construction and operational costs are low; however, due to the augmentation of water abstracted and delivered to domestic users, annual direct costs increase by 5 to 7 % (4 % in present value terms).

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[2] Under normal availability conditions

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

Groundwater, being available throughout the year, traditionally provided the water needed for domestic use and irrigation. The construction of dams on the main rivers of the island, in the last 35 years secured an additional supply. However, groundwater remains the main source for the non-governmental irrigation sector and for most of the village water supplies.

The biggest and most dynamic aquifers are phreatic aquifers developed in river or coastal alluvial deposits. During the last decade, aquifers exhibited serious depleting trends. Repeated and persistent drought episodes reduced direct and indirect groundwater recharge, while the construction of dams further reduced recharge of downstream aquifers.

A recent assessment of groundwater resources shows an overall annual negative balance of 15 hm^3. Most coastal aquifers are at a very low level and partially intruded by seawater.

Groundwater resources in Cyprus are overexploited by about 40 % of sustainable extraction. The average annual extraction for domestic water supply over the period of 1991 - 2000 was 25 hm^3; for irrigation it was 102 hm3, and for industrial use around 2.5 to 3 hm^3. The use of groundwater for domestic water supply has been significantly reduced in recent years, being replaced by seawater desalination.

The Akrotiri aquifer in the Limassol study region was the most dynamic aquifer in the island with the annual recharge being about 32 hm^3 and the extraction through some 500 wells and boreholes amounting to 10 to 15 hm^3. The balance was being lost to the sea and the nearby Salt Lake through the subsurface. The completion of the Kouris dam of 115 hm^3 capacity in 1987 changed the hydrologic regime and cut off the main source of replenishment through infiltration within the Kouris riverbed. Presently the estimated annual recharge from local rainfall and return flow from irrigation is of the order of 6 to 8 hm^3 while the extraction remains near the pre dam-construction levels. A major part of the balancing replenishment is made up by artificial groundwater recharge through releases from surface reservoirs into ponds and the dry streambed.

Until recently a large part of the domestic water supply of Limassol, a population in excess of 100,000 at the eastern fringe of the study area, relied upon groundwater from this aquifer. At present, a number of communities, as well as the British Bases, still pump groundwater for their needs. The local demand for the irrigation of citrus orchards and seasonal crops relies on surface water from Kouris dam, Polemidhia dam and Germasogeia dam, local groundwater, groundwater from within the Limassol city (high in nitrates) and tertiary treated effluent from the Limassol sewage treatment plant.

At the eastern part of the study region, another small aquifer develops between the Germasogeia surface reservoir and up to 4 km downstream, before the development of the delta area. This small aquifer has been relied upon to meet the major portion of the increasing demand for the water supply of the town of Limassol and neighbouring villages with high seasonal demand due to tourism.

Since the construction of the dam in 1968 the recharge of the aquifer depends on controlled releases from the dam and on occasional spills. During the last ten years the dam spilled only three times, in 1993, 1995 and 2004.Due to the artificial recharge through controlled releases, the extraction from this aquifer was increased twofold; about three times the active storage of the riverbed aquifer.

The groundwater levels are presently below mean sea level throughout most of the area of the Akrotiri aquifer. Sea intrusion has propagated up to 2 km and an important part of the aquifer has been rendered useless. The reduction of replenishment (leaching effect) and the increased agricultural activity using surface water from the Kouris dam has caused a trend of built up of nitrate and other elements in the groundwater.

There is no charge for groundwater extraction and the operation and maintenance costs for pumping to each farmer are far below the charge for surface water obtained from the Government water works. This situation renders the use of groundwater preferable to the farmers. Strict pumping control with the issuing of annual pumping permits is enforced in the area in view of the water resources situation of the aquifer.

Due to the need for sustainable exploitation of groundwater resources, an option to enhance groundwater abstractions was not analysed for the case study of Limassol.

Regional Experiences from Belice Basin, Italy

Experiences from current practices

The main resource of the area is the surface water of the Belice River Basin. A minor exploitation of groundwater is undertaken. However, available information about existing infrastructure and abstracted water volumes is not sufficient to describe this practice. Groundwater is used by domestic users through private wells, and is accounted by the local water supplying authorities as local resources.

Under the above considerations, the option was not examined for Garcia-Arancio case study.

Regional Experiences from Tel-Aviv and Arava regions, Israel

Experiences from current practices

In Israel there are three main sources of natural water, in addition to several secondary sources. The main sources are:

- The Jordan river and the Sea of Galilee – natural surface water
- The coastal aquifer
- The mountain aquifer.

In addition, there are several peripheral aquifers. The regions covered by the project are fed by the following aquifers:

1. The Tel Aviv region is situated above the coastal aquifer. At present the supply of natural water to this region comes from this aquifer and from the Sea of Galilee, via the NWC.
2. The above three main water resources are interconnected in the conductance system of the NWC, which enables transfer of water along a north-south axis, from the Sea of Galilee in the north, to the Negev region in the south, and in an east-west axis, from the Sea of Galilee region to the Coastal region.

The Coastal aquifer

This 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 hm^3. The annual renewal from precipitation is 300-400 hm^3, 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, and the salination level of the aquifer has increased, affecting several wells.

The chloride level has a broad range, from 50 to 600 mg chlorides/litre. About two-thirds of the water is still beneath the 250 mg level, the maximum permitted for domestic consumption. As a result of irrigation and pollution, salinization of the aquifer is expected to continue for many years. In addition, as the aquifer lies under the most densely populated part of the country, the Coastal strip, there is an additional environmental crisis, resulting from the contamination of the aquifer.

The current policy is to rehabilitate the Coastal Aquifer, with the aim of raising the average water level and putting a stop to quality deterioration. This is performed through the selective limitation of pumping approval in areas with severe salinity and quality problems. Together with the policy of high water levels for the Sea of Galilee (which implies a reduction in water export from the lake to the south), this will, over time, reduce the supply of local and imported fresh water to the Tel Aviv region. This increases the need and pressure to create alternative water sources by desalination and wastewater recycling.

The Mountain aquifer

This aquifer is situated in Israel and the Palestinian Authority. The total storage capacity is about 1,000 hm^3. Israel extracts about 500 hm^3/yr and an additional 50 hm^3 by agreement with the Palestinian Authority. Salination levels are relatively low: 50-200 mg chlorides/litre. In some sub-regions, overpumping during the 1990s and a decrease in the volume of the reservoir have led to an increase in subterranean salinization.

For this reservoir too, the policy of the water economy is to raise levels and improve the salinity situation. In addition, it is highly probable that the allocation of water to the Palestinian Authority will increase substantially. As a result, there will be competition for the water from the NWC, and the need for desalination plants in the Coastal region will increase.

Other aquifers

Additional aquifers are situated in the Western Galilee region, the Gilboa region, the Negev region, and the regions of Arab settlements. Their total annual production is, on the average, 270 hm^3. The salinity level in the Western Galilee is low, 50-100 mg chlorides/litre. In the other aquifers the salinity level is higher: 250-400 mg chlorides/litre.

Demand pressure is lower, because of the detachment from the national tri-basin water system. In the Western Galilee and the Carmel mountain regions there is potential for increased recycling. The addition of these areas to the national system - which has already started – would give the national system an additional water source of 30-50 hm^3/yr.

Costs and investment

Table 10 presents groundwater costs for the National Water Carrier according according to the Mekorot company budget, from the Sea of Galilee to Rosh Ha-ayin. Costs for the plan for the Tel Aviv region are in preparation.

Table 10 Cost components for the National Water Carrier, Israel

Cost component	
Financial value of assets (after depreciation):	220 million US$
Pumping and conveyance cost (in US$/m^3):	
Energy	0.60
Capital	0.09
Maintenance	0.08
Total	**0.77**

Production and conveyance costs for the Coastal aquifer: 0.10-0.12 US$/m^3.

Table 11 presents the costs for the groundwater investment plan for the Israeli water economy for the period 2004-2010 according to the interim master plan/

Table 11 Groundwater investment plan

Cost Component	Cost (million US$)
Desalinization	200
Upgrading quality of well-water	150
General improvement of quality	150
Improvement of conveyance systems	550
Innovations and improvements (including maintenance)	650
Monitoring and research	50
Total	1,750
Unforeseen 10%	175
Total	**1,925**

Approximately 60% of the planned investments will be financed by the National Water Company.

Experiences from the scenario analysis

Relative to the reference scenarios (BauN and BauC), the examination of groundwater exploitation 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 0.64 €/m^3.

Under this scenario and **normal weather conditions**, the demand of all consumers is met for all the years of the time horizon, and all agricultural plots are fully cultivated. The total level of over pumping during the planning horizon is 267.8 hm^3, and is equal to the level of desalination under normal weather conditions. The values of NPV(SWS) associated with this scenario is lower by about 68 million € than the respective value under the reference, BauN, scenario. The high (environmental) cost associated with over-pumping explains this difference. This implies that **the option to reduce water deficits via over-pumping is socially undesirable in the region of Tel Aviv.**

Like in the case of normal weather conditions, over-pumping of groundwater under **cyclical weather conditions** satisfies the demand of all consumers during all the years of the time horizon. The total level of over pumping during the planning horizon is very high, 1,395.1 hm^3. It is much higher than the total amount of desalination under the desalination scenario, since annual desalination cannot exceed the capacity of the desalination plants while over pumping in our analysis is not administratively constrained. The values of NPV(SWS) associated with the scenario of over-pumping 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.** Due to the absence of water shortage for the agricultural sector under the scenario of over-pumping, 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 huge, 618.7 million €.

It can be concluded that from social point of view and from the point of view of the greens' lobby over-pumping is the worst scenario, with the lowest value of NPV(SWS) and the highest environmental cost. On the other hand, under cyclical weather conditions, the highest percent improvement in the deficit of all sectors is obtained with over-pumping, which enables to increase supply as much as needed. On this ground, this management option may be advocated by political lobbies of all sectors, especially the agricultural one.

Regional Experiences from Tenerife, Spain

Experiences from current practices

Groundwater is still the main water resource on the island, representing more than 90% of total available water. From the beginning of the century 1,047 water galleries have been drilled, some deeper than 7 km, and most of them do not yield any water at present. In total more than 1600 galleries were made, creating a really spectacular water mining work. Subsequently, massive exploitation of the aquifer started through vertical drillings in the costal area, summing up 417 wells.

At the end of the 1970s the maximum exploitation limit was reached, and over exploitation of the aquifer started to take place, with the well-known effects of salinisation and marine intrusion at the coastal level. Exploitation of galleries, located at medium altitudes, reached a point of equilibrium, that is to say, they only produce water coming from rainfall, melted snow or cloud condensation. There are no renewable reserves in this sense.

Under these conditions water extraction only depends on yearly rainfall, except for a few important, very deep wells that are still extracting fossil water from a deeper aquifer, whose level drops year after year.

Present-day abstraction that scarcely exceeds 212 hm^3/yr 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.

Impact on aquifers, caused by overexploitation that reached its maximum in 1970, is clearly reflected by water gallery yield. Figure 7, shows how, starting from 1970, and in spite of increasing the length of drilled galleries, the quantity of water extracted progressively decreases, until it reached the present situation. This led to the start of vertical drillings in the coastal area, at an average depth of 120 m. This process can be compared to what has happened to gallery exploitation, although marine intrusion brought additional, fast deterioration in water quality.

Figure 8 shows the simulation of phreatic level descent, with 20 m isolines. One of the clearest samples of water resource depletion is that, being groundwater exploitation almost exclusively private, no new important drillings have been made in the last decades.

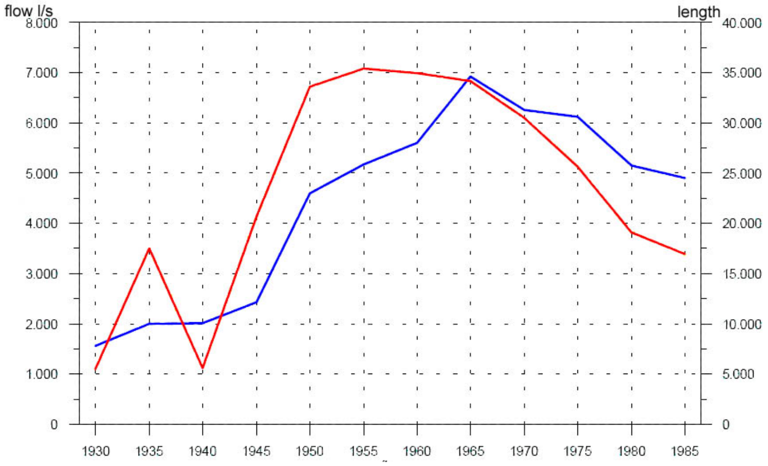


Figure 7 Evolution of water galleries drilled and water extracted. Source:PHI

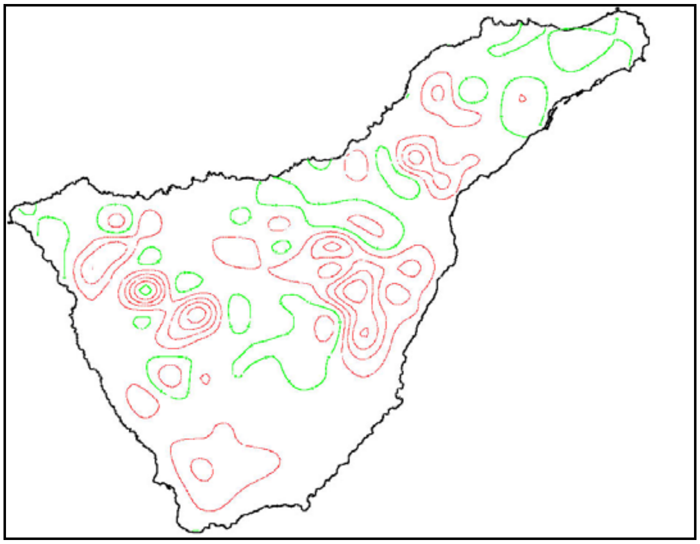


Figure 8. Isolines showing phreatic level descent recorded in the period 1985-2000. Source: PHI.

Three main phases can be distinguished during the period 1930-1985, with regard to the ensemble of extraction works (galleries and wells). The second phase (1945-1965) is characterised by gallery drillings while in the last one well drillings prevail.

It is evident that there is a big disparity with regard to present costs of groundwater exploitation, which depend on pumping needs, (wells or galleries), the building date of the infrastructure (amortization) and administration costs. Nevertheless, analysing the different data available groundwater cost are between 0.20 and 0.30 €/m^3. This cost does not include transport, of course, and it is very far from the actual selling price that in a few cases can reach 0.60 €/m^3. Total energy cost of water extraction (mainly attributable to wells) is estimated around 8,500 Tm of fuel-oil/year (CCA).

Experiences from the scenario analysis

No scenarios have been analysed for this option. Under the present conditions there is no possibility to reduce deficit through new extractions. The base scenario considers the yearly average extraction as a constant value, which cannot be increased.

Regional Experiences from Ribeiras do Algarve, Portugal

Experiences from current practices

As stated in the River Basin Plan, as far as Portugal is concerned, Algarve is the region where groundwater assumed the most important role. In fact, the exploitation of these resources made tourism and irrigated areas development possible, in the beginning of the 1970s. The intensive use of groundwater for different purposes led to high density of vertical boreholes (10 boreholes/km^2), probably the highest in the country. Currently, 17 aquifers have been identified and the major groundwater resources are located in the costal area and are essentially of carbonated nature (Figure 9). Groundwater recharges may vary considerably due to irregular distribution of precipitation in the south of Portugal, leading to temporary overexploitation situations. Nevertheless, after high precipitation periods the aquifers' natural reserves are restored and the excess of recharge is discharged through temporary water-springs.

Additionally to the seventeen aquifers identified at Ribeiras do Algarve River Basin, three other of low retention capacity (Aljezur, Almodôvar and Odemira) have been considered according to the River Basin Plan.

Notwithstanding the fact that the Águas do Algarve S.A. Company supplies surface water to most of Algarve's settlements, the Aljezur and Monchique Municipalities and most of irrigation sites still depend on groundwater availability.

Generally, aquifers in the Algarve River basin, with the exception of Querença Silves aquifer, present chloride and nitrate concentrations over the legal limit and aquifers located by the sea exhibit salinisation risks. The Querença Silves aquifer is the most important aquifer in the whole region (storage capacity of approximately 1060 hm^3), the only that possesses water quality and quantity considered relevant for future sustainable abstraction. Other aquifers are also important in terms of storage capacity, for example Campina de Faro aquifer (723 hm^3) being its storage capacity equals 2/3 of Querença Silves.

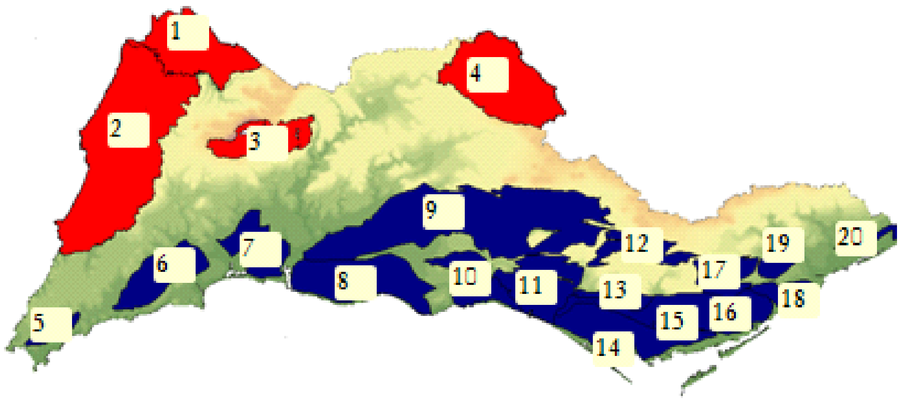
After the shift from groundwater to surface water supply for domestic use (see below), most of the aquifers do not present water quantity deficiency, with the exception of São Bartolomeu, Covões and Monchique, particularly after long dry periods.

Since Águas do Algarve, S.A. (Water Distribution Company) became responsible for the Primary Water Supply System a gradual increase in all aquifer's level was enabled therefore re-establishing aquifers natural balance. An exception applies to Alzejur and Monchique Municipalities, which still rely on groundwater distribution for irrigation and domestic use. Nevertheless, the quantification of the previous information has to be improved.

No data are available on groundwater exploitation costs.

Experiences from the scenario analysis

The option of Groundwater Exploitation was not examined for Ribeiras do Algarve River Basin. Combined/sustainable management of surface and groundwater resources, at this stage, has not been considered as a development strategy, but may be considered in the future.



1 – Odemira
2 – Aljezur
3 – Monchique
4 - Almôdovar
5 – Covões
6 – Almádena Odeáxere
7 – Mexilhoeira Grande
8 – Ferragudo Albufeira
9 – Querença Silves
10 – Albufeira Ribeira de Quarteira

11 – Quarteira
12 – S. Brás de Alportel
13 - Almansil Medronhal
14 - Campina d Faro
15 – Chão de Cevada
16 – São João Venda Quelfes
17 – Peral Moncarapacho
18 – Luz Tavira
19 – Malhão
20 – São Bartolomeu

Figure 9 Location of aquifers in the Ribeiras do Algarve River Basin, (marked in blue) & Location of low retention aquifers in the Ribeiras does Algarve River Basin (marked in red)

Chapter 5 Storage Reservoirs and Dams

Overview

Storage reservoirs and dams are widely used as a method of water resources management. Water is a critical natural resource and its distribution in time (wet and dry seasons throughout a year) and space (away from big cities and water demanding agricultural areas) has had as a result the construction dams and reservoirs all over the world; an estimated 800,000 dams were in operation worldwide in 1997 (Halls and Yamazaki, 2000). The construction and use of storage reservoirs have played an important role in the establishment and the development of towns and farms, by ensuring domestic water supply and by providing irrigation water. Dams and reservoirs also provide flood control and, therefore, protect people and property, keep rivers navigable, provide electricity (19% of world electricity, Walz et al. 2000) from renewable energy to towns and factories, and create recreational opportunities such as fishing and water sports. Reservoirs cover an area of more than 500,000 km^2 and the water stored behind dams is estimated to some 3600km^3. Dams regulate about 60% of the world's river flow (UNEP, 2001).

However, a number of problems are caused by the construction and operation of dams, such as the relocation of people occupying the areas required for the construction of the dam, together with a number of environmental implications.

Reservoirs may be divided into different types on the basis of **site** (highland and lowland reservoirs), **size** (small, medium, and large reservoirs), **intended purpose** (irrigation, water supply, fish production, hydropower generation), and **technical design** (river dam reservoirs and retention/detention water storage ponds).

Regional Experiences from Paros Island, Greece

Experiences from current practices

Although Paros is an island where run-off could be considered significant with respect to other Cycladic islands, no dams or storage reservoirs have been constructed thus far. Surface water exploitation is mainly associated with the construction of small interception dams, aiming to enhance groundwater replenishment.

In the past, a number of storage reservoirs have been proposed and could be financed in the future by the relevant Ministries and authorities.

Experiences from scenario analysis

In recent studies, two separate proposals have been made for the construction of storage reservoirs; the first involved the construction of a dam for domestic supply and the second the construction of an interception dam.

The first storage reservoir, which through a drinking water treatment plant and a perimetric network would be able to supply the entire island, would store water from nearby springs as well as runoff. The total capacity of the reservoir was estimated at 450,000 m^3.

The second interception dam would be used for aquifer enhancement in an area with significant groundwater exploitation for both agricultural and domestic purposes. The capacity of the dam was estimated at 98,000 m^3.

Scenario analysis demarcated that storage reservoirs are an effective solution in meeting domestic and irrigation needs, with maximum improvements similar to those of desalination (almost 75 and 30 % respectively[3]). This however is valid under the assumption of average/normal availability conditions. Run-off and hence storage are strongly dependent on precipitation levels. Therefore the sole dependence of a supply system on storage reservoirs was found to make the system vulnerable to periodic droughts.

Dependence however on surface water resources can be an effective option for minimising groundwater exploitation, while allowing for the replenishment of local aquifers. In fact, the groundwater exploitation index that was examined during the analysis showed a decrease ranging from 5 to 10 %, depending on availability and demand assumptions. Therefore the option can be perceived as a measure that could help in the mitigation of environmental impacts associated with groundwater extractions.

Since alternative financing schemes were not examined at this stage, the costs associated with the implementation of the option were considerably high. Even without including additional operational costs for pumping and treatment, the construction of the dam for domestic supply incurred very high capital costs. This resulted in an overall increase of direct costs around 30 %. In terms of cost, this ranks this option as similar to desalination, which is a much more flexible solution in terms of supply and reliability.

However, the interception dam can, with significantly lower costs, help in the mitigation of the impacts of aquifer overexploitation, and assist in sustaining the irrigation of the traditional vineyards in the nearby areas.

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

Since 1960, attention was turned to the systematic study and construction of water development works, both for storage and recharge purposes. After a comprehensive survey of the island’s water resources, a long-term plan for the construction of major development projects was followed, involving the construction of a large number of dams. The current total storage capacity of surface reservoirs has reached 307.5 hm^3 of water from a mere 6 hm^3 in 1960, and will reach 325.5 hm^3 with the completion of the Kannaviou dam. This is a truly impressive achievement when compared to other countries of the same size and level of development as Cyprus.

In Cyprus there are today 106 dams and ponds: 35 large dams with a capacity of 286.1 hm^3 of water of which 4 are recharging-flood protection dams, 42 small dams with a capacity of 16.1 hm^3 of which 32 are recharging-flood protection dams, and 26 ponds with a capacity of 2.5 hm^3. Eighty-one percent (81%) of the dams, i.e. 85 in number, are earth fill or rock fill dams and the remaining 19%, i.e. 20 in number, are concrete dams.

There are three major dams in the Limassol Region, that provide water to cover the needs of the area before water is exported from one of them (Kouris Dam) through the Southern Conveyor to the east, outside the region. These three dams are:

- **The Kouris Dam** (capacity of 115 hm^3) that provides water to the domestic and tourist needs of the area, mainly through the Limassol Water Treatment Plant. This dam controls most of the flow that until 1987 was used to replenish the Akrotiri Aquifer. The same reservoir also provides water for the irrigation needs of the area in the Kouris Delta.
- **The Germasogeia Dam** (capacity of 13.5 hm^3), which provides some minor quantities for local irrigation and is mainly used for controlled releases in the downstream aquifer. A major portion of this recharge was used for supplying the needs of the Limassol Urban area. Currently, the aquifer is mainly used by, and it is the only source

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[3] Under average availability conditions.

of water for the domestic needs of a number of villages in the area and for the highly developed tourist area in the east of Limassol. Water from this dam (4.1 hm^3) used to be exported to the Akrotiri area west of Limassol, meeting a large part of the irrigation needs. This practice has been abandoned in the last few years, and the same pipeline is now used for transferring treated waste water to the same area.

- **The Polemidia Dam** (capacity of 3.3 hm^3) used for irrigation purposes only, due to degraded water quality affected by an upstream waste disposal area. It is also currently used for storing treated effluent from the Limassol – Amathus Waste Water Treatment Plant. This water is provided for controlled irrigation through an existing network.

No scenario involving new surface reservoirs has been tried out for the Limassol Region.

Regional Experiences from Belice Basin, Italy

Experiences from current practices

The agricultural and domestic users of the Garcia-Arancio and of the Belice Basin territory rely almost totally on surface water stored in the artificial reservoirs of Arancio and Garcia. The Arancio Lake was built in 1951-1952 on the Caboj River, on a hill about 15 km far from the coast, to serve as a water supply basin for the irrigation of the surrounding farmlands. Its capacity is 32.8 hm^3, its surface is 3.7 km^2 and total upstream watershed area is about 205 km^2. The useful volume is 30.8 hm^3 and water in the lake is used only for irrigation. The Garcia Lake is an artificial lake created on the Belice Sinistro River with the construction of the Garcia dam. The dam was built during the period 1977-1985; and the area of the upstream watershed is 366 km^2. The maximum capacity of the lake is 80 hm^3, while the useful capacity is 63 hm^3. The average yearly water availability has been recently estimated at 55.2 hm^3.

The construction of the Arancio reservoir boosted the agricultural development of the region. The increased local water availability allowed the progressive expansion of the irrigated districts. The effectively irrigated area has increased from 700 ha in 1957 to 12,165 ha in 1991. In addition, reservoir construction also affected in time the types of crops grown in the area. In the 1950s the most frequent cultivations were, typically, annual crops and almond groves that did not demand large amounts of water. Little by little these were replaced by viticulture and artichoke plantations that provided a better and plentiful production due to the increased provision of water.

After the artificial dam of Garcia became operational in 1985, an additional 30 hm^3/yr were made available to the irrigated districts, which were used as complementary to the Arancio reserves to face the summertime peaks of irrigation demands. The two lakes were connected through pipelines with diameter ranging from 1,600 to 2,500 mm, and since the capacity level of the Garcia Lake is 194 m, while the Arancio Lake is 179 m, water transfer is performed through gravity without incurring further energy costs. Although the primary purpose of the Garcia reservoir construction was related to irrigation demand coverage and cultivated land expansion, later on domestic users also started to be supplied by the lake. The water resources of Garcia Lake were used to complement the volumes supplied by the two big aqueducts of Montescuro Ovest and Favara di Burgio.

The operation and maintenance costs for the reservoirs Arancio and Garcia are about 0.009 €/m^3 of water abstracted.

Experiences from the scenario analysis

The two artificial lakes are a fundamental part of the water system of the region and play an essential role in the satisfaction of the regional water requirements. No new reservoirs were examined in the case study analysis. However, two structural interventions aimed at augmenting the exploitable storage volumes of the two lakes are being planned by the water agencies of the Belice Basin, and therefore were simulated as an alternative policy option. They are:

- The expansion of the existing pumping station on the Belice river, which recharges the Arancio lake during winter, and
- The connection of Garcia lake with the right branch of the Belice River.

According to the water management plans of the Land Reclamation Authority, the Belice pumping station will be equipped with new pumps, which will boost river exploitation up to 15 hm^3 of water withdrawn per month from the present 8 hm^3. This additional volume of water is to be 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. As related to the exploitation of the right branch of Belice, infrastructure is managed by the agencies responsible for the exploitation of the Garcia Reservoir for domestic use. The annual volume that will be transferred is 6 hm^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 system, both inside and outside the Belice basin.

The two interventions were combined in order to evaluate the positive impact over the unmet demand that was expected for both urban and agricultural water uses. The expansion of the station recharging the Arancio lake brings advantages to the supplied irrigated districts, while the supply to the Garcia is supposed to influence mostly the urban demands, as they have a higher allocation priority with respect to irrigation requirements.

According to the simulation results, from the implementation year 2004 the situation improves. Unmet domestic demand decreases by about 20 % after the transfer of water to Garcia lake; however there is a negative trend along the examined period, which is due to the declining runoff available at the river reach where water is abstracted. Additionally from the analysis of the water flows in the river reach and in the new Belice-Garcia pipeline it appears that only an average yearly value of 3.8 hm^3 recharges Garcia lake against the 6 hm^3/yr of the designed structural intervention. So, water is not sufficient and availability also diminishes in time. Of course the effect of the runoff scenario is similar for the river reach related to the expansion of the existing pumping station: the yearly water abstraction is about 6 hm^3 against the 15 hm^3/yr that the new plant can manage. However in this case there is another limiting factor. In fact the supply enhancement option should permit the transfer of more water from the Belice to the Arancio lake, which means more water for all the irrigated districts. Regarding the irrigation deficit, its percentage improvement is lower, with a mean value of 8 %, and even 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 lies on the geographical location of the river reach from where water is pumped to recharge the Arancio lake: as it is downstream the connection of Belice to the Garcia, its water flow is reduced by the abstraction towards Garcia lake.

The construction cost of the connection Belice River- Garcia reservoir is 22.9 million €, while the cost for the pumping plant expansion is 25 million €, with a total of 47.9 million €. The increment of direct costs characterizing the implementation of this policy option 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 of 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 of the Garcia lake.

Regional Experiences from Tel-Aviv and Arava, Israel

Experiences from current practices

The only significant natural source of surface water in Israel is the Jordan Sea of Galilee system. The operative storage capacity of the Sea of Galilee has a range of 6 m between its minimum and maximum. Beyond the maximal level the water flows into the Dead Sea via the southern branch of the Jordan River. The active storage capacity is 1,020 hm^3. The average annual production is 640 hm^3, of which 440 hm^3 are extracted from the lake for consumption in Israel. Some 60 hm^3 are transferred to Jordan, in the framework of the peace agreement between Israel and Jordan. An additional 140 hm^3/yr are drawn from the northern branch of the Jordan River, for use in the northern part of the country. The salinity level of the Sea of Galilee is about 250 mg chlorides per liter. This is in spite of the fact that some of the saline, underground springs sources that used to feed the lake in the past were diverted a few years ago to the Dead Sea via a “Saline Water Carrier”. As the lake “exports” water to the Central region, chlorides are exported too, which leads to environmental implications. The Sea of Galilee is a valuable ecological and tourist asset, being the most popular vacation site in the country. As a result, a crisis in the water economy, leading to a low water-level policy, has several environmental, public and economic implications. The Master Plan of the water economy calls for preservation of high water levels by means of, inter alia, desalination and recycled wastewater as alternative water sources, as discussed previously.

Regional Experiences from Tenerife, Spain

Experiences from current practices

Features and singularities of groundwater ownership, with supplying turns for every owner, oblige water storage in small individual reservoirs for agricultural use. This was the origin of a very complex microsystem of 8,105 storage pools and tanks, with a total capacity of 24 hm^3. From several points of view, especially with regard to water losses, this is quite an inefficient system.

On the other hand, the development of reservoirs to harness surface run-off was one of the greatest failures of all the hydraulic projects implemented between 1940 and 1970, because of the irregular nature of rainfall and the difficult characteristics of the terrain. The current inventory of reservoirs (45 operating irregularly) provide a storage capacity of 4.5 hm^3, used occasionally for storing groundwater from galleries or for harnessing surface run-off water.

Through the combination of these two circumstances and with the aim to make water also accessible to non-owners in an easy way, 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 total storage capacity of 4.38 hm^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.

This regulatory system has a positive impact as it decreases water deficit at three different levels:

- It allows a rational use and distribution of water, more appropriate to meet variable agricultural needs, depending on crops and time of the year.

- It allows collection and storage of surface waters that under different conditions would be too costly to collect and store.
- It allows mixing water from different sources for agricultural use (desalination, treated surface water, groundwater) lowering the existing pressure on white water that can be diverted to domestic use in larger quantities. It is therefore a system bringing efficiency to the island water distribution ring.

Water handled by Balten through the reservoir system is supplied at cost (infrastructures, energy, administration), and depending on the zone the price varies between 0.27 and 0.38 €/m^3. These numbers include direct costs and are called “price of preference right”.

Experiences from the scenario analysis

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 hm^3/year. At the same time, maximum exploitation of surface waters is included as an added resource, for a quantity of 4 hm^3/year.

This system allows decreasing the irrigation deficit with rates that vary from 25% (high demand) to 58% (stabilised demand). Environmental impacts are the big restraint to this system and to its further generalisation. Therefore the Hydrological Plan only considers already existing locations (natural collecting pools formerly artificially modified) without any possibility of enlargement.

Culmination of the Plan and intensive use of reservoir infrastructures allows for an important reduction in the cost faced to supply this water for agricultural use, between 20 and 35%. Analysed scenarios considered this cost reduction applying it progressively until 2020.

Another important aspect to take into account is the indirect influence of the system on the improvement of global costs of water transport and the positive effects on desalination costs due to storage possibility and/or mix with different quality water.

Regional Experiences from Ribeiras do Algarve, Portugal

Experiences from current practices

Before the creation of the Primary Water Supply System for urban use (in the late 1990s), groundwater supply always assumed a very important role in Ribeiras do Algarve River Basin, since the existing aquifers were the only water source with both adequate quality and quantity. Domestic water supply was based on a large number of network systems, managed by the Municipalities. At present, surface water is the most significant source of domestic water supply. In fact, from 1995 and onwards, the management of the Primary Water Supply System was based on two Inter-Municipal Companies: one for the West part of the basin, “Águas do Barlavento Algarvio” and another for the East part, “Águas do Sotavento Algarvio”. In 2000, the two companies merged, forming “Águas do Algarve, SA.”, which aimed to guarantee water supply for most of the River Basin territory. Since then, this company has become responsible for the surface water Primary Water Supply System distribution, as a result of the environmental concern around groundwater exploitation resources. Since 2001, Águas do Algarve Company also has the Concession for wastewater collection and treatment services.

This company is currently operating the Primary Water Supply System in most of the region, based exclusively on surface water. In the western part, abstractions originate from the Funcho and the Bravura storage reservoirs. For the eastern part there is a major import from the Odeleite-Beliche system (two dams located in the Guadiana River Basin). Figure 10 presents the location of the major water supply and irrigation sources of the River Basin.

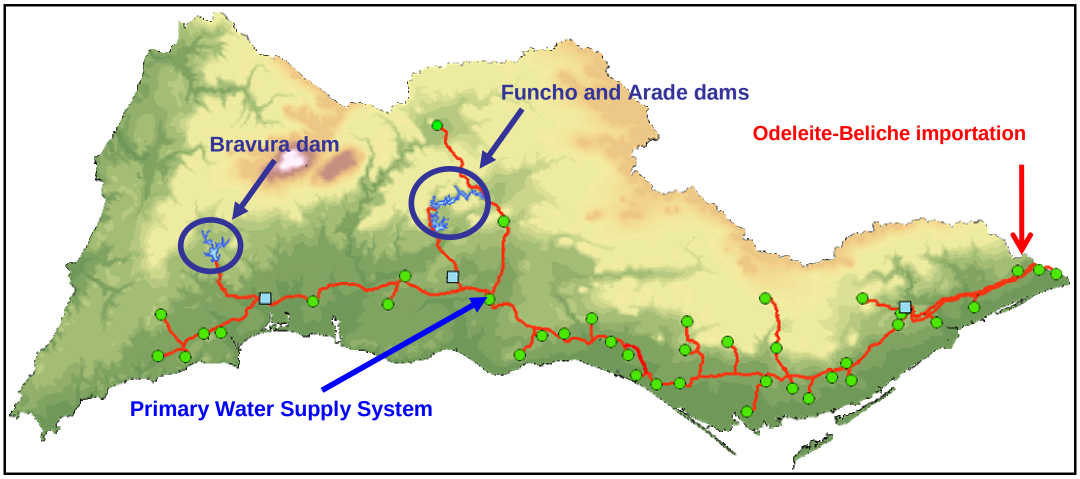

Figure 10 Primary water supply system and storage reservoirs

The Arade dam, constructed in 1956, at 10 km distance from Silves Municipality, on the Arade River, and its river basin area is about 829 km^2. The storage reservoir has a gross storage capacity of approximately 28.4 hm^3 and a useful storage of 27.3 hm^3. The Arade dam was constructed for irrigation purposes, and more specifically to supply water to the public irrigation sites of Silves, Lagoa and Portimão.

The Bravura dam, constructed in 1958, is located in the Lagos Municipality and has a river basin area of 77 km^2. The storage reservoir has a gross storage capacity of approximately 34.8 hm^3 and a useful storage of 32.3 hm^3. This storage reservoir was constructed for irrigation purposes and is integrated in the Alvor public irrigation site. However, it has been used also by the Águas do Algarve company for domestic water supply purposes, with an annual abstraction below 4 hm^3 (6 hm^3 from 2006).

The Funcho dam was the last to be constructed (1993), and is located on the Arade River, in Silves Municipality. The storage reservoir has a gross storage capacity of approximately 47 hm^3 and a useful storage of 43 hm^3. This reservoir was constructed for irrigation purposes but is currently being mostly used for domestic water supply.

Moreover, the Sotavento public irrigation site is currently supplied by Odeleite-Beliche dam system. Beliche Dam was constructed in 1986 and has a gross storage capacity of 48 hm^3 and a useful storage of 44 m^3. Odeleite Dam was constructed in 1996, has a gross storage capacity of 130 hm^3 and a useful storage of 116 hm^3. If the irrigation demand grows significantly, the construction of a new dam will probably be considered, the Foupana dam.

The Odelouca dam construction has already begun but has been suspended, expecting developments at the financial, environmental and social sustainability level. This dam, exclusively aimed at supplying water for domestic use, is located on the Odelouca River in Monchique, with a river basin of 393 km^2, a gross storage capacity of approximately 157 hm^3 and a useful storage of 134 hm^3. The main goal for the new infrastructure is to assure 95% of domestic demand coverage in the Barlavento and will allow water from Funcho dam to be reallocated to agriculture.

With the creation of the Primary Water Supply System in the end of the 1990s, a real improvement was made, allowing an efficient domestic water supply throughout the whole year, with good quality. One of the main goals was to ensure that 90% of the population benefits from domestic water supply. That is now occurring, with losses in the Primary Water Supply System below 3%.

Moreover, public irrigation sites are supplied with surface water. This way, some of the existing storage reservoirs are also needed for agriculture supply. The implementation of the

Odelouca dam will improve irrigation demand coverage through the reallocation of Funcho dam to agriculture purposes.

No cost data are available for all currently used dams. Nevertheless, Arade dam, constructed in 1956 and Bravura dam, constructed in 1958, are already fully depreciated.

Experiences from the scenario analysis

In addition to the above three existing storage reservoirs in the Ribeiras do Algarve River Basin, there is a new dam already under construction exclusively for domestic water supply: the Odelouca dam. As referred to in the previous section, its construction has been suspended although it is assumed that it will start operation in 2008 and no network enhancements are being predicted. The Odelouca dam will guarantee 95 % of the domestic demand coverage in the Barlavento. This target will be reached even during the dry periods.

Scenario analysis demarcated Odelouca storage reservoir as an effective solution in meeting domestic coverage, with an improvement o up to 25% by 2035 under severe shortage conditions. The expected domestic demand coverage in Barlavento above 95% is achieved under all scenarios examined. With regard to irrigation, the construction of the Odelouca dam, for domestic supply purposes diminishes the unmet irrigation demand verified in the Silves, Lagoa and Portimão public irrigation sites in 2010, 2018 and 2021. The unmet demand peaks that are predicted for those years are addressed, as water from Funcho dam is reallocated to agriculture purposes.

The Odelouca dam capital cost is, in total, 69.9 million €. Odelouca dam construction and operation will increase direct costs up to 11 % in terms of present value, while the overall cost recovery rate will decrease by 5% until 2033. From this year onwards and because the storage dam capital cost is totally depreciated, the excess of water supplied to the system causes a residual increase of 0.3% of the cost recovery rate, making it a profitable investment considering the storage reservoir lifetime.

Chapter 6 Conservation measures in domestic use

Overview

Higher standards of living are changing water demand patterns. This is reflected mainly in increased domestic water use, especially for personal hygiene. Most of the European population has indoor toilets, showers and/or baths for daily use. The result is that the majority of the urban water consumption is for domestic use. Most of the water used in households is for toilet flushing (33%), bathing and showering (20 – 32%). The lowest percentage of domestic use is for drinking and cooking (3%). Examples of the percentage breakdown of indoor water uses in different countries are shown in Figure 11 and Figure 12.

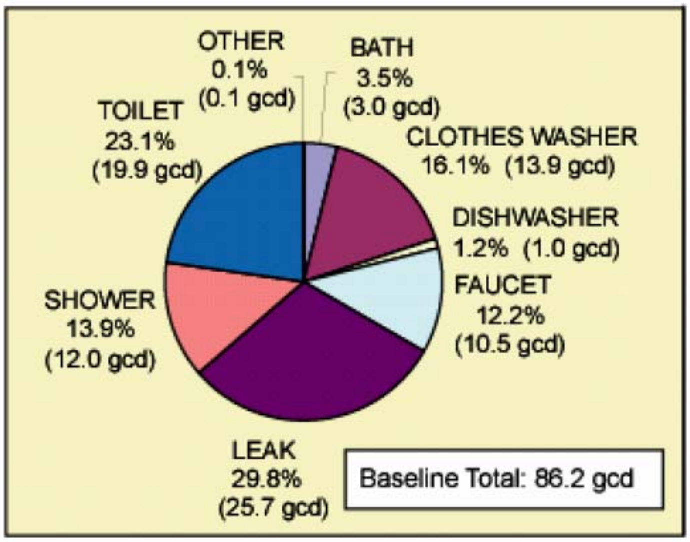

Figure 11 East Bay Municipal Utility District Service Area (USA): Baseline indoor per capita water use, percentage including leakage (33 homes studied) (East Bay Municipality Utility District, 2003)

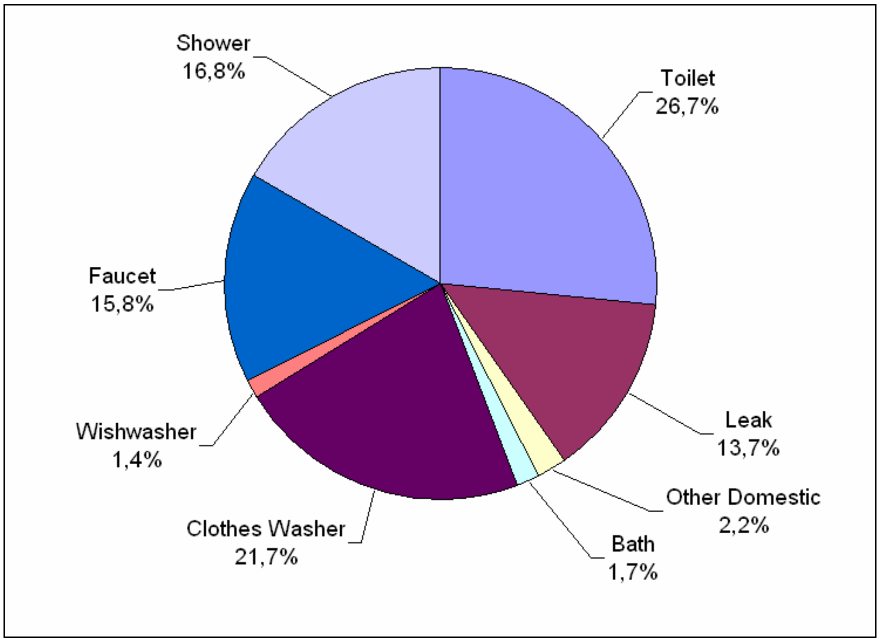

Figure 12 Breakdown of indoor water use in Canada (CRD, 2004)

Table 12 Patterns of water use by households in England and Wales, Finland and Switzerland

Household uses	England & Wales (%)	Finland (%)	Switzerland (%)
Toilet flushing	33	14	33
Bathing and showering	20	29	32
Washing machines and dishwashing	14	30	16
Drinking and cooking	3	4	3
Miscellaneous	27	21	14
External Use	3	2	2

Source: European Environment Agency, 2001

Statistics show that there is potential to improve the water efficiency of common household appliances such as toilets, taps and washing machines. Some appliances are best adapted to collective buildings such as public toilets (taps which turn off automatically); nevertheless, most are not widely used because they are expensive. Further research and development in recent years has refined these appliances, making them more accessible to the public (European Environment Agency, 2001). Table 13 presents the efficiency of typical water saving devices in households. Behavioural changes towards water use in the domestic environment, achieved through public awareness and education campaigns, are vital to water conservation. A multi-stakeholder and participatory approach involving water users and service providers, governmental agencies and non-governmental organizations needs to be encouraged. Raising awareness of water issues at all levels is deemed critical in the successful implementation of water conservation programmes and activities.

Table 13 Efficiency of typical water-saving devices in households

Equipment	Description	Water saving
Taps with air devices	Introduction of air bubbles into the water, increasing its volume => less flow but same effect	Flow reduction of around 50%
Taps with thermostats	They keep the selected temperature	Reduction of around 50% of water and energy
Taps with infrared sensors	Water is available when an object is underneath	Reduction between 70 and 80%
Electronic taps, or taps with buttons for a timed length of flow	Water running for a limited time	
Double-command toilets	Command for 6 l/flush Command for 3 l/flush	
Water-saving devices for old equipments		
Device to mix water and air for taps	Increase the volume of water (reduction of flow)	Flow reduction of around 40%
Device to interrupt toilet flush		Flow reduction of around 70%
Device to limit shower flow		

Source: (European Environment Agency, 2001)

Regional Experiences from Paros Island, Greece

Experiences from current practices

Conservation, in all the Southern Aegean Islands used to be effected through cisterns, which were functioning both as water tanks and rain-fed reservoirs. Their use, which provided a buffering effect in the spatial and temporal distribution of the water supply, used to make a significant difference in the coverage of demand, since problems of seasonal deficits and reduced flow at peak consumption times were very frequent. However, this practice was abandoned because of the tourist development that created the possibility of high profits by room rentals. Inhabitants chose to pay high prices for water rather than build reservoirs, as they could build rooms instead. Surprisingly enough and even under the economic development pattern that has been followed, there are stakeholders that think that a cistern of appropriate capacity should become a prerequisite for the construction of new buildings in Cyclades, and that such a requirement should be enforced by law (Aegean Information Network, December 2000).

Concerning other domestic conservation measures, the Municipal Office for Water Supply and Sewerage has taken some initiatives in order to increase the awareness of both residents and tourists on the fragility of the water resources of the island. Through the organisation of a conference in 2001[4], the mobilisation of resources and the realisation of campaigns, the Water Utility tries to minimise water consumption during the peak summer months. However, there have been no direct or indirect subsidies to consumers for the application of water saving devices.

The impact of the undertaken initiatives was evident during the stakeholder consultation procedure. The Union of Agricultural Associations and the Union of Hotel Room Owners have become increasingly aware of the stress exerted on the water resources of Paros, and are strongly in favour of technological adjustments and rationalisation of water use.

No data on the costs undertaken for promoting domestic conservation have been made available.

Experiences from the scenario analysis

Two options have been considered for promoting conservation in the domestic sector:

- The construction and use of cisterns in households, and
- The installation of low flow taps in households and hotels.

Cisterns

The subsidisation of cistern construction in households of Paros was examined, assuming an initial penetration of the intervention at the range of 50% of households (initial capacity of 39,100 m^3) and the possibility for expanding this capacity by 20% after 5 years or more.

Overall, the option can help to alleviate pressure on available resources during the high demand summer months while improving the reliability of domestic supply. However, the small capacity of cisterns renders the impact of the option minor, with a maximum improvement of 10%. It should be noted that an expansion of the application of the option in the hotel sector is considered unrealistic, given the current legislative and socio-economic environment. Additionally the measure was not effective in years of low water availability and drought, while the initial noted improvement diminished as demand escalated.

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[4] In collaboration with the Ministry of the Aegean, the Municipality of Paros, the National Technical University of Athens, the Greek Union of Municipal Offices of Water Supply and Sewerage, and the Greek Committee of Water Resources Management.

The high subsidies required for allowing the penetration of cisterns into the supply system are reflected in direct costs. In present value terms, direct costs increase by about 15 % while annual financial costs may increase by up to 30 %.

Other domestic conservation measures

The scenario evaluated for the application of conservation methods in the domestic sector, in this case including 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.

Reduction of domestic demand through the use of water saving devices was found to directly improve, besides domestic deficit, irrigation demand coverage, since smaller quantities are abstracted to supply domestic water use. Such an improvement of the order of 40 to 60 % is indicative of the effect that soft conservation measures could have on the performance of the supply system. Environmental performance, expressed in the form of groundwater (over)exploitation, was found to exhibit an improvement of about 5 to 8%.

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 9-10%. This reduction is due to the reduced water production, and associated running costs of the system. The effect is more pronounced than other types of efficiency improvements, since the cost associated with the implementation of the option is much lower.

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

In late 1980 the Limassol Water Board, established in 1951 as a non-profit, semi-government organization charged with the responsibility of supplying potable water to the town and environs of Limassol, embarked on a detailed programme of leakage management. The efforts made and importance placed by the Water Board for proper leakage management is reflected in the reduction of the non-revenue water over the years, from 25 % of total water produced in 1987 to about 16 % in 2002. The figure of 16% compares very favourably with the non-revenue water of the most advanced utilities and the Water Board of Limassol is considered among the best utilities in the world with regard to the performance of its infrastructure system.

Water conservation is not to be equated with temporary restrictions on customer water use. Although water restrictions can be a useful emergency tool for drought management or water shortage situations, water conservation programs concentrate on continuous improvements in water use efficiency. To this end the Water Board embarked on a promotional campaign through television, radio and leaflets to increase public awareness for water conservation.

In 1991, the Government legislated against the use of hosepipes for washing cars and pavements at all times, a law that the Water Board strictly enforced during drought periods. The drought of 1997 forced the Government to announce a reduction of 20 % for potable water and 40 % for irrigation water supplies. In 1998 the water situation became worse with water reserves reaching an all-time low. Restriction measures became more stringent as the available quantities of water were diminishing and the Government, much to the discontent of the public, went ahead with further measures, enforcing greater restrictions to water supplies with targeted figures of 28% for potable water and 56% for irrigation use.

The Water Board of Limassol promptly responded to the drought measures announced by the Government and in February 1997 restricted supply to consumers to four days a week. In

1998 with the announcement of the increased restriction measures the Water Board was forced to further decrease the availability of water, reducing the time of the water being available to consumers to 12 hours out of every 48 hours.

In addition, the Water Board enforced the following measures:

- Production and distribution of 100.000 plastic water bags for use in toilet cisterns.
- Hosepipe ban for washing cars, pavements, patios, etc.
- Public awareness programs to promote water conservation.
- Promotional leaflets on water conservation sent with water bills.
- Cost-of-service-based water rates.

The above actions resulted in an overall reduction in the use of domestic water of approximately 15% per annum.

Experiences from the scenario analysis

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.

Under the worst case scenario, this option results in substantial reductions in domestic deficit. It also has positive effects in groundwater exploitation index and direct cost. This is due to the reduction of the groundwater abstractions in order to supply domestic purposes. 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 nominal capacity (40,000 m^3/d).

Regional Experiences from Tel-Aviv and Arava regions, Israel

Experiences from current practices

Water conservation is the most reliable and the least expensive way of stretching the country's water resources and the challenge is being met in all sectors. In the domestic and urban sectors, conservation efforts focus on improvements in efficiency, resource management, repair, control and monitoring of municipal water systems. Citizens are urged to save water. The slogan *“Don't waste a drop”* is known in every home in Israel. Parks have been placed under a conservation regime, including the planting of drought-resistant plants and nocturnal irrigation. Additional water-saving measures include controlled exploitation, spatial distribution of new boreholes, and application of a block rate pricing system with a penalty for exceeding allocation rights. Promotion of household water pressure reducing devices, dual-flush toilets, pull handle taps and cisterns with double quantity dispensers, coupled with increased public awareness and media campaigns, play a significant role in reducing domestic water use.

An average Israeli household has 3.8 residents and consumes 230 m^3 of water per year. Its investment in the commonly used water saving devices is about 85-90 US$. The water saving associated with this devices is about 80 m^3/yr, implying an annual cost reduction of about 105 US$/household, according to the current water prices to urban consumers. In other words, at current water prices, investment in water saving devices at the household level is very profitable; the investment costs will be recovered within a year, while the technical life span of the saving devices ranges from 5 to 10 years.

The total planned investment in urban water saving devices, education and media campaigns to save water in the current decade (2000-2010) is about 160 million US$, and it is expected to save about 100-130 hm^3/yr. The cost per cubic meter of desalinated water is greater by about 3.5 times than the cost of water saving - - about 0.12 €/m^3) - - implying that substitution of desalinated water by "saved water" has the potential to reduce the costs required to meet aggregate demand in Israel by about 40 million US$ per year.

Experiences from the scenario analysis

In the analysis of the conservation option it was assumed 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. Based on a comprehensive study that conducted in Israel, the direct costs required to save 20% of water consumed in the domestic sector are 0.12 €/m^3.

Relative to the **reference scenario BauN**, under the conservation 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. 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 remaining years of the planning period. As for the welfare indicator, the values of NPV(SWS) associated with the conservation scenario 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 is socially profitable.** Due to the lack of water shortage for the agricultural sector under this scenario, its associated environmental costs are zero.

Unlike the parallel scenario under normal weather conditions, where water conservation implies that the demand of all consumers is met for all the years of the time horizon, water conservation **under cyclical weather conditions** does not eliminate water deficits. With regard to the reference scenario, BauC, an improvement in all sectors is evident, especially in the agricultural sector. Water conservation reduces the period for which agricultural demand for 74 hm^3/yr is not fully met from 13 years (under the reference scenario) to 7 years. The contribution of water conservation to the improvement in the deficit of all sectors during the dry periods is very significant. The value of NPV(SWS) associated with the conservation scenario under cyclical weather conditions 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 is socially desirable.** The environmental cost under the the conservation scenario (and cyclical weather conditions) - - 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.

Under cyclical weather conditions, water conservation in the domestic sector is the best management option from social point of view, and **the second-best one is to increase the amount of recycled water. Under normal weather conditions the social ranking of these two management options is reversed.** The environmental costs associated with water conservation are lower than those associated with additional recycling, so environmentalists will probably also prefer the former to the latter.

Regional Experiences from Tenerife, Spain

Experiences from current practices

It is really contradictory that Tenerife (and the Canary Islands in general) are in the presence of advanced technologies for desalination and agricultural water saving, but small progress has been made in domestic water saving and consumption management. Institutional water saving campaigns either did not give enough importance to this problem, or have not been continuous in time, being integrated in larger environmental campaigns. Water supply companies, especially in the metropolitan and tourist areas, are now starting these awareness campaigns, since they are starting to face difficulties to meet the increasing demand.

Present average values registered in the domestic sector of 160-180 l/person/d are substantially high, if compared with the national average (147 l/person/d). But they are also high compared to other islands of the Canary archipelago, such as Lanzarote, where the average recorded water consumption is of 103 l/person/d (including tourist consumption, 50% of the total).

Nevertheless, the debate on growth and crisis of resources put this issue on the table again. 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 spreading fast.

Experiences from the scenario analysis

Data 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 refers to a water amount of 6.7 hm^3/yr.

Scenarios were not so ambitious in this case, aiming to an increase of 10% in domestic water saving in the next 5 years, since the starting point is a situation where final consumers lack water saving and management culture.

Application of saving measures has an outstanding effect on overcoming domestic deficit, especially in the Stabilised demand scenario. Nevertheless it is necessary to say that, except in a Low Demand scenario, this measure alone does not achieve a stop to aquifer overexploitation. That is, despite its being one of the most efficient measures to overcome/reduce domestic deficit, it is not enough to have a decisive effect on environmental impacts.

Costs relative to the implementation of this line of action have been considered at two levels:

1. Costs for campaigns for demand side best practice knowledge dissemination. These costs have been projected during the next 10 years, starting from 2006, obtaining an effect of 0.012 €/m^3 on cost of supplied water (estimations made jointly with two water management companies).
2. With regard to implementation of saving water systems in houses, concessionary companies estimated an average of 10,000 households per year, requiring an average investment of 150 € per household (the scenario contemplates the implementation of saving measures of 150,000 households).

Investment results are very interesting in the different scenarios, since they are practically equivalent in amount to the cost of the energy saved. That is, we invest in best practices and energy saving systems for the same cost of the energy we stop consuming. But besides that, all scenarios show an acceptable coverage of domestic deficit. The cost to implement water saving technical measures in average, distributed in 10 years until covering the total number of households, is 0.009 €/m^3/yr, the value considered within the analysis of the option.

Chapter 7 Irrigation Method Improvements and Crop Changes

Overview

Throughout the world, irrigation is the main use of water. Agriculture accounts for more than 70 %of freshwater abstracted from lakes, rivers and groundwater sources. Significant water consumption is based on the low technical level of irrigated farming and irrigation systems, especially for the traditionally irrigated areas with very low water consumption efficiency. Furrow-based flooding, the traditional irrigation method is still widely used in developing countries. This cheap and low-tech method results in significant water loss by runoff. Also, poor management causes the salinisation of about 20 % of the irrigated land on Earth, which leads to the reduction of crop production. The countries most severely affected are mainly in arid and semi-arid regions. It is essential to apply updated watering techniques, such as sprinkling, channelling, subsoil irrigation and drip irrigation and to transfer knowledge on these techniques. There are other options to raise water efficiency in arid regions: replacing the crops requiring more water for less water-intensive crops, and replacing non-food crops, such as cotton, with food crops (UNEP – ROAP, 2004).

In irrigation four methods are most commonly used:

- Surface irrigation, by flooding or furrows;
- Subsurface irrigation, in which the surface is wet little if at all;
- Trickle irrigation from pipes near the plant; and
- Sprinkling, in which the soil surface is wet as it is by rainfall.

Irrigation methods vary in different parts of the world and even on different farms within a community, due to the wide variety in soils, topography, water supply, crops, and customs. For example, forage crops such as alfalfa, clover, hay, and pastures, in some areas are irrigated by the use of corrugations. Flooding irrigation methods, as well as border strips and basins are more suitable for forage crops and rice, while row crops are irrigated by furrows (Hansen et al., 1980).

The intervention in favour of less demanding crops and of an increment of irrigation efficiency by irrigation method change is a soft measure on the side of the Demand Management category of policy options. It can certainly be adopted in order to save water in case of limited resources for irrigation, however the extent of the implementation costs with respect to possible benefits, is what actually determines the feasibility of this option.

The selection of one particular irrigation method is dependent on natural factors, such as soil type, slope, and climate, but also on the type of crop cultivated: drip irrigation is used for individual plants, trees and row crops as vegetables and sugarcane, but it is not suitable for some crops, such as rice. The selection between the appropriate combination of irrigation method and crop type should also incorporate economic considerations. Since the direct costs of sprinkler or drip irrigation systems are higher, these methods are usually adopted for cultivations that have a high value on the agricultural market, such as vegetables and fruit trees, which also require more water demanding.

Another important consideration relates to the specific deficit conditions faced in an area. Under certain conditions, improving efficiency can have more positive effects than a change towards less water demanding crops, or vice versa. In the case of crops irrigated with surface or sprinkler methods, two situations may apply: 1) the deficit is seasonal and the degree of water scarcity is not so high as to compromise entire harvests, and as a consequence the economic development of the region, or 2) the deficit is permanent and the survival of the agriculture-based economy is seriously in danger. In the first case the solution of changing irrigation method to increase distribution efficiency is more profitable, as it can save enough water to cover the unmet agricultural demand, and at the same time the investment is justified by the benefits from continuing to cultivate and sell the high value crops. On the other hand, if severe water scarcity is affecting the region, the amount of water made available from efficiency operations cannot be sufficient and the high capital cost would not be recovered by the benefits. Under such circumstances, replacement of cultivated crops is preferrable, provided that is approved by the local administration and that it is not in conflict with the local development policy (South Pacific Applied Geoscience Commission, 1998).

Regional Experiences from Paros Island, Greece

Experiences from current practices

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 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. Substitution of water intensive crops, such as vegetables, with others, less water intensive or rainfed ones, is an option that is not under consideration by the Union of Agricultural Associations, since such an effort would create strong social opposition.

The impact of the lack of efforts for efficiency improvements is evident on the overexploitation problems that have been noted in some areas of Paros. Low irrigation efficiencies and wasteful water use increase irrigation groundwater abstractions. However, the major problem is still the lack of a regulatory framework for metering and controlling abstractions which would give additional incentives to farmers to promote efficient water use.

No data are available on the costs associated with previous efforts for increasing efficiency or for substituting crops.

Experiences from the scenario analysis

The measure examined in this case was the 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. The improvement was scheduled to be implemented gradually in 4 time steps, with time intervals of at least two years between each, and the maximum feasible penetration was defined by the crop cultivation patterns in each region of the island.

Under all shortage conditions examined, improvement in irrigation deficits is significant, ranging from 25 to 50 % (under high demand and average and low availability conditions respectively). However, although it would be expected that efficiency improvements would have a significant impact in terms of environmental performance, this is not the case. Even after such assumptions, irrigation demand was not fully met. Additionally, the effect of irrigation improvements was further diminished in cases of drought, when available supply is low and a higher priority is given to domestic uses. However, the option is the only identified means of modernizing irrigation and ensuring the preservation of agricultural activities for the island.

Direct cost increases were relatively low, ranging from 4% to 6%, depending on availability and demand assumptions. This leads to the conclusion that even the application of expensive efficiency improvement methods is an economically efficient method for improving demand coverage and enhancing groundwater protection.

Regional Experiences from Belice Basin, Italy

Experiences from current practices

Irrigation efficiency in the Garcia-Arancio districts has been progressively and continuously improving. In the 1950s an irrigation network of hydraulic grade line canals was used. The first pipelines were built in the 1960s, enabling fields located at a higher altitude to be irrigated with water from the Arancio Lake. In the 1980s the Consorzio Basso Belice began replacing 850 km of hydraulic grade line canals with a pressure line. This work made the water system more efficient, while at the same time it minimised water consumption. In the past, the pipeline network was regulated at users' request. It currently works under a fixed rotating shift scheme put into place to meet specific water provision needs. Thus, the diameter of the outlet pipes and therefore network building costs could be both reduced. At the end of the 1980s the irrigation network in operation was 1,280 km long, and it included 430 km of pipelines, while the remaining 850 km were hydraulic grade line canals. By 1993 the whole network was made up of pressure lines. It was then possible to initiate the automation of the irrigation system, to introduce new irrigation methods, such as sprinkler and drip irrigation; and to use the areas previously occupied by the canals for cultivation.

The automation of the irrigation network improved the water supply system and even reduced its cost. The water supply is directly controlled by the operators, who can immediately identify any break in the network, and consequently any water leakage. On the other hand, the user can check at any time the effective volumes of water supplied. The main and secondary water supply systems of the districts are provided with flow meters, electronic valves and sluice valves operated by a computer network. On-site computers, located near the junctions of the network, control up to 189 valves each.

Detailed information about the costs incurred for automating the distribution network and for replacing open surface canals with pipelines was not available from the local agencies. However, they were certainly covered by the benefits derived from the radical improvement in distribution efficiency, reduced labour costs for operation and maintenance due to the surveillance system and remote controls, and the production of high value crops that took the place of low water demanding cultivations after the construction of the Arancio reservoir.

Experiences from the scenario analysis

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 land reclamation agency confirmed a factor of 0.98 that is the result of fifty years of progress of agricultural practice in the case study area. However, water can be further saved by using the drip irrigation method in place of sprinklers. At the time being, 40 % of the cultivated areas is irrigated by drip but the majority is still by sprinklers. The agency stated that a gradual shift to a complete use of the drip method is on the agenda, and as a consequence this option has been analysed under different scenarios in order to assess its potential impact within a demand management approach to water scarcity. The replacement of one method over the other has been supposed to happen progressively with a tendency of +2 % per year. Applied from 2005 up to 2020, this means a growth of drip irrigation from 40 % to 72 % in sixteen years, and a correlated reduction of sprinkler systems from 60 % to 28 %.

The impact analysis reveals that this type of policy measure does not significantly influence water availability for agricultural use in the case study. There is a slightly positive effect on the irrigation demand coverage, +2%, but it appears after 2009, almost halfway in the examined period, and only for the worst scenario, i.e. in the combination of the most unfavourable weather conditions and maximum forecasted water demand growth. Under this option, irrigation effectiveness lies in the satisfactory range of 80-100 %. On the other side domestic demand coverage drops to 55 % at the end of the examined time period. Therefore, this intervention alone is not sufficient to cover the existing unmet demands of the irrigated districts.

Direct costs for this option were not available, but were approximated by an indicative value of 0.1 €/m^2. From the evaluation of the irrigation improvement option, it resulted that the environmental cost reduces 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 from the option implementation, about +20%, is very high and not acceptable compared to the small advantages the option generates.

Regional Experiences from Tel-Aviv and Arava regions, Israel

Experiences from current practices

The total amount of cultivated land in Israel is 351,460 hectares. The irrigated area is 196,998 hectares, 56% of the total cultivated area. The continuing water scarcity is an excellent economic incentive for breakthroughs in irrigation technologies. Israeli inventions such as drip irrigation and micro-sprinklers reduce water loss by up to 20 %. Computer-assisted irrigation management enhances these results. Despite the modest role of agriculture in the national product, less than 2% of the GDP, irrigation consumes about 60% of the limited freshwater supply of the country for cultivation and export, as water-intensive crops such as cotton and citrus are exported. Drip irrigation is viewed by many as one of the most important agro-technological innovations in Israel. It has many advantages over other irrigation methods, including:

- Water is discharged uniformly from every dripper fitted onto the lateral pipe. This is true even on moderately sloping terrain. Furthermore, the development of compensated drippers enables uniform irrigation on steeper slopes and the ability to extend laterals with drippers over greater distances.
- Via the drippers, fertilizers can be supplied to the plant together with the water (“fertigation”). Water and fertilizers are delivered directly to the root system rather than to the total area of the field, thereby economizing on both water and fertilizers.
- The quantity of water delivered can be optimized to fit different soil types, avoiding percolation of water beyond the root zone. Furthermore, sandy soils, which cannot be watered by furrows or flooding, can be efficiently irrigated with drippers.
- The growth of weeds is minimized.
- Between the planted rows the dry ground facilitates comfortable access to the field for workers and machines throughout the season.
- Exploitation of poor quality water (saline water or effluents) is made possible because:
  - Drip irrigation, unlike sprinkler irrigation, makes it possible to utilize saline water. This is because direct contact between water and leaves is avoided, thus obviating burns.
  - Drip irrigation causes salts to be continuously washed away from the root system, avoiding salt accumulation in the immediate vicinity of the roots. This is important when irrigating salinized soils or irrigating with saline water.
  - Drip irrigation allows the use of minimally treated sewage water because the water is delivered directly to the ground, minimizing health risks.
- Drippers with a given discharge of water, of the magnitude of several liters per hour, can be installed at any spacing to accommodate the needs of any crop.

Drip irrigation is the most efficient method of irrigation when it comes to water saving. Since the drippers deliver the water directly to the soil adjacent to the root system, which absorbs the water immediately, evaporation is minimal. This characteristic is especially important under the conditions prevailing in arid zones. In irrigation by sprinklers or by surface methods, evaporation is enhanced by winds, while in drip irrigation the impact of winds is minimal. In addition, high-quality drip irrigation equipment can last for fifteen to twenty years if maintained properly.

Water use efficiency (WUE) is defined as the ratio between the amount of water taken up by the plant and the total amount of water applied. Studies show that drip irrigation has a WUE of about 95 %, versus 45 % for surface irrigation and 75 % for sprinkler irrigation. It can therefore be concluded that drip irrigation has many advantages over other methods of irrigation, and that it is also superior to surface and sprinkler irrigation in regard to water saving, especially under conditions of limited water supply.

Regional Experiences from Tenerife, Spain

Experiences from current practices and the scenario analysis

Irrigated agriculture is the main water consumer on the island of Tenerife. In 1991 water demand for agricultural use rose to 109.2 hm^3/year, accounting for 52.7% of the total water consumed in that period. Nevertheless, this sector is clearly in decline, as a consequence of both the foreseeable decrease in EU economic help and protection of some of the export crops and the increase of water price due to competition with other activities, where water cost is just a marginal issue.

This tendency is clearly shown by the fact that in the period 1991-2000 water consumption for agricultural use decreased by 11.36 %, while domestic use demand increased by 11% in the same period. Nevertheless, all scenarios maintain the area of irrigated lands declared within the map of agricultural crops made in 2001 by the Ministry of Agriculture and Fishery of the Canary Island Government.

Within this use switching process, big agricultural properties have undertaken a large-scale process to automatise irrigation methods. In the case of banana plantations, and in particular its reconversion to greenhouse crop, drip irrigation is massively incorporated, estimating 8% of water saved. Innovation in the irrigation of this particular crop has a relevant importance as it absorbs 60% of total water consumption, holding 4,116 ha of cultivated lands. Nevertheless, all scenarios consider that the areas likely to change the type of crop have already done so in the past, and therefore increases in water saving are not very high.

The same criterion has been used for the other categories of automatized export crops such as tomatoes (1,266 ha), subtropical fruits (432 ha) and flowers (500 ha). On the other hand, in the case of other crops such as vegetables, saving possibilities can reach 7% of present water consumption, which would mean an amount of about 3 hm^3/yr.

Another measure that starts to have a great influence, although it is not quantified yet, is the implementation of information systems (digital, on-line or through agricultural agencies) to provide farmers with real time irrigation recommendations for each crop and/or area in each period, in relation to climatic conditions.

Environmentally speaking, although it seems a paradox, there is a drawback for drip irrigation since, while it positively contributes to saving water, it speeds the process of soil salinisation, making soil washing and ion dilution processes more difficult. Therefore the extension of advanced irrigation methods to other traditional crops, such as vegetables, vineyards or potatoes has to be considered carefully.

Costs due to the application of localised irrigation in greenhouses can reach 100,000 € per hectare, with an amortization period of 10 years. This involves a maximum investment of 520 million € for all automated areas, that corresponds to a cost of 0.09 €/m^3 of water saved, assuming an average life of installations of ten years, the total amount of water saved being 56 hm^3. This is a very advantageous perspective, even if we take into account the low cost of water for agricultural use that is about 0.20 €/m^3. The main handicap is obviously the high cost of the initial investment required.

This ensemble of measures does not have a direct incidence on improving domestic deficit, at least within the high consumption scenarios analysed, since they alone do not achieve overcoming the situation of aquifer overexploitation.

Regional Experiences from Ribeiras do Algarve, Portugal

Experiences from current practices

The improvement of irrigation methods and crop changes enables a general trend in the reduction of water consumption for irrigation purposes.

The irrigation sites represent approximately 70% (almost 124 hm^3) of the total water consumption at the Ribeiras do Algarve River Basin, of which 27 hm^3 are supplied from surface water. The irrigation sites were classified as: public (36 %) generally supplied by surface water, private (61 %) on which farmers manage their own boreholes, and golf courses (3 %) using both surface and groundwater supply sources. The first public irrigation site implemented in the Algarve Region dates from the 1940s and the most common irrigation methods are furrow and flood. The irrigated area foreseen growth rate varies both for public and private irrigation sites causing a prospected increase in water requirements and therefore enhancing the irrigation water deficit. It is predicted that an area of 10,650 ha of public irrigation sites is to be implemented by 2006.

Nevertheless, surface water sources are shared by both irrigation and domestic use, which prevails over irrigation whenever scarcity situations occur, creating conflicts between farmers and Municipalities. Low irrigation efficiencies and inefficient water use increase irrigation groundwater abstractions. Return flow of agriculture is estimated to be around 30% of the total volume abstracted. The infiltration of water used in irrigation into soil dissolves nitrates and chlorines, therefore contributing to aquifer’s water quality degradation.

The Water National Plan of Portugal presents costs for the implementation of the whole irrigation site implementation but no specific costs are provided for irrigation methods.

Experiences from the scenario analysis

The option of irrigation method improvements comprises change from furrow to sprinkler irrigation methods through the development of a programme of implementation.

The scenario foresees that for private irrigation sites there will be a gradual decrease of surface irrigation method percentage coverage from 20 % in 2006 to 15 % in 2012 and to 10 % in 2020, and an increase of sprinkler irrigation method percentage coverage from 80 % in 2006 to 85 % in 2012 and to 90 % by 2020. Efficiency improvements will be introduced in private irrigation sites whenever these are lower than 65 % by 2006 and 70 % from 2020 onwards, for furrow irrigation method, according to the Ribeiras do Algarve River Basin Plan.

Concerning public irrigation sites, Mira and Silves, Lagoa and Portimão (Figure 13), a change in percentage coverage from 100% furrow into 100% sprinkler, will be implemented by 2006. For the latter irrigation sites, the furrow irrigation method efficiency will be upgraded from 65% to 70% in 2020.

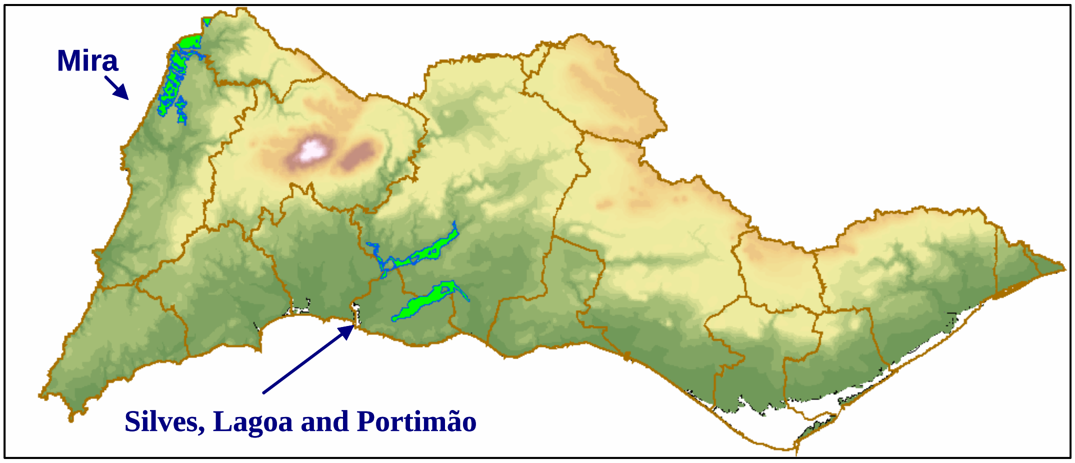


Figure 13 Public irrigation sites: Mira, Silves, Lagoa and Portimão

Between 2006 and 2035, the irrigation deficit improvements at the whole River Basin, obtained from the application of this option, are on average 16%. The extra water volume accumulated in the Funcho/Arade storage reservoir can therefore be used during dry periods at the Silves, Lagoa and Portimão irrigation sites. Particularly at this irrigation site, the irrigation deficit improvement after the introduction of this option reaches 80% in 2021.

Direct costs will increase by 0.4% in terms of present value relatively to the worst-case scenario. Particularly at the irrigation sites where this option is implemented, this increase is of 11% relatively to the same scenario. The overall rate of cost recovery for the whole Ribeiras do Algarve River Basin also decreases in 2006 by 14%, year of the new irrigation system implementation, and there is practically no difference in the following years.

Chapter 8 Network Improvements and Enhancements

Overview

The provision of adequate and safe drinking water supplies and the availability of appropriate wastewater facilities form a basis to improve the health and the standards of living of the developing world populations. These benefits will be accrued when the installed systems operate continuously and reliably, to the extent of their capacity and in agreement with acceptable levels of services quality. In a number of cities of the developing world, more than 25 % of the water produced is lost before reaching the consumers, with some drinking-water supply networks losing more than 50 % of the total water produced. Water supply networks in several developing countries are constructed predominantly with poor quality asbestos-cement, plastic (PVC, HDP), concrete or steel. Most industries have metered water consumption whereas this is generally not the case for domestic consumption. However, there are still serious difficulties with regard to the lack of spare parts and technical assistance and local skills vis-à-vis imported equipment or installations, especially electronic instrumentation. The water supply systems frequently function intermittently because of deficient operation, neglected maintenance and high levels of leakage. It is not unusual that water distributed by leaking pipelines of the distribution network is contaminated with wastewater from defective sewers.

Although many factors contribute to the situation described above, the greatest impact stems from a lack of effective management and lack of clearly defined objectives and policies and where institutional, managerial and operational adjustments would be particularly crucial to making the most of existing facilities. Such adjustments, aimed particularly at reducing the unaccounted-for water to acceptable levels, should be viewed as a pre-condition for implementing new projects dealing with rehabilitation, replacement or expansion of services.

Efforts are being made by various international institutions, including the World Health Organization (WHO) to promote better management practices and improved operation and maintenance as a strategy to make the most of existing water supply and sanitation systems and to reduce unaccounted-for water.

Water losses in the distribution network can reach high percentages of the volume introduced. The problems associated with distribution networks are not only related to the efficiency of the network, and consequently to leakages, but also to water quality aspects (contamination of drinking water is a main pressure in the distribution network).

The concept of network leakage covers different aspects:

- Losses in the network due to pipes not properly sealed. Leakage usually occurs at the pipe joints, and is particularly relevant in old and extended networks;
- Losses in users' installations before the water is metered;
- Mechanical problems occurring due to undermeasurement when the water flow is low;
- Differences in the estimated water use, which are counted as losses and occur when certain water uses are not measured but estimated, as for example in public gardens or street cleaning.

The UK regulator has set a mandatory leakage target for each water company in England and Wales, with the incentive to show that unaccounted water is not leakage but is actually water being used legitimately. In 1998-99, leakage levels reported by water companies were 22 % lower than in 1996-97.

In Switzerland, network losses in some communities and small suppliers are estimated to be around 30 % of the water introduced. Nevertheless, in cities like Zurich, where leakage control of 40-50 % of the total distribution network length is carried out every year, losses decreased from 10 to 5 % over the last 10 years.

Preventive maintenance and network renewal are the main factors affecting leakage of a network. The international survey for IWSA presents an average of 0.6 % of annual pipe replacement.

The present situation can be characterized by very different replacement rates of between 0.1 and 2 %. In Switzerland, the average service life of an installation is assumed to be 50 years, but new types of external and internal well-protected pipes could have a service life of 200 years. The Zurich Cantonal Water Authority recommends replacement of 2 % of the total distribution network length (EEA, 2001).

Regional Experiences from Paros Island, Greece

Experiences from current practices

The water supply network of Paros is highly fragmented, due to the past administrational structures governing the water supply, when each municipal department was responsible for the construction and maintenance of its own water distribution network and the exploitation of local water resources. As a result there are a number of separate water supply networks, each supplied by local resources, some in the most heavily populated parts of the island facing water shortages during the summer peak.

At the same time, network improvements have become a necessity. The poor maintenance of internal networks, particularly in the traditional settlements, has resulted in augmented losses and pressure drops. The main problem is associated with the fact that in the traditional settlements there are still parts of the network that are undocumented. Additionally, in some regions the extensive networks, along with the required expansions in order to meet the needs of rapidly developing areas, create additional problems in network maintenance. One of the reasons is that the staff occupied with network maintenance is limited (the ratio of employees/hydrometers is considerably low when compared to other, similar water service providers). Most of the recent efforts of the Municipal Office of Water Supply and Sewerage are concerned with the expansion of existing networks rather than network rehabilitation.

The fragmented nature of domestic distribution networks, besides inhibiting the alleviation of water deficits through a more even distribution of resources, creates strong social conflicts between the inhabitants of the different municipal departments. Water-rich areas strongly protest against sharing their water resources, while the aggravated deficiency of other areas creates problems in their economic development.

The impact of poor maintenance is high losses associated with supply distribution (around 25% of distributed supply). This, when combined with water deficiency that the island faces during the summer months, makes the need for network improvements and replacements imperative, especially in the high-consumption areas.

The unification of all the networks of the island, through the construction of a perimetric network, has been proposed in the Master Plan of Paros (Markantonatos, 2000). The intervention was proposed to be combined with the construction of a storage reservoir and drinking water treatment plant, at the southern part of the island. The capital costs entailed in the proposed intervention were extremely high, around 5 M€, and thus far no funds have been approved for its realisation.

No data have been provided on costs of previous network improvements and replacements. Network replacements have been integrated in the Master Plan of the island, where the highest costs (70 %) are associated with the replacement of networks in traditional settlements and tourist areas. The total cost is estimated to be around 1 M€.

Experiences from the scenario analysis

Network enhancements

Instead of analysing the costly construction of a perimetric network, the scenario analysis focused on the effect from the implementation of network expansions in order to unify the distribution networks of neighbouring municipal departments. The analysis did not incorporate the integration of additional supply enhancement options, such as boreholes or storage reservoirs, but mainly aimed to analyse the extent to which scarcity problems could be alleviated by a more equal spatial distribution of resources.

Under average availability conditions, the analysis on unification of the island's fragmented networks showed that such an option can lead to an increase of about 40 % in domestic demand coverage. This effect becomes smaller as demand increases, since larger water quantities are required for satisfying local needs before making water transfers through the new connections. Overall, the measure had a positive effect only in domestic demand coverage, an effect that is higher in water-rich years and high availability conditions. However, benefits observed are not great and are highly dependent on the yearly water availability.

All in all the option is not exceedingly expensive, with direct cost increasing only by 5% (in terms of present values). This stands only for the assumption that the unifications proposed are between neighbouring municipal departments. Those results demarcate that through combination with other, small-scale structural solutions, network unifications may prove to be an effective solution for alleviating water scarcity problems.

Network improvements

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. The network replacement program was estimated to last around 4 years, with the assigned scheduling of network replacements being made according to demand size, and current network status.

Reduction of losses through distribution network replacements shows a significant improvement in terms of domestic and irrigation demand coverage as well as groundwater exploitation. The effect is much more evident under normal/average availability conditions, reaching almost 60 % in domestic deficit coverage, but it decreases as demand gradually grows. The improvement of irrigation demand coverage and groundwater overexploitation is much lower, of about 10 %.

As with other measures that limit domestic water consumption, network replacement results in a decrease of direct costs of about 4 %. Therefore, capital expenses associated with network improvements can adequately be met through the reduction of annual operational costs associated with domestic abstractions.

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

In 1985, the Limassol Water Board embarked on an ambitious network improvement and expansion programme involving a major extension of the distribution system, which included division of the distribution network into pressure zones, each with adequate storage reservoir capacity. A series of pumping stations to lift water to higher zones was constructed. A comprehensive Supervisory Control and Data Acquisition system (SCADA) with remote terminal units was installed at all sources of water, reservoir and pumping station sites with its central control room at the offices of the Water Board was commissioned in 1988.

The topographical location of the city of Limassol is such that the elevation of the supply area varies from 0 at the coast to 315 m above sea level at the foothills. To ensure acceptable pressure limits to consumers, the entire supply area (70 km^2) is divided into seven pressure zones, each with its own storage reservoir. Ductile iron trunk mains varying in diameter from 300 mm to 800 mm supply the District Metered Areas (DMA) from their respective reservoir. The total length of the trunk mains and distribution mains is approximately 750 km.

The development of the infrastructure system takes place in a much organised fashion with new areas of supply being incorporated into their respective pressure zones, strictly governed by the areas ground contours. Each pressure zone is subdivided into DMA's, which have a single metered source with physical discontinuity of pipework at boundaries.

In late 1980 the Water Board embarked on a detailed programme of leakage management. The efforts made and importance placed by the Water Board for proper leakage management is reflected in the reduction of the non-revenue water over the years, from 25 % of total water produced in 1987 to about 16 % in 2002.

Experiences from the scenario analysis

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 Limassol Municipality, Limassol Tourist Part and Germasogeia Municipality. The measure will be applied in 2008.

Under the worst case scenario, this option shows an improvement in domestic deficit, and to a lesser extent in groundwater (over)exploitation. This measure alone cannot ensure the coverage of domestic needs, especially after 2012 when water production of the water treatment plant of Limassol is expected to reach the nominal plant capacity (the improvement after 2012 falls from 25% to less than 5% in year 2033). The option has also little influence in the reduction of irrigation deficits.

Regional Experiences from Belice Basin, Italy

Experiences from current practices

Improvements of distribution networks of aqueducts in the Garcia-Arancio districts concern the replacement of a fifty years old system, the Montescuro, whose losses are about 41%. Losses from internal distribution systems of settlements are also subject to improvement. The Montescuro system originates from the springs of the Sicani Mountains, beyond and East of the case study area, and traverses the Belice Basin from the east to west, carrying water for 100 km, and covering 65% of its urban demand. Beyond the region, it carries water to some territories of Palermo, Trapani and Agrigento.

The reduction of losses is a major policy measure in the area, but also for the entire Sicily region. Losses arise from inadequate maintenance of the pipelines but in the past water policy was always oriented towards the augmentation of available water resources rather than towards demand water management and water saving.

The local water authorities are expecting to save a significant amount of water with the Montescuro system replacement, which can be allocated for meeting increasing domestic demands. Moreover, although this policy option directly influences domestic demand coverage, an indirect positive effect appears for irrigation demand also: by reducing the water diverted to Montescuro from the Garcia Lake, more water becomes available for irrigation, to cover the summer demands.

The direct cost for this replacing the Montescuro aqueduct and for repairing internal urban networks was estimated being about 61.4 million €.

Experiences from the scenario analysis

Under the comprehensive scenario analysis context, the intervention was assumed to have effect from year 2007. The target efficiency to be reached was in the range of 79-90 %. The replacement of pipelines was coupled with an expansion of the treatment capacity of the drinking water plant of Sambuca di Sicilia, from 300 l/s to 600 l/s., which receives water from the Garcia Lake and provides the Montescuro with additional water volumes.

As expected, a positive impact characterizes domestic water savings, and consequently domestic demand coverage. There is an average 12% improvement of the domestic demand deficit, which is reached after the replacement of the aqueduct network. Instead, this option brings no positive effect to irrigation demand coverage, except for isolated and not significant improvements under the best scenario.

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 hm^3, it is not exploited at its maximum due to the limited surface water available. The maximum volume of water treated is 9 hm^3, just half of the new capacity. The situation is similar to the enhancement option of the Belice exploitation, where a negative availability scenario, i.e. forecast available runoff, makes this structural option not sufficient and completely successful.

The direct cost for plant expansion is about 5.16 million €. The analysis of the option pointed out that the increments of direct and environmental costs are limited. Environmental costs in particular change slightly: the system relies more on the water of the Montescuro aqueduct being distributed more efficiently, using less water from the already overexploited water resources of Garcia and Belice.

Regional Experiences from Tenerife, Spain

Experiences from current practices

A particular system of exploitation, private ownership and distribution resulted in more than 1,200 inventoried canals and pipelines, for a length of more than 4,000 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 almost the totality of water collected. Management of a significant proportion of these main networks is private, and corresponds to the water distribution systems for irrigation.

In spite of the continuously implemented improvement actions, 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 to his plot, it is absolutely impossible to exactly measure the exact volume of losses. Nevertheless the Infrastructure Management Plan (2000) evaluated the average total network losses at 22 hm^3/year.

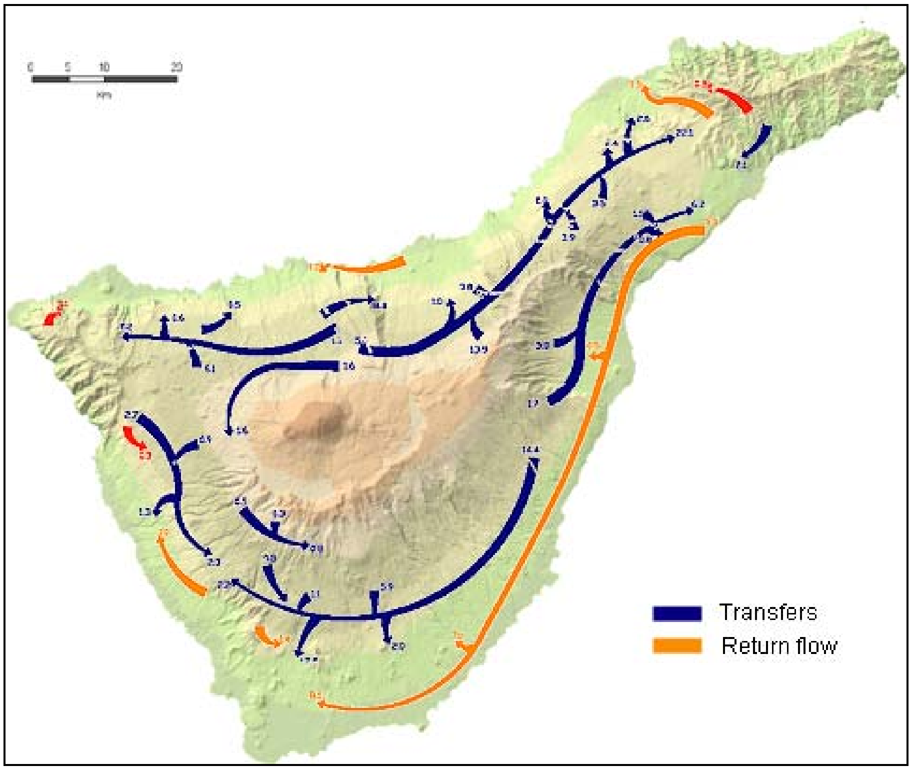


Figure 14 Water transfers between the different areas of the island

Taking into account the main network (775 km), the system can practically be considered a closed ring, although located at different levels that distributes water resources according with surplus, market and demand. This network includes main transfer canals, pipes from water galleries, pressure pipes raising water from galleries and wells at lower altitudes and finally pipelines for distribution of transferred water. It also includes a few segments of pressure transfer pipes for pumping water at different altitudes (Figure 14).

The regulatory reservoir system, promoted by the Island Council, is connected to this network, and in its turn interacts with a secondary return-flow network ring that distributes treated wastewater. This second ring is not closed, and its major segment, operating since more than 15 years, connects the metropolitan area to the southern tourist area. Connection to the northern area is still under development.

Therefore, the main problem related to water deficit is not due to the capacity to re-allocate water resources, but to the losses recorded within transfer and distribution. In spite of improvements made, general network losses are still about 18 %. Within this context it has to be underlined that canals managed by public authorities show higher losses than private ones.

At a different level, the efficient management of the municipal distribution networks greatly depends on municipal capability, or on the body/company which has a concession to run the service. This level situation presents large variations: on one hand are 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 are estimated as a whole to 22%, about 7 hm^3/year.

The complex network shaping the island water ring represents a building effort without precedents and a very strong exploitation and rationalisation of resources. Nevertheless this level of exploitation, comprising the totality of groundwater resources available, subtracts flows that were traditionally very important to maintaining high-value habitats linked to water, such as valleys, gallery woodlands, water ponds and outflows in escarpments and cliffs. This ecological function of water disappeared when the admissible exploitation limit was surpassed.

Even recognising the advantage of rationalising resources through a closed distribution system, this availability allows an open competency between final users: agricultural, tourist, industrial and domestic, with agriculture being in the worst position in these markets.

As a function of the total volumes transferred, an estimation of the costs to eliminate water losses has been calculated, giving as a result an average of 0.025 €/m^3 of water for bigger canals/pipelines and transfers, and 0.08 €/m^3 for the others. These numbers correspond to the average direct costs, since the cost to transfer water fluctuates, according to BALTEN fares, between 0.032 €/m^3 and 0.065 €/m^3.

Experiences from the scenario analysis

Scenarios establish a progressive reduction of losses, until achieving a minimum value of 10%. This means, compared with the starting situation, a deficit reduction of 5.7 hm^3/yr for irrigation water and 6.7 hm^3/yr for water supply to settlements.

Under a stabilised demand scenario this strategy allows broadly covering both domestic and irrigation deficits during a large period of time, until 2015, This effect is moderate under Business-As-Usual demand assumptions. Nevertheless, the potential of this option is obvious in the remarkable improvement in the trends of the aquifer overexploitation, notable under all cases.

Regional Experiences from Ribeiras do Algarve, Portugal

Experiences from current practices

The Primary Water Supply System existing in the River Basin already supplies most of the settlements in the different Municipalities with surface water. However, the Aljezur and Monchique Municipalities and some smaller settlements are not yet served and are still totally dependent on groundwater. The lack of the Primary Water Supply System in Aljezur and Monchique Municipalities obliges those settlements to use groundwater, facing in most cases, serious quality problems. The existent Primary Water Supply System is represented in Figure 15.

During its first years of activity, Águas do Algarve Company observed an unsustainable annual growth in demand of 9%, high above the 2% foreseen in the contract. At the same time, network improvements have become necessary. The poor maintenance of internal networks, particularly in some settlements has resulted in augmented losses and pressure drops. At present, network losses are on average 37% ranging from 16% in Albufeira Municipality to 61% in Olhão Municipality. Albufeira and Portimão Municipalities have already started investing in secondary network improvements.

The Águas do Algarve Company has been continually investing in enhancing and improving the Primary Water Supply System and, as stated before, Albufeira and Portimão Municipalities have already started investing in their Municipal water network systems. No data has been provided on costs of previous network improvements and replacements in the Municipalities but Águas do Algarve S.A. capital costs projections in enhancing and improving the Primary Water Supply System have been made available and are estimated to be approximately 66,300,000 € for all the entire concession period.

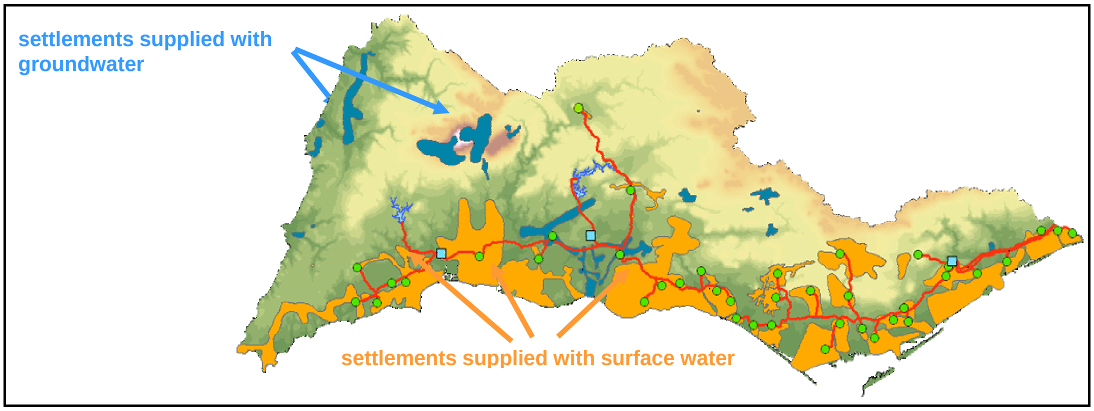


Figure 15 Primary Network System

Experiences from the scenario analysis

Network enhancements (System expansion, pipe replacements and new connections)

The implementation of network expansions will be carried out in order to provide surface water to Aljezur Municipality, Monchique Municipality and other small settlements. The analysis did not include the integration of additional supply enhancement options, such as boreholes or storage reservoirs, but mainly aimed to analyse the extent to which scarcity problems could be solved by a more equal spatial distribution of resources. The system enhancement is foreseen as schematized in Figure 16:

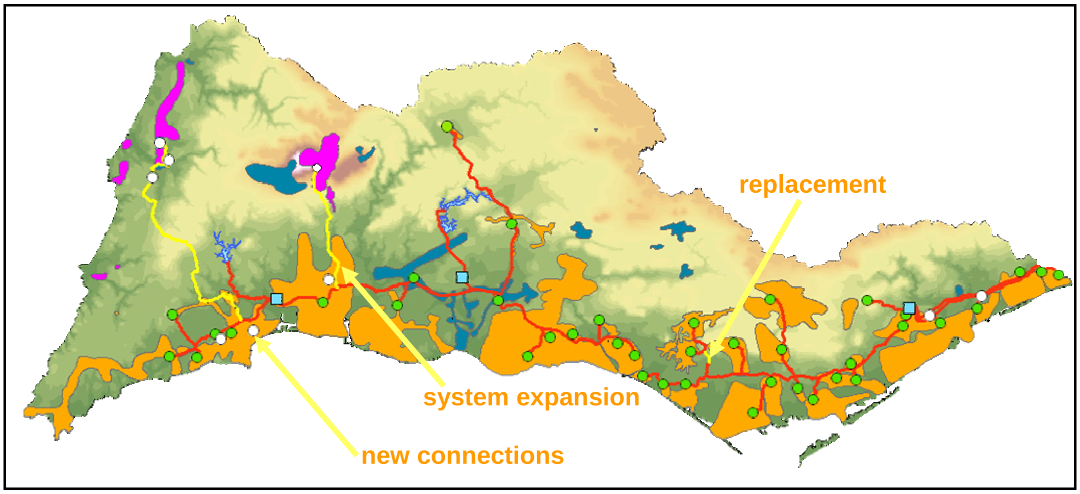


Figure 16 System enhancements: system expansion, replacement and new connections

The system expansion causes a slight improvement on domestic demand coverage up to 0.5%, whereas domestic demand coverage increases up to 2%.

However, the dependence on surface water resources increases, and this option can be effective in minimising groundwater exploitation, while allowing for the replenishment of local aquifers. In fact, the groundwater exploitation analysis showed a decrease ranging from 5 to 10 %, depending on availability and demand. Hence, the system expansion option can be perceived as a measure that could help in the mitigation of environmental impacts associated with water abstractions.

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 (present value estimates). On the other hand, after the capital cost depreciation for network expansions (2032), direct costs decrease up to 33 % by 2034. Cost recovery rates decrease by 1% for the whole Ribeiras do Algarve region.

Network improvements (Reduction of Losses)

Losses reduction were applied to water supply (secondary) network systems in all settlements of Ribeiras do Algarve River Basin, supplied with surface and groundwater. A reduction of 15 % in 15 years from 2005 to 2020 was examined.

A reduction in settlements network losses causes, under shortage conditions, an average improvement of 33 % in domestic deficit after the application of the measure. This improvement is associated with the eastern part of Algarve (Barlavento) where the measure has a higher impact. It should be noted that this part of Algarve is strongly dependent on the Funcho storage reservoir, which is affected by availability conditions. However, as demand increases and supplied volumes remain constant, the effect of the option becomes less pronounced. Consequently, this measure improves the irrigation deficit on a smaller extent, about 3 %. This improvement is attributed to the public irrigation sites Silves, Lagoa and Portimão that also depend on the Funcho storage reservoir.

Losses reduction, (not accounting for implementation periods), decrease direct costs by 1 % and increase cost recovery rates by 10% with respect to low availability and high demand reference conditions.

Chapter 9 Pricing

Overview

Water charges are based on different policies, depending on the availability of water resources at the national or regional level. This complexity makes the assessment of the influence of water price on the reduction on water demand problematic. It also makes the comparison of water prices between different countries difficult. Complexity relates to the different concepts included in water bills (tariff structures and charging methods), as well as to the different national water management systems.

In general, water bill composition over the last few years has depended on the development of water policies. Components of water bills usually include a part related to the water supply service (e.g. water supply, water treatment, and network maintenance), and other parts related to other institutions (e.g. treatment tax, collection system and other taxes).

In general, users see the inclusion of different components into water bills as a way of paying more taxes not necessarily related to the water used, especially if the new taxes are calculated for a fixed quantity of water. Water prices are also influenced by the quality of the water supplied. The cost of providing water of a certain quality to the user, of maintaining a functional supply network, and of providing high quality customer services, all play important role in the formulation of the overall price.

In this respect, pricing can be used as a tool to control water uses in domestic, rural, and industrial settings.

Regional Experiences from Paros Island, Greece

Experiences from current practices

Domestic pricing in Paros is volumetric, following a tariff structure where the price of water differs according to the consumed volume and the season (prices are higher during the summer). Although there is a unique service provider for the entire island, there are different tariffs for each municipal department. In spite of the water stress conditions, the price of water remains considerably low when compared to the prices applied in other, similar regions in Greece. For a typical consumption of 30 m^3/trimester, Paros shows a total charge of 10.80 €, while on other islands the same charge ranges from 20 to 37 €. Therefore it can be concluded that the conservation incentives of existing tariffs are extremely low. However, very strict penalties are applied for wasteful water use (use of domestic water for car washing, irrigation, filling-up of swimming pools, patio and balcony hosing instead of sweeping and mopping etc).

On the other hand, irrigation pricing is almost non-existent. Only the farmers of the western part of the island pay a very small fee which covers part of the operational expenses of the local water service provider.

Although the current domestic pricing system meets the operational expenses of water service provision, it does not provide incentives that could promote water conservation and therefore result in the protection of fragile water resources. The impact of penalty enforcement is questionable, since control mechanisms are insufficient, especially during the summer. The same conclusions stand for irrigation, where the lack of metering and the absence of a pricing system, even in the simplest form of area pricing, foster overexploitation and wasteful water use.

Experiences from scenario analysis

The domestic water pricing scheme that was examined was a gradual increase of average prices up by 50%. Additionally, for estimating the impact that a small pricing system would have on irrigation demand, it was assumed that initially prices for irrigation would be set at 0.07 €/m^3, gradually increased by 0.02 €/m^3 every two years during the period 2005-2009. In both cases and in absence of estimates, high elasticities have been assumed.

Domestic pricing performs better under average or high availability conditions, while the limited water availability under a drought diminishes the effect of the pricing scheme, even with an assumed high demand reduction. Similar, but smaller improvements are observed for irrigation demand coverage, and groundwater exploitation (around 25 and 10% respectively).

As with domestic use, irrigation pricing has a significant impact on agricultural demand. The high price increase and the relatively high tentative elasticity assumed led to a considerable improvement of domestic and irrigation deficits, and groundwater exploitation. Although one would expect that improvements would be of the same magnitude as those of domestic pricing, this is not the case. The low priority of irrigation compared to domestic demand coverage renders the use more vulnerable to availability variations, and almost diminishes the effect that pricing would have on the alleviation of the respective deficit and groundwater over abstraction.

Since direct costs are associated with domestic use only, domestic pricing results in a significant decrease of direct costs, which exceeds 10%. The opposite stands for irrigation pricing, where the minimisation of irrigation consumption results in higher water availability for the domestic sector.

Regional Experiences from Limassol region, Cyprus

Experiences from current practices

Cyprus applies a quota system for the allocation of Government irrigation water in combination with penalty charges for over-withdrawals. These market-based structures contribute to the efficient use of water. Under conditions of water scarcity, especially during droughts, priority and preference is given to covering a higher proportion of the domestic supply followed by greenhouse cultivations and permanent crops. Seasonal crops under these conditions are reduced dramatically.

Cyprus has a strongly regulated water market. The Water Development Department (WDD) is a natural monopolist for domestic water and for part of the irrigation water; because about half of the supply of irrigation water comes from Government Water Works.

Contrary to the costs of domestic water that is fully charged to customers, the price of irrigation water does not cover full financial, let alone economic, costs. This so-called under-pricing has various effects on society, a number of which are economic while others are social and environmental effects.

At present farmers pay 0.055 to 0.07 CY£/m^3 for Government irrigation water (about 0.10 €/m^3) depending on the irrigation project they are in, while the price for domestic water in 2001 was 0.335 CY£/m^3 (about 0.58 €/m^3). The WDD has calculated that the costs of supplying government irrigation water in 1999 was 0.287 CY£/m^3 (about 0.49 €/m^3).

The WDD supplies potable water from Government Water Works to the three Water Boards of Nicosia, Larnaca and Limassol as well as to the 83 Municipalities and Village authorities in the four Districts, Nicosia, Larnaca, Limassol and Famagusta. Water is also supplied to the Turkish occupied part of Nicosia and Famagusta, although the latter do not pay any water charges.

The present water tariff of CY£ 0.335 per m^3 (about € 0.58) set by the WDD was approved by the Council of Ministers in 1993. With the commencement of the operation of the Limassol Water Treatment Plant in 1994, the same price of 0.335 CY£/m^3 was approved by the Council of Ministers in 1994 for the Limassol area.

Setting progressive block tariffs, seasonal prices and over-consumption penalties for the purpose of promoting efficiency and conservation objectives in water use, lies within the jurisdiction of the local authorities and the Water Boards that are responsible for the distribution of the water within the various urban and rural centers. The water tariff structure imposed by the Water Boards is made of two parts: a fixed charge and a volumetric charge. Tariff rates are progressive; the volumetric charge increases as consumption increases. This progressively promotes water conservation. Household water use metering is universal in Cyprus. In contrast, the WDD sells the water in bulk and at a unified price.

In Limassol, domestic water is sold at a price appreciably lower than that of Nicosia and Larnaka. For example, a household having a water consumption of 180 m^3 per year pays only 31.80 CY£ in Limassol, 54.00 CY£ in Larnaka and 77.40 CY£ in Nicosia. This stems from the fact that the Limassol Water Board receives about 4.4 hm^3/yr from the Government Water Works without any charge (as a replacement of own sources affected by dam construction).

For publicly supplied irrigation water, the WDD sets water tariffs, which need to be ratified by Parliament. The present tariff is 0.0631 CY£/m^3 (0.11 €/m^3). The Loan Agreements with the World Bank and the Kuwait Fund suggest that the price of the water should be at least 38% of the weighted average unit cost, i.e. 0.1164 CY£/m^3 (0.20 €/m^3). It follows that the price should be increased to be in accord with the financial covenants of the Loan Agreements. The increase from 0.0631 CY£/m^3 to 0.1164 CY£/m^3 can be progressive in time.

The water tariff levels for other uses follow a middle course in between the existing irrigation and domestic tariff levels. For example, the present water tariffs for industrial use and animal husbandry are 0.20 CY£ and 0.13 CY£/m^3 respectively. All tariffs need the approval of the Council of Ministers and then of the House of Representatives.

In view of the WFD Implementation Procedures, a pricing reform is underway by the Government, regarding domestic and irrigation supply from the Government Water Works. Accordingly, from 01/01/2004 the bulk domestic water tariff was adjusted to 0.45 CY£/m^3 for water supply in the areas of Larnaca, Famagusta, Nicosia and Limassol, and to 0.33 CY£/m^3 for the district of Paphos. Irrigation water tariffs are progressively increasing in all Government Irrigation Projects, to reach the uniform tariff target of 0.11 CY£/m^3 in 2007.

Experiences from the scenario analysis

Irrigation Water Pricing

This option examines the case of raising the irrigation water prices from 0.07 CY£/m^3 to 0.11 CY£/m^3 within a period of 3 years. The adopted values of the elasticities for the permanent crops are 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. 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. This option also has positive effects in groundwater exploitation index but does not affect the domestic deficit.

Domestic Water Pricing

The domestic water supplies in the study area are managed by the Limassol Water Board and by the Municipalities, Improvement Board and Village Water Committees. A block structured water tariff is applied in the study with an average cost of 0.5 CY£/m^3. The present water tariff charged by the WDD to the three major city Water Boards is only 0.27 C£/m^3, while charges to the Municipalities and Village Authorities are 0.335 C£/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.

Under this management option the domestic deficit throughout the simulation period (2002 – 2033) is reduced by almost 38%. 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). This option has also positive effects in groundwater exploitation index and total direct costs.

Regional Experiences from Belice Basin, Italy

Experiences from current practices

An intervention involving domestic pricing was tried out to understand to what extent a rising water selling price would influence the allocation of water among the conflicting uses and the exploitation of alternative resources. This information will be used by the local agencies for water services to establish the proper price which assures adequate cost recovery for interventions required to face the forecasted increase in consumption rates.

Experiences from the scenario analysis

An increase in the water selling price for domestic users was examined for the case study of Garcia-Arancio. Standard values of demand elasticity were used, such as 0.2 for the permanent population of settlements, and 0.35 for the seasonal component and the tourists. The price was assumed to grow 1.87 % each year in the examined period, from an initial value of 0.8 €/m^3 to a final 1.1 value of €/m^3 after twenty years.

Results show the evident impact of the price increase over domestic demand and deficit. Demand is reduced according to the elasticity demand parameter specified for the permanent and seasonal population, and as a consequence the deficit is heavily affected. However this effect was expected, along with the trend of the improvement, which follows the specified growth of the selling price. Of course the unmet demand for irrigation is not affected by this option, given that no price elasticity was assigned to irrigation sites. The only exception is under the worst scenario, which is characterized by a growing demand scenario and the low availability conditions. In this case the significant reduction of the domestic demand leaves more water available for the irrigation sites and an improvement of deficit appears.

In terms of costs, a reduction of direct costs by 0.8 % completes a positive effect of the option.

Regional Experiences from Tel-Aviv and Arava regions, Israel

Experiences from current practices

There is no private ownership of water in Israel. By the Israeli Water Law of 1959, all water sources are publicly owned, and their utilization is controlled by the Water Commissioner. A single government-owned company, Mekorot, operates the NWC and provides approximately 60% of the total water supply; regional cooperatives, 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 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.

Prices of water delivered by Mekorot are set by the parliamentary finance committee, and are based on the 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 (skillfully 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. 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. Private water producers set prices independently.

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/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.

Water prices vary with quality. Water with over 400 mg of chlorides per liter is charged at a lower rate than fresh water, according to its salinity level, with the average price being $0.16/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 120 mcm per year, for agricultural use in the southern region (western and northern Negev), 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 the price charged for the agricultural consumers. In other words, 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 operating 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.

Production (extraction) levies are imposed on all the producers, including Mekorot, and are intended to reflect the “shadow price” or “scarcity rent” of some of the limited groundwater resources. They also pay the production and conveyance costs. Levies for water extraction from the Coastal Aquifer are equal to 0.10 $\$/m^3$ while for extraction from other aquifers, they are equal to 0.09 $\$/m^3$

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. The person officially in charge of determining water policy is the **Minister of Infrastructure** or the **Minister of Agriculture** depending on the existing governmental coalition. 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.

As mentioned above, decisions on water prices are made in the political arena and are affected by pressure from interest groups. Each of them attempts to affect public decisions in its favour. The two strongest groups in the Israeli water sector with different interests are the workers of Mekorot and the farmers. The main interest of the farmers is to receive a large water allocation at the lowest possible price. Water is a significant input in agricultural production in arid and semi-arid regions like Israel, and many farmers give firm support to their representatives in the political arena. The agricultural lobby is very well organized, and up to now its influence on water policies and pricing decisions has been significant. The share of water costs in the budget of households or in the cost of manufacturing is relatively small. Therefore urban and industrial water users do not have much incentive to organize political lobbies and, in effect, do not compose a strong opposition to the agricultural lobby. The consequences of the success of the agricultural lobby have been over-utilization of water for many years, hydrological deficits, intrusion of seawater into the coastal aquifer, the contamination of reservoirs, and the reduction of the carry-over capacity of the system. These detrimental effects are among the major reasons for the current severe water crisis. Although still very influential, the agricultural lobby has lost some of its political power in the last two decades.

Unlike the urban and industrial sectors, the agricultural demand is elastic and can be reduced significantly if water prices will be increased. Many experts suggest a sharp raise in the price of water to the agricultural sector in order to reduce consumption significantly. The price elasticity of the agricultural demand for irrigation water in Israel is estimated to range between -0.5 to -1.

No scenario involving changes in water prices was examined for the region of Tel Aviv.

Regional Experiences from Tenerife, Spain

Experiences from current practices

Domestic Water Pricing

Different price policy options have been applied and tested in Tenerife since more than two decades. Table 14, elaborated from data relative to each municipality shows the difference of criteria applied, although under the common denominator of adopting a progressive price system, increasing unit price as soon as consumption increases.

The application of this price system, especially in the metropolitan area of Santa Cruz de Tenerife, had excellent results since its introduction. The annual report of EMMASA (municipal water company) showed that in 1993 the city was buying less water than in 1974, thanks to the application of a combined strategy of progressive prices and network loss prevention.

Nevertheless, although the pricing policy is similar in all municipalities bar a couple of exceptional cases, both prices and segments of application show large variations, which cannot be justified within an interconnected insular system.

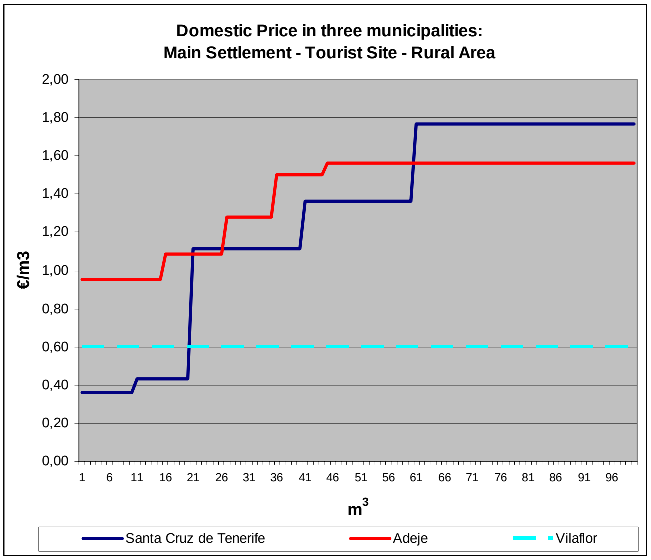


Figure 17 Domestic water Price differences in Tenerife

Differences are illustrated in Figure 17, showing the progressive price system of two representative municipalities (connection fees are not included). The case of Vilaflor is considered exceptional, being a rural municipality with widespread population. But comparing Adeje (tourist municipality) with Santa Cruz (metropolitan area), the important difference existing in the first segment of consumption is evident.

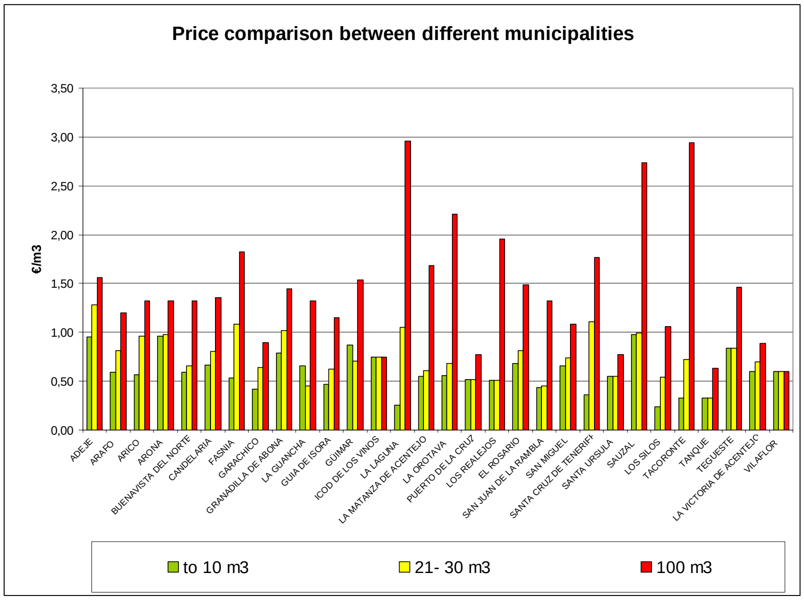


Figure 18 Price comparison between municipalities of different sizes

Table 14 Progressive price system in the different municipalities of the island

Municipality	Water quantity in m^3								
	<=10	11–15	16-20	21-30	31-40	41-50	51-60	61-75	>75
ADEJE	0.96	0.96	1.09	1.28	1.50	1.56	1.56	1.56	1.56
ARAFO	0.59	0.81	0.81	0.81	1.03	1.03	1.03	1.20	1.20
ARICO	0.57	0.96	0.96	0.96	1.08	1.08	1.08	1.08	1.32
ARONA	0.96	0.96	0.97	0.97	0.85	0.85	1.10	1.32	1.32
BUENAVISTA DEL NORTE	0.60	0.66	0.66	0.66	0.66	0.66	1.32	1.32	1.32
CANDELARIA	0.66	0.81	0.81	0.81	0.97	0.97	0.97	1.35	1.35
FASNIA	0.53	1.08	1.08	1.08	1.68	1.68	1.68	1.68	1.82
GARACHICO	0.42	0.42	0.42	0.64	0.64	0.74	0.90	0.90	0.90
GRANADILLA DE ABONA	0.79	0.78	0.78	1.02	1.02	1.44	1.44	1.44	1.44
LA GUANCHA	0.66	0.00	0.45	0.45	0.45	0.45	0.45	0.45	1.32
GUIA DE ISORA	0.47	0.47	0.47	0.63	0.63	0.97	0.97	1.15	1.15
GÜIMAR	0.87	0.71	0.71	0.71	1.02	1.02	1.02	1.54	1.54
ICOD DE LOS VINOS	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
LA LAGUNA	0.26	0.26	0.26	1.05	1.88	2.51	2.96	2.96	2.96
LA MATANZA DE ACENTEJO	0.55	0.61	0.61	0.61	0.90	0.90	0.90	1.68	1.68
LA OROTAVA	0.56	0.56	0.56	0.68	0.68	1.05	1.05	1.05	2.21
PUERTO DE LA CRUZ	0.52	0.52	0.52	0.52	0.62	0.62	0.77	0.77	0.77
LOS REALEJOS	0.51	0.51	0.51	0.51	0.51	0.94	0.94	0.94	1.95
EL ROSARIO	0.69	0.81	0.81	0.81	0.81	1.24	1.24	1.37	1.49
SAN JUAN DE LA RAMBLA	0.44	0.44	0.45	0.45	0.45	0.45	0.45	0.45	1.32
SAN MIGUEL	0.66	0.66	0.66	0.74	1.08	1.08	1.08	1.08	1.08
SANTA CRUZ DE TENERIFE	0.36	0.43	0.43	1.11	1.11	1.36	1.36	1.77	1.77
SANTA URSULA	0.55	0.55	0.55	0.55	0.60	0.60	0.60	0.77	0.77
SANTIAGO DEL TEIDE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SAUZAL	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.95	2.73
LOS SILOS	0.24	0.48	0.48	0.54	0.73	0.87	1.06	1.06	1.06
TACORONTE	0.33	0.33	0.33	0.72	1.11	1.38	2.95	2.95	2.95
TANQUE	0.33	0.33	0.33	0.33	0.46	0.63	0.63	0.63	0.63
TEGUESTE	0.84	0.84	0.84	0.84	1.05	1.05	1.05	1.05	1.47
LA VICTORIA DE ACENTEJO	0.60	0.70	0.70	0.70	0.77	0.77	0.89	0.89	0.89
VILAFLOR	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

However, what is really surprising is that this criterion is not applied to special consumers, particularly within the tourist sector. In this case fares are surprisingly flat and vary between 1.17 €/m^3 and 1.28 €/m^3 in the tourist municipalities of the south, and are of 1.08 €/m^3 in the only predominantly tourist municipality of the north of the island. This policy does not seem to favour water saving in this sector, which is an increasingly important resource consumer.

Within the first price segment (consumption until 10 m^3) variations between 0.29 and 0.96 € are recorded, the differences being less pronounced in the case of middle consumption segments.

Irrigation Water Pricing

One of the most relevant features of water resources on the island is that the ownership of most available water is private. Members of "Water Communities" are also the major users of water sold or distributed for irrigation. Established prices for water owners, when consuming more than their share, vary between 0.20 €/m^3 and 0.30 €/m^3. However, for non-owners, reference prices taken into account are those established by the public company, which vary between 0.27 €/m^3 and 0.38 €/m^3 according to the zone.

Under these special conditions, any price policy in the agricultural sector is pointless, since the market actors themselves are those who regulate the situation. Non-owner consumers mostly have to face the problem of resource unavailability in the market, rather than a price problem.

No pricing scenarios were analysed for Tenerife.

Regional Experiences from Ribeiras do Algarve

Experiences from current practices

Domestic pricing in Ribeiras do Algarve is volumetric, following a tariff structure where the price of water differs according to the consumed volume.

There are two levels of water service supply: the first level represented by Águas do Algarve Company is responsible for the Primary Water Supply System; on a second level, each Municipality is responsible for providing water and sewerage services to each settlement network. There is an exception to this scheme for Aljezur and Monchique Municipalities, currently entirely supplied by groundwater, and where the Municipality is the unique water service provider.

There is a unique tariff charged to all the Municipalities by Águas do Algarve S. A. of 0.33 €/m^3. This value guarantees the total recovery of all operational costs of the service provided by that Company. On the contrary, there are different tariffs set by each Municipal department ranging from 0.41 €/m^3 in Vila do Bispo Municipality to 1.04 €/m^3 in Aljezur, according to the National Water Plan. These tariffs consist of a fix fraction (referred as water-meter renting) and a variable dependant on the amount of water consumed.

Still according to the National Water Plan, the rate of cost recovery, concerning water distribution and sewage service of each Municipality is 30% on average, varying from 60% in Portimão to 16% in Vila do Bispo. Therefore, it can be concluded that in order to fulfil the WFD principle of "recovery of the costs of water services, including environmental and resource costs", Municipalities urgently need to revaluate water prices and water service management.

On the other hand, irrigation pricing is only applied to public irrigation sites. Farmers associations that set water-selling prices according to the operational and maintenance costs manage the latter. Water irrigation fee composition varies according to each farmer's association, i.e. while some farmers pay only a fixed fee, others pay a tariff composed by two shares, one for each irrigated hectare and other for each m^3 of water consumed. The tariffs vary from 0.15 €/m^3 in Silves, Lagoa and Portimão irrigation site to 0.02 €/m^3 in Sotavento irrigation site, covering part of the operational expenses of the local water service provider.

For private irrigation sites, managed by each farmer and irrigated only by groundwater, there are no tariffs associated. Each farmer is responsible for capital, operation and maintenance costs and no groundwater abstraction limit is imposed.

The current domestic pricing system, when analysing Municipalities as a service provider and according to the Water National Plan, does not meet financial costs directly associated with water service provision and does not provide incentives for protection of fragile water resources, i.e. resource and environmental costs. On the contrary, Águas do Algarve S.A. already meets water primary network operational expenses in terms of direct costs, although the company does not yet consider environmental costs in the economic analysis. In relation to irrigation consumption, only farmers belonging to public irrigation sites pay a price which, in most cases, meets specific operation and maintenance costs but does not meet capital costs. In private irrigation sites, which correspond to 61% of the irrigation area, farmers do not pay any price for use of water but are responsible for capital and specific operation and maintenance costs associated with groundwater exploitation. Similarly to what happens for domestic use, no environmental costs are charged.

Experiences from scenario analysis

The domestic water pricing scheme that was examined was a gradual increase of average prices up to 50% corresponding to a price increase of 0.02 to 0.03 €/m^3 for each Municipality every two years, between 2005 and 2020.

Relating to irrigation, a price increase of 4%/year corresponding to a 0.01 €/m^3 water selling increase every two years, for some selected public irrigation sites and golf courses that did not meet operational costs. In both cases and in absence of estimates, a value of - 0.5 for elasticity was assumed.

Chapter 10 Discussion

Overview of experiences from the Case Studies

Desalination

Although desalination is a water supply enhancement option of increasing popularity in certain countries, at the same time it is highly unpopular in others due the high financial costs. In the Greek islands, desalination has recently been widely used to cover the increased water demand during summer months. At the same time, the use of the desalinated water for irrigation during the off-peak season has helped in resolving certain social conflicts in water usage between farmers and domestic users, which constituted desalination as a socially favourable structural solution.

On the other hand, in other countries desalination is either not widely practiced, e.g. in Italy, or there is a lot of concern over the use of this option. In Cyprus, for example, concern derives from the fact that the power grid of the island (and therefore desalination energy supply) is dependent on fossil fuels. Additional constraints are related the fact that desalinated water is made available at high cost even at times when no freshwater deficit is experienced. Even in this case, however, a certain quantity of water should be bought by the Government from the private entrepreneur. In Israel, up to now the commercial supply of desalinated water was marginal. In recent years the policy of the Israeli Water Commission changed in favour of one that will prevent shortfalls in water supply in order to ensure stabilization of the country's water supply system in the future. Emphasis is given currently on the implementation of large-scale desalination and water recycling and reuse in an effort to protect the vulnerable, already overexploited natural freshwater resources. The main reason for the delay in implementing desalination was the high cost and conflicts between the government-owned company, Mekorot and private entrepreneurs over privatisation of the water sector.

The island of Tenerife, and the Canary Islands in general, are among the most advanced areas in the world with regard to water desalination. For reducing impacts related to brine discharge, strict environmental regulations are applied to all units under operation. With regard to energy consumption, recently adopted strategies focus on the increase the share of renewable energies (mainly wind power) to respond to these new demands until maximum penetration to the grid is achieved. At present it is estimated that between 2003 and 2006 a number of new desalination plants will start functioning, increasing total capacity by more than 30%. With respect to future water management policies, one important outcome of the undertaken analysis is that perceiving desalination as a unique solution to deal with currently increasing water demands has the evident risk of resulting to oversized infrastructure, and therefore high costs to be recovered by the end-users.

In Ribeiras do Algarve, desalination is not a widely practiced option. In examining alternatives, it has been estimated that the construction of one of two desalination units enabled a decrease of 0.22 hm^3 (11%) at the overall irrigation unmet demand, solving local problems. Overall, the increase in financial costs isminor; however when estimating financial costs on a local basis, it was found that the option can cause a cost increase up to 250%.

Recycling and Reuse

The application of water recycling and reuse is still very limited in Greece; there is little consideration for the use of treated effluents for crop or landscape irrigation due to the limited public acceptance. Although water recycling had been suggested for Paros in the past, such efforts were not applied due to social reluctance and high costs involved.

However, this is not the case in other Mediterranean countries, where impacts are considered positive. In Cyprus, and in order to promote water reuse, the Government undertakes all the costs concerning the construction and operation of tertiary treatment facilities as well as the conveyance of the treated effluent to the farms A campaign to convince farmers to accept treated sewage effluent is an ongoing process, supported by initially setting the price for treated water to zero cost. Interest in reusing this water is currently gaining momentum; however problems are experienced with respect to the interseasonal storage of treated wastewater.

The Land Reclamation Agency of Garcia-Arancio districts in Italy has started considering wastewater reuse as an effective potential water management option for providing adequate and reliable water supplies to irrigation, and assist in the conservation of water resources.

In Israel, although there is conflict on water use and cost between the interrelated sectors, water recycling and reuse are considered socially desirable options. Potential expansion is expected to create conflicts between the allocation of treated wastewater to the agricultural sector and ecological utilisation (landscape irrigation, river rehabilitation etc). In addition, conflicts arise for purification of standards and consequently allocation of costs between the urban and agricultural sectors. While the supply of effluents by the cities is stable over the year, most of the agricultural demand is limited to the dry summer period. This necessitates the allocation of large land areas for the construction of environmentaly friendly, expensive reservoirs, to store the treated wastewater from winter to summer, and support of the sector through Governmental subsidies. Examination of future expansion implies that increase of the supply of recycled water to agriculture is a socially profitable option.

In the island of Tenerife, only 54% out of 365,041 dwellings are connected to the sewerage network, a fact that represents a serious environmental handicap and an important loss in the capacity of recycling wastewater. However, Tenerife has been a pioneer in wastewater reutilisation for garden irrigation and transfer of water surplus to the drier south of the island for agricultural use. Within the examination of future alternatives, one conclusion drawn was that the measure can involve a considerable reduction of the agricultural water deficit, as well of the deficit related to gardening and golf courses. However, the effect in reducing groundwater (over)exploitation is limited to only a few circumstances.

In Ribeiras do Algarve, Portugal, treated wastewater is mainly used for irrigating golf courses. Capital costs, as well as operation and maintenance costs, are considered to be totally supported by golf course owners, in areas where this method is implemented. In the analysis of future alternatives, water reuse is expected to solve water availability problems by considerably decreasing unmet demand, and protecting aquifers from overexploitation, abandoning the poor quality groundwater supply and enabling sustainable development.

Groundwater Exploitation

During the last decade, aquifers in the Mediterranean have exhibited serious depletion trends. Repeated and persistent drought episodes reduced direct and indirect groundwater recharge, while the construction of dams further reduced recharge of downstream aquifers.

Groundwater exploitation is a commonly used method in Greece, where until recently the groundwater reserves were adequate. The main advantages of the method were the low cost entailed in the use of boreholes (lower than the cost of major structural solutions, such as reservoir construction or desalination), and the ease in implementation. However, additional groundwater exploitation is the option that has the worst performance among the examined structural interventions. Although it may assist in meeting some domestic requirements, this effect is almost diminished in cases of drought and increasing demands.

During the last decade, aquifers exhibited serious depleting trends in Cyprus. Repeated and persistent drought episodes reduced direct and indirect groundwater recharge, while the construction of dams further reduced recharge of downstream aquifers. Groundwater resources in Cyprus are overexploited by about 40 % of sustainable extraction, while a recent assessment of groundwater resources shows an overall annual negative balance of 15 hm^3. Most coastal aquifers are at a very low level and partially intruded by seawater. However, in recent years the use of groundwater for domestic water supply has been significantly reduced, being replaced by seawater desalination. Currently groundwater is exploited to mainly supply irrigation in areas not connected to the public water supply system. There is no charge for groundwater extraction and the operation and maintenance costs for pumping to each farmer are far below the charge for surface water obtained from the Government Water Works. This situation renders the use of groundwater preferable to the farmers.

In the Belice River Basin the main resource of the area is the surface water; however, a minor exploitation of groundwater is present. Additionally, groundwater is used by domestic users through private wells, and is accounted by the local water supplying authorities as local resources.

In Israel, the current policy focuses on aquifer rehabilitation, with the aim of raising the average water level and putting a stop to quality deterioration. This is performed through the selective limitation of pumping approval in areas with severe salinity and quality problems. Reduction in groundwater abstraction increases the need and pressure to create alternative water sources by desalination and wastewater recycling. In the examination of alternatives, the option to reduce agricultural water shortages via over-pumping was found to be socially undesirable. On the other hand, under low availability conditions, the highest percent improvement in the deficit of all sectors is obtained with over-pumping. On this ground, this management option may be advocated by political lobbies of all sectors, especially the agricultural one.

In Tenerife, groundwater is still the main water resource, representing more than 90% of total available water. From the beginning of the century 1,047 water galleries have been drilled, some deeper than 7 km, and most of them do not yield any water at present. In total more than 1600 galleries were made, creating a really spectacular water mining work. At the end of the 1970s the maximum exploitation limit was reached, and over exploitation of the aquifer started to take place, with the well-known effects of salinisation and sea intrusion at the coastal level. Under the above conditions the possibility to cover the existing deficit through new boreholes is rejected, with the exception of only a few cases of low significance.

Algarve is the region of Portugal where groundwater assumed the most important role. In fact, the exploitation of these resources made tourism and irrigated areas development possible, in the beginning of the 1970s. The intensive use of groundwater for different purposes led to high density of vertical boreholes (10 boreholes/km^2), probably the highest in the country. After the shift from groundwater to surface water supply for domestic use, most of the aquifers do not present water quantity deficiency. Combined/sustainable management of surface and groundwater resources, at this stage, has not been considered as a development strategy, but may be considered in the future.

Storage Reservoirs and Dams

The use of dams or storage reservoirs for water supply is a widely used option. However, in the island of Paros no large dams or storage reservoirs have been constructed thus far, and consequently surface water exploitation is mainly associated with the construction of small interception dams, aiming to enhance groundwater storage. Two proposals for the construction of storage reservoirs have been made; the first involving the construction of a dam, with 450,000m^3 capacity, for domestic supply and the second the construction of an interception dam, the estimated capacity of which was about 98,000 m^3. The scenario analysis for these two new constructions demarcated that storage reservoirs, particularly when used for aquifer replenishment, can be an effective solution in meeting the domestic and irrigation needs of the area, as well as in minimising groundwater exploitation.

In Cyprus, since 1960, attention was turned to the systematic study and construction of water development works, both for storage and recharge purposes. A long-term plan for the construction of major development projects was followed, involving the construction of a large number of dams. The current total storage capacity of surface reservoirs has reached 307.5 hm^3 of water from a mere 6 hm^3 in 1960, and will reach 325.5 hm^3 with the completion of the Kannaviou dam. This is a truly impressive achievement when compared to other countries of the same size and level of development as Cyprus.

In Garcia-Arancio and the Belice Basin the agricultural and domestic water needs are mainly met by the supply of surface water stored in the two interconnected artificial reservoirs of Arancio and Garcia. The construction of the two reservoirs covered the water needs of both areas, boosting the agricultural development in the region served by the Arancio reservoir, and providing water for irrigation and domestic use in the area served by the Garcia reservoir. In the examination of alternatives, the expansion of the station recharging the Arancio lake can bring advantages to the supplied irrigated districts, while additional supply to the Garcia is supposed to influence mostly the urban demands, as they have a higher allocation priority with respect to irrigation requirements.

The only significant natural source of surface water in Israel is the Jordan Sea of Galilee system. The Sea of Galilee is a valuable ecological and tourist asset, being the most popular vacation site in the country. As a result, a crisis in the water economy, leading to a low water-level policy, has several environmental, public and economic implications. The Master Plan of the water economy calls for preservation of high water levels by means of, inter alia, desalination and recycled wastewater as alternative water sources.

In Tenerife, the development of reservoirs to harness surface run-off was one of the greatest failures of all the hydraulic projects implemented between 1940 and 1970, because of the irregular nature of rainfall and the difficult characteristics of the terrain. The current inventory of reservoirs (45 operating irregularly) provide a storage capacity of 4.5 hm^3, used occasionally for storing groundwater from galleries or for harnessing surface run-off water. This system allows decreasing the irrigation deficit with rates that vary from 25% to 58%. Environmental impacts are the big restraint to this system and to its further generalisation. Therefore the Hydrological Plan only considers already existing locations (natural collecting pools formerly artificially modified) without any possibility of enlargement. In the analysis of alternatives, culmination of the Plan and intensive use of reservoir infrastructures allows for an important reduction in the cost faced to supply this water for agricultural use, between 20 and 35%. Analysed scenarios considered this cost reduction applying it progressively until 2020. Another important aspect to take into account is the indirect influence of the system on the improvement of global costs of water transfer and the positive effects on desalination costs due to storage possibility and/or mix with different quality water.

In the Ribeiras do Algarve, groundwater supply assumed a very important role until the late 1990s, with domestic water supply being based on a large number of municipal network systems utilizing the water from the existing aquifers. Surface water is at present the most significant water source for domestic water supply due to the current trend towards identification, construction and exploitation of storage reservoirs. Moreover, public irrigation sites are supplied with surface water from the existing storage reservoirs. Additional dam construction has been prioritized in matters of covering the domestic water demands. Scenario analysis has demarcated Odelouca storage reservoir as an effective solution in meeting domestic coverage, with an improvement o up to 25% by 2035 under shortage conditions. At the same time, Odelouca dam can improve irrigation demand coverage through the reallocation of surface water from existing dams to agricultural purposes.

Conservation Measures in Domestic Use

Conservation is a popular option, which has been widely practiced in the Mediterranean. In all the Southern Aegean Islands of Greece, conservation used to be effected through cisterns, functioning both as water tanks and rain-fed reservoirs. In Paros the construction and use of cisterns in households, and the installation of low flow taps in households and hotels provides an estimated improvement of 10% in the alleviating the pressure on available water due to the use of cisterns. However, the expansion of the application in the hotel sector is considered unrealistic, given the current legislative and socio-economic environment. Conservation measures in Paros were found to result in a decrease of about 9-10% of the total direct cost of the system, occurring due to the lowered water production.

In Cyprus, several conservation measures have been taken in an effort to deal with prolongued drought. The application of conservation measures in the domestic sector was assessed assuming that a reduction of 10% in the domestic demand could be accomplished. This option was identified to have positive effects in terms of groundwater overexploitation and direct cost. This is due to the reduction of the groundwater abstractions in order to supply domestic purposes. This measure alone cannot, however, ensure the coverage of the increasing domestic needs.

Water conservation is a common practice in Israel; the country is currently investing in water conservation measures (urban water saving devices), public education, and media campaigns on water saving, the amount of 160 million US$ for the decade 2000-2010, which is expected to result in water savings of about 100-130 hm^3/year. As the unit cost of desalinated water is greater by about 3.5 times than the cost of water saving, the water conservation approach is a socially profitable and desirable option for Israel.

Irrigation method improvements and Crop changes

Although agriculture in Paros Island is not the major economic activity, it is vital to the local economy and social structure. The measure examined in this case was the transition from the currently used irrigation methods, mainly furrow irrigation, to drip irrigation, which is most efficient, for all crop types except cereals. Although improvement in irrigation deficits was found to be significant, irrigation demand was not fully met, especially in cases of drought, when available supply is low and a higher priority is given to domestic uses. However, the option is the only identified means of modernizing irrigation and ensuring the preservation of agricultural activities for the island.

In the Garcia-Arancio district, irrigation efficiency has been progressively and continuously under improvement. Water can be further saved by using the drip irrigation method instead of sprinklers, which at present are most popular in the region. Although a gradual shift to a complete use of the drip method is on the agenda, the impact analysis reveals that this kind of policy measure does not influence remarkably the water availability for agricultural use. In the long run, the estimated positive effect on irrigation demand coverage is minor (only 2%) and only under high shortage conditions (worst case scenario). The estimated increase of direct cost is high, reaching approximately 20%.

In Israel, where the continuing water scarcity is an excellent economic incentive for breakthrough in irrigation technologies, drip irrigation and micro sprinklers result in an estimated reduction in water loss by up to 20 %. 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, as water-intensive crops such as cotton and citrus are exported. Drip irrigation is viewed by many as one of the most important agro-technological innovations in Israel.

In the Ribeiras do Algarve River Basin the irrigation sites represent approximately 70% of the total water consumption, about ¼ of which is supplied from surface water. The irrigation improvement option selected for the area comprises a change from furrow to sprinkler irrigation methods through the development of a programme of repairs. The irrigation deficit improvement in the whole River Basin, between 2006 and 2035, is estimated at an average of 16%. The extra water volume accumulated in Funcho / Arade storage reservoir can therefore be used during dry periods at Silves, Lagoa and Portimão irrigation site.

Network improvements and Enhancements

In most of the examined cases, network improvements have become a necessity due to poor maintenance of internal networks. In the case of Paros poor maintenance, particularly in the traditional settlements, has resulted in augmented losses and pressure drops. The scenario analysis for the Paros case, which focused on the effects from the implementation of network expansions aiming at the unification of the distribution networks of neighbouring municipal departments, showed that this option can lead to an increase in domestic demand coverage of about 40 %. Overall, the measure had a positive effect only in domestic demand coverage. However, the benefits observed are not great and are highly dependent on the yearly water availability.

In the area of Limassol, network losses are reported to be as low as 16%. However, it is believed that losses can be of the order of 25% or more. Thus, the option of reducing 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, and showed an improvement in domestic deficit, and to a lesser extent in the groundwater exploitation index. However, this measure alone cannot ensure the coverage of the domestic needs and also has little effect in irrigation deficit reduction.

In the Belice Basin case, the replacement of pipelines showed an average of 12% improvement of the domestic demand deficit, while there is no positive effect on the irrigation demand coverage except for individual improvements and only under the best scenario.

Similarly to Paros, one of the options chosen for Ribeiras do Algarve was the network expansion in an effort to provide surface water to Aljezur Municipality, Monchique Municipality and other small settlements. The analysis, which did not include the integration of additional supply enhancement options such as boreholes or storage reservoirs, demonstrated a slight improvement on the domestic demand coverage up to 0.5%, whereas the domestic unmet demand increases up to 2%. However, this option can be effective in minimising groundwater exploitation, while allowing for the replenishment of local aquifers. The losses reduction option applied to water supply (secondary) network systems showed a reduction of 15% in 15 years.

Pricing

Domestic pricing in Paros is volumetric, following a tariff structure where the price of water differs according to the consumed volume and the season. Although there is a unique service provider for the entire island, there are different tariffs for each municipal department. The examined domestic water pricing scheme involved a gradual increase of average prices up to 50%, which was found to perform better under average or high availability conditions; the limited water availability under a drought diminishes the effect of the pricing scheme. Although it would have been expected that the effects of irrigation pricing would have been of the same magnitude as those of domestic pricing, this is not the case. The low priority of irrigation compared to domestic demand coverage almost diminishes the effect that pricing would have on the alleviation of the respective deficit and groundwater overabstraction.

Cyprus has a strongly regulated water market. The Water Development Department (WDD) is a natural monopolist for domestic water and for part of the irrigation water since about half of the supply of irrigation water comes from Government Water Works. Government irrigation water is supplied on the basis of a quota system, in combination with penalty charges for over-withdrawals. These market-based structures contribute to the efficient use of water. Under conditions of water scarcity, especially during droughts, priority and preference is given to covering a higher proportion of the domestic supply followed by greenhouse cultivations and permanent crops. Seasonal crops under these conditions are reduced dramatically. Although domestic water is fully charged to customers, the price of irrigation water does not cover full financial, let alone economic, costs. This so-called under-pricing has various effects on society, economic, social and environmental. In view of the WFD Implementation process, a pricing reform is underway by the Government, regarding domestic and irrigation supply, expected to assure adequate financial cost recovery for Government freshwater supply. The option of raising the irrigation water prices gradually within a 3-year period was estimated to result in a reduction of irrigation demand of approximately 10%. Additionally, this option has positive effects in groundwater exploitation index but does not affect the domestic deficit. The option of imposing an increase by 60% in the water tariffs, imposed gradually after 2008, showed that the domestic deficit is reduced by almost 38% throughout the simulation period (2002 – 2033), with direct effects in groundwater exploitation index and total direct costs.

The possibility of raising the water selling price for domestic users was examined for the Garcia-Arancio district. Standard values of demand elasticity were used, such as 0.2 for the permanent population of settlements, and 0.35 for the seasonal component and the tourists. Analysis of different scenarios shows the evident impact of the increase in price over the domestic deficit. The demand is reduced according to the elasticity demand parameter specified for the permanent and seasonal demands.

In Israel, all water sources are publicly owned, and their utilization is controlled by the Water Commissioner. Prices differ according to the quality of water supplied and the type of use, and are generally regarded not as an allocation instrument but as a means of improving income distribution: farmers pay the lowest charges, industry pays higher charges and households pay the highest. 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. Private water producers set prices independently. Production (extraction) levies are imposed on all water producers, including Mekorot (the public water supply company), and are intended to reflect the “shadow price” or “scarcity rent” of some of the limited groundwater resources. Producers also pay the production and conveyance costs. Decisions on water prices are made in the political arena and are affected by pressure from interest groups. The share of water costs in the budget of households or in the cost of manufacturing is relatively small. Therefore urban and industrial water users do not have much incentive to organize political lobbies and, in effect, do not compose a strong opposition to the agricultural lobby. However, unlike the urban and industrial sectors, the agricultural demand is elastic and can be reduced significantly if water prices will be increased. Many experts suggest a sharp raise in the price of water to the agricultural sector in order to reduce consumption significantly.

In Tenerife, and with regard to domestic water, different pricing policy options have been applied and tested since more than two decades. Although the pricing policy is similar in all municipalities bar a couple of exceptional cases, both prices and segments of application show large variations, which cannot be justified within an interconnected insular system. With respect to irrigation water, one of the most relevant features of water resources on the island is that the ownership of most available water is private. Members of “Water Communities” are also the major users of water sold or distributed for irrigation. Under these special conditions, any price policy in the agricultural sector is pointless, since the market actors themselves are those who regulate the situation. Non-owner consumers mostly have to face the problem of resource unavailability in the market, rather than affordability issues.

Domestic pricing in Ribeiras do Algarve is volumetric, following a tariff structure where the price of water differs according to the consumed volume. There are two levels of water service supply: the first level represented by the company responsible for the Primary Water Supply System; on a second level, and with two exceptions, each Municipality is responsible for providing water and sewerage services to each settlement. The current domestic pricing system, when analysing Municipalities as a service provider and according to the Water National Plan, does not meet financial costs directly associated with water service provision and does not provide incentives for protection of fragile water resources. On the contrary, operational costs of the primary water supply system are completely met. Irrigation pricing is only applied to public irrigation sites. Farmers associations that set water-selling prices according to the operational and maintenance costs manage the latter. Water irrigation fee composition varies according to each farmer's association, i.e. while some farmers pay only a fixed fee, others pay a tariff composed by two shares, one for each irrigated hectare and other for each m^3 of water consumed. In most cases only operation and maintenance costs are recovered but not capital costs.

Specific Considerations and Constraints

During this work effort, the applicability of various technological water management options has been examined under different geological, climatic and socio-economic conditions. The suitability for implementation and the popularity of each of the described options have been based on a series of factors such as cost, applicability, efficiency, and social acceptability.

Based on the findings from the described Case Studies, the main barrier to the implementation of desalination appears to be the high cost involved with the operation of a desalination unit, as well as the issue of private sector involvement. Although perceived as the marginal water supply source, desalination is generally recommended for coastal areas facing water stress problems. Recycling and reuse, proven to be very efficient in terms of water saving, are widely practiced in some areas and are highly unpopular in others. In certain areas or countries, water recycling is considered a socially undesirable practice; negativity derives from the lack of public education on the efficiency of the treatment methods, resulting in the water users' perception that the water to be consumed is still contaminated. Reluctance in practicing water reuse on a domestic level is also a matter of public education. An additional drawback of recycling is the high cost of construction and operation of treatment units, inter-seasonal storage and conveyance systems. Such costs often require that recycled water is subsidized by the public authorities.

Although the exploitation of groundwater reserves is the commonly used supply enhancement approach, the overexploitation of aquifers, a common problem in the Mediterranean region, urges for the application of alternative options or combinations of methods. Depletion and salinisation trends are in most cases aggravated by persistent drought episodes that cause recharge reduction. Still however, the ease in application and low financial costs render groundwater exploitation an option of high popularity in areas with inadequate surface water resources.

Storage reservoirs and dams, along with extensive conveyance systems, have been the focal point of supply-oriented water management approaches. Ecosystemic considerations, as well as potential climate changes, and water allocation constraints are of growing importance in future planning, while small-scale systems are becoming increasingly popular.

Water conservation is an efficient and easy in application way of saving water. It can be applied on a domestic level and it does not require large investment, being mainly dependant on changes in attitudes towards water consumption and conservation, as well as on willingness of the public to adopt water conservation measures. Efforts invested in conservation campaigns have thus far proven extremely successful, especially in cases of drought, when public sensitivity increases considerably. However, there is still potential for the achievement of great water savings, while domestic conservation methods also tend to lead to lower water service costs, thus being cost-effective not only for the consumer but also for the water service provider.

Methods pointing towards conservation in the agricultural sector, i.e. crop changes and improvement of irrigation methods, also require strong public involvement. Public acceptability can either constitute a motive or a deterrent in the adoption of different or new irrigation methods, while economic incentives on a farm level have been in most cases proven to be the answer. The transition from one irrigation method to another may require large investments, which are not always promoted by the relevant authorities. In this case, the cost entailed in improving irrigation efficiency is undertaken by the farmer.

In spite of the diversity of water pricing policies, pricing is generally accepted as an instrument that can assist in ensuring the financial sustainability of water services, while at the same time providing incentives for a more efficient water usage. Regulation of water consumption through tariff increases is a common practice in cases of drought. Transparency in cost allocation usually serves to offset the strong social opposition; however careful consideration should be given on the differentiated effect of policies in the different social groups.

The findings from the research undertaken in the Case Studies have demonstrated the current water management trends in the selected regions for the Case Studies. Possibilities for the implementation of new management options and for the adoption of integrated management have also been examined. Issues such as cost, efficiency, option applicability and social acceptability have been taken into consideration in an attempt to identify the advantages, the ease in application, and the constraints involved with the selected option or the integrated approach.

The options examined in the five Case Studies, taking into account the site and country characteristics and individualities, with the identified advantages and disadvantages, can form part of an integrated management approach. Such experiences, when disseminated, can be used as a baseline for integrated management application in areas facing similar water management issues, and as a basis for the identification of good and bad practice examples on water management. The current work can be utilised as preparatory ground for similar research in other areas and countries, and can also be seen as an incentive for undertaking the challenge of promoting and adopting more integrated approaches to environmental management.

Chapter 11 Overview of Specifications

Desalination

General Overview

General Considerations

The efficiency of desalination can be significantly reduced due to the equipment used during the process. Frequent problems to be dealt with are fouling of membrane surfaces with solids (e.g. colloidal material, dissolved organics, bacteria, etc. in membrane processes) and/or the formation of scale (due to the precipitation of dissolved minerals in distillation processes). Consequently, the water fed to desalination units usually requires some type of pre-treatment. The level of pre-treatment required depends on the desalination process used, and feed water quality.

Pre-treatment may include coagulation and settling; filtration; treatment with activated carbon to remove organics; disinfection to kill microorganisms; dechlorination (when chlorine and chlorine sensitive membranes are used); and the addition of acid, polyphosphates, or polymer-based additives to inhibit scaling. Generally speaking, these are all standard water treatment techniques (U.S. Congress, 1988).

Energy Consumption

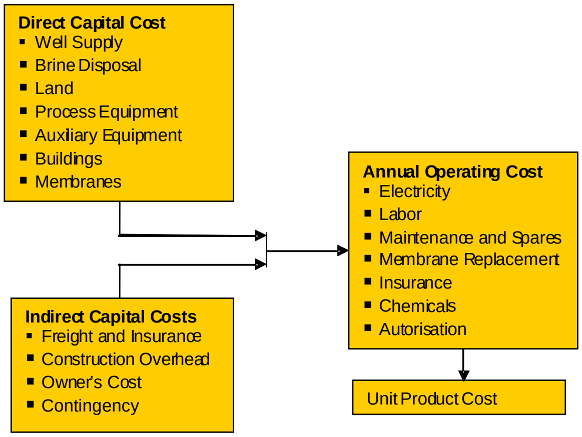
Desalination is an energy costly procedure. Theoretically, about 0.86 kWh/kg (3 kJ/kg) of energy is needed to desalinate 1 m^3 of normal sea water (3.45 % salt at a temperature of 25^oC). In practice, desalination plants use 5 to 26 times as much as this theoretical minimum, depending on the type of process used.

Desalination as currently practiced is driven almost entirely by the combustion of fossil fuels, either for electricity production or for heating of the steam required at the distillation processes (DESWARE, 2001).

Costs

General

The cost of water desalination varies depending on water source access, source water salinity and quality, specific desalination process, power costs, concentrate disposal methodology, project delivery method, and the distance to the point of use. The figure below presents the different cost components of desalination plants.



Desalination costs include:

- Energy costs, which may account for 30 to 60% of the operational costs. Thus, slight variations in power rates have direct impact on treatment cost;
- Cost for removal of suspended matter, and conditioning of water via the use of anti-scalants, as well as the lowering of the pH;
- Cost for post-treatment, which includes re-mineralization of the product water, pH adjustment, and disinfection;
- Cost of disposal method. The preferred disposal methods for large seawater desalination facilities is dilution by use of existing outflows, such as cooling water effluent of power generation facilities, or open sea discharges. Seawater desalination plants dispose larger water volumes than brackish groundwater facilities. Disposal alternatives include a wider array of options,

such as evaporation ponds, discharge to a municipal wastewater collection treatment system, and deep-well injection.

Typical production costs of brackish groundwater desalination plants range from 0.19 to 0.62 US$/m^3 (Arroyo, 2004).

Capital Cost

Direct capital costs include purchase cost of major equipment and auxiliary equipment, land and construction.

Major equipment includes processing equipment, as well as instrumentation and controls, pipes and valves, electric wiring, pumps, process cleaning systems, and pre- and post-treatment equipment. These are some of the most expensive items, and their cost depends on the type of process and capacity. Equipment costs may be less than 1000 US$ (e.g. a laboratory-scale RO unit used to treat low-salinity water). On the other hand, the equipment cost for a 100,000 m^3/d RO system could approach 50 million US$. MSF and MED equipment is generally more expensive than RO systems - current estimates for a plant with capacity of 27,000 m^3/d are 40 million US$. **Auxiliary equipment** is needed for open intakes or wells, transmission piping, storage tanks, generators and transformers, pumps, pipes and valves. **Land costs** may vary considerably, from zero to a sum that depends on site characteristics. Government-owned plants normally have zero charges. Plants constructed under build-own-operate-transfer (BOOT) contracts with governments or municipalities can have near zero or greatly reduced charges.

Construction costs include cost for the building and well construction, as well as the membrane costs. Building cost varies from 100 to 1000 US$/m^2; this cost is site-specific and depends on the building type. Well construction cost is estimated about 650 US$/m depth for construction, and an average well capacity is estimated of 500 m^3/d. The cost of membrane modules depends on plant capacity, and ranges from 500 to 1000 US$ for a module with capacity in the range of 50–100 m^3/d.

Construction overheads, include fringe benefits, labour burden, field supervision, temporary facilities, construction equipment, small tools, contractor's profit and miscellaneous expenses. They are about 15% of direct equipment and labour costs (which depend on the size of the plant).

Capital unit cost of desalination plants which depend mostly on plant size, feed water quality and already existing infrastructure. They typically range:

- for sea water:700-2000 US$/m^3/d installed capacity;
- for brackish water: 150-700 US$/m^3/d installed capacity.

Indirect capital costs, such as freight and insurance usually equal 5% of the total direct costs. **Owner costs**, include engineering and legal fees, and are approximately 10% of direct material and labour costs. **Contingency costs** are generally estimated at 10% of the total direct costs.

Operational Costs

Annual operating costs are the expenditures incurring after plant commissioning and during the actual operation. They include energy, labour, chemicals, spare parts and other.

Electricity costs vary over the range of 0.04-0.09 US$/kWh. The upper end of the range is characteristic of European countries, while the lower value can be attained in the Middle East Countries and the U.S.

Table 15 Estimated chemical costs and dosing rates

Chemical	Unit Cost ($/kg)	Dosing Rate (g/m^3 water)	Specific Cost (g/m^3 water)
Sulphuric acid	0.504	0.242	0.0122
Caustic soda	0.701	0.140	0.0098
Antiscalant	1.9	0.050	0.0095
Chlorine	0.482	0.040	0.00193

Labour costs are site-specific and depend on plant ownership (public or private). Recent trends in plant operations point to automisation of plant operation and maintenance. This often reduces the required number of full-time employees, such as managers, engineers and technicians.

Chemicals frequently used in the pre- and post-treatment processes of desalination plants include sulphuric acid, caustic soda, various antiscalants and chlorine. Their cost is mainly influenced by market prices. In addition, chemical treatment differs from thermal and membrane processes, with higher costs for the

	latter. Table 15 provides estimates for the unit cost of chemicals used in thermal and membrane desalination, dosing rates and specific rates per unit volume of product water (Ettouney et al., 2002). **Membrane replacement.** Membrane replacement rates may vary between 5%/yr for membranes treating low-salinity brackish water to 20% per year for membranes treating high-salinity seawater. Higher replacement costs may also reflect inefficient operations and/or pre-treatment systems. **Maintenance and spare parts**. This is typically less than 2% of the total capital cost on an annual basis. **Insurance**. Insurance is 0.5% of the total capital cost.
Total Unit Cost	The total unit of desalinated water mostly depends mostly on capital amortization and energy cost. Typical costs are provided in Table 16 (Bushnak, 2003).

Table 16 Typical unit cost of desalted water

Plant Size – Feed type	US$ /m^3
Large plants	0.40-1.00
Medium plants	1.00-1.50
Small plants	Over 1.50
Brackish water source	0.10-1.00

Environmental Impacts	
Land	Brine discharges
Air	CO_2, SO_x, NO_x emissions, with visual as well as sound impacts, combustion of fossil fuel for energy production.
Water	Feedwater intake
Research Technology Advances	Desalination allows for cost-efficient technology enhancements via additions of filtration elements to minimize or optimize initial capital investments to better match the projected water demands.
Advantages & Disadvantages	
Advantages	Desalination plants have many potential values and benefits, such as: • Providing additional water supply to meet existing and projected demands; • Replacing water lost from other sources and alleviating drought conditions; • Replacing water that can be used for river and stream ecosystem restoration; • Enhancing water reliability and supplying high quality potable water; • Reducing groundwater overabstraction and substituting the use of polluted groundwater (Minton et al., 2003); • Allowing modular expansion and cost-saving technology innovations via additions of filtration elements (for membranes processes) and improved energy recovery devices; • Providing site flexibility. Sea water desalination plants can be located close to the final point of use to minimise water transmission costs (Arroyo, 2004).
Disadvantages	The main desalination disadvantages are (Minton et al, 2003): • High energy consumption and costs; • Ecological impacts of feedwater intake, brine discharges, and greenhouse gases emissions; • Difficulty in clarifying linkages between new water supply, potential growth, land use and available infrastructure, and • Regulatory and permitting requirements.

Desalination Technologies: Multiple-Effect Distillation (MED)

Description			
The incoming feed water is heated and then passed through a series of evaporators, or "effects". In the first effect, water vapour is given off by the hot brine, which lowers the brine temperature. The brine is then transferred to the second effect, where it comes in contact with one side of a series of tubes. The water vapour produced in the first effect is also transferred to the second effect where it condenses on the other side of the tubes. The heat produced during condensation is transferred back to the brine, thereby boiling and further evaporating the brine in the second effect. The vapour pressure in each succeeding effect is lowered to permit boiling and further evaporation at successively lower temperatures in each effect (U.S. Congress, 1988).			
Maturity	Commercial √	Demonstration	Experimental
Experiences	MED is a proven technology and has been used in many parts of the world to provide good quality product water. It is generally more tolerant of poor quality feed water than other desalting processes (U.N.E.P., 2002). The worldwide MED capacity in 1998 was 682 (4.1%) plants with capacity in the range of 100-60,000 m^3/d; 653 (3.8%) plants of 500-60,000 m^3/d; 48 (3.6%) plants of 4,000-60,000 m^3/d; Total worldwide capacity: 4.1% (Wangnick Consulting GmbH, 1998). MED has been widely used for industrial applications, (e.g. for sugar production by sea water distillation). Some of the early water distillation plants used the MED process, but this process was displaced by MSF units because of cost factors, fewer operating problems and their apparent higher efficiency. However, interest in the MED process has increased and a number of new designs have been developed. Small single and multiple effect units are more common. (C.R.E.S., 1998). The MED process is often used as part of a dual purpose facility where the steam to run the desalination unit is taken from the low pressure end of a steam turbine that is used to generate electricity. The remaining steam and condensate is then returned to the boiler to be reheated and reused. Individual MED units generally have a capacity of 1,000 to 20,000 m^3/d. Several of these units can be grouped around an electricity power plant to utilize low pressure steam. Facilities with a total water output of 200,000 m^3/d or more are not uncommon in the Middle East, while smaller facilities, consisting of several 5,000 m^3/d units, are used in islands like St. Thomas and St. Croix in the Caribbean. The use of MED units needs to have the full commitment of the community as they are large and will require considerable funds to purchase and operate (U.N.E.P, 2002).		
Technical Characteristics			
Feed Water Used	Brackish Water	Sea Water √	
Need for pre-treatment	√		
Need for post-treatment	√		
Type of energy used	Thermal		
Energy Consumption	290 kJ/kg; 200 MJ/m^3 (Stikker, 2002)		
Uses	Domestic √	Agricultural	Industrial √
Limitations	Use of high-quality construction materials that increase the capital costs of the plants and production costs (U.N.E.P., 2002).		
Costs			
Capital Cost	The capital cost of the MED distillation units tends to be in the range of 1,000 to 2,000 US$/m^3/d of installed capacity, not including steam supply infrastructure and site preparation. If the unit is built as part of a dual purpose plant (electricity and water production facility), then the cost of the electricity and steam plants must be added to that of the distillation plant. However, potential income from this ancillary operation should also be included in the financial appraisal (U.N.E.P., 2002).		

	Capital cost: 35,050,000 - 70,400,000 US$ for capacity 22,730- 37,850 m^3/d (unit capital cost 1,562 - 1,860 \$/m^3/d (Ettouney et al., 2002).
Operational Cost	**Annual production costs** tend to be in the range of 1 to 4 US\$/m^3/d of water produced, depending on the size of the unit (U.N.E.P., 2002). **Annual energy cost** ranges between 3,719,000 €/yr to 1,000,000 US\$/yr for unit capacity 22,730 m^3/d-37,850 m^3/d (energy unit cost of 0.39 €/m^3/d-0.06 €/m^3/d). **Chemicals unit cost** ranges between 0.0606 – 0.024 US\$/m^3/d for capacity in the range of 22,730 m^3/d-37,850 m^3/d (Ettouney et al., 2002).
Total Unit Cost	0.87 to 1.31 US\$/m^3/d for plant capacity 22,730 m^3/d to 37,850 m^3/d.
Environmental Impacts	
Land	Impacts of brine discharge
Air	Emission of greenhouse gases (combustion of fossil fuels)
Water	Impacts of feedwater intake and brine discharge
Research & Technology Advances	

MED has potential for development in terms of unit size and reduction in energy consumption. Good water flow distribution over the heat transfer tubes is critical to achieving scale free operation and minimising temperature difference between effects. Even flow distribution becomes more difficult to ensure as tube bundle size increases. Feedwater flow rates to each effect need to be monitored and controlled accurately so that any reduction in flow is detected quickly. Low temperature MED plants are less complex than MSF in terms of auxiliary equipment and pumps and are well suited for application in remote locations (Wade, 1993).

Desalination Technologies: Multi-Stage Flash Distillation (MSF)

Description

In the MSF process, incoming feed water is first heated in a brine heater before it enters the first chamber, or stage. The brine boils violently and a small portion instantaneously "flashes" into water vapour. As the brine passes through successive stages operated at continually lower temperatures and vapour pressures, more and more of the brine flashes into steam. The water vapour produced is then condensed on the outside of tubes conveying incoming brine to the brine heater. The distilled water produced in each stage often passes through each succeeding stage and is allowed to ''reflash"; this allows the transfer of additional heat to the incoming feed water.

A typical MSF plant may have 20 to 50 stages. Many stages increase the overall efficiency of heat recovery in the plant and decrease its operating costs but they also increase the capital cost of the plant. In most recently built MSF plants, 50 to 75 percent of the waste concentrate from the last stage is mixed with the incoming feed water to increase the heat recovery and decrease the amount of water requiring pre-treatment. However this also increases the corrosion and scaling (precipitation of inorganic minerals) in the plant due to the increased salt concentration in the circulating brine. An average MSF plant recovers a volume of fresh water between 25% to 50% of the volume of incoming feed water (U.S. Congress, 1988).

Maturity	Commercial √	Demonstration	Experimental

Experiences	MSF has potential for development in terms of unit size and reduction of energy consumption. Good water flow distribution over the heat transfer tubes is critical to achieving scale free operation and minimising temperature difference between stages. Even flow distribution becomes more difficult to ensure as tube bundle size increases. Feedwater flow rates to each effect need to be monitored and controlled accurately so that any variation in flow is detected quickly. Low temperature MSF plants are more complex than MED in terms of auxiliary equipment and pumps and are well suited for application in remote locations (Wade, 1993). The worldwide MSF capacity in 1998 was 1,244 (44.4%) plants of 100-60,000 m^3/d unit capacity; 1,033 plants (46.8%) of 500-60,000 m^3/d unit capacity; 496 (64.0%) plants of 4,000-60,000 m^3/d unit capacity. Total worldwide capacity: 44.4% (Wangnick Consulting GmbH, 1998). The MSF distillation process has played a vital role in water provision in many areas, especially in the Middle East, which concentrates 75% of the installed capacity worldwide. The installed capacity of the process has grown considerably over the last twenty-five years, and MSF was developed and adapted for large scale applications, usually greater than 5,000 m^3/d. At present, the largest MSF plant is of 60,000 m^3/d capacity. In Europe the MSF process is mainly used in Italy and Spain (C.R.E.S., 1998).

Technical Characteristics

Feed Water Used	Brackish Water	Sea Water √
Need for pre-treatment	√	
Need for post-treatment	√	
Type of energy used	Thermal and Electricity (only auxiliary)	
Energy Consumption	290 kJ/kg; 400 MJ/m^3 (Stikker, 2002).	

Uses	Domestic √	Agricultural	Industrial √

Limitations	MSF systems consume much more energy than other desalination systems (e.g. RO) and large units should be combined with power plants in order to use steam from steam turbines or heat recovery steam generators. In addition, MSF systems can only operate at full capacity, and therefore should be supplied with all the thermal energy required whenever under operation. The system becomes unstable with partial steam supplies (Darwish & Najem, 2000).

Costs

Capital Cost	The capital cost of the MSF distillation units tends to be in the range of 1,000 to 2,000 \$/m^3/d of installed capacity, not including steam supply systems and site preparation. If the units are built as part of a dual purpose (electricity and water

	production) facility, costs of the electricity and steam plants must be added to the one of the distillation plant. However, the potential income from these ancillary operations should also be included in the economic assessment (U.N.E.P., 2002). Capital cost: 72,600,000 - 76,817,000 US$ for unit capacity 32,000 - 45,460 m^3/d (unit capital cost 2,269 - 1,690 US$/$m^3$/d) (Ettourney et al., 2002).
Operational Cost	**Annual production costs** tend to be in the range of 1 to 4 US$/$m^3$/d of water produced, depending on the size of the unit. **Annual energy cost** ranges between 11,539,000 – 12,453,000 US$/yr for plant capacity 32,000- 45,460 m^3/d (unit energy cost 1.098 $/$m^3$ – 0.88 $/$m^3$). **Chemicals unit cost** ranges between 0.207– 0.058 US$/$m^3$ for unit capacity 32,000 - 45,460 m^3/d (Ettourney et al., 2002).
Total Unit Cost	0.77 to 1.44 US$/$m^3$ for unit capacity 27,000 - 32,000 m^3/d (Ettourney et al., 2002).
Environmental Impacts	
Land	Impacts of brine discharge
Air	Emission of greenhouse gases (combustion of fossil fuels)
Water	Impacts of feedwater intake and brine discharge
Research and Technology Advances	
MSF technology is now in a mature phase of technical development, and it seems unlikely that there will be significant further technological advances in the process. There is still scope for improvement in material selection to reduce maintenance time and costs. However, the use of high grade materials can be expensive. Aluminium brass tubes perform well in heat recovery stages and cupro-nickel is probably only justified in high temperature stages (e.g. above 90°C).	

Desalination Technologies: Vapour Compression (VC)

Description			
In Vapour Compression (VC) systems water vapour is collected and compressed. Compression causes the vapour to condense on one side of a tube wall. The heat given off during condensation is then transferred (through the tube walls) to the feed water, and enhances its evaporation. In this process, the major energy input is provided by the compressor, which not only compresses the vapour, but also reduces the vapour pressure in the vaporization chamber. Energy may also be required to heat the incoming feed water during start-up (U.S. Congress, 1998). Two VC processes exist, Mechanical Vapour Compression (MVC), in which a mechanical compressor is used, and Thermal Vapour Compression (TVC), in which a thermocompressor or ejector is used to increase the vapour pressure (C.R.E.S., 1998).			
Maturity	Commercial √	Demonstration	Experimental
Experiences	VC units are widely used but have much smaller capacities, and, hence a lower overall total capacity than MSF and MED units. VC units are usually built in capacities ranging from 20 to 2,000 m^3/d, and are often used for supplying water to island resorts, industries, and off-shore drilling sites (U.N.E.P., 2002). The VC process has been in use since the end of the 19th century. Because of its compactness, ease of operation and transportability, military applications have been developed. The process is mainly used in the Western countries (C.R.E.S., 1998). One of the important features of the VC process, is that as all thermal processes, it is not as sensitive to the quality of the feed water as membrane processes, and can operate with raw water obtained directly from the sea. The MVC system is the most attractive among various single stage desalination processes. MVC systems are compact, confined, and do not require an external thermal source, as opposed to MED, MSF and TVC units. The system is driven by electric power; therefore, it is suitable for small communities connected to power grids. Another advantage of the MVC system is the absence of condenser and cooling water requirements (Faisal et al., 1997). The worldwide VC capacity in 1998 was 903 plants of 100-60,000 m^3/d unit capacity (4.3%); 486 plants of 500-60,000 m^3/d unit capacity (4.2%); 42 plants of 4,000-60,000 m^3/d unit capacity (1.9%); Total worldwide capacity: 4.3%. (Wangnick Consulting GmbH, 1998).		
Technical Characteristics			
Feed Water Used	Brackish Water	Sea Water √	
Need for pre-treatment	√		
Need for post-treatment	√		
Type of energy used	Electricity		
Energy Consumption	8-12 kWh/m^3 (C.R.E.S., 1998)		
Uses	Domestic √	Agricultural	Industrial √
Limitations	The disadvantages of the MVC system include: • High energy requirements in electricity; • Limitations imposed on the vapour compression range (flow rate of and temperature increase of compressed vapour); • Requirement for maintenance and spare parts for the compressor (blades, shaft, sealing, motor). The first disadvantage sets barriers to the use of MVC systems in areas with limited energy resources. The second disadvantage bounds the operation of the system to low maximum brine temperatures (60-70°C). This results in larger heat transfer area for the evaporator, and increases capital costs. In addition, single unit production capacity is limited to 800 m^3/d. To some extent this problem is addressed by operating MVC and multi-effect evaporation units with 3 to 4 effects. This can increase plant capacities up to 3,000 m^3/d.		

	Finally, high maintenance requirements increase the operating cost and dictate use of highly skilled personnel (Faisal et al., 1997).
Costs	
Capital Cost	The capital cost for VC units tends to be around 2,500 to 3,000 US$/m^3/d of installed capacity (U.N.E.P., 2002). Capital cost: 894,000 - 1,586,000 US$ for unit capacity 1,000 - 1,200 m^3/d (unit capital cost 894 - 1,322 US$/m^3/d) (Ettourney et al., 2002).
Operational Costs	**Annual production costs** tend to be in the range of 1 to 4 US$/m^3/d of water produced, depending on the size of the unit (U.N.E.P., 2002). **Annual energy cost ranges** between 168,000– 2,690,000 US$/yr for unit capacity 500 - 20,000 m^3/d (unit energy cost 0.057– 0.4 US$/m^3). **Chemicals unit cost** ranges between 0.025– 0.05 US$/m^3 for unit capacity 100 - 20,000 m^3/d (Ettourney et al., 2002).
Total Unit Cost	5.0 to 0.46 US$/m^3 for unit capacity 100 - 20,000 m^3/d (Ettourney et al., 2002).
Environmental Impacts	
Land	Impacts of brine discharges
Air	Emission of greenhouse gases (combustion of fossil fuels for electricity production)
Water	Impacts of feed water intake, brine discharge

Desalination Technologies: Reverse Osmosis (RO)

Description

Principle: If waters with different salinities are separated by a semi-permeable membrane, ‘‘pure” water from the less salty brine will diffuse or move through the membrane until the salt concentrations on both sides of the membrane are equal. This process is called osmosis. With RO, salty feed water on one side of a semi-permeable membrane is typically subjected to pressures of 200 to 500 lb/sq in. for brackish water, and 800 to 1,200 lb/sq in. for seawater. ‘‘Pure” water then diffuses through the membrane, leaving behind a more salty waste concentrate (brine).

About 10 gallons of water will pass through a square foot of membrane each day. The higher the operating pressure, the greater the flow of product water. The percentage of incoming feedwater that is recovered as product water after one pass through a RO module ranges from about 15 to 80%; however, this percentage can be increased, if necessary, by passing the waste water through sequential membrane elements. Brackish water RO plants typically recover 50 to 80% of the feed water, with 90 to 98% of the salt being rejected by the membrane. Recovery rates for sea water RO plants vary from 20 to 40 %, with 90 to 98% salt rejection. Water is usually processed at ambient temperatures.

Membranes, usually made of cellulose acetate, aromatic polyamide, polyimide, polysulfones, or thin film composites, can last as long as 7 years, depending on the type of membrane used and the quality of the feed water. Membranes used for seawater generally have to be replaced every 3 to 5 years. Membranes can be designed to remove particular inorganic and organic substances (e.g. trihalomethanes). In the last years low pressure membranes, and pressure exchanger systems have decreased pressure requirements for some RO units by up to 50%. The efficiency of RO plants will undoubtedly increase and costs decrease, as membranes are improved. Such improvements may involve increased rejection of salt; increased membrane resistance to compaction, chlorine, and microorganisms; and large-scale production of standardized RO elements (U.S. Congress, 1988). Two types of RO membranes are commercially used. These are the Spiral Wood (SW) membranes and the Hollow Fibre (HF) membranes. Both are used to desalt both sea water and brackish water. The choice between the two membrane types is based on factors such as cost, feed water quality and unit capacity in terms of water production (C.R.E.S., 1998).

Maturity	Commercial √	Demonstration	Experimental

Experiences

A large number of RO plants have been installed for both sea and brackish water desalination. The process is also widely used in manufacturing, agriculture, food processing and pharmaceutical industries. Due to their modular design, RO units are available in a wide range of capacities. Large plants are made up of hundreds or thousands of modules. Also, very small units (0.1 m^3/d) for ships, houses or hotels are available. (C.R.E.S., 1998).

The RO system became more attractive through the continuous improvements in membrane materials, the raising of both feed pressure and temperature limits, and production of potable water from high salinity water in the Gulf area in one single stage. The main advantages of the RO process when compared to the also popular MSF process are (Darwish & Najem, 2000):

- It consumes less energy, and only in the form of mechanical energy delivered by motor(s).
- There is no need for RO units to be combined by a power plant.
- Start/stop operations are simple.
- RO units are delivered and operated in modules; therefore there is no need to shut down the entire plant for emergency or routine maintenance.

RO systems are also characterized by simplicity of design: the plants can be broken into small pieces for shipment, which make them ideal for use as emergency water supplies. The many manufacturers of reverse osmosis equipment components tend to keep prices in balance, ensuring adequate market competition. Energy requirements are not as sensitive to the proportion of the salts removed as ED, and RO units remove both ionic and non-ionic substances. Energy can be recovered from the pressurized waste stream (U.N.E.P., 2002).

The worldwide RO capacity in 1998 was 7,851 plants of 100-60,000 m^3/d unit capacity (39.1%); 3,835 plants of 500-60,000 m^3/d unit capacity (37.9%); 613 plants of 4,000-60,000 m^3/d unit capacity (25.7%); Total worldwide capacity: 39.1%. (Wangnick Consulting GmbH, 1998).

Technical Characteristics

Feed Water Used	Brackish Water √	Sea Water √
Need for pre-treatment	√	

Need for post-treatment	√		
Type of energy used	Mechanical (Electricity)		
Energy Consumption	5– 15 kWh/m^3 (Seawater) 2 kWh/m^3 (Sea water with energy recovery systems, i.e. pressure exchangers) 1– 3 kWh/m^3 (Brackish water) (C.R.E.S., 1998).		
Uses	Domestic √	Agricultural √	Industrial √
Limitations	Disadvantages of RO systems include (Pilat, 2001): • They require high quality of feed water and are sensitive to pre-treatment problems. • RO systems require a dechlorination process to protect RO membrane from degradation by free chlorine oxidation. • Water recovery is normally low in the range of 65%-75%. • Membranes require special and expensive cleaning chemicals. It is important to determine if these chemicals can be discharged to the environment without further treatment. • Membranes have a limited lifetime of 5-7 years due to their sensitivity to various operating factors. • SW RO membrances can not be cleaned manually, and therefore should be replaced. Reverse osmosis membranes are very sensitive to suspended solids, including colloids, of the feedwater, and adequate pre-treatment is very important for membrane maintenance. Skilled personnel, chemicals and spare parts are essential (U.N.E.P., 2002).		
Costs			
Capital Cost	The capital cost for RO units tends to be around 250 to 750 US/m^3/d of installed capacity (not including site preparation, utilities, buildings, and feed water system). The capital cost of a seawater RO unit could range from 800 to 1,250 US$/m^3/d of installed capacity.		
Operational Costs	**Annual energy cost** ranges between 1,710,000–4,300,000 US$/yr for plant capacity ranging between 1,000 - 37,850 m^3/d (unit energy cost 0.52 US$/m^3 – 0.35 US$/m^3). **Chemicals unit cost** ranges between 0.35 US$/m^3–0.07 US$/m^3 for plant capacity 100-37,850 m^3/d. Membrane replacement costs range between 5,600 US$/yr-1,900,000 US$/yr for plant capacities between 100 and 32,000 m^3/d (Ettourney et al., 2002).		
Total Unit Cost	Total production costs range between 0.64 US$/m^3 and 0.58 US$/m^3 for corresponding plant capacity ranges between 100 m^3/d and 20,000 m^3/d (Ettourney et al., 2002).		
Environmental Impacts			
Land	Impacts of brine discharge, membrane disposal after replacement		
Air	Emission of greenhouse gases (combustion of fossil fuels for electricity production)		
Water	Impacts of feed water intake, brine discharge, chemicals discharge		
Research & Technology Advances			
RO plants have considerable potential for future development, particularly in membrane technology, pre-treatment, optimized design and energy recovery systems. Development of chlorine tolerant membranes, adoption of biocides, and combination with nanofiltration would be a significant advance. Selection of the site and design of seawater intakes to avoid silt entertainment is of great importance in establishing effective and reliable pre-treatment. It is difficult to design and operate filtration systems to produce low SD1 levels from shallow coastal water conditions. RO plants are much less tolerant than distillation in this respect. There is continuing work in developing better reverse osmosis membranes that work at lower pressures or are more selective in their removal characteristics (U.N.E.P., 2002).			

Desalination Technologies: Solar Distillation

Description			
Solar distillation is a process in which the energy of the sun is directly used to evaporate sea or brackish water (C.R.E.S., 1998). Solar distillation units can have many configurations, but the most common one is referred to as a **greenhouse still**. In this unit saline feed water is supplied continuously or intermittently to a pool of water inside an airtight, glass enclosure, similar to a greenhouse. The black pool bottom absorbs the solar energy and heats the water. Water vapour rising from the brine condenses on the cooler inside surface of the glass. The droplets of water vapour then run down the glass into troughs along the lower edges of the glass which channel the distilled water to storage tanks. After half of the feed water has evaporated, the remaining waste concentrate must be discharged to minimize precipitation of salts (U.S. Congress, 1988).			
Maturity	Commercial	Demonstration	Experimental √
Experiences	The process of solar distillation has been used for many years, usually for small scale applications. Well designed units can produce around 2.5 l/m^2/d with a thermal efficiency of 50%. Solar stills are simple in operation and maintenance requiring only the cleaning of the plant, and especially of the glass roof (C.R.E.S., 1998). Solar desalination is not used extensively and remains largely experimental. There are no large-scale installations, generally because of the large solar collection area required, the entailed high capital costs and the vulnerability to weather-related damage. An inventory of known wind- and solar-powered desalting plants listed about 100 plants scattered over 25 countries. Most of these installations had capacities less than 20 m^3/d. However, this inventory did not account for the many small solar stills used by individual families. Simple solar stills, which work by humidification, can be operated and maintained without experienced personnel. However, constant maintenance is required for efficiently producing freshwater. Ponds must be kept filled with feedwater, to prevent scale formation caused, and glass and collection troughs should be kept clean and in good condition, to minimise vapour leaks through broken glass panes. In contrast to these simple stills, hybrid units, employing solar collectors to raise water temperature and achieve true boiling, tend to be complex and their operation requires trained technicians. All units are likely to require some imported materials. For example, even simple stills require glass and sealer that may have to be imported and the extent to which weather (wind, blowing sand, etc), wandering animals and birds can affect the quality of the glass needed for the solar stills should not be underestimated. This is especially true for islands that are subjected to weather phenomena such as high winds, hurricanes, etc. The level of community involvement in the use of solar distillation units depends on the type and size of the units. Due to the complexities and responsibilities inherent in the use of solar desalination technologies, there should be a real local understanding and commitment to this type of installation before proceeding. Although solar distillation has been available for a long time, it is difficult to find successful, long-term applications. The technology can work, especially simple solar stills, but must be carefully adapted to the particular needs and limitations. A general rule of thumb for solar stills is that a solar collection area of about 1 m^2 metre is needed to produce 4 l/d of water. Thus a facility with a solar collection area of 1 hectare should produce about 40 m^3/d (U.N.E.P., 2002).		
Technical Characteristics			
Feed Water Used	Brackish Water √	Sea Water √	
Need for pre-treatment	√		
Need for post-treatment	√		
Type of energy used	Thermal - Solar		
Energy Consumption	–		
Uses	Domestic √	Agricultural	Industrial √
Limitations	Solar desalination has high capital costs and the operation of solar systems can be complex. In addition, a major production facility would take up a large land area,		

	which could create problems if the facility was located in areas where land was scarce and/or expensive (U.N.E.P., 2002).
Costs	
Capital Costs	Since there is limited commercialization of solar units, capital and operating costs are not as well established as for the other processes. For hybrid plants (distillation and photovoltaic), capital costs of the solar generating system can be assumed to significantly exceed these of the desalination plant. In partial contrast, solar stills are expensive to construct correctly, and, although thermal energy used in the distillation process is free of charge, additional energy is usually required to pump the water to and from the facility (U.N.E.P., 2002).
Operational Costs	Solar desalination technologies can significantly reduce energy costs (U.N.E.P., 2002).
Environmental Impacts	
Land	Impacts of brine discharges
Air	-
Water	Impacts of feed water intake, brine discharges
Research & Technology Advances	
Solar desalination should benefit from the development of a process called membrane distillation for direct or solar-assisted desalination. This involves using a membrane which allows water vapour to pass through but retains water as liquid. Further development of this and other technological advances should help to make solar devices more cost effective (U.N.E.P., 2002).	

Desalination Technologies: Electrodialysis (ED)

Description

Electrodialysis (ED) is a process that uses a direct electrical current to remove salt, other inorganic constituents, and certain low molecular-weight organic substances from brackish water with concentrations of dissolved solids up to 10,000 ppm. With this technique several hundred flat, ion permeable membranes and water flow spacers are vertically assembled in a stack. Half of the membranes allow positively charged ions (cations), to pass through. The other half-anion-permeable membranes allow negatively charged ions (anions) to pass through. Anion-permeable membranes are alternately placed between the cation-permeable membranes, and each membrane is separated from the adjacent membrane in the stack by a polyethylene flow spacer. This assemblage of one cation membrane, a flow spacer, one anion membrane, and another flow spacer comprise the cell pair, which is the basic building block of an ED cell.

An electrical current (powered by an external D.C. electric power source) is established across the stack by electrodes positioned at both ends of the stack. Brackish water is pumped at low pressures (50 to 70 lbs/sq. in.) into the 0.04-inch flow spacers between each membrane. Cations pass through the cation-permeable membranes and anions through the anion-permeable membranes, thereby concentrating between each alternate pair of membranes. Between each set of membrane pairs adjacent to the concentrating compartments, the brackish water is partially desalinated. ED does not remove uncharged molecules.

Partially desalted water is passed through additional ED stages until the desired concentration is achieved. A variation of conventional ED is Electrodialysis reversal, or EDR, which is an automatic, self-cleaning electrodialysis process. Polarity reversal reverses the flow of ions through the membranes, so that the spaces collecting concentrated brine begin collecting less salty product water. Alternating valves in the water collection system automatically direct the flow in the appropriate direction depending on the direction of the current. Typical freshwater recovery rates for EDR now range from 80% to 90% of the feed water volume.

ED plants are constructed and operated in much the same way as RO plants. Similarly, some pre-treatment may be required; however, EDR typically requires much less pre-treatment of incoming feed water than other desalination processes. If scaling and/or clogging of the membranes becomes a problem, effective chemical cleaning is achieved by circulating a chemical solution through the membrane stacks. Membrane stacks can also be disassembled and the membranes cleaned by hand. Although this is time consuming, it helps to avoid frequent membrane replacement. Under proper operating conditions ED membranes are guaranteed for up to 5 years, but can have an effective life of 10 years or more (U.S. Congress, 1988).

Maturity	Commercial √	Demonstration	Experimental

Experiences

ED has been in commercial use since 1954, over the ten years before RO. Since then, this process has seen widespread applications for a number of purposes, including the production of potable water. Due to its modular structure, ED is available in a wide range of sizes, from small (less than 2 m^3/d) to large product water capacities (C.R.E.S., 1998).

ED tends to have lower costs than RO, when feed water salinity is less than 3,000 ppm, and higher costs than when feed water salinity is greater than 5,000 ppm. Seawater desalination with ED is not yet economically attractive, due to the dependency of the energy consumption on the feed water salinity (U.S. Congress, 1988).

Electrodialysis units are relatively easy to operate. However, they require that the technical experience on the respective system components. Feed water for an electrodialysis plant is usually groundwater from wells. This limits the amount of particulates and microorganisms in the feedwater and reduces maintenance needs. ED units also require a reliable electricity source, and this is the most significant component of their operational costs, in addition to the chemicals needed for the pre-treatment of raw water.

The electrodialysis process has the advantage of being simple to use, and, since the product water does not go through the membrane and the passages through the membrane stack are larger, the process is less susceptible to scaling. It is an efficient technology when the feed water is likely to contain a high concentration of suspended solids. The process requires relatively little chemical pre-treatment of the source water, and has the advantage of being quiet compared to thermal and reverse osmosis units. Electrodialysis has the capability of achieving high recovery volumes (more product and less brine), with the amount of energy used being proportional to the mass of salts removed.

The efficiency of the process increases as the temperature of the feedwater increases. Electrodialysis is best suited for feedwater with a TDS of 4,000 ppm or less, and in situations where feedwater are high in silica (which tend to create problems with reverse osmosis plants). It is also suited for brackish feedwater where the TDS exceeds 10,000 mg/l, but is not economically viable for seawater desalination (U.N.E.P., 2002).

	The worldwide ED capacity in 1998 was 1,470 (5.6%) plants of 100-60,000 m^3/d; 230 plants (4.7%) of 500-60,000 m^3/d; 60 (2.1%) plants of 4,000-60,000 m^3/d; Total worldwide capacity: 5.6% (Wangnick Consulting GmbH, 1998).		
Technical Characteristics			
Feed Water Used	Brackish Water √	Sea Water	
Need for pre-treatment	√		
Need for post-treatment	√		
Type of energy used	Electricity		
Energy Consumption	Energy consumption ranges between 1.5 to 4 kWh/m^3 for product water concentration of 500 ppm TDS and feed water concentration in the range of 1,500-3,500 ppm TDS (C.R.E.S., 1998).		
Uses	Domestic √	Agricultural	Industrial √
Limitations	Electrodialysis units are presently supplied by only one significant manufacturer. Thus, there is a lack of significant competition which can help to minimize the capital cost of ED units. For optimal operation the units require a reliable source of electricity, which may not be available in remote areas. The process will only remove ions or charged particulates from the source water, and problems with clogging have been experienced when feed water has high counts of bacteria. Since the efficiency of the plant is a design feature, determined by the number of stages in the ED plant, the use of ED with a feedwater of variable or increasing TDS concentration may create problems that can be more readily handled with a reverse osmosis unit (U.N.E.P., 2002).		
Costs			
Capital Cost	The 1995 capital cost for electrodialysis units was in the range of 250 to 750 US$/$m^3$/d of installed capacity, not including site preparation, buildings, and feed water intake systems (U.N.E.P., 2002).		
Operational Cost	Production costs, including depreciation, tend to be in the range of 0.25 to 1.0 US$/$m^3$/d of water produced depending on unit size. Both capital and operating costs are very site-dependent. (U.N.E.P., 2002).		
Environmental Impacts			
Land	Impacts of brine discharges		
Air	Emission of greenhouse gases (combustion of fossil fuels for electricity production)		
Water	Impacts of feed water intake and brine discharge		
Research & Technology Advances			
Electrodialysis is a mature technology. Research concentrates on producing more effective and longer-lasting components (U.N.E.P., 2002).			

Desalination Technologies: Ion Exchange (IX)

Description

In this process, undesirable ions in the feed water are exchanged for desirable ions as the water passes through granular chemicals, i.e. ion exchange resins. Cation exchange resins are typically used to remove calcium and magnesium ions, while special resins are available for adsorbing organics. Many homeowners also have IX units for softening water prior to use. For industries requiring extremely pure water, ion exchange resins are often used after RO or ED for removing specific ions from water and wastewater (U.S. Congress, 1988).

Maturity	Commercial √ (small scale)	Demonstration	Experimental

Experiences

Treating water with ion exchange resins is a relatively simple process.

Costs are mostly associated with the periodic regeneration or replacement of the IX resins. The higher the concentration of dissolved solids in the feed water, the more often the resins will need to be replaced or regenerated with other chemicals (strong acids, bases, or high concentration chemical solutions). Also, organic substances may foul some resins, thereby reducing their exchange capacity. In general, IX becomes competitive with RO and ED only for the treatment of relatively dilute solutions containing a few hundred ppm of dissolved solids. IX is rarely used for salt removal on a large-scale. (U.S. Congress, 1988).

There are several basic requirements for the ion-exchange process to be economically efficient for brackish water desalination. In particular (Department of the USA Army, 1986):

- The ion-exchange resins should operate at high capacities;
- The ion-exchange resins should be regenerated according to the stoichiometric equivalence capacity;
- Acid and base regenerants should be available at low cost;
- Waste regenerants should be rinsed from the ion-exchange resins with a minimum of water, so that the capacity of the resin is not exhausted significantly;
- Regenerant waste volumes should be minimized, and unused regenerants should be recovered and reused to reduce the volume discharged.

Technical Characteristics

Feed Water Used	Brackish Water √	Sea Water √
Need for pre-treatment	√	
Need for post-treatment	√	

Uses	Domestic √	Agricultural	Industrial √

Limitations

The use of ion exchange in brackish water desalination has several limitations, summarized as follows (Department of the USA Army, 1986):

- The volume of water treated is inversely proportional to ionic concentration in the water;
- Regenerant consumption per unit volume of treated water is high and becomes higher as the salinity of the feed water increases;
- The size of the ion-exchange equipment follows the same rationale-the more saline the water, the larger the ion-exchange equipment;
- Low salinity water, usually product water, is required for regeneration of the ion-exchange resins.

Costs

Reliable cost estimates for different IX processes are not widely published, but appear to be very ion- and process- dependent (U.S. Congress, 1988).

Environmental Impacts

Land	Impacts of brine discharges
Water	Impacts of feed water intake and brine discharges

Desalination Technologies: Freeze Desalination

Description

When salty water freezes, ice crystallizes from pure water leaving the dissolved organic and inorganic solids (e.g., salt) in liquid pockets of high salinity brine. Traditional freezing processes involve five steps: precooking of the feed water, crystallization of ice into slush, separation of ice from the brine, washing of the ice, and melting. Although freshwater can be obtained quite easily from ice when seawater freezes naturally, the engineering involved in constructing and operating a freeze desalination plant is quite complicated.

Freeze desalination has the potential to concentrate a wide variety of waste streams to higher concentrations with less energy than any of the distillation process discussed above. In fact, energy requirements for freezing and reverse osmosis are comparable. Pre-treatment of incoming feed water is not necessary and corrosion is much less of a problem with freezing due to the low operating temperatures.

One variation of the freeze desalination concept with additional potential involves spraying seawater or contaminated freshwater, into the air when temperatures fall below freezing point for significant periods of time. The partially frozen spray is collected in a reservoir where the pure ice accumulates and the unfrozen saltwater drains back into the sea (U.S. Congress, 1988).

Maturity	Commercial	Demonstration	Experimental √

Experiences	On an operational level, water passes through different stages of cooling. This allows for complete utilization of temperature differences between the streams of the different stages without any losses. This increases unit size and initial construction costs, but decreases the operational costs. Due to the process complexity, and because the energy costs of cooling water are higher than heating costs, the use of this technology is still limited, and few desalination plants have been constructed. One desalination plant supplied by photovoltaics was constructed in Saudi Arabia. However, it was subsequently found to be inefficient, and was abandoned (UNEP-DTIE-IETC, 2000). Freezing has some inherent advantages over distillation in terms of energy requirements, while scaling and corrosion problems are minimized because of the low temperatures involved. Freezing processes have the potential to condense waste streams to higher concentration than other processes, and the energy requirements are comparable to reverse osmosis. While the feasibility of freeze desalination has been demonstrated, further research and development remains before the technology will be widely available (Mielke, 1999). A small number of plants have been designed constructed over the past 40 years. The process has not been commercially applied for potable water production. At this stage, freezing desalination technology is mostly applied for the treatment of industrial wastes (Department of Agriculture, Fisheries & Forestry–Australia, 2002).

Technical Characteristics

Feed Water Used	Brackish Water √	Sea Water √

Water Uses	Domestic √	Agricultural	Industrial √

Limitations	The main limitation of the process is that it involves handling ice and water mixtures that cannot be easily processed. Freeze desalination also has high energy requirements and therefore energy costs. However it is capable of removing all harmful constituents that may be present, thus making it more suitable for industrial waste treatment than the production of potable water.

Environmental Impacts

Land	Impacts of brine discharge
Air	Emission of greenhouse gases (combustion of fossil fuels for energy production)
Water	Impacts of feed water intake, brine discharge

Research and Technology Advances

New research efforts focus on efforts to reduce the number of steps, and especially the need to wash the ice crystals. Although small-scale commercialisation of freezing was attempted in the late 1960s, there are still significant operational problems. Only a few isolated commercial freezing plants exist at present (Sonune & Ghate, 2004).

Recycling and Reuse

General Overview

Overview

Water recycling makes use of advanced wastewater treatment processes to produce high quality reclaimed water for certain uses, such as for the irrigation of urban landscaping and food crops eater raw, contact recreation, and many industrial applications. The main advanced wastewater treatment processes for water reclamation can be classified into filtration, nitrification, denitrification, phosphorus removal, coagulation and sedimentation, and carbon adsorption. Other advanced wastewater treatment processes of constituent removal include ammonia stripping, breakpoint chlorination for ammonia removal, selective ion-exchange for nitrogen removal, and reverse osmosis for TDS reduction and removal of inorganic and organic constituents.

Advanced wastewater treatment processes such as chemical coagulation, sand or mixed media filtration, and ion exchange are not designed to remove many organic substances, particularly soluble organics. When these processes follow conventional secondary treatment, they typically remove 40 to 85 % of the total BOD, COD, and TOC. The removal of biological contaminants by advanced treatment processes designed to remove either inorganic or organic constituents is incidental and, generally, not too efficient. An exception is reverse osmosis, which can be very effective in removing most viruses and virtually all larger microorganisms. Activated carbon adsorption has been shown to adsorb some viruses from wastewater, but adsorbed viruses can be displaced by organic compounds and enter the effluent (EPA, 1992).

Wastewater treatment processes

Filtration	Filtration is a common treatment process used to remove particulate matter prior to disinfection. Filtration involves the passing of wastewater through a bed of granular media, which retain the solids. Typical media include sand, anthracite, and garnet. Removal efficiencies can be improved through the addition of certain polymers and coagulants.
Nitrification	Nitrification is the term generally given to any wastewater treatment process that biologically converts ammonia nitrogen sequentially to nitrite nitrogen and nitrate nitrogen. Nitrification does not remove significant amounts of nitrogen from the effluent; it only converts it to another chemical form. Nitrification can be done in many suspended and attached growth treatment processes when they are designed to foster the growth of nitrifying bacteria. In the traditional activated sludge process it is accomplished by designing the process to operate at a solids retention time that is long enough to prevent the slow-growing nitrifying bacteria from being wasted out of the system. Nitrification will also occur in tricking filters that operate at low BOD/TKN ratios either in combination with BOD removal, or as a separate advanced process following any type of secondary treatment. A well designed and operated nitrification process will produce an effluent containing 1.0 mg/l or less ammonia nitrogen. Ammonia nitrogen can also be removed from effluent by several chemical or physical treatment methods such as air stripping, ion exchange, RO and breakpoint chlorination. However, these methods have generally proven to be uneconomical or too difficult to operate for ammonia removal in most municipal applications. Ammonia removal may be required for discharges to surface waters due to the high toxicity of ammonia to aquatic organisms, and to the relatively high biological oxygen demand of ammonia that acts as an aquatic plant nutrient often responsible for eutrophication.
Denitrification	Denitrification is any wastewater treatment method that completely removes total nitrogen. As with ammonia removal, denitrification is usually best done biologically for most municipal applications, in which case it must be preceded by nitrification. In biological denitrification, nitrate nitrogen is used by a variety of heterotrophic bacteria as the terminal electron acceptor in the absence of dissolved oxygen. In the process, the nitrate nitrogen is converted to nitrogen gas which escapes to the atmosphere. A carbonaceous food source is also required by the bacteria in these processes. Denitrification can be achieved using many alternative treatment processes. These include variations of many common suspended growth and some attached growth treatment processes provided they are designed to create the proper microbial environment. The denitrification reactor must contain nitrate nitrogen, a carbon source and facultative heterotrophic bacteria in the absence of dissolved oxygen. Biological denitrification processes can be designed to achieve effluent nitrogen concentrations between 2.0 mg/l and 12 mg/l nitrate nitrogen. The

	effluent total nitrogen will be somewhat higher depending on the concentration of TSS and soluble organic nitrogen present. Denitrification may be necessary where reclaimed water reaches potable water supply aquifers. It may also be required prior to using effluent for agricultural irrigation of certain crops during specific times in their growing cycle (such as sugar cane and corn).
Phosphorus Removal	Phosphorus can be removed from wastewater by either chemical or biological methods, or a combination of the two. The choice of methods will depend on site specific conditions, including the amount of phosphorus to be removed and the addition of iron, aluminium or calcium salts. Biological phosphorus removal relies on the culturing of bacteria that will store excess amounts of phosphorus when exposed to anaerobic conditions followed by aerobic conditions in the treatment process. In both cases, the phosphorus is removed from the treatment process with the waste sludge. Chemical phosphorus removal can attain effluent orthophosphorus concentrations less than 0.1 mg/l, while biological phosphorus removal will usually produce an effluent phosphorus concentration between 1.0 and 2.0 mg/l.
Coagulation – Sedimentation	Chemical coagulation with lime, alum, or ferric chloride followed by sedimentation removes SS, heavy metal, trace substances, phosphorus, and turbidity.
Carbon Adsorption	One of the most effective advanced wastewater treatment processes for removing biodegradable and refractory organic constituents is granular activated carbon. Carbon adsorption can reduce levels of synthetic organic chemicals in secondary effluent by 75 to 85 %. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption preceded by conventional secondary treatment and filtration can produce an effluent with a BOD of 0.1 to 5.0 mg/l, a COD of 3 to 25 mg/l, and a TOC of 1 to 6 mg/l. Carbon adsorption treatment will remove several metal ions, particularly cadmium, hexavalent chromium, silver, and selenium. Activated carbon has been used to remove unionized species, such as arsenic and antimony, from an acidic stream, and it also decreases mercury to low levels, particularly at low pH values.
Advanced treatment by chemical coagulation, sedimentation, and filtration unit processes	Advanced treatment by chemical coagulation, sedimentation, and filtration unit processes has been demonstrated to remove more than 2 logs (99%) of seeded poliovirus. This treatment chain reduces the turbidity of the wastewater to very low levels, thereby enhancing the efficiency of the subsequent disinfection process. Chemical coagulation and sedimentation alone can remove up to 2 logs (99%) of seeded poliovirus. The primary purpose of the filtration step is not to remove viruses but to remove floc and other suspended matter, which coincidentally may contain adsorbed or enmeshed viruses, thereby making the disinfection process more effective. Chemical coagulation and filtration followed by chlorine disinfection to very low total coliform levels can remove or inactivate 5 logs (99.999%) of seeded poliovirus through these processes alone and subsequent to conventional biological secondary treatment can produce reclaimed water free of measurable levels of viruses. Virus inactivation under alkaline pH conditions can be accomplished using lime as a coagulant, but pH values of 11 are required before significant inactivation is obtained. The mechanism of inactivation under alkaline conditions is caused by denaturation of the protein coat and by disruption of the virus.
Costs	
Costs vary widely and are highly dependant on the chosen technique.	
Environmental Impacts	
Land	Water Recycling and Reuse often encourage a more intensive use of land in a municipality. In a developed urban environment, landscaping of green space may be enhanced. Open green spaces used for recreation can be developed on a previously undeveloped land. More intensive land use could occur due to the increased water availability for: • agricultural activities; • industrial activity on sites not previously dedicated to industrial use; • creation of new residential areas.
Air	-

Water	**In-stream flows** are considered valuable to the environmental system. Where wastewater discharges have occurred over an extended period of time, the indigenous flora and fauna have adapted and, in some cases, become dependent on that water. In some cases, water recycling projects have been halted over concerns related to water rights because the elimination of an existing discharge was expected to result in a decreased volume of water available to downstream users. **Hydrogeological impacts.** One of the better known sources of potential groundwater pollution is nitrate, which may be found in or result from the application of reclaimed water. Additionally, physical, chemical, and biological constituents found in reclaimed water may pose environmental risks. In general these concerns increase when there are significant industrial wastewater discharges to the water reclamation facility.The impacts of these constituents are influenced by the hydrogeology of the reuse application site; in karstic formations there is potential for constituents within the reclaimed water to ultimately reach the aquifer. In many reclaimed water irrigation programs, a groundwater monitoring program is required to detect the impacts of reclaimed water constituents, but such programs will also detect other sources of pollution (EPA, 1992).
Advantages & Disadvantages	
Advantages	Water reuse and recycling can: • Provide a reliable local water supply, which serves against future droughts and potential uncertainty associated with traditional water supplies, • Enable some suppliers to reduce imports during average and above-average years, and “bank” this imported water for use during dry years, • Provide economic benefits by retaining businesses, and by attracting new businesses with a reliable water supply, • Possibly improve environmental conditions by reducing the need to divert additional supply from sensitive watersheds, • Reduce the quantity of treated wastewater discharged into the environment, • Possibly reduce the cost of wastewater treatment and disposal, Water recycling projects that include a demineralization step can also provide a significant enhancement to water quality. In addition, the yield of indirect potable reuse optimizes a water recycling project through the use of the existing water supply infrastructure, including seasonal storage and distribution facilities.
Disadvantages	Disadvantages are mainly related to **hydrogeological impacts** due to nitrate pollution (Environmental Impacts section).

Treatment Technologies for Water Reuse: Biological (Secondary) Treatment

General Description			
Secondary treatment follows primary treatment where the latter is employed and utilizes an aerobic biological treatment process for the removal of organic matter and, in some cases, nitrogen and phosphorus. Aerobic biological treatment occurs in the presence of oxygen whereby microorganisms oxidize the organic matter in the wastewater. Several types of aerobic biological treatment are utilized for secondary treatment, including activated sludge, trickling filters, rotating biological contactors (RBCs), and stabilization ponds. These processes accomplish biological oxidation in relatively small basins and utilize sedimentation tanks (secondary clarifiers) after the aerobic process to separate the microorganisms and other settleable solids from the treated wastewater. In the activated sludge process, treatment is provided in an aeration tank in which the wastewater and microorganisms are in suspension and continuously mixed through aeration. Trickling filters utilize media such as stones, plastic shapes or wooden slats in which the microorganisms become attached. RBCs are similar to trickling filters in that the organisms are attached to support media, which in this case are partially submerged rotating discs in the wastewater steam. Stabilization ponds are often arranged in series of anaerobic, facultative, and maturation ponds with an overall hydraulic detention time of 10 to 5 days, depending on the design temperature and effluent quality required. They utilize algae to provide oxygen for the system. This process is considered a low-rate biological process (EPA, 1992).			
Maturity	Commercial √	Demonstration	Experimental
Experiences	The activated sludge, trickling filter, and other attached growth processes are considered high-rate biological processes due to the high concentrations of microorganisms utilized for the metabolization of organic matter. These high-rate processes are capable of removing up to 95% of BOD, COD and SS originally present in the wastewater and significant amounts of many (but not all) heavy metals and specific toxic organic compounds. Trickling filters are not as effective as activated sludge processes in removing soluble organics because of less contact between the organic matter and microorganisms. Activated sludge treatment can reduce the soluble BOD fraction to 1-2 mg/l while the trickling filter process typically reduces the soluble BOD to 10-15 mg/l. Biological treatment, including secondary sedimentation, typically reduces the total BOD to 15-30 mg/l, COD to 40-70 mg/l, and TOC to 15-25 mg/l. Very little dissolved minerals are removed during conventional secondary treatment. In stabilization ponds most organic matter removal occurs in the anaerobic and facultative ponds. Maturation ponds, which are largely aerobic, are designed primarily to remove pathogenic microorganisms following biological oxidation processes. Well-designed stabilization pond systems are capable of reducing the BOD to 15-30 mg/l, COD to 90-135 mg/l and SS to 15-40 mg/l. Stabilization ponds are capable of providing considerable nitrogen removal under certain conditions, e.g., high temperature and pH and long detention times. Stabilization ponds are effective in removing microorganisms from wastewater. Well designed and operated pond systems are capable of achieving a 6-log reduction of bacteria, a 3-log reduction of helminths, and a 4-log reduction of viruses and cysts (EPA, 1992).		
Technical Characteristics			
Uses	Secondary treatment may be acceptable for reuse applications where the risk of public exposure to the reclaimed water is low, such as in irrigation of non-food crops as well as landscape irrigation where public access is limited (EPA, 1992).		
Limitations	Stabilization ponds require relatively large land areas and are most widely used rural areas and in warm climates and/or where land is available at reasonable cost (EPA, 1992).		

Treatment Technologies for Water Reuse: Chemical Treatment – Disinfection

Description

The most important process for the destruction of microorganisms is disinfection. The most common disinfectants are chlorine, ozone and ultraviolet light. Other disinfectants, such as gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater but are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

The chlorine dosage required to disinfect a wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the interfering substances are organic constituents, which consume the disinfectant; particulate matter, which protects microorganisms from the action of the disinfectant; and ammonia, which reacts with chlorine to species than free chlorine. In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality. Chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulphur dioxide.

Ozone (O_3) is a powerful disinfecting agent and a powerful chemical oxidant in both inorganic and organic reactions. Due to the instability of ozone, it must be generated onsite from air or oxygen carrier gas. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes.

Ultraviolet (UV) is a physical disinfecting agent. Radiation at a wave length of 254 mm penetrates the cell wall and is absorbed by cellular nucleic acids. This can prevent replication and cause death of the cell (EPA, 1992).

Maturity	Commercial √	Demonstration	Experimental

Technical Characteristics and Experiences

Wastewater reuse conserves freshwater resources, by making use of the potentially large volumes of low quality water for irrigation and similar uses. (UNEP –SPAGC, 2002).

When evaluating disinfection alternatives several factors should be considered, including disinfection effectiveness and reliability, capital and operating and maintenance costs, practicality (e.g., ease of transport and storage or onsite generation, ease of application and control, flexibility, complexity, and safety), and potential adverse effects such as toxicity to aquatic life or formation of toxic or carcinogenic substances.

The efficiency of disinfection with **chlorine** is dependent upon the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of the chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than are viruses, which in turn are less resistant than parasite ova and cysts (EPA, 1992).

Chlorine is an extremely volatile and hazardous chemical, and proper safety precautions must be exercised during all phases of chlorine shipment, storage, and use (EPA, 1986).

Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent, removes colour, and contributes dissolved oxygen (EPA, 1992). Ozone can exert beneficial impacts on the environment. Since ozone decomposes rapidly to oxygen after application, the dissolved oxygen levels in the treated effluent can be elevated significantly, often to saturation levels. Ozone is believed to present fewer potential environmental and health hazards than chlorine. The important criteria for design include maximum transfer efficiency in the contactor to maximize ozone utilization and minimize applied dose and power consumption requirements along with efficient ozone generation equipment design (UNEP –SPAGC, 2002).

UV radiation is receiving increasing attention as a means of disinfecting reclaimed water because it may be less expensive than disinfection with chlorine, it is safer to use than chlorine gas, and – in contrast to chlorine – it does not result in the formation of chlorinated hydrocarbons. The effectiveness of UV radiation as a disinfectant (where faecal coliform limits are on the order of 200/100 ml), has been well established. Little information is available on the ability of UV disinfection to achieve high levels of disinfection; however, in one pilot plant study, a UV dose of 60 mw-s/cm2 or greater consistently disinfected filtered secondary effluent to a total coliform level to 2.2/100 ml or less. The study also indicated that filtration, which was effective in removing significant amounts of SS and providing an effluent with a turbidicity of less than 2 NTU, enhanced the performance of the UV disinfection (EPA, 1992). Since ultraviolet light is not a chemical agent, no toxic residuals are produced. Although certain compounds may be altered by the radiation, the energy levels used for disinfection are too low for this to be a significant cause for concern. Major advantages of ultraviolet light are its simplicity, lack of impact on the environment and aquatic life and minimal space requirements. Required contact times are very short, on the order of seconds rather than minutes. The equipment is simple to operate and maintain, but fouling of the quartz sleeves or Teflon tubes must be dealt with on a regular basis. Fouling is normally handled by mechanical, sonic or chemical cleaning. This process is considered to be an effective alternative to chlorination (EPA, 1986).

Uses	Chemical treatment may be acceptable for reuse applications in urban parks, irrigation and certain industrial processes.
Limitations	Wastewater treatment facilities require a high level of operation and maintenance,

Limitations	and close monitoring of discharge effluent quality to minimize health and environmental risks associated with wastewater reuse. Wastewater reuse carries a potential public health risk when directly reused for potable use or indirectly reused to irrigate crops that are commonly eaten without cooking (e.g. vegetable crops such as tomatoes and most fruit crops). Consumers may also be unwilling to use treated wastewater for agricultural and domestic uses. Variations in wastewater flows and composition may lead to variable quality of the treated water for irrigation use. Close monitoring of the treatment processes by skilled staff is required (UNEP –SPAGC, 2002). The use of chlorine disinfection of wastewater can result in several adverse environmental impacts, especially due to toxic levels of total residual chlorine in the receiving water and formation of potential toxic halogenated organic compounds. Chlorine residuals have been found to be acutely toxic to some species of fish at very low levels. The chlorine residuals are stable and can persist for many hours at toxic levels. Other toxic or carcinogenic chlorinated compounds can bioaccumualate in aquatic life and contaminate public drinking water supplies. Ozonation has been shown in some instances to produce toxic mutagenic and/or carcinogenic compounds, but little is presently known about these organic by-products (EPA, 1986). The use of ozone is relatively expensive and energy intensive, ozone systems are more complex to operate and maintain than chlorine systems, and ozone does not maintain a residual in water (EPA, 1992). An ozonation system can be considered to be relatively complex to operate and maintain compared to chlorination. The process becomes still more complex if pure oxygen is generated on-site for ozone production. Ozonation system process control can be accomplished by setting an applied dose responsive to wastewater flow rate (flow proportional control), by residual control, or by off-gas control strategies (EPA, 1986). High suspended solids concentrations, colour, turbidity, and soluble organic matter in the water can react with or absorb the ultraviolet radiation reducing the disinfection performance. High levels of wastewater disinfection (e.g. 2.2 total coliforms per 100 ml) will be difficult to achieve with ultraviolet disinfection. There is also a negligibly likelihood of producing harmful chemicals in the wastewater (EPA, 1986).
Costs	
Capital Costs	The costs of wastewater treatment are inevitably high, but will vary widely according to location, type of wastewater being treated, and public requirements governing the degree of treatment needed before reuse is acceptable. Costs for small island applications are not readily available. However, the main component of the cost would be the cost of the wastewater treatment plant Ozone disinfection is relatively expensive, with the cost of the ozone generation equipment being the primary capital cost item, especially since the equipment should be sized for the peak hourly flow rate as with all disinfectant technologies. Concerning ultraviolet disinfection, total costs appear to be competitive with chlorination (UNEP –SPAGC, 2002).
Operational Costs	Operating costs of ozonation can be very high depending on power costs, since ozonation is a power intensive system. The major operating costs are power consumption and annual replacement of the ultraviolet lamps. (UNEP –SPAGC, 2002).
Research and Technology Advances	
As wastewater discharge standards for urban areas, hotels, and industries become stricter, more cost effective methods to treat wastewater that could be reused or recycled are likely to be developed, especially in the case of industry (UNEP –SPAGC, 2002).	

Treatment Technologies for Water Reuse: Aquatic Treatment Technology

Description

Lagoons and ponds refer broadly to basins constructed in, or on the ground surface, using earthen dikes to retain the wastewater. Within the lagoons, natural stabilization processes occur with necessary oxygen being obtained from atmospheric diffusion, photosynthetic and/or mechanical sources. More specifically, there are stabilization ponds, complete mix aerated ponds, partial mix aerated lagoons, anaerobic lagoons and various hybrids (DEP, 2004).

The surface water layer is aerobic while the bottom layer, which includes sludge deposits, is anaerobic. The intermediate layer is aerobic near the top and anaerobic near the bottom, and constitutes the facultative zone. Aerated lagoons are smaller and deeper than facultative lagoons. These systems evolved from stabilization ponds when aeration devices were added to counteract odours arising from septic conditions. The aeration devices can be mechanical or diffused air systems.

Hydrograph controlled release (HCR) lagoons is a system where wastewater is discharged only during periods when the stream flow is adequate to prevent water quality degradation. When system conditions prohibit discharge, wastewater is accumulated in a storage lagoon (UNEP-IETC, 1997).

Maturity	Commercial √	Demonstration	Experimental

Experiences

Facultative lagoons are the most common form of aquatic treatment-lagoon technology currently in use (UNEP-IETC-UNEP, 1997).

The main features of any lagoon facility are the total volume for treatment and the flexibility to increase or decrease total detention time by varying the liquid level of each lagoon at any time of the year. In fact, detention time consists one of the few operational variables.

Sizing of the treatment lagoons must be directly related to climatic conditions and not dictated by a set detention time. The three critical points are:

1) **Winter**, when temperatures and reaction rates are low,
2) **Spring** turnover, when benthic demand from sludge settled all winter is high, and
3) **Summer,** when temperatures and reaction rates are high.

Consideration should also be given to nitrification. Winter conditions normally define the volume of the lagoon, while the second or third critical points define aeration capacity. Volume for ice cover and sludge accumulation should be taken into account in the design of the system, while small trapezoidal configurations with small bottom areas which lead to unfavourable aeration and mixing zones should be avoided.

The number of cells may have a significant effect on overall sizing. Normally three or four cells should be provided. At a minimum each cell must be removable from service while maintaining treatment. Additional recommendations, accumulated from experience are:

- Ensuring a minimum of 3 m depth for partial mix aerated lagoons.
- Ensuring multiple inlets and outlets, to minimize short-circuiting of the wastewater and allow even wastewater distribution across each lagoon.
- Provision of bypass capabilities for each lagoon, in order to allow for each lagoon to be temporarily taken off the system to ensure periodic maintenance, process control, and discharge flexibility.
- Provision of step feed in the first lagoon cell.
- Provision of the appropriate means to vary the water level in each lagoon (this may consist of a flow structure with an adjustable weir gate). This allows the detention time of each cell to be increased or decreased independently. Valves must function in any season and may require frost protection.
- Installation of measurement instruments to measure the water level in each lagoon (this allows operators to accurately measure the water level in each lagoon and assists in the operation of the facility throughout the year).
- Consideration of multiple draw off levels for all cells and especially for the final lagoon cell (this allows for best possible quality of effluent to be discharged to the receiving water body).
- Installation of lagoon baffles to reduce short circuiting.
- Aeration equipment should be capable of maintaining a minimum dissolved oxygen of 2 mg/l at all times. The sizing of aeration equipment should consider future growth, benthal release, nitrification, standby equipment, and potential peak loads from domestic, commercial and industrial wastes users (Published literature typically recommends providing 2-5 lbs of

	oxygen per lb of BOD loading.) • To improve operator control, timers, variable frequency drives and/or D.0, monitoring to control output of aeration equipment should also be provided. • Recirculation facilities, consisting of of portable or permanent pumping facilities that allows for the effluent to be recirculated from one cell to another cell in order to assist in the treatment of wastewater should also be installed, while influent and effluent monitoring stations should be provided (DEP, 2004). In addition, the installation normally requires a thorough review of existing wastewater collection and pumping stations, and their upgrade, where needed. Provisions should also be made for future plant expansion, such as additional treatment lagoon cells, garages, sludge or spray/snow disposal areas, or other types of treatment facilities. The same stands for the capacity of electrical service entrance, and expansion space in the motor control centre and aeration systems.
Limitations	According to a survey of DEP, conducted in 2004, Inflow and Infiltration (**I/I**) can impact the following aspects of lagoon operation: • **Detention time**. Excess flows reduce the time wastewater can be treated within the system. If it reduces the detention significantly or occurs during cold, winter periods when treatment activity is low, it can especially impact BOD removal. • **Seasonal impacts**. Often I/I is worse at certain periods of the year, especially during the spring and in late fall. At these periods, the wastewater in the lagoons is colder and biological processes are slower. Excessive flows reduce the time for treatment just when more treatment is needed. Seasonal increases in influent flow and changes in its nature may affect the established process for awhile. Lagoons have periodic seasonal benthic release and pond turnover periods which usually take place in the spring and fall. Excess flows during these periods can result in pass through of excess wastes and nutrients to downstream units and can impact the final discharge. • **Short circuiting**. Although short circuiting is not identified as a common problem, it is recognized as an important factor at a few facilities. Obviously, if a lagoon system is prone to short-circuiting, high flows will exacerbate this condition. Often short circuiting is associated with temperature stratification within the lagoons, especially in cold weather. In these circumstances, high influent flows of a higher temperature can flow across the top layer of the lagoon above the colder, deeper, heavier layers thus receiving only partial treatment in the passing. At times influent waters can be warmer than the deeper lagoon layers due to changes in the seasons, heated sources of water from industries, homes and businesses and due to the lagoon cooling affects of mixing and aeration during colder ambient air conditions. • **Stratification disruption**. Many lagoons are designed to stratify into zones of aerobic and anaerobic treatment. Aerobic decomposition takes place in the top layer where there is sufficient oxygen and anaerobic decomposition takes place in the lower water and sludge layers where oxygen is lacking. There is an interchange between the layers through settling and benthic release. This relationship allows extended treatment through aerobic, anaerobic and facultative processes. Excessive flows, especially of a different temperature, can disrupt this stratification, causing partial treatment. Colder, more dense influent flows can disrupt the bottom anaerobic treatment layer while warmer ones can skim across the top inhibiting zonal treatment interchanges. • **Storage**. Excessive flows restrict storage options. • **Process control**. The largest impact of excessive flows can be its effect on their process control options. Many operators actively operate their lagoon systems by controlling detention times, lagoon levels, individual cell loadings and through step feeding. Some operators put individual lagoon cells on or off line, store seasonally, operate to promote Daphnia, store during poor water quality periods, manage lagoon loading and holding times to control algae growth and algae die off, etc. Excessive flows can disrupt these treatment strategies by using up the extra capacity needed to make them possible. For example, controlling detention times and individual cell loadings can be impossible under high flow conditions. Lagoons licensed only for seasonal discharges can run out of storage and be forced to discharge during unlicensed periods or when effluent quality limits are not being met.

	• As in other types of systems, I/I can impact headwork's performance, contribute to grit build- up within the system, cause excessive pumping, increased wear of equipment, bypasses etc.
Advantages and Disadvantages	
Advantages	According to SRIO, 2004, the main advantages of lagoon systems are: • They can be cost-effective to design and construct in areas where land is inexpensive. • They use less energy-intensive than most wastewater treatment methods. • They are simple to operate and maintain and generally require only part-time personnel. • They can handle intermittent use and shock loadings better than many systems, making them a good option for campgrounds, resorts, and other seasonal properties. • They are very effective at removing disease-causing organisms (pathogens) from wastewater. • The effluent from lagoon systems can be suitable for irrigation (where appropriate), because of its high-nutrient and low-pathogen content.
Disadvantages	According to SRIO, 2004, the main disadvantages of lagoon systems are: • They require more land than other treatment methods. • They are less efficient in cold climates and may require additional land or longer detention times in these areas. • Odour can become a nuisance during algae blooms, spring thaw in cold climates, or with anaerobic lagoons and lagoons that are inadequately maintained. • Unless they are properly maintained, lagoons can provide a breeding area for mosquitoes and other insects. • They are not very effective at removing heavy metals from wastewater. • Effluent from some types of lagoons contains algae and often requires additional treatment or "polishing" to meet local discharge standards.

Treatment Technologies for Water Reuse: Constructed Wetlands Treatment

Description

Constructed wetlands treatment systems are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. Dissolved biodegradable material is removed from the wastewater by decomposing microorganisms which are living on the exposed surfaces of the aquatic plants and soils. Decomposers such as bacteria, fungi, and actinomycetes are active in any wetland by breaking down this dissolved and particulate organic material to carbon dioxide and water. This active decomposition in the wetland produces final effluents with a characteristic low dissolved oxygen level with low pH in the water. The effluent from a constructed wetland usually has a low BOD as a result of this high level of decomposition.

Aquatic plants play an important part in supporting these removal processes. Certain aquatic plants pump atmospheric oxygen into their submerged stems, roots, and tubers. Oxygen is then utilized by the microbial decomposers attached to the aquatic plants below the level of the water. Plants also play an active role in taking up nitrogen, phosphorus, and other compounds from the wastewater. This active incorporation of nitrogen and phosphorus can be one mechanism for nutrient removal in a wetland. Some of the nitrogen and phosphorus is released back into the water as the plants die and decompose. In the case of nitrogen much of the nitrate nitrogen can be converted to nitrogen gas through denitrification processes in the wetland" (EPA, 2002).

System Types	Constructed wetlands treatment systems generally fall into one of two general categories: Subsurface Flow Systems and Free Water Surface Systems. **Subsurface Flow Systems** are designed to create subsurface flow through a permeable medium, keeping the water being treated below the surface, thereby helping to avoid the development of odours and other nuisance problems. Such systems have also been referred to as "root-zone systems", "rock-reed-filters" and "vegetated submerged bed systems". The media used (typically soil, sand, gravel or crushed rock) greatly affect the hydraulics of the system. **Free Water Surface Systems** are designed to simulate natural wetlands, with the water flowing over the soil surface at shallow depths. Both types of wetlands treatment systems typically are constructed in basins or channels with a natural or constructed subsurface barrier to limit seepage. Constructed wetlands treatment systems have diverse applications and are found around the world. While they can be designed to accomplish a variety of treatment objectives, for the most part, Subsurface Flow Systems are designed and operated in a manner that provides limited opportunity for benefits other than water quality improvement. Free Water Surface Systems are usually designed to maximize wetland habitat values and reuse opportunities, while providing water quality improvement.		
Maturity	Commercial √	Demonstration	Experimental
Experiences	Constructed wetlands are designed to take advantage of many of the same processes that occur in natural wetlands, within a more controlled environment. Some of these systems have been designed and operated with the sole purpose of treating wastewater, while other have multiple objectives (e.g. use of treated wastewater as water source for the creation and restoration of wetland habitat for wildlife use and environmental enhancement, EPA, 2002).		
Limitations	Constructed wetlands are site-specific. In colder climates larger cells are needed for preventing freezing and maintaining operation efficiency targets. On steep slopes, cut-and-fill may be necessary to keep the effluent flow slow enough for proper absorption (Toolbase Services, 2004).		

Costs

Costs vary enormously depending on the chemical qualities of the wastewater and the site conditions. A complete system for a household (not including design) can range from 2,000 to 10,000 US$. Downsizing the leach field can offset other costs depending on national legislation and regulations. A properly constructed and maintained wetland can last much longer than conventional septic systems (Toolbase Services, 2004).

Groundwater Exploitation

General Overview

Description	
Well Types	**Shallow wells**. Shallow wells are water retrieval works the depth of which does not exceed 15 -20 m and they are constructed by means of digging, boring, thrusting and injection: Dug wells were first used in antiquity. Their depth reaches up to 20 m or even a little bit more, depending on the depth of the groundwater table. Their diameter ranges from 1 to 10 m, although diameters of 1.5-3 m are most commonly observed. Their yield is quite high when they are situated in shallow aquifers and they are usually constructed in shallow loose soil or in karstic formations (Watt & Wood, 1976). The depth of the wells should exceed the depth of the groundwater table, during the driest month, by 3-5 m. • **Bored wells** can give small quantities of water with low cost of construction in shallow aquifers and loose earth materials. Manual or mechanical augers are used for the construction of such wells. When these wells are constructed with a manual Auger, their depth does not exceed 15 m and their diameter 20 cm. With a mechanical Auger wells deeper than 30 m and wider than 1m are constructed. • **Driven wells** consist of a series of connected pipes that are pressed inside the soil by consecutive thrusts until they reach a few meters below the groundwater table. In principle they are cylindrical filter pipes that their edge has a conical shape. Their diameter is at the range of 3-10 cm and their depth does not exceed 15 – 20 m. • **Jetted wells** are constructed by ejecting water under pressure. The high water velocity erodes the soil and at the same time the casing, which advances gradually as the well becomes deeper is carrying the water and the soil particles outside the well. These wells have a diameter of 3-10 cm and a depth of 15-20 m (Huisman, 1972). Their yield is low and use is recommended for loose and fine materials. **Deep wells** The construction of deep groundwater wells is performed by means of percussion or rotary drilling or even a combination of both. The successful construction of a groundwater well is heavily site dependant and its design should always be considered as a unique case. For example different approaches should be adopted for loose and for compact soil.
Well Drilling Methods	The two main drilling methods are percussion and rotary drilling. With the **Percussion method**, drilling can be carried out by: • **A cutting edge** (drill bit), lifted upwards and pushed downwards by means of steel cable (cable tool percussion method); • **Free falling of the cutting edge** (drill bit) where the cable is substituted by rods (for deeper and faster drilling); • **Hydraulic drilling** where rotation, percussion of the cutting edge (drill bit) is combined with injection of pressurized water (hydraulic percussion method). With the **Rotary Method**, drilling can be carried out using: • **Rotary drilling with foot-valve**. This is an old abandoned method of drilling, which can be considered as an evolution of the percussion drilling using elements instead of a steel cable which rotate instead of having a percussion effect. • **Hydraulic rotary drilling with normal circulation**. Drilling is performed by a rotating cutting edge through which a pulp out of silt (betonite activated with Na_2CO_3) and water or detergent (the drilling mud) is carried inside the hole. This pulp is used for (a) cooling and lubricating the cutting edge (drill bit), (b) the lifting of the cuttings to the surface by constant circulation of the pulp, (c) the supporting of the loose walls of the drill hole without using temporary casing, and (d) the insulation of the walls so that losses are minimized. • **Hydraulic rotary drilling with reverse circulation**. This method allows drilling in loose geological formations. The drilling mud consists of water which is pumped from the inside the drilling column with the aid of a powerful centrifugal pump or a compressor out to a pool where the cuttings are collected. Then, the water flows through a small ditch into the drill hole between the drilling column and the walls of the borehole, so that the water

level is kept at ground level.

Apart from the two main drilling methods the following methods, which utilize pressurized air or water, can also be applied:

- **Direct Rotary Air Method**: It is a fast drilling method for cohesive or semi-cohesive rocks. The basic equipment is the same as the equipment for rotary normal circulation drilling with the difference that the pump is replaced by a powerful air-compressor, while instead of drilling mud air is used as the circulation fluid.
- **Jet Drilling**: The method is based on the injection of water with a high velocity and the utilization of the water's pressure energy for loosening the cohesiveness of soft rocks. This method combines the effect of percussion with the eroding effect of the injected water.

Well completion

When drilling is over, the hole which was opened will become a well after its completion. Completion is the sum of various tasks aiming to increase the hydraulic conductivity around the well and the prevention of fine material from entering the well. These tasks are the following:

- Casing and application of a concrete slab on top of the well;
- Application of screens;
- Application of a gravel pack around the well.

In cohesive soils, as in the case of limestone, completion is not necessary so the wells are practically open holes.

Energy Consumption

Fuel consumption depends on motor and pump efficiency (E_m and E_p respectively), and can be calculated for various types of fuel for lifting 1 m^3 of water for 1 m (Table 17).

Table 17 Fuel consumption for water pumping (Bouwer, 1978)

Fuel	Thermal efficiency	E_p	E_m	Fuel for the lift of 1 m^3 for 1m	
				g	cm^3
Petrol	10,000	0.8	0.25	1.170	1.7
Oil	10,000	0.8	0.30	0.975	1.2
Propane	11,000	0.8	0.25	1.060	1.8
Natural Gas	10,000	0.8	0.25	-	1.171(liquified)

Costs

The creation of a cost inventory for wells, as is the case for the construction branch in general is a difficult task because apart from construction characteristics/constituents the cost is heavily dependant on the labor offer at the drilling site. Therefore the following should only be viewed as indicative and should be used with caution for every unique case.

Well drilling cost varies seasonally. During the winter period the cost is rising, while it drops during the summer period. On the other hand limitations in personnel, transportation means and natural resources differentiate the cost locally. In general the cost estimation of wells is made on the basis of (U.S. Water Resources Service, 1981):

- Local labour cost;
- Presence of experts in the area;
- Seasonal factors;
- Geologic conditions and formations.

Costs are generally higher for islands and remote areas.

According to Ackermann (1969) and Kallergis (1999), costs of wells is influenced by (a) Available drilling, equipment, (b) Local technical drillings, (c) Road network and site accessibility, (d) Presence of water in the area, (e) Depth and well diameter, (f) Costs for fuel, labour, piping and casing, gravel packing and well construction costs.

Capital Cost

Ackerman (1969) proposed the following formula for the estimation of well construction costs in the Illinois region:

$$Cost = a \cdot d^n$$

where a and n are constants that depend on geological conditions and the well diameter and d is the depth of the well in meters (Table 18).

Table 18 Values for a and n for the calculation of the construction cost of a well for various geological formations (Ackermann 1969, Bouwer 1979).

Well Type	Geological Formation	Well Diameter (cm)	a	n
Without gravel pack	Sand, gravel	15-25 30-38	1141 1324	0.299 0.373
With gravel pack	Sand, gravel	40-50 60-85 90-107	1104 1205 1779	0.408 0.482 0.583
Without gravel pack	Psamites, limestone, dolomite	15 20-30 38-60	3.10 4.70 10.22	1.413 1.450 1.471
Deep wells without gravel pack	Psamites	20-30 38-48	0.267 7.15	1.87 1.429

Schleicher (1975) gives a cost of 60 -120 US$/m depth for depths up to 150 m and diameters of 30 – 80 cm, in loose materials. Gibb (1971) has presented a series of diagrams for the estimation of cost of household wells.

Ackerman (1969) has also proposed the following formula for the estimation of the cost of procurement and installation of centrifugal pumps (with the motor):

$$Cost = 7.26 \cdot Q^{0.453} \cdot H^{0.642}$$

where Q is the pumping rate in m^3/24h and H the total pumping head in m.

Operational Cost	The operational cost is calculated according to the local cost of fuel, the depth of the well, and the water flow. Yearly operational costs can vary between 9,103 € and 20,103 €.
Total Production Cost	Water production cost is estimated between 0.4 €/m^3 and 0.6 €/m^3.

Environmental Impacts in Water Resources Systems

In summary, changes to surface water bodies in response to groundwater pumping commonly are subtle and may occur over long periods of time. The cumulative effects of pumping can cause significant and unanticipated consequences when not properly considered in water-management plans. The types of water bodies that can be affected are highly varied, as are the potential effects.

Generally, the development of groundwater resources should be limited so that the levels of stress as well as effects on economic, social and environmental values are kept at acceptable values. Commonly this concept is referred to as sustainable yield and the rate of extraction is frequently limited as a fraction of recharge.

Streams

Streams either gain water from inflow of ground water or lose water by outflow to ground water. Many streams do both, gaining in some reaches and losing in other reaches. Furthermore, the flow directions between ground water and surface water can change seasonally as the depth of the ground-water table changes with respect to the water table in the stream or can change over shorter time frames when rises in stream surfaces during storms cause recharge to the stream bank.

Under natural conditions, groundwater contributes to stream flow in most physiographic and climatic settings. Thus, even in settings where streams are primarily losing water to ground water, certain reaches may receive groundwater inflow during some seasons.

A pumping well can change the quantity and direction of flow between an aquifer and stream in response to different rates of pumping. The adjustments to pumping of an actual hydrologic system may take place over many years, depending upon the physical characteristics of the aquifer, degree of hydraulic connection between the stream and aquifer, and locations and pumping history of wells. Reductions of stream flow as a result of ground-water pumping are likely to be of greatest concern during periods of low flow, particularly when the reliability of surface water supplies is threatened during droughts.

The eventual reduction in surface water supply as a result of groundwater development complicates the administration of water rights. Traditionally, water laws did not recognize the physical connection of ground water and surface water. Today, in parts of the Western United States, groundwater development and use are restricted because of their effects on surface water rights. Accounting for the effects

	of groundwater development on surface water rights can be difficult. For example, in the case of water withdrawn to irrigate a field, some of the water will be lost from the local water system due to evaporation and use by crops, while some may percolate to the groundwater system and ultimately returned to the stream. Groundwater pumping can affect not only water supply for human consumption but also for fish habitats and other environmental needs. Long term reductions in stream flow can affect riparian zones that have a critical role in maintaining wildlife habitat and enhancing the quality of surface water. Pumping-induced changes in the flow direction to and from streams may affect temperature, oxygen levels, and nutrient concentrations in the stream, which may in turn affect aquatic life. During recharging and discharging, streams, water and dissolved chemicals can move repeatedly over short distances between the stream and the shallow subsurface below the streambed. The resulting subsurface environments, which contain variable proportions of water from ground water and surface water, are referred to as hyporheic zones. Hyporheic zones can be active sites for aquatic life. For example, the spawning success of fish may be greater where flow from the stream brings oxygen into contact with eggs that were deposited within the coarse bottom sediment or where stream temperatures are modulated by ground-water inflow. Groundwater pumping effects on hyporheic zones and aquatic life are not well known.
Lakes	Lakes, both natural and man made, can have complex associated groundwater flow systems. Lakes interact with ground water in one of three basic ways: some receive groundwater inflow throughout their entire bed; some have seepage loss to groundwater throughout their entire bed; and others, perhaps most lakes, receive groundwater inflow through part of their bed and have seepage loss to ground water through other parts. Lowering of lake levels as a result of groundwater pumping can affect the ecosystems supported by the lake, diminish lakefront aesthetics, and have negative effects on shoreline structures, such as docks. The chemistry of ground water and the direction and magnitude of exchange with surface water significantly affect the input of dissolved chemicals to lakes. In fact, ground water can be the principal source of dissolved chemicals to a lake, even in cases where groundwater discharge is a small component of a lake’s water budget. Changes in flow patterns to lakes as a result of pumping may alter natural fluxes to lakes of key constituents, such as nutrients and dissolved oxygen, in turn altering lake biota, their environment, and the interaction among them.
Wetlands	Similar to streams and lakes, wetlands can receive groundwater inflow, recharge groundwater, or both. Wetlands are in many respects groundwater features. Public and scientific views of wetlands have changed greatly over time. Only a few decades ago, wetlands were generally considered to be of little or no value. It is now recognized that wetlands have beneficial functions such as wildlife habitat, floodwater retention, protection of the land from erosion, shoreline protection in coastal areas, and water quality improvement by filtering of contaminants. The persistence, size, and function of wetlands are controlled by hydrologic processes. For example, the persistence of wetness for many wetlands is dependent on a relatively stable influx of groundwater throughout changing seasonal and annual climatic cycles. Characterizing groundwater discharge to wetlands and its relation to environmental factors such as moisture content and chemistry in the root zone of wetland plants is a critical but difficult to characterize aspect of wetlands hydrology. Wetlands can be quite sensitive to the effects of groundwater pumping. Groundwater pumping can affect wetlands not only as a result of progressive lowering of the water table, but also by increased seasonal changes in the depth of the water table. The amplitude and frequency of water-level fluctuations through changing seasons, commonly termed as the hydroperiod, affect wetland characteristics, such as the type of vegetation, nutrient cycling, and the type of invertebrates, fish, and bird species present. The effects on the wetland environment from changes to the hydroperiod may depend greatly on the time of year at which the effects occur. For example, lower than usual water levels during the nongrowing season might be expected to have less effect on the vegetation than similar water-level changes during the growing season. The effects of pumping on seasonal fluctuations in groundwater levels near wetlands add a new dimension to the usual concerns about sustainable development that typically focus on annual withdrawals.
Springs	Springs are typically present where the water table intersects the land surface. Springs serve as important sources of water to streams and other surface water bodies, as well as being important cultural and aesthetic features by themselves. The constant source of water at springs leads to the abundant growth of plants and,

	many times, to unique habitats. Ground-water development can lead to reductions in spring flow, changes of springs from perennial to ephemeral, or elimination of springs altogether. Springs typically represent points on the landscape where groundwater flow paths from different sources converge. Groundwater development may affect the amount of flow from these different sources to varying extents, thus affecting the resultant chemical composition of the spring water.
Coastal Environments	Coastal areas are a highly dynamic interface between the continents and the ocean. The physical and chemical processes in these areas are quite complex and usually poorly understood. Historically, concern about groundwater in coastal regions has focused on seawater intrusion into coastal aquifers. More recently, groundwater has been recognized as an important contributor of nutrients and contaminants to coastal waters. Likewise, plant and wildlife communities adapted to particular environmental conditions in coastal areas can be affected by changes in the flow and quality of groundwater discharges to the marine environment.
Research and Technology Advances	
Possible adjustments to pumping of an actual hydrological system depend upon the physical characteristics of the aquifer, degree of hydraulic connection between the stream and aquifer, locations, and pumping history of wells.	
Advantages & Disadvantages of Drilling Methods (Kallergis, 1999)	
Advantages	**Percussion Method:** • Simplicity, • Easy maintenance, often a motive for application in remote areas, • Low amounts of water needed compared to other drilling methods, • Few workers needed for operation, • Low energy demand, • Low costs from 0.5/3 to 2/3 of the rotary method. **Rotary Method:** • Fast drilling rate, • Avoidance of using temporary casing during the drill, and • Capability of performing geophysical surveys. **Direct Rotary Air Method** • High drilling rates, and • Capability of drilling in karstic or weathered rocks with minimal or no use of water while the well remains clean (free of pulp), **Jet Drilling**: High drilling rate
Disadvantages	**Dug wells:** • Easily polluted with surface water, • Material transfer along with the water. **Percussion Method:** • Slow pace, • Limited drilling depth, • Need for constant casing when drilling in loose formations (high cost of casing), and • Difficulty in removing the temporary casing from deep wells. **Rotary Method:** • High equipment costs, • Complexity; • Need for removal of the mud cake that is created from the water bearing strata, and • Complex problems arising from mishandling the drilling mud. **Direct Rotary Air Method:** Presence of water and free spaces inside rock in which case the drilling velocity is defined by the aquifer’s discharge. **Jet Drilling:** can be used for exploratory drilling.

Drilling Methods: Percussion Drilling

Description

With cable tool percussion, drilling can be carried out:

- By a **cutting edge** (drill bit), which is lifted upwards and pushed downwards by means of steel cable (cable tool percussion method);
- By **free falling of the cutting edge** (drill bit) where the cable is substituted by rods (for deeper and faster drilling);
- By **hydraulic drilling** when rotation, percussion of the cutting edge (drill bit) is combined with injection of pressurized water (hydraulic percussion method).

Effectiveness in various soil types	Cable Tool Percussion Drilling in various soil types can be characterized in terms of effectiveness as follows (Speedstar div. by Todd, 1980): • **Fast** for unweathered schists, weathered schists, limestones, karstic limestones, dolomites basalts in thin layers over sediments, metamorphic rocks, and granites. • **Slow** for silt -clay plastic schists, loose psamites, cohesive psamites, and basalts in thick layers. • **Difficult** for sand dunes, loose sand-gravel, and quick sand. For glacier deposits, cable tool percussion drilling can be characterized as difficult, slow and requiring use of driver casing.		
Maturity	Commercial ☑	Demonstration ☐	Experimental ☐
Experiences	The successful construction of a groundwater well is heavily site dependant and its design should always therefore be considered as a unique case. The basic advantages of the percussion method are (Kallergis, 1999): • Simplicity, • Easy maintenance, which makes it often applicable for isolated areas, • Low amounts of water needed compared to other drilling methods, • Few workers needed for operation, • Low energy demand, and • Low costs (0.5/3 to 2/3 of the rotary method cost). Application (Materials): Loose and whichever cohesive rock. Yields are in the range of 0.5-650 m^3/h.		

Technical Characteristics
(Mandel – Shiftan, 1981; U.S. Soil Conservation Service, 1969; Modified and extended by Kallergis, 1999)

Drilling Rate	About 3-15m/8h; falling fast in depths>200m
Maximum drilling depth	Theoretically > 500m. Practically about 300m.
Drill hole diameter	Maximum: about 66 cm. For drills of medium size 30 – 41 cm. Often telescopic drilling required.
Technical Simplicity	Simple process. The drilling might be interrupted without damaging the well. Presence of casings of variable diameter required.
Casing	Impossible to conduct a casing schedule beforehand. Common casing material: Steel pipes or corrugated steel pipes.
Geological Information	The cuttings are coarse in hard rocks. The fine particles are suspended in the water. Mixing with material from non-cased parts possible.
Hydrological Information	Change in water table elevationis directly observed. Water sampling is possible during the drilling.
Cleaning & development of the well	In loose aquifers development might require over-pumping, reverse cleaning etc. In all other cases cleaning and development are easy.
Limitations	Main limitations of percussion drilling are its slow pace, the limited drilling depth, the need for constant casing when drilling in loose formations (high cost of casing)

	and the difficulty in removing the temporary casing from deep wells. Furthermore percussion drillings cannot be used for geophysical surveying (Kallergis, 1999).
Costs	
In general the cost estimation of wells is made on the basis of (U.S. Water Resources Service, 1981): • Local labour cost; • Presence of experts in the area; • Seasonal factors; • Geologic conditions and formations. Costs are generally higher for islands and remote areas.	
Environmental Impacts	
Land	Subsidence Desertification
Air	-
Water	Groundwater table depression Saltwater Intrusion Facilitation of surface pollution dispersion
Ecosystems	Saltwater Intrusion Facilitation of surface pollution dispersion Desertification

Drilling Methods: Rotary Drilling

Rotary with Drilling Mud Method Classification

Rotary with drilling mud can be carried out in the following ways:

- **Rotary drilling with foot-valve**: It is an old abandoned method of drilling, which can be considered as an evolution of the percussion drilling using elements instead of a steel cable which rotate instead of having a percussion effect.
- **Hydraulic rotary drilling with normal circulation**, where drilling is performed by a rotating cutting edge through which a pulp out of silt (betonite activated with Na_2CO_3) and water or detergent (the drilling mud) is carried inside the hole. This pulp is used for:
  - Cooling and lubricating the cutting edge (drill bit),
  - Lifting of the cuttings to the surface by constant circulation of the pulp,
  - Supporting of the loose walls of the drill hole without using temporary casing, and
  - Insulation of the walls so that losses are minimized.
- **Hydraulic rotary drilling with reverse circulation**. This method allows drilling in loose geological formations. The drilling mud consists of water which is pumped from the inside the drilling column with the aid of a powerful centrifugal pump or a compressor out to a pool where the cuttings are collected. Then, the water flows through a small ditch into the drill hole between the drilling column and the walls of the borehole, so that the water level is kept at ground level.

Effectiveness in various soil types	The effectiveness of rotary with drilling mud in various soil types can be classified as (Speedstar div. by Todd, 1980): • **Fast** for Sand Dunes, Loose Sand-Gravel, Quick Sand, Silt-Clay, Unweathered Schists, Plastic Schists, Weathered Schists, Loose psamites, Cohesive psamites, Limestones, Dolomites • **Slow** for Basalts in thin layers over sediments, Basalts in thick layers, Metamorphic rocks, Granites • **Slow to impossible** for Karstic Limestones • **Difficult to impossible** for Glaciers deposits		
Maturity	Commercial ☑	Demonstration ☐	Experimental ☐
Experiences	The successful construction of a groundwater well is heavily site dependant and its design should therefore always be considered as a unique case. Rotary drilling is the fastest drilling method apart from hard rock. Advantages include (Kallergis, 1999): • Fast drilling rate; • Avoidance of using temporary casing during the drill; and • Capability of performing geophysical surveys. Application (Materials): Silt Sand, Gravel < 2 cm. Cohesive soft to hard rock. Yields are in the range of 0.5-650 m^3/h.		

Technical Characteristics (U.S. Soil Conservation Service, 1969; Modified and extended by Kallergis, 1999)

Drilling Rate	In hard rocks 15-30 m/8h In soft rocks up to 150 m/8h.
Maximum drilling depth	Without limit in case of wells
Drill hole diameter	The common diameter at the beginning of the drilling is 15 cm (medium size drills). For larger diameters drills of the heavy type are required. No telescopic drilling required.
Casing	Casing can be pre-defined. Common casing material is steel pipes or corrugated steel pipes or plastic.
Technical Simplicity	Complicated process. Interruption of the drilling might damage the well. The procurement of the required water is often difficult and costly.
Cleaning & well development	The destruction of the drilling cake is often difficult. The cleaning of the wells with chemicals might be required.

Geological Information	Size of cuttings from hard rocks 2-4 mm. The fine materials are carried with the drilling mud. The mixing of materials is probable. Electric logging is usually required.
Hydrological Information	During the drilling the well should be filled with drilling mud. Sudden loss might be evidence of a permeable formation.
Limitations	Main disadvantages and potential limitations include (Kallergis, 1999): • High cost of equipment; • Equipment complexity; • The need for removal of the mud cake that is created from the water bearing strata; • Complex problems that arise from mishandling the drilling mud.
Costs	
In general the cost estimation of wells is made on the basis of (U.S. Water Resources Service, 1981): • Local labour cost; • Presence of experts in the area; • Seasonal factors; • Geologic conditions and formations. In general construction costs are higher for islands and remote areas.	
Environmental Impacts	
Land	Subsidence, Desertification
Air	-
Water	Groundwater table depression Saltwater Intrusion Facilitation of surface pollution dispersion
Ecosystems	Saltwater Intrusion Facilitation of surface pollution dispersion Desertification

Storage Reservoirs and Dams

General Overview

Overview

The term “**reservoir**” includes several types of artificial water-bodies and/or water storage facilities, i.e.:

- **valley reservoirs**, created by constructing a barrier (dam) perpendicular to a flowing river, and
- **off-river storage reservoirs**, sited outside the main river valley, on minor tributary or completely off stream, and subsequently supplied with water either by gravity or by pumping from the river.

In addition to single reservoirs, **reservoir systems** include:

- **cascade reservoirs**, consisting of a series of reservoirs constructed along a single river, and
- **interbasin transfer schemes**, designed to move water through a series of reservoirs, tunnels and/or canals from one drainage basin to another.

Several types of dams can be constructed to make reservoirs, including earth-fill, gravity, arch and buttress. Very small dams (dam height of 3-6 m above the natural river bed) could be used to store river water for drinking purposes or to divert the water flow of smaller rivers for various purposes, including the operation of mill water wheels. The most common type of dam is earth-filled, and approximately 85 % of the dams of heights between 15-60 m are of this type. Arched dams are usually constructed where very high dam walls are required, and account for 40-50 % of the very large dams (dam height of 150 m or more) around the world.

Storage reservoirs and dams are widely used as a method of water resources management. Water is a critical natural resource and its distribution in time (wet and dry seasons throughout a year) and space (away from big cities and water demanding agricultural areas) has as a result the construction dams and reservoirs all over the world; an estimated 800,000 dams were in operation worldwide in 1997 (Halls and Yamazaki, 2000). The construction and use of storage reservoirs have played an important role in establishing and the development of towns and farms by ensuring domestic water supply and by providing irrigation water. Dams and reservoirs also help control flood waters and therefore protect people and property, keep rivers navigable, provide electricity (19% of world electricity, Walz et al., 2000) to towns and factories, and create recreational opportunities such as fishing and water sports.

Uses and multi-purpose reservoirs

Water uses of reservoirs include:

- Water supply for domestic use,
- Irrigation,
- Hydroelectric energy production,
- Flood control and storm water management,
- Navigation,
- Water flow control,
- Debris control,
- Fish and wild life pond,
- Fire protection,
- Recreation.

Different purposes require different operation schemes, e.g. flood management requires a free storage capacity water to reduce the flood peaks, water supply provision is based on a filled reservoir to cope with drought periods.

The operation of this multi purpose reservoir system requires decisions to be made regarding source selection and abstraction to meet particular requirements. Abstraction from these dams depends on water availability and water quality as well as priorities and restrictions (e.g. primary purpose: drinking water supply and low-flow augmentation; secondary purpose: irrigation and energy production).

Often dams are operated based on long-term operation schemes, optimized through consideration of multiple objectives. In other cases the operation is based on experience of the personnel or to demand coverage until the reservoir is empty. Due to the dynamic system (nature, economy, laws and science) that influence dam and reservoir operation, a process has to be adapted to changing conditions that can ensure their long-term efficiency and minimise adverse impacts.

The varying conditions of reservoir management can be divided into two categories related to (Brass and Schumann, 2003):

- Changes in older objectives like land use changes (deforestation in inundation areas) that can increase flood risk,
- Introduction of completely new objectives and expected runoff changes due to global climate change.

Changes in basic conditions and objectives result in the need to adapt reservoir management policies in a continuous process instead of applying a steady operation policy.

Maturity	Commercial ☑	Demonstration ☐	Experimental ☐

Limitations	Limitations on dam construction and operation are focused on the geological and topographical conditions of the site, the hydrological characteristics of the selected area and dam lifetime. The valley sides of the proposed reservoir as well as the dam and its foundations must be adequately watertight to the intended water level of the reservoir to prevent dangerous or uneconomic leakage. As far as the hydrological characteristics, it is important that the size and capacity of a reservoir is relative to the runoff conditions and the selected area so that the dam will fill up within the specified timeframe to meet its designed performance of water supply. The lifetime of a reservoir is affected by the sediments that are transported by the river. As water enters in the dam, sediments are losing their and gravity causes settling inside the dam building up layers of sediments that eventually could fill up the whole dam. There are methods for protecting a dam from sediments by either preventing them to enter or by removing them from the bottom. Those methods can extend the lifetime of a dam; however this practice can increase operational costs especially in cases where such process has not been foreseen from the beginning. The safety of dams is also an important issue that has always been taken under consideration as dam failure due to structural design, operation or seismic activity can result in severe consequences, such as: • Population at Risk. • Property Damages and Lost Project Benefits. • Social, Environmental, and Cultural Resource Damages. In addition, in many cases there are problems of controlling the surrounding environment to avoid contaminating the water from point and non-point sources, particularly in cases where water is intended for domestic usage.
Costs	
Costs of a reservoir include capital costs, operation, maintenance, and replacement (OM&R) costs. Value of project benefits which would be lost with implementation of alternatives should also be included in the economic assessment. Costs depend upon the scale of a given project.	
Capital Cost	Capital costs are the initial costs incurred in implementation of the alternative. They include expenses for data collection, analyses, project formulation, environmental compliance, repayment contract negotiation, final design, earth works, sealing and construction of the dam. Construction costs range from 0.16 €/m^3 to 0.60 €/m^3 for large dams, and from 1 €/m^3 to 5 €/m^3 for smaller sized structures (Santiago et al., 2000).
Operational Cost	Operational costs are related to the everyday activities at the project facilities. Those include expenses for: • Reservoir operation, including periodic repair and replacement of project features, • Operations of project recreation facilities, and • Emergency management activities. If large dams are built in an environmentally sound manner, and have no significant hydraulic problems, maintenance costs are low and the structures can be operated without specialized staff. Small dams have few costs, although they must be inspected periodically to ensure that they are not subject to siltation or misuse.
Environmental Impacts	
General	The larger the project, the greater the potential impacts will be on the natural and social environment. These include: • Resettlement and relocation of communities • Socioeconomic impacts: affected population as well as the affected activities such as agriculture, irrigation, forestry, commercial and industrial • Environmental and ecosystem concerns • Changes in the sediment regime of the river • Safety aspects.

	The construction of a reservoir has both positive and negative impacts to ecosystems. Positive as far as the creation of a new ecosystem inside the reservoir and negative as far as the downstream ecosystem and the river estuary is concerned. The reduced flows as well as the removal or settling of suspended solids can result in limiting the amount of sediment available for supporting the estuaries, which are eroded by the sea, and can lead to irreversible loss of species and ecosystems, particularly in the case of large reservoirs. However, controlled flow releases can maintain downstream ecosystems and living communities. Changes in turbidity and sediment regimes can also have significant impacts on species that are adapted to different environments. Trapping of sediments and woody debris may also affect the entire food chain downstream of the reservoir. Another major concern is the effect of a reservoir (valley reservoirs) in blocking the migration of aquatic organisms. For fishes like salmon that breed at river springs of rivers, blocking of paths can drastically reduce their population. Finally, water in the reservoir itself can be populated with species that are vectors of human and animal diseases.
Land	Large reservoirs usually occupy large spaces and consequently drastically transform the landscape. Reservoirs situated in arid and semi-arid areas where surface water is naturally scarce can cause problems of salination or mineralization, as salts from the soils are transported to, and accumulate in, the reservoir.
Air	Recent studies have concluded that there are Greenhouse Gas emissions from the reservoirs due to rotting vegetation and carbon inflows from the catchment (Walz et al. 2000). However, the amount of carbon dioxide consumed by the algal photosynthesis taking place in the reservoirs, has to be taken into account, since the process counterbalances the emissions of GHG.
Water	The construction of dams and reservoirs has two hydraulic effects: • The flow velocity upstream of the dam will change drastically, transforming the flowing water system to a (more or less) standing water body, • The drastic change in the diurnal and seasonal variations in the water regime of the river. These two effects, in turn may have a number of consequences on water quality, biodiversity and the entire river ecosystem. The most significant of those consequences are listed below. The reduced velocity in the reservoir reduces the ability of water to carry sediments and thus makes water in the reservoir less turbid. Generally, the water abstracted from a reservoir needs therefore less treatment than water taken from a river. However, reduction of solids and sediments may have adverse effects on the ecosystem downstream. Furthermore, the chemical, biological and physical processes in the reservoir are affected by temperature, which in turn, depends on the inflow rate and the volume of the reservoir.
Advantages & Disadvantages	
Advantages	The advantages of a reservoir are related to its use and the purpose for its construction. Reliable water provision for domestic use, irrigation, industrial processes and power generation is considered to be the main advantage. Dams and reservoirs play an important role in controlling floods, retaining sediments and recharging groundwater. In addition, they can constitute a source of recreation, and provide habitats for numerous species of animals.
Disadvantages	The construction of a reservoir, as it occupies large areas of land, may force the resettlement and relocation of communities. Furthermore several activities, such as agriculture, forestry, commerce and industry, have to be abandoned when a new dam is constructed. Another major disadvantage is the significant environmental impact related to the disturbance caused to a river system by blocking its natural route. These impacts have led to increased controversies over their role in water resources planning, especially with respect to their construction and operation.

Implementation

Planning and operation of dams do not only focus on technical aspects. Full consideration should be given to whether or not the project is socially, environmentally and economically justified, and whether the normal functions of the river will be preserved.

Design Steps	Site selection Estimation of reservoir capacity in relation to annual river flow Flood water provisions
Operation	• Manual, based on the experience of the personnel, or • Fully automated, that can include real-time rainfall and flow forecasting schemes in order to protect the dam and the downstream communities.

Research and Technology advances

Research is focused on the dam design, and on the methods that can be applied in order to minimise the dam impacts as well as to optimise performance. New methods are introduced to limit the amount of sediments and nutrients trapped inside the dams, as well as water paths that allow the migration of organisms.

Micro dams based on local renewable sources are gaining ground over large dams.

Conservation measures in domestic use

General Overview

Overview
The impact of the use of water-saving devices on water demand is different depending on the importance of household demand in relation to total urban water demand. For example, a 10-70% reduction in household water demand in the Netherlands, with a total demand of 1,014 million m^3, 57% of which goes to households, would result in a water reduction of between 58 and 405 million m^3 (between 6 and 40 % of the total urban demand). In the UK, with a total demand for urban use of 12,117 million m^3 of which 44% is for household demand, the water reduction would be between 533 and 3.732 million m^3 (between 4 and 31% of the total urban demand). Public information and education is a critical priority in water conservation. A multi-stakeholder and participatory approach involving water users and service providers, governmental agencies and non-governmental organizations needs to be encouraged. Raising awareness of water issues at all levels is deemed critical in the successful implementation of water conservation programmes and activities. It is anticipated that water conservation activities, such as water loss reduction programmes and public awareness campaigns for rational water use could result in significant water savings. (UNESCAP, 2001). The main difficulty often lies in encouraging use and increasing market penetration of the water saving devices. Initiatives can include the short- or long-term renovation buildings, such as offices, sports facilities, schools or apartment blocks, when companies or local authorities decide to integrate water efficiency as a design criterion. Increasing the market penetration of appliances in the domestic field is more difficult and requires information campaigns explaining the reasons and advantages of the new appliances, for example in terms of reduced water bills. This is obviously a long-term process, since the turnover of such appliances in individual homes is slow (European Environment Agency, 2001).

Specific Water Conservation Measures in Domestic Use	
Water Saving Devices	Water-saving devices on taps, and toilets with 6 l/flush, could achieve reductions in use of around 50% (European Environment Agency, 2001). In recent years, the EU has established conditions required for the “ecological labelling” of dishwashers (Official Journal of the European Communities, 7 August 1993) and of washing machines (Official Journal of the European Communities, 1 August 1996). Amongst other conditions, dishwashers cannot use more than 1.85 l of water per cutlery item. Washing machines cannot use more than 15 l/kg of clothes in a cycle of 60°C, and both types of machines must give clear instructions about water and energy saving. In addition to regulations, new technologies also have a positive impact in the use of water by these domestic appliances, and have achieved important reductions over the last 20 years. Several simple actions can be undertaken by the users to this direction: • **Adjustment of flow valves to the faucet;** • **Checking regularly for leaks;** • **Use of aerators** for faucet flow controllers on existing faucets. Aerators are attached to the faucet head and add air to the water flow while reducing water flow. They are available at common ratings of 0.5, 0.75 and 1.0 gpm. Flow rates as low as 0.5 are adequate for hand wetting purposes in a bath room setting. Higher flow rate kitchen aerators deliver water at 2.0 to 2.5 gpm for more general washing purposes. Aerators cost \$5 to \$10 installed and typically yield a payback within a few months. • **Installation of flow regulators**. Flow regulators can be installed in the hot and cold water feed lines to the faucet. Common flow rate designs include 0.5, 0.75, 1.0, and 1.5 gpm. Flow restrictors can be used where aerators cannot be used or where there is faucet abuse (aerator removal is problematic). Flow restrictors can be installed for less than \$25 and also yield payback within months (NCDENR, 1998).
Behavioural changes	Behavioural changes involve changing water use habits so that water is used more efficiently and reduce the overall water consumption in a home. These practices require a change in behaviour, not modifications in the existing plumbing or fixtures in a home. Behavioural practices for residential water users can be applied both indoors in the kitchen, bathroom, and laundry room, and outdoors (US EPA, 2004). According to US EPA, the following examples can be mentioned: • In the **kitchen**, 40 to 80 liters of water per day can be saved by running the

	dishwasher only when it is full. If dishes are washed by hand, water can be saved by filling the sink or a dishpan with water rather than running the water continuously. An open conventional faucet lets about 20 liters of water flow every 2 minutes. • Water can be saved in the **bathroom** by turning off the faucet while brushing teeth or shaving. Water can be saved by taking short showers rather than long showers or baths and turning the water off while soaping. This water savings can be increased even further by installing low-flow showerheads, as discussed earlier. Toilets should be used only to carry away sanitary waste. • Water can be saved in the **laundry** room by adjusting water levels in the washing machine to match the size of the load. If the washing machine does not have a variable load control, water can be saved by running the machine only when it is full. If washing is done by hand, the water should not be left running. A laundry tub should be filled with water, and the wash and rinse water should be reused as much as possible. • **Outdoor** water use can be reduced by watering the lawn early in the morning or late in the evening and on cooler days, when possible, to reduce evaporation. Allowing the grass to grow slightly taller will reduce water loss by providing more ground shade for the roots and by promoting water retention in the soil. Growing plants that are suited to the area ("indigenous" plants) can save more than 50% of the water normally used to care for outdoor plants. As much as 60 liters of water can be saved when washing a **car** by turning the hose off between rinses. The car should be washed on the lawn if possible to reduce runoff. Additional savings of water can result from sweeping sidewalks and driveways instead of hosing them down. Washing a sidewalk or driveway with a hose uses about 20 liters of water every 5 minutes. If a home has an outdoor pool, water can be saved by covering the pool when it is not in use.
Check regularly for leaks	Toilets are notorious for their hidden leaks. They can waste hundreds of m^3/d undetected. Leaks occur when the toilet is out of adjustment or when parts are worn, so it's important to check it periodically. Most leaks, aside from toilets, are in faucets and are more commonly caused by worn washers. It is important to check all faucets in the house once or twice a year. If any of them drip after have been turned off firmly, there is a need to replace the washer.
Water metering	In a number of countries, domestic users are charged a flat rate. Examples include the UK, where the charge is based on the value of property, Ireland, where users pay flat rates for water through their local taxes, and Iceland, where users pay an annual fixed charge per m^2 of property plus an overall charge per property. However, in most countries, water is metered and the charge is related in some way to the volume consumed. The impact of the introduction of metering on water consumption is difficult to separate from other factors, in particular the applied water charges. It is also essential to have a correct balance between real water consumption and unaccounted water. Water losses are better measured if a meter is installed at the waterworks as well. Immediate savings from the introduction of revenue-neutral metering are estimated to be about 10-25% of consumption, and this is due to the effects of information, publicity and leakage repair, as well as the non zero marginal pricing. Immediate savings from the introduction of revenue-neutral metering are estimated to be about 10-25% of consumption. The introduction of metering, as part of water demand management, is usually accompanied by a revised charging system and regulation on leakage. Usually, water meters have been used to determine water consumption, but in some countries, e.g. Denmark, meter readings are also used to calculate a pollution tax, on the basis that water consumption indicates the discharge to the sewage treatment plant. In introducing water metering to new regions, there are social impacts to be taken into account, such as impacts on socially disadvantaged households which are more vulnerable to water metering and pricing – large family size, medical conditions (European Environment Agency, 2001a).
Sanitary/domestic uses – Toilets – Showerheads – Faucets	The three major types of **toilets** include gravity flush, flush valve, and pressure assist toilets. Pre-1977 gravity toilets will consume 5 to 7 gallons per flush (gpf). Pre-1977 flush valve toilets use 4.5 to 5.0 gpf. Gravity and flush valve style toilets

	manufactured between 1977 and mid 1990s mostly use 3.5 gpf, although some 5.0 gpf gravity flush toilets continued to be manufactured during that period (NCDENR, 1998). Studies have shown that there is little correlation between toilet costs and flush performance. Therefore, a good quality toilet that will perform well can be purchased for as little as 75 €, and a toilet installation will typically cost between 40 € and 120 €. Savings will be achieved with replacement of old toilets with new reduced flow toilets. **Showerhead replacement or modification** is another very cost effective practice. Most conventional showerheads use 3 to 7 gpm at 60 psi water pressure. New standards require showerheads to use no more than 2.5 gpm. These new water efficient showerheads come in many different models and features and typically perform very well. Water efficient showerheads also reduce energy consumption for hot water generation. Flow restrictors are washer-like disks that fit inside the showerhead and limit water flow. Flow restrictors are very inexpensive (less than 5 €) and easy to install. Newer designs are not noisy at higher pressures. Temporary cut-off valves can be attached to, or incorporated into, the showerheads to allow the user to temporarily cut-off water while soaping, shampooing, or shaving. The water can be reactivated at the previous temperature without need to re-adjust hot and cold water valves (NCDENR, 1998). The best water efficiency option is to purchase new 2.5 gpm showerheads. The products vary in price, from 3 € to 48 €. Good single setting showerheads can be purchased for less than 10 €. The newer code compliant showerheads have a narrower spray area and a greater mix of air and water than conventional showerheads (NCDENR, 1998). **Conventional faucet flow rates** can range from 3 to 5 gpm. A leaking faucet dripping one drip per second can waste 36 gallons of water per day. Any new faucet purchase must have a flow rate less than 2.5 gpm. Many types of faucet and water control systems are available for commercial faucets. These include (NCDENR, 1998): • Automatic shutoff (once handle is released, valve shuts off). • Metered shutoff (once new lever is depressed, the faucet delivers a water flow for a pre-set time period, e.g. 5 to 20 sec, and then automatically shuts off).
Cisterns	A cistern is a tank (usually underground) for storing hauled water and/or rain water from a roof or other catchment area. Cistern water must have continuous chlorination for domestic water potable use. A floating intake takes water from a cistern below any floating scum and above the bottom layer where particulates may have settled. (EPA, 2004b)
Costs	
The cost of conservation measures is mainly related to the cost of campaigns for public education, and to the installation cost for water saving devices cost normally paid by the end-user.	
Environmental Impacts	
Air	Reduced energy consumption for water treatment with direct positive effects on land and air due to the smaller consumption of fossil fuels and production of reduced amounts of air pollutants.
Water	Water conservation, especially in areas where water resources are scarce.
Advantages & Disadvantages	
Advantages	The advantages of non-structural solutions such as the uses of household water saving devices, plumbing modifications and replacement options are: • The need for educational campaign to change consumer behaviour is limited to the initial implementation of the measure. • It is possible to influence the different water consumption behaviours of tourists that could otherwise have significant impact on water conservation. • There is no need for modification in the existing plumbing or fixtures in a home, as changing habit is often the most cost effective way of reducing water use. Overall advantages deriving from the adoption of water conservation measures are: • Reduced pumping costs, deferment of system expansion

	• Increased life of existing capacity • Reduced hydraulic loading of sanitary sewer facilities • Lower water bills • Lower energy bills • Water treatment benefits, such as reduced energy consumption, reduced chemical costs and low residual-sludge volumes. The attenuation of peak flows by conservation practices, such as using household water saving devices, would allow scaled-down designs and lower system investment costs for those facilities designed to meet peak demands such as water treatment plant, pumping station and storage and piping in the distribution system. Customers should benefit through reduced water costs and direct tax policies. Major advantages of water conservation devices are that they are relatively inexpensive, and can easily be installed by the homeowner (Sharpe W. E. and Shelton T. B., 2001).
Disadvantages	All conservation measures for domestic water uses, including behavioural change solutions, bare similar disadvantages: • Extensive development of this kind of solutions may reduce the income of public water systems; • The use of household water saving devices, plumbing modifications and replacements increase the need for new investments in the form of new equipment installation. However, the main disadvantage is that **it is not always easy to influence** public attitudes and behaviours towards water conservation and the efficiency of public campaigns is not always obvious.

Domestic Conservation: Gravity Flash Toilets

Description

The most common type of toilets are gravity-fed models which rely on the weight of the water and head pressure (height of the water in the tank) to promote the flush. Gravity toilets depend on the volume of water in the tank to flush waste and usually require water pressure of no more than 10 - 15 psi to operate properly. The tank and bowl are usually two separate pieces, although this is not obvious once they are in use. A few one-piece toilets are also available (California Urban Water Conservation Council, 2004).

Maturity	Commercial √	Demonstration	Experimental

Experiences	Retrofit options of gravity flush systems are most effective on units that consume more than 3.5 gpf (pre-1980s models). For toilets that consume 3.5 gpf or less, retrofit options may hamper toilet performance or increase maintenance cost. Displacement devices, including bags or bottles, can reduce water flow by approximately 0.75 gpf. They function by displacing flush water stored in the tank. The devices are inexpensive and easy to install, but do require regular maintenance. Bricks or other friable objects should never be used for displacement, since granular contaminants can prevent proper closure of the flapper and damage flow valves. Toilet dams are flexible inserts placed in a toilet tank to keep 0.5 to 1.0 gallons out of each flush cycle, which last for five to six years. A plumber should be consulted before installing such devices. Early closure flapper valves replace the existing flush valve in the tank. These devices are adjustable to optimize performance and can save 0.5 to 2 gpf. Early closing flappers are inexpensive and usually can be installed in 10-15 minutes, barring other problems with toilet mechanisms. Dual flush adapters allow users to use a standard flush for solids removal or a modified smaller flush for liquid and paper. Dual flush adapters have been more popular in Europe than the United States, and can save between 0.6 and 1.2 gpf. To use this retrofit option, facility managers should provide user instructions about the proper use of dual flush systems (NCDENR, 1998).

Technical Characteristics

Replacements	Replacing older commodes with 1.6 gpf models will provide the most water savings. Faster payback can be achieved in situations: • Where there are many users per toilet. • Where high water consuming (5 to 7 gpf) toilets are currently in use (NCDENR, 1998).

Costs

Retail prices for two-piece toilets range from 75 - 200$. One-piece models cost somewhat more (Minton et al., 2003).

Most 1.6-gpf replacements have a payback period of less than four years.

Most retrofit options are available for less than 20 $ (NCDENR, 1998).

Domestic Conservation: Pressure-assist Toilets

Description			
The pressure-assisted toilet relies on air pressure within a cylindrical tank (metal or plastic-like material) inside the toilet tank. Air inside the cylinder forces a vigorous, rapid, and occasionally noisy flush. The cylinders, along with the "roaring/whooshing" sound when you flush it, are sure signs of a pressure-assisted toilet. Pressure-assist toilets require a minimum water pressure of 25 psi to operate efficiently (California Urban Water Conservation Council, 2004).			
Maturity	Commercial √	Demonstration	Experimental
Costs			
Retail prices for pressure-assist toilets are generally over 150$ (California Urban Water Conservation Council, 2004).			

Domestic Conservation: Flush Valve (Flushometer) Toilets

Description			
Flush valve or flushometer toilets use water line pressure to flush waste into the sanitary sewer system. They consist of a valve and a toilet cowl fixtrure (California Urban Water Conservation Council, 2004).			
Maturity	Commercial √	Demonstration	Experimental
Experiences	Most commercial and industrial facilities use flush valve toilets, especially in higher use frequency areas (California Urban Water Conservation Council, 2004). Valve inserts are available and can reduce flush volumes by 0.5 to 1.0 gpf. Some of these devices consist of plastic orifices, perforated with holes in a wheel and spoke pattern. Others actually replace the existing valve mechanisms of a 5 gpf unit with a 3.5 gpf valve without changing the toilet bowl fixture. Ultra-low valves (1.6 gpf) should not be retrofitted without changing a fixture bowl (NCDENR, 1998).		
Replacement			
Replacing inefficient units with an ultra low (1.6 gpf) flush valve mechanism and toilets will result in the maximum water savings. It is important to note that both the low flow valves and bowls should be replaced simultaneously. A 1.6-gpf valve must be used with an appropriately designed 1.6 gpf bowl, or the unit will not perform adequately (NCDENR, 1998).			

Domestic Conservation: Cisterns

Description	
Cisterns are storage tanks for rainfall that has been collected from a roof or some other catchment area.	
Maturity	Commercial √ Demonstration Experimental
Experiences	Although usually located underground, cisterns can be placed at ground level or on elevated stands either outdoors or within buildings. Cisterns should be watertight, have smooth interior surfaces, enclosed lids, and be large enough to provide adequate storage. They should be fabricated from non-reactive materials such as reinforced concrete, galvanized steel, and plastic. Concrete blocks or wood are sometimes used, but these are difficult to keep watertight. Cisterns should be cleaned by using a stiff brush to scrub all inside surfaces. A good disinfecting solution is 1/4 cup 5.25% liquid chlorine bleach in 10 gallons of water. In addition, they should be flushed cistern thoroughly with clean water to remove any sediments after construction, cleaning or maintenance. Cistern drains should not be interconnected with waste or sewer lines, in order to avoid backflow contamination. Mosquito larvae thrive in stagnant water. They can be controlled by the use of commercially available pesticides such as Alfa-sid or DIPEL (Bucklin, 2003).
Technical Characteristics (Bucklin, 2003)	
Catchment Systems	Galvanized steel and aluminum roofs are the best commonly used catchments for cisterns, since rough surfaced materials collect dirt and debris that affect the quality of the water collected. Gutters and downspouts should be easy to clean and inspect. Rainwater picks up dust, soot, bird droppings, leaves and other foreign materials that add objectionable organisms, color and odor to the water. Water should not be collected under overhanging trees. Generally, gutter guards and roof washers can improve the quality of the collected water, while gutter guards made of 1/4" to 1/2" mesh hardware cloth placed over the gutters keep out leaves and other large objects. Sand, gravel or charcoal filters are sometimes used to filter water before it enters the cistern but they require frequent maintenance to prevent contamination. Roof washers are cheaper to construct and need less maintenance than filters. A roof washer traps the first flow from the roof and channels this dirty water away from the cistern. After the first flow, water from the rest of the rainfall flows to the cistern. The roof washer should have a capacity of about 10 gallons for each 1000 square feet of roof area.
Cistern Size and Catchment Area	The cistern size must be adequate to supply water needs during extended periods of low rainfall. A margin of about one-third should be allowed for water leaked from pipes, blown from the roof by wind, lost to evaporation and channeled away by the roof washer. The required catchment area depends on the amount of water needed, the cistern size, and the frequency of rainfall. The cistern and catchment area must be sized together. The catchment area must be large enough to collect enough water from rainfalls when they do occur.
Location	Underground and surface cisterns should be located in areas that are sloped to drain surface water away from the cisterns. Cisterns are usually located near their catchments. Cisterns should not be placed near sewage pipelines or other sources of possible contamination. The site should be on firm ground to avoid settling, which can cause cracking of cistern walls. Cisterns should be located as far from trees as possible because tree roots can crack cistern walls.
Costs	
Capital Cost	Metal Cisterns(Texas Metal Cisterns, 2004): Tank capacity from 150 to 230 gallons: 230 – 460 $ Tank capacity from 830 to 1480 gallons: 590 - 870 $ Tank capacity from 1630 to 2500 gallons: 850 - 1150 $. Tank capacity from 325 to 1700 gallons: 350 – 1400 $

Implementation	
Design and Construction	An opening large enough to provide easy access of a person into the cistern should be left at the top. This opening needs to have a watertight cover with a lock to reduce the risks of contamination or accidents. An overflow pipe should also be provided. The cistern must be watertight. Inlets and outlets should be screened and valves should permit control of water flow. Positive ventilation should be provided when someone is working in a cistern, since there may be hazardous gases present or insufficient oxygen. A water sealant should be applied to concrete tank surfaces. Elevated tanks can be fabricated from concrete, metal, or plastic. The weight of these tanks is considerable. One gallon of water weighs 8.3 pounds, and each cubic foot of water weighs 62.4 pounds. Concrete weighs about 150 pounds per cubic foot. Wind loads may also be a problem on exposed elevated tanks. Elevated tanks should be placed on structurally sound towers. They can also be designed as part of a building. When a cistern is elevated, the amount of pressure developed will depend upon the height of the water surface. About one pound of pressure is developed for each 2 1/2 feet the water surface is above the water outlet. To achieve a satisfactory rate of flow, a head of at least 20 feet of elevation is usually necessary. Friction causes pressure losses as water flows through a pipe. There is less loss in a large pipe than in a small pipe. It is best to use at least 1 1/4 inch pipe for main supply lines. Elevated tanks fabricated from plastics and fiberglass-reinforced plastic may have a shorter lifetime than metal or concrete tanks. If possible, tanks fabricated from synthetic materials should be located in shaded areas to reduce the damaging effects of ultraviolet radiation. Wooden cisterns are generally not satisfactory, particularly when they are used below ground, because they are difficult to keep sealed and allow pollution and ground water to enter through their cracks. The excavation for below-ground cisterns should be large and deep enough to permit the laying of the foundation and walls. Underground tanks should be made from concrete to reduce problems of wall deterioration because of contact with the soil (Bucklin, 2003).
Financing	In several countries cisterns purchased for rainwater collection are exempt from sales tax, while implementation of such systems can also be directly subsidised by the water competent authorities (Texas Metal Cisterns, 2004).
Advantages and Disadvantages	
Advantages	The advantages of cisterns and rainwater harvesting systems are: • They can co-exist with and provide a good supplement to other water sources and utility systems, thus relieving pressure on other water sources. • They provide a water supply buffer for use in times of emergency or breakdown of the public water supply systems. • They are flexible and can be built to meet almost any requirement. Construction, operation, and maintenance are not labour intensive. • They can reduce storm drainage load and flooding in city streets. In addition, users of these systems are usually the owners who operate and manage the catchment system, hence, they are more likely to exercise water conservation as they are aware of the quantity of water in storage and, therefore, they will try to prevent possible drying up of the storage tank.
Disadvantages	The disadvantages of cisterns and rainwater harvesting systems are: • Catchment area and storage capacity of a system are relatively small, and during a prolonged drought, the storage tank may dry up. • Maintenance can be difficult, while the collected water can be of insufficient quality, thus improper for certain domestic uses. • Cisterns and rainwater harvesting systems are often not be part of the building code and lack clear guidelines for users/developers to follow. • Rainwater utilisation has not been recognized as an alternative of a water supply system by the public sector. Governments and/or local authorities typically do not include rainwater utilisation in their water management policies, and citizens do not demand rainwater utilisation in their communities. • Rainwater storage tanks may take up valuable space, and landtake is a major concern, especially in urban areas.

Irrigation Systems and Methods

General Overview

Solution design	
Proper system design requires information on physical and chemical properties of the soil, chemical properties, of the water source, climatic parameters, expected crop response to irrigation, economic costs, and benefits of all aspects of the irrigation system, as well as social impacts and constraints of the proposed system. No two systems are identical, particularly in terms of soil physical and chemical parameters, field topography, and water quality. The time and energy required for data collection should not be underestimated. A false sense of security concerning data availability can arise from the solution of too many textbook problems in system design in which required input parameters are given. Field measurements can quickly emphasize the difficulty in acquiring a good data base for system design (Cuenca, 1989). Once the physical, chemical, climatological, economic and social data are collected, it is necessary to proceed with the choice of system to accomplish the stated objective. Occasionally, only one particular type of irrigation system will be suitable for a particular area, due to equipment availability, operator experience, or terrain characteristics. However, there are cases where a number of systems can possibly be applied and alternative designs can be developed. The ultimate system choice may then be made considering expected economic return, experience, system maintenance requirements, and parts availability. Type of terrain and crop, power cost and availability, and sometimes water quality will dictate which system is the most advantageous for each case. An unbiased look by the design engineer at the realities of system cost, benefits, and constraints can balance the enthusiasm of equipment manufacturers for their particular product. Current availability of equipment for installation and long-term availability of replacement parts must also be considered.	
Irrigation System Selection	Basic criteria for the selection of an irrigation method are the expected accuracy or input data, and how reasonable is the final solution. An example of the first criterion might be the **specification** of system operating time per irrigation. If the estimated crop water requirement based on a combination of climatic, plant, and soil data is only accurate within plus or minus 10 %, which is in fact better than can normally be expected, there is no need to specify the system operating time to the nearest 15 minutes in a 12-hour application. It must be underlined that in irrigation system design one must take into account the interaction of natural systems which are by definition not deterministic. Such systems do not have a precisely predictable reaction to a given stimulus. Different factors required as input for design have a different expected accuracy. While it may be possible to predict friction loss in a new pipe with relative accuracy, the actual pumping level in a well, which has a seasonal water level fluctuation is much more difficult to specify. Both of these data are necessary to compute the power requirements of a pump. The final solution is no more accurate than the least accurate input parameter. The second criterion by which systems may be judged is rationality in application. The system operational constraints should be agreed upon between engineer and operator before the design has progressed too far. The design may proceed along one path until a conflict is reached between two constraints – for example, intake rate of the soil and the operating schedule specified by the grower. At that point, it may be necessary to completely alter the proposed design, perhaps even going to a different type of irrigation system. Such design changes take time, but ultimately not as much time as trying to manage a poor design (Cuenca, 1989).
Considerations	
General Considerations	Three major considerations influence the time of irrigation and how much water should be applied: • Water needs of the crop, • Water supply availability of water, and • Capacity of the root-zone soil to store water. The water needs of the crop are of paramount importance in determining the time of irrigation during the crop-growing season on irrigation projects which obtain their water supplies from storage reservoirs or from other dependable sources of water. Some irrigated areas have a limited water supply during the irrigation season, but an abundance of water during late autumn or winter and early spring. Irrigation farmers cannot always apply water when the crop is most in need;

	sometimes to save water they must apply it even when crop does not need it, provided that the soil has the capacity to store additional water. Therefore, crop needs, available water supply, and storage capacity of the soil must be considered in a discussion of the proper time to irrigate. Growing crops use water continuously, although the rate of use varies with the kind of crop grown, age of the crop, and atmospheric conditions – all variable factors. At each irrigation, a volume of water sufficient to supply the needs of the crop for a period varying from a few days to several weeks, is stored in the unsaturated soil in the form of available soil water. How frequently water should be applied to soils of different properties in order to best supply crop needs is a question of real and practical significance. A factor of major importance in arriving at the desirable frequency and time of irrigation is the water need of the crop (Hansen et al., 1980).
Seasonal use of water by different crops	Irrigation farmers must select their crops, to some extent, on the basis of time at which water will be available. In areas having no storage reservoirs, larger quantities of water are available early in the season. During the forepart of the crop-growing season, streams in mountain areas fed by melting snow banks and drifts are much larger than during the summer. Under such conditions alfalfa, wheat, and oats may well be produced as each of these crops requires large amounts of early-season water. Canning peas may be matured before a water shortage begins. Alfalfa continues to grow throughout the late summer months, provided water is available. Sugar beets, potatoes, and corn require less water early in the season, but during the late summer months these crops need an abundance of water. Unless late-season water is assured, it is inadvisable to attempt to grow sugar beets and potatoes (Hansen et al., 1980).
Irrigation Frequency	Irrigation frequency depends upon several factors. During the active growing period of the crop, the most important factor governing frequency of irrigation is the need to keep adequate moisture in the soil for the crop. Two approaches can be made based upon the need for water by the root-zone soil. Both depend upon the capacity of the soil within the root zone to store water and the amount of water to be depleted. The available water per increment of soil depth multiplied by the depth to which moisture will be depleted will give the total water-holding capacity. However, maximum production can be obtained on most crops if not more than 50 % of the available water is removed during the vegetative, flowering, and wet-fruit stages of growth. For some crops, removing not more than 25 % of the available water will produce maximum yields. Yet, the cost of irrigating frequently usually makes the 50 % depletion more economical than irrigating when only 25 % has been depleted. At least 75 % of the available moisture can generally be removed during the dry-fruit stage without detrimental results. Frequency of irrigation can be determined by dividing the amount of moisture to be depleted from the soil by the consumptive use per day. Frequency of irrigation can also be determined by noting when the amount of moisture consumptively used is equal to the amount to be depleted from the soil (Hansen et al., 1980).
Crop water requirements	Irrigation systems are designed and constructed to meet deficiencies in crop water requirements caused by shortages in precipitation or soil-moisture capacities. However, it is astounding how little effort is sometimes put into estimating the crop water requirements for design and management of irrigation systems. The share of system capital costs spent on improved estimates of crop water requirements may be negligible compared to that spent on proper pipeline sizing or other hydraulic considerations, even though the crop water requirement is the driving force for the entire system. It is not unreasonable to expect that an improved crop water requirement estimate may make a substantial change in system size specifications and profitability. There are numerous examples of systems in many countries which have proven to be economically unprofitable and have eventually failed due to improper estimates of crop water requirements. The explanation for this secondary importance typically applied to crop water requirements, is probably twofold. First of all, engineers are normally not well versed in, and in fact can often be uncomfortable with, principles of agronomy and crop production. Training in this area is rarely given much priority in an engineering curriculum and often even the terminology appears forbidding. Secondly, there are a multitude of methods used to estimate crop water requirements and this plethora of methods is often confusing to engineers (Cuenca, 1989).

Costs	
General	The estimation of direct costs for irrigation systems, such as capital, operation and maintenance costs, is connected to the three components a system is generally formed by headworks, conveyance system, and on-farm systems. The headworks are the technical infrastructures required to abstract water from the water bodies: intakes, dams and reservoirs for rivers, and pumps, wells for groundwater. Water abstracted feeds the conveyance system, which is the network of canals, channels, and pipelines that convey water from the source to the on-farm systems. Then water is distributed to the crops by means of the on-farm systems with one of the existing irrigation methods. While the capital cost of headworks and conveyance networks for irrigation systems are very site-specific, the capital, operation and maintenance costs of the on-farm systems have typical ranges in €/ha according to the irrigation methods. They go from the lower costs of surface irrigation, with 80-800 €/ha, to the higher costs of sprinkler irrigation with 1500-4000 €/ha, and of the drip methods, with 2500-6000 €/ha (South Pacific Applied Geoscience Commission, 1998). Actual costs vary widely. Initial cost will increase as labour-saving devices are added, while in this case the operational cost will decrease. Careful analysis should be made to arrive at a reasonable balance between equipment costs and power costs (Hansen, 1980).

Costs	
Capital Costs	Capital costs refer to the permanent irrigation systems. Permanent systems, where the main and lateral lines are not moved, will cost more than portable lines.
Operational Costs	Typically, operational costs for an irrigation system should include the following: • Water costs, • Power costs, • Repair, operation, and maintenance, • Labour, and • Taxes When considering the return to be expected from a new irrigation system (including depreciation and return on initial investment), considerations should be made on any any savings resulting from: • Increase yield and quality, • Less land out of production, • Reduction in land preparation, tillage, and harvesting costs, • Saving in labour, repair and maintenance, and operating cost, and • Saving in water and power costs

Irrigation Technologies: Sprinkler Irrigation

Description

Sprinkler systems typically include the sprinkler, the riser pipe, the lateral distribution pipe, the main line pipe, and, often, the pumping plant. Sprinkler systems may be classified as semi-permanent or portable according to the make-up of the components.

Semiportable sprinkler systems consist of buried main pipelines, portable lateral pipelines and sprinklers, and a fixed pumping plant. In semi-permanent installations, the main lines are buried, and lateral lines and sprinklers remain fixed during the irrigation season. Labour is then reduced to a minimum, and system is operated properly. One man can irrigate 40 to 80 ha/d compared to approximately 20 ha/d with portable systems. A variation of this system has sprinklers mounted on quick-coupling risers so that they can be moved along the buried lateral lines. This reduces the number of sprinklers and increases the labour needed for the operation of the system.

The fully portable system has portable lateral pipe lines with sprinklers and portable pumping plant. A fully portable system can be mobbed readily from field to field, thus extending its utility. The size of pipe, length of the boom, nozzle sizes, and pressures can be varied to cover the desired area at each setting (Hansen et al., 1980).

Maturity	Commercial √	Demonstration	Experimental

Experiences

When considering where sprinkler irrigation can be used to greatest advantage, the normal requirement of uniform distribution of water is of utmost importance. The method of irrigation which can most economically distribute the required water uniformly is generally the best method. Some of the conditions which favor the sprinkler irrigation are as follows:

- Soils too porous for good distribution by surface methods.
- Shallow soils the topography of which prevents proper leveling for surface-irrigation methods.
- Land having steep slopes and easily erodable soils.
- Irrigation stream too small to distribute water efficiently by surface irrigation.
- Undulating land too costly to level sufficiently for good surface irrigation.
- Labor available for irrigating is either not experienced in surface methods of irrigation or is unreliable; good surface irrigation requires trained reliable labor.
- Land needs to be brought into top production quickly. Sprinkler systems can be designed and installed quickly.
- Sprinkler systems have several secondary agricultural uses which are important in addition to the primary use for distributing irrigation water to be stored in the soil.
- Light frequent irrigations, so easily managed by using sprinklers, are helpful in many situations, such as the following: shallow-rooted crops, germination of new plants, control of soil temperature on certain corps as tobacco.
- Sprinklers can also provide frost protection.

Additionally, several fertilizers, pesticides, and soil amendments can be applied quickly, economically, easily, and effectively through sprinkler-system spray. The equipment is simple and the labor requirement is slight. By controlling the time of application most of the material can be leached to the desired depth. Being in solution, these materials are distributed over the surface of the land quite uniformly.

Irrigation can be used also to improve both quality and yield of some crops by reducing the temperature on hot days. Potatoes, tomatoes, grapes, apples, strawberries, and similar wet fruit crops have responded favorably to evaporative cooling by sprinkling. In some climates, early frost frequently occurs during flowering of fruit trees, reducing yield dramatically. Sprinkler irrigation has been used successfully in the spring to cool the trees and soil, thereby delaying flowering and reducing the hazard of damage from an early frost.

Semi-permanent systems find favour where frequent light irrigations are desirable and where the farmers are totally dependent upon irrigation to supply water required during the season. The most extensive use has been on potatoes which show market increases in yield and quality with light frequent irrigations. Shallow-rooted crops, like radishes, are also responding well to permanent systems (Hansen et al., 1980).

Technical Characteristics	
Types of Sprinklers	Three general types of sprinklers are used: fixed nozzles attached to the pipe, perforated pipe, and rotating sprinklers. The earlier sprinkler systems were fixed nozzle pipe types. Parallel pipes are installed about 15 m apart and supported on rows of posts. Water is discharged at right angles perpendicularly form the pipe line. The entire 15 m width between pope lines may be irrigated by turning the pipes through about 135 degrees. Perforated sprinkler lines are used more extensively in orchards and nurseries. Generally rates of application are in excess of 20 mm depth per hour and pressure heads are less than 25 m, often as low as 7 m. They do not cover a very wide strip. Rotating sprinklers are used very extensively. The advantage of this sprinkler over other types is its ability to apply water at a slower rate while using relatively large nozzle openings. This factor is particularly favorable in water containing silt and debris since less stoppage of sprinklers is experienced. Application rates less than 2.5 mm/h are possible with these sprinklers. This slow rate is desirable on soils having low infiltration rates and advantageous to the small farmer doing his irrigation along with his field work. This low rate of application makes it necessary to move the sprinklers only once or twice a day on soils with low water-holding capacity. Pressure heads for rotating sprinklers normally range from 20 m for the smaller sprinklers to over 70 m for large units (Hansen et al., 1980).
Pressure Heads	Sprinkler systems operate under a wide range of pressure heads from 3.5 m to over 70 m. the desirable pressure head depends upon power costs, area to be covered, type of sprinkler used, sprinkler spacing, and crop being irrigated. Low pressure heads range from 3.5 to 10 m; medium from 10 to 20 m; intermediate from 20 to 40 m, and high pressure heads form 40 to 70 m. giant sprinklers usually operate at pressure heads in excess of 55 m sprinklers in the low-pressure head range have small areas of coverage and relatively high sprinkling rates for the recommended spacings of the sprinklers. Their use is generally confined to soils having infiltration rates of more than 12 mm/h during the irrigation. Medium-pressure head sprinklers cover large areas, and have a wider range of precipitation rates, and water drops are well broken up. High-pressure head sprinklers cover large areas, precipitation rates for recommended spacing are higher than for the medium pressures. Distribution patterns are usually good but are easily disrupted by winds because of higher water trajectories. They have high-application rates, above 20 mm/h. The wetted diameter of the circle is from 60 to 120 m. Distribution patterns are very good in calm air but are easily disturbed by winds. In general, sprinklers can be obtained which will fit practically any operating condition in the field.
Operation	A sprinkler system may be well designed for the crop and field, but the results of its application depend upon its efficient operation. A correctly designed sprinkler system will supply adequate water during periods of maximum water demand by the crop. Over-irrigation will result if the system is operated at full capacity when the water demand of the crop is less than the maximum. Excessive application will cause leaching of soluble nutrients, low water-application efficiencies, reduction in quality and quantity of crops, and, ultimately, a drainage problem (Hansen et al., 1980).

Limitations

Since permanent sprinkler systems are often used to apply small quantities of irrigation water, it should be taken into account that wind may be a serious problem. Short periods of application do not allow for natural shifts in wind direction and variations in wind velocity which produce a more even distribution of water (Hansen et al., 1980).

Costs

The average annual cost of equipment is normally 40 % of the total annual cost. Fuel and repair would average about 30% and labour 30 %.

The sprinkler system should be designed to apply water at the lowest annual cost. A balance should be sought between pipe size and pumping costs in a system operated by pumping.

The life expectancy of a sprinkler system varies with treatment, use, and storage but will be average about 15 years.

Design Steps in Implementation

The most important factors in the successful implementation of sprinkler irrigation systems are first, the correct design, and second, the efficient operation of the designed system. The basic information for the design is obtained from four sources, namely, the soil (soil type, depth, texture, permeability, and available water-holding capacity of the root zone), the water supply (the location of the water delivery point in relation to the fields to be irrigated, the quantity of water available, and the delivery schedule), the crop to be irrigated (the maximum consumptive use of water per day, the root-zone depth, and the peculiarities of irrigation), and the climate (natural precipitation, and wind velocities and direction).

The sprinkler system must have the capacity to meet the peak water-use demands of each crop during the irrigation season. Allowance of capacity must be made for unavoidable water losses by evaporation, interception and some deep percolation.

A sprinkler system must apply water so that it will not cause physical damage to the crop. In orchards, high-velocity streams of water from sprinkler nozzles have bruised growing apples and peaches when sprinklers have been placed too close to the trees. Also, in crops having fine seedling plants, a fine spray must be applied, or the plants will be beaten into the ground. Such a spray requires high pressures to break up the water drops at the nozzle.

Additionally, droplets must be small enough so that the soil is not damages. Some soils will puddle under the impact of large droplets, causing the soil to crust. Smaller nozzles operated at higher pressures reduce drop size.

Wind can be critical, influencing water distribution. It is difficult to obtain good distribution of water in winds in excess of 15 km per hour. Lateral lines should be set at an angle to the prevailing wind. It may be necessary to decrease the spacing between sprinklers and between lateral lines as much as 40% to obtain satisfactory distribution in the windy condition.

Irrigation Technologies: Trickle (Drip) Irrigation

Description

Trickle irrigation, also referred to as drip irrigation, consists of an extensive network of pipes usually of small diameter that deliver filtered water directly to the soil near the plant.

Flow may be controlled manually or may be set automatically to deliver:

- The desired volume of water,
- Water for a predetermined time, or
- Water whenever soil moisture decreases to a predetermined amount.

Lateral lines are generally flexible PVC for polyethylene pipe 12 to 32 mm in diameter. Emitters are inserted into the lateral lines at a predetermined spacing chosen to fit crop and soil conditions. Twin bore pipe, porous pipe, and pipe with small perforations is used in some installations to function both as a lateral conveyance pipe and as an emitter system (Hansen et al., 1980).

Maturity	Commercial √	Demonstration	Experimental

Experiences	Often greater crop yields and better quality are obtained, probably the result of the ability to maintain a nearly constant moist soil in the root zone. Fruit that contains considerable moisture when harvested (such as tomatoes, citrus, deciduous fruits, grapes, and berries) respond well to trickle irrigation. Irrigation water can be applied very efficiently to small trees and widely spaced plants, where adequate water can be placed in the root zone without wetting the soil where no roots exist. In arid regions with good management the ratio of transpired to applied water is usually at least 0.90. Water application efficiencies approaching 100 % and water savings of 30 to 50 % over other irrigation methods are obtained for those crops and conditions favouring trickle irrigation. Insect, disease, and fungus problems are reduced by minimizing the wetting of the soil surface. Fewer weeds, less soil crusting, reduced cultivation, and thus less soil compaction and less interference with harvesting are benefits of trickle irrigation (U.S. Congress, 1988). A major advantage of trickle systems is that the close balance between applied water and crop evapotranspiration reduces surface runoff and deep percolation to a minimum. The fact that limited portions of the field surface are moistened also tends to reduce weed growth which would otherwise consume irrigation water. There is evidence that trickle systems generally produce a higher ratio of yield per unit area and yield per unit volume of water than typical surface or sprinkler irrigation systems. There could be a number of reasons for this apparent increase in water use efficiency. One is that the frequent application of water in the vicinity of the root zone produces a continuously high soil-water content at the roots. The plants therefore come under very little stress if the trickle system is properly operated during the growing season. A second reason is that the limited moistened surface area reduces weed growth and the weeds are not competing with the crop for water and nutrients. Trickle systems have also been found applicable in marginal lands which could not be irrigated by other methods of application (Cuenca, 1989).

Technical Characteristics

Emitter	The water outlet device in the pipe is called an "emitter" discharging only a few liters per hour. From the emitter, water spreads laterally and vertically by soil capillary forces augmented in the vertical movement by gravity. The area wetted by an emitter depends upon the flow rate, soil type, soil moisture, and the vertical and horizontal permeabilities of the soil. Emitters must produce a relatively small flow and yield a nearly constant discharge. The flow cross section needs to be relatively large to reduce clogging of the emitters (Hansen et al., 1980).
Control Head	The "control head" usually located at the source of the water, consists of flow control valves, measuring devices, pressure controls, and filters. Usually a fertilizer injection system is located also at the control head. The filter system must remove essentially all debris, sand, and clay to reduce clogging of the emitters (Hansen et al., 1980).

Limitations

Trickle irrigation is not practical or economical for closely planted crops such as cereals and alfalfa.

Clogging of the small conduits and openings in the emitters is the most serious problem. Sand and clay particles, debris, chemical precipitates, and organic growth can block flow from emitters. The clogging often occurs gradually, reducing flow and causing poor water distribution along the lateral with a reduction in crop growth.

Dissolved salt is left in the soil as the water is used by the plants. The greatest deposition is near the edge of the wetted zone at the soil surface. If rain flushes the salts near the surface down into the active root zone, severe damage to the crop may result. The more saline the irrigation water, the more severe the salt deposition problem can become.

As with all types of irrigation the buildup of excess salts must be periodically flushed out of the potential root zone. Application of water with sprinklers or surface irrigation may be necessary.

Since only part of the soil is wetted, care must be taken to see that root growth is not inhibited by supplying moisture to too small a soil volume. Roots will not penetrate a dry soil. In windy areas, movement of dry cultivated surface soil between emitters may be a hazard to growing crops (Hansen et al., 1980).

Trickle systems operate on the principle of applying a very precise amount of water directly in the vicinity of the root zone. This application normally requires very limited fluctuations of pressure from the design head at the point of water application. These constraints of accurate crop water accounting the tight pressure tolerances along the distribution line require a higher level of technology and sophisticated equipment for trickle systems than for surface or sprinkler applications. The design operating conditions of trickle system must be carefully maintained during the growing season for the application system to be effective. The pressure constraints require increased maintenance throughout the season compared to surface or sprinkler systems.

Trickle systems have a limited buffering capacity within the soil profile in case of equipment malfunction compared to surface or sprinkler systems. This is a direct result of applying limited quantities of water to the root zone which is associated with the high overall irrigation efficiency of trickle systems. This limited buffering capacity puts further emphasis on a thorough maintenance program (Cuenca, 1989).

Costs	
Capital Costs	The capital costs required for trickle distribution systems are higher than those required for surface of sprinkler systems. This is especially the case in comparison with surface irrigation systems unless excessive land leveling is necessary.
Operational Costs	The cost of equipment, labor, and water to remove excess salts must be considered when analyzing the cost and efficiency of trickle irrigation. Trickle systems can be the most cost-effective method of irrigation in areas not well suited to surface or sprinkler irrigation.

Environmental Impacts	
Land	The salinisation of the soil profile at the edges of the wetted cone.
Air	-
Water	The overall impact on water resources of the use of trickle irrigation systems, compared to surface or sprinkler systems, is uncertain due to the potential importance of the individual advantages and disadvantages of the method on any particular project. Considering the overall objective of irrigation project development to be long-term increases in crop production using the most cost-effective means, trickle systems may or may not be optimal depending on the specific soil, field topography, climate, and market conditions of a location. In some cases, where there is government support for development of irrigation projects, the improvement in crop production due to trickle systems may not be correctly evaluated against the true production costs which are highly subsidized within the project. Development of trickle irrigation projects should be analyzed applying the same economic and sociological principles as for other application systems.

Irrigation Technologies: Surface Irrigation - Uncontrolled or "wild" flooding

Description

Several improved flooding methods have been developed.

Where water is applied from field ditches without any levees to guide its flow, or otherwise restrict its movement, the method is defined as uncontrolled or "wild" flooding.

Water is brought to the field in permanent supply ditches and distributed from ditches built across the field (Hansen et al., 1980).

Maturity	Commercial √	Demonstration	Experimental
Experiences	The size of steam used, the depth of water as it flows over the soil surface, and the rate of percolation of water into the soil all influence application efficiency. In uncontrolled flooding, the smoothness of the land surface and the attention and skill of the person(s) irrigating are also important. The spacing of the ditches is determined by the grade of the land, the texture and depth to the soil, the size of steam, and the nature of the crop. The distances between the diversions from ditches down the steepest slope are similarly determined. Flooding from field ditches is well adapted to some lands that have such irregular surfaces that the other flooding methods are impractical. However, even on lands that may advantageously be irrigated by the other flooding methods, irrigators often continue to use uncontrolled flooding because of the low initial cost of preparation of land for this method. The extra labour cost in the application of water and the greater losses of water by surface runoff and deep percolation usually offset the apparent advantages of low initial cost of preparation of land. (Hansen et al., 1980; Cuenca, 1989).		

Technical Characteristics	
Crops	Pasture, grain
Topography	Irregular surfaces with slopes up to 20%
Water supply	Small continuous flows on steeper land or large flows on flat land (Cuenca, 1989).
Soils	Soils of medium to fine texture with stable aggregate which do not crack on drying (Cuenca, 1989).
Remarks	Little land grading required. Best adapted to shallow soils, since percolation losses may be high in deep permeable soils. (Cuenca, 1989).

Limitations

This method is practiced largely where irrigations water is abundant and inexpensive. If the water is made to flow over the surface too quickly, an insufficient amount will percolate into the soil, whereas if water is kept on the soil surface too long, lossed will result from percolation beyond the root zone. Applying water efficiently is an important issue with uncontrolled flooding methods.

In areas where land, water or labour is expensive, or soil is deep and not likely to crust badly, and where the land is not too rough or steep, it is generally advisable to plan for controlled flooding in border strips or level or contour basins.

Costs	
Capital Cost	Low initial cost of land preparation. Low initial cost of system.
Operational Cost	High labor cost and greater losses of water.

Irrigation Technologies: Surface Irrigation – Border-Strip Flooding

Description			
In the border-strip irrigation method, the farm is divided into a number of strips, preferably not over 10 to 20 m wide and 100 to 400 m long, separated by low levees or borders. Water is turned from the supply ditch into these strips along which it flows slowly toward the lower end, wetting the soil as it advances (Hansen et al., 1980).			
Maturity	Commercial √	Demonstration	Experimental
Experiences	The surface is essentially level between levees, so that the advancing sheet of water covers the entire width of land strip; but lengthwise of the levee the surface slopes somewhat according to the natural slope of the land. It is desirable, although not essential, that the slope be uniform within each levee. If practical, it is best to use border slopes between 0.2 to 0.4 %; however slopes as low as 0.1 % and as high as 8 %. Special care is essential to prevent erosion of soil on the steeper slopes. The size of stream turned into a single border strip varies from 15 to 200 l/s, depending on the type of soil, the size of border, and the nature of the crop. Because of the relatively high initial cost of preparing land for the border method, it is desirable to plan the location of the levees and strips so that different crops can be irrigated. Crops which are to be furrow-irrigated, such as sugar beets, potatoes, and corn, may be grown on land on which forage crops have been irrigated through the border method. Provided that soil conditions are favourable to lateral water movement underneath the low, broad border levees, it is practical to plant and mature crops on the levees. However, it is difficult to furrow the levees satisfactorily and to keep irrigation water in furrows on the levees. The border method is suitable to soils of wide variation in texture. It is important, however, to study the physical soil properties before preparing land for border irrigation. Rather impervious subsoils overlain by compact loams permit long border strips, whereas open soils having highly permeable, gravely subsoils necessitate short narrow strips. At the head of each border strip a gate is placed in the supply ditch for convenience in turning water into and out of the strip (Hansen et al., 1980).		
Technical Characteristics			
Crops	Grain, lucerne, orchards		
Topography	Land graded to uniform plane with maximum slope less than 0.5%		
Water flows	Large flows, up to 600 l/s		
Soils	Deep soils of medium to fine texture		
Remarks	Very careful land grading necessary. Minimum of labour required for irrigation. Little interference with use of farm machinery. (Cuenca, 1989).		
Costs			
High initial costs for land preparation			
Environmental Impacts			
Land	Soil erosion hazards.		
Air	-		
Water	-		

Irrigation Technologies: Surface Irrigation – Check flooding

Description			
Check flooding consists of running comparatively large streams into relatively level plots surrounded by levees.			
Maturity	Commercial √	Demonstration	Experimental
Experiences	The check flooding method is well suited to highly permeable soils, which must be quickly covered with water in order to prevent excessive losses through deep percolation near supply ditches. It is also suited to heavy soils into which water percolates so slowly that they are not sufficiently moistened during the water flow. This necessitates retaining the water on the surface to assure adequate penetration. Checks are sometimes prepared by constructing levees along contours having vertical intervals of 5 to 15 cm and connecting them with cross levees at convenient places. These are called contour checks and are formed by building longitudinal levees approximately parallel to the contours, and connecting them at desirable places with levees at right angles. The check method of irrigation is advantageous for grain and forage crops in areas where large irrigation channels are available, and also on projects which depend on the seasonal flooding of nearby waterways, which must be directed to the land quickly and efficiently to prevent loss of the water. On flat lands the area of each check may be several acres. Levees should be about 2 m wide at the base and not over 25 cm high, in order to avoid obstructions to farm machinery, and assure satisfactory growth of crops on the levees (Hansen et al., 1980).		
Technical Characteristics			
Crops	Orchards, grain, rice, forage crops		
Topography	Irregular land; slopes less than 2%		
Water supply	Flows greater than 30 l/s		
Soils	Soils of medium to heavy texture which do not crack on drying		
Remarks	Little land grading required. Checks can be continuously flooded (as for rice), water ponded (as for orchards), or intermittently flooded (as for pastures) (Cuenca, 1989).		
Environmental Impacts			
Land	Soil erosion hazard		
Air	-		
Water	-		

Irrigation Technologies: Surface Irrigation - Basin flooding

Description			
In basin flooding, water can be held in the basin at the desired depth for the required time. Water is conveyed to the basin from the supply ditch, either by flowing through one basin and into another, or preferably by small ditches constructed so that the water may be turned directly from a ditch into each basin (Hansen et al., 1980).			
Maturity	Commercial √	Demonstration	Experimental
Experiences	Basin flooding is used extensively to irrigate rice, and frequently used for orchard irrigation. On some farms a basin is made for each tree, but under favourable conditions of soil and surface slope, two to five or more mature trees can be included in one basin (Hansen et al., 1980).		
Technical Characteristics			
Crops	Grain, field crops, orchards, rice.		
Topography	Relatively flat land. Area within each basin should be leveled.		
Water supply	Can be adapted to streams of varying sizes.		
Soils	Suitable for soils of high or low intake rates; should not be used on soils that tend to become waterlogged.		
Remarks	High installation costs. Considerable labour required for irrigating. When used for close-spaced crops, a high percentage of land is used for levees and distribution ditches. High efficiencies of water use possible (Cuenca, 1989).		
Environmental Impacts			
Land	Soil erosion hazard		
Air	-		
Water	-		

Irrigation Technologies: Surface Irrigation - Furrow method

Description

Using furrows for irrigation necessities the wetting of only a part of the surface (from one-half to one-fifth) thus reducing evaporation losses, lessening the puddling of heavy soils, and making it possible to cultivate the soil sooner after irrigation (Hansen et al., 1980).

Maturity	Commercial √	Demonstration	Experimental

Experiences	Nearly all row crops are irrigated by the furrow method, rather than by flooding. Grain and alfalfa crops are irrigated often by means of small furrows designated corrugations. These corrugations are advantageous when the available irrigation streams are small, and also for land of uneven topography. Furrow irrigation is adaptable to a great variation in slope. It is customary to run the furrows down the steepest slope to avoid overflowing the banks of the furrows. It also provides flexibility, permitting a large stream in each furrow when the water is first turned in, thus wetting the furrow through its entire length quickly, and then decreasing it so that just enough water enters the furrow to keep it wet, thereby reducing to a minimum the runoff from the lower end of the furrow (Hansen et al., 1980).

Technical Characteristics

Length of Furrows	On some soils, furrows having slopes of 10 to 15 % are successfully used by allowing only very small streams to enter the furrows and by careful inspection to control erosion. Slopes of 0.5 to 3 % are preferable, but many different classes of soil are satisfactorily irrigated with furrow slope from 3 to 6 %. The length of furrows varies from 25 m or less for gardens to as much as 500 m for field crops. Furrow lengths of 100 to 200 m are common. Excessive deep percolation losses and soil erosion near the upper end of the field result from use of very long furrows. However, reduction of waste land for ditches and turning of machinery favour longer rows.
Spacing and Depths of Furrows	Spacing of furrows for irrigation of corn, potatoes, sugar beets, and other row crops is determined by the proper spacing of the plant rows, one irrigation furrow being provided for each row. In orchard irrigation, furrows may be spaced form 1 to 2 m apart. Soils having unusually favourable capillary properties, or impervious subsoils, may permit orchard furrows 3 to 4 m apart. With the greater spacing it is essential to check on the moisture distribution after each irrigation by making borings with a soil auger or tube to fine whether or not the lateral moisture movement form furrows is adequate. Furrows from 20 to 30 cm deep facilitate control and penetration of water into soils of low permeability. They are well suited to orchards and to some furrow crops. Other furrow crops, such as sugar beets, are best irrigated with furrows from 8 to 10 cm deep. It is highly desirable in irrigating sugar beets and similar root crops to have the furrows deep enough, and the stream in each small enough, so that the water cannot come in contact with the plant.
Water Distribution to Furrows	Water is distributed to the furrows from earth-supply ditches or from wood or concrete flumes or metal or concrete pipe placed underground. The earth-supply ditch is very common. Small openings are made through the bank, and the water flows into one or more furrows. The use of small diameter 100 cm of application of water to their furrow-irrigated crops by frequent regulation of the size of stream flowing into the furrow. For this purpose, gated pipes are especially helpful. Small, easily adjusted gates in the pipe facilitate control of the size of stream delivered to the furrow. Streams as small as 0.1 l/s or as large as 1 l/s or more can be delivered. The lightweight aluminium or galvanized gated pipe is easily placed, easily connected, and easily moved after irrigation.

Limitations

This method necessities careful supervision to avoid erosion of the supply-ditch openings, and consequent excess flow in some and inadequate flow in others.

Environmental Impacts

Land	Soil erosion hazard, saline deposition

Network Improvements

General Overview

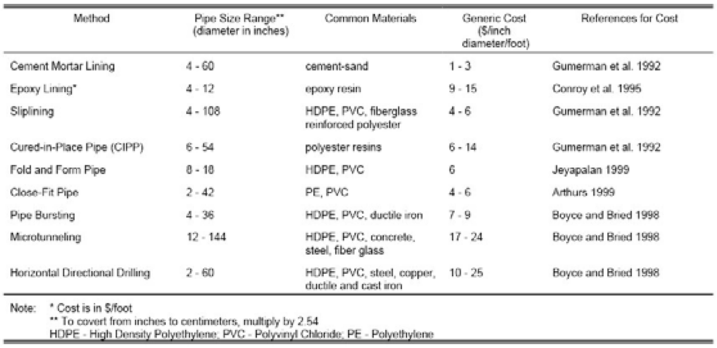
Overview	
Definition of unaccounted for water	There is no universally applied or accepted definition of unaccounted-for water. In general, unaccounted-for water is the difference between the water supplied to a distribution system and the water that leaves the system through its intended use. Some have defined unaccounted-for water as water supplied to a system less all metered water leaving the system. Other utilities use a broader definition whereby unaccounted for is all water that cannot be accounted for through measurement or estimation. The value or percentage of unaccounted-for water is an excellent overall indicator of the operating efficiency of a water system. Many reasons have been identified as contributing to, or causing poor services and high levels of unaccounted-for water. These range from poor organizational structures in the responsible agency, lack of spare parts, inappropriate technology, lack of trained staff, absence of career opportunities, insufficient funds, inadequate legal framework problems, lack of motivation by sector personnel, non-involvement of the users, the low profile of actions addressing optimization of services including leakage control, inadequate tariff and collection systems and negative political interference. These causes tend to be interrelated and intertwined. Poor quality pipes and valves used in distribution systems or pipes installed without the appropriate technical requirements will result in serious leakage problems during the whole life span of the project.
Network Efficiency Estimation	**Full network assessment** Many suppliers argue that a large number of factors should be taken into account in leakage performance and that simplistic indicators such as those described above may not be comparable. Although drinking water is a ready-to-use product and may be costly to produce if extensive treatment is required, leakage reduction is not always economically viable. Increasing production to "feed leaks" may be cheaper than extensive pipe repairs. (EEA, 2001). **Efficiency of a distribution network** There are several ways of expressing the efficiency of a distribution network: • **Efficiency ratio** (%) = (metered volume/distributed volume) x 100. It is the simplest ratio to calculate because it only uses measured values. It compares the measured delivery volumes with the volume released into the network. However, the value of this ration should be interpreted carefully as it cannot be used to compare different networks, since it does not take into account the total volumes involved (metered, unmetered, network maintenance). It is more useful to use this ration to analyze trend over time for a particular network, rather than using its absolute value. Nevertheless, it is possible to give some rough guidelines. • **Net efficiency ratio**, which probably constitutes a better indicator, and can be calculated as follows: Net efficiency ratio (%) = ((metered volumes + unmetered authorized consumed volumes + volumes used for network maintenance)/(distributed volumes)) x 100. This value gives a better idea of the actual leakage in the network, since it takes into account all types of water that are used (metered/unmetered/network maintenance). However, two of the expressions (unmetered volumes and network volumes) are rough estimations, meaning that the indicator can be erroneous. Also, the network manager can increase the net efficiency value by inappropriate estimates of maintenance volumes (cleaning etc.). • **Linear leakage index**. The physical state of networks can be compared by relating the lost volumes to the length of the network, where: Linear leakage index (m^3/day/km) = losses/length of network. The length of the network may include the total distance of pipework between the producer and the water buyers, or simply only the principal mains distribution pipes, excluding private access pipes. An alternative expression for urban networks is l/property/day. Estimated leakage expressed in this manner can be compared to optimal leakage (benchmark annual leakage which takes into account metered connections, base level of leakage and network pressure and its variations) to produce an international leakage index. The base level of leakage is the aggregation of loss sources which are individually too small

	to be detected by active leakage control techniques. Even if all backlog bursts have been eradicated, new bursts are always occurring and take time to become apparent, located and repaired. • Linear flow index, used to evaluate the rate of use of a network and its nature, i.e. Linear flow index (m^3/day/km) = metered volumes/length of network. Rural areas generally have a low index (less than 10) whereas urban zones have a higher value (over 30). The index can be used to provide a context for other indicators mentioned above (optimal efficiency and linear leakage index).
Leakage Control and Metering	Leakage can occur from pipes, valves, hydrants, fittings, and tanks within both community delivery systems and individual user systems. There are a number of methods of leak detection, which include passive leakage control (detection by visual inspection only as is often done by the community); regular soundings (detection by systematic soundings at valves and other locations using special electronic devices); district metering (detection by metering and analysis of flows into various pre-determined districts over a period of time, followed by systematic soundings); waste metering (detection by metering of low flows at night from predetermined waste districts served by a single pipeline, followed by systematic soundings); and, combined district and waste metering. These measures may be used in combination. For example, if passive leakage control is undertaken, regular soundings, district metering and waste metering methods can further reduce leakage. An economic analysis is generally required to determine the most cost-effective method, but, ultimately, a balance between doing nothing and attempting to stop every leak must be achieved (UNESCO, 1991). Experience has shown that universal metering can have beneficial effects on water conservation. Metering includes installing bulk meters on the main distribution lines as well as on the individual household connections. Water pricing can be used not only to raise revenue but also to improve the efficiency of water use. The latter effect is an example of water conservation by demand management. When people have to pay for water they are more likely to conserve its use and minimize losses due to leaks. A simple method to determine if an individual metered system is leaking is to turn off all water taps and see if the meter indicates any flow. If it does, the system needs to be checked. In formulating a water pricing policy, a number of factors are important, including the capital and recurrent costs of treatment and distribution of water; the current level of government subsidy; the amount of any external (generally aid) funding; the types of water consumers (i.e., domestic, industrial, etc.) and relative levels of demand; and, the ability and willingness of the consumers to pay. Leakage control is used widely. In Seychelles, leakage detection programmes reduced the water losses from 40% of water supplied to 22%. The benefit/cost ratio of this programme in 1985 was estimated at approximately 5:1. In Malta, leak detection methods reduced losses from 55% of water supplied in 1968 to 25% of water supplied in 1977. Metering and pricing is used by most larger public water supply systems. Leakage-detection equipment needs to be maintained. Meters need to be tested regularly and, if necessary, repaired. The operation of a pricing system requires meter readers, and an appropriate billing and revenue collection system. Leakage control requires trained technicians to conduct the leakage detection, and trained plumbers to repair the leaks. The maintenance of meters requires skilled technicians, although, if necessary, meter reading can be done at the community level.
Technological approaches	Maintenance and network renewal is one of the main elements of any efficient water management policy. Losses in the water distribution network can reach high percentages of the volume introduced. Leakage covers different aspects: losses in the network because of deficient sealing, losses in user installations before the water is metered, and sometimes the consumption differences between quantities use (measured) and those not measured are also counted as losses. Leakage figures from different countries indicate not only the different aspects included in the calculations (e.g. Albania up to 75%, Croatia 30-60%, Czech Republic 20-30%, France 30%, and Spain 24-34%). Many suppliers argue that a large number of factors should be taken into account in leakage performance and that the indicators described may not be comparable. Generally, network meters are considered necessary to enable good network management. For most rural municipalities, distribution network maintenance is not a priority (lack of regular monitoring, networks plans). This situation coincides with a price of water which is lower than the national average and also with a lack

	of a general use of domestic meters. (EEA, 2001).
Replacement and Rehabilitation of water distribution systems	Water distribution pipe problems can be addressed either through rehabilitation or trenchless or open-cut replacement. **Rehabilitation** is defined as improvement of the functional service of an existing pipeline system by lining the interior. It involves placing a water tight surface inside of an existing pipe without requiring extensive excavation of the soil. **Replacement** means installing a new pipeline without incorporating the existing pipeline by either open cut or trenchless replacement. **Water distribution system rehabilitation methods** Pipeline rehabilitation methods use the existing pipe either to form part of the new pipeline or to support a new lining. Rehabilitation is achieved by cleaning the pipe to remove scale, tuberculation, corrosion, and other foreign matter. Linings, to be effective, must make intimate contact with the pipe surface. Proper surface preparation significantly affects the strength and bonding of lining (Ashton et al. 1998). These methods can be divided into two categories: non-structural and structural. Non-structural lining involves placing a thin coating of corrosion resistant material on the inner surface of the pipe. The coating is applied to prevent leaks and increase the service life. However, coating does not increase the structural integrity of the pipe. The only coatings considered as proven techniques for water distribution pipes are cement mortar and epoxy. **Water distribution system replacement methods** Replacement of pipelines can be accomplished by using either **trenchless** or **open-trench** techniques. **Trenchless replacement** involves inserting new pipe along or near the existing pipe without requiring extensive excavation of soil. Trenchless replacement can be done with minimal disruption to surface traffic, business, and other activities, as opposed to open trenching, thus significantly reducing the social costs of construction. The best known trenchless replacement techniques are pipe bursting, microtunneling, and horizontal directional drilling. **Open-trench replacement** is the most commonly used method for replacement of water mains. It involves placing new pipe in a trench cut along or near the path of the existing pipe. There are two basic types of open-trench replacement: (1) conventional; and (2) narrow. The conventional open-trench method uses the same approach as that used to place new pipe. The narrow-trench replacement method is similar to conventional open-trench method, but the trench width is kept to the absolute minimum possible. It is primarily used for installing polyethylene pipes (Morris 1996).
Effectiveness of the Technology	Leakage control is very effective as a water conservation measure. "Unaccounted-for" water can usually be reduced by up to 50%. The use of metering and water pricing can reduce water consumption by 25% to 30%, on average.
Costs	

Tracing and repairing leakage can be very expensive. Increasing water production to feed leaks may prove cheaper in some system. The consequence is that local authorities may decide not to trace leakage despite low efficiency ratios but continue their wasteful use of water (EEA, 2001).

Table 19 Summary of Rehabilitation-Replacement Methods



Method	Pipe Size Range** (diameter in inches)	Common Materials	Generic Cost ($/inch diameter/foot)	References for Cost
Cement Mortar Lining	4 - 60	cement-sand	1 - 3	Gumerman et al. 1992
Epoxy Lining*	4 - 12	epoxy resin	9 - 15	Conroy et al. 1995
Sliplining	4 - 108	HDPE, PVC, fiberglass reinforced polyester	4 - 6	Gumerman et al. 1992
Cured-in-Place Pipe (CIPP)	6 - 54	polyester resins	6 - 14	Gumerman et al. 1992
Fold and Form Pipe	8 - 18	HDPE, PVC	6	Jeyapalan 1999
Close-Fit Pipe	2 - 42	PE, PVC	4 - 6	Arthurs 1999
Pipe Bursting	4 - 36	HDPE, PVC, ductile iron	7 - 9	Boyce and Bried 1998
Microtunneling	12 - 144	HDPE, PVC, concrete, steel, fiber glass	17 - 24	Boyce and Bried 1998
Horizontal Directional Drilling	2 - 60	HDPE, PVC, steel, copper, ductile and cast iron	10 - 25	Boyce and Bried 1998

Note: * Cost is in $/foot
** To covert from inches to centimeters, multiply by 2.54
HDPE - High Density Polyethylene; PVC - Polyvinyl Chloride; PE - Polyethylene

The costs for leakage control comprise the purchase of equipment, the training of personnel, and the conducting of leakage studies. Leak detection may be done by the water utilities corporation as part of their general maintenance costs. Alternatively, consultants can be hired to perform leakage detection, but this latter option tends to be expensive and is generally non-sustainable.

The costs of consumer metering involve purchase and installation of the meters, the regular reading of the meters, and periodic billing and revenue accounting. The cost of the meters is in the range of 150 to 200 € per domestic installation.

Table 19 presents representative costs that can be used to estimate the order-of-magnitude costs for rehabilitation and replacement of distribution system pipelines. Costs given only address the base installation costs of rehabilitation/replacement technologies. A series of separate additional items should be added to the base installation cost to get the total cost, such as removal and replacement of existing valves, fire hydrants, and other contingent work, traffic control, utility interference, removal of obstruction, and bypass piping and temporary service connections to existing services.

Advantages & Disadvantages	
Advantages	**Leakage control systems** can help to**:** • Improve knowledge and administration of the water supply system; • Provide for improved security of water quality due to fully pressurised pipes; • Reduce the volume of unaccounted-for water by fixing leaks and locating illegal connections, both of which increase revenues and help to conserve available water resources. **Metering policies** can assist in: • Increasing consumer awareness on water consumption habits; • The development of a pricing structure that is appropriate to the individual water supply system (i.e. providing rewards for conservation and penalties for wastage); • A better monitoring of the overall water consumption; • Pinpointing where leakage control programmes would be most beneficial. Metering, pricing and the use of water-saving devices also help to conserve water. Rehabilitation and trenchless replacement reduce the amount of excavation required to repair pipe.
Disadvantages	Disadvantages include: • The cost of implementing leakage control, metering and the use of water saving devices; • The cost of maintaining the systems once they are in place. Metering is not generally popular with consumers and politicians. Decisions on metering and pricing policies need to be made after consultation with local communities. In particular, the ability of consumers to pay needs to be assessed. Special measures to relieve the financial burden on particularly disadvantaged groups may need to be considered. Open-trench replacement is cost-intensive and is plagued by the expected problem of working within developed areas where pipes may be beneath streets, sidewalks, customer landscapes, utility poles, etc.

Pricing

General Overview

Overview

The economic theory of the demand for a commodity such as water takes one or two forms, depending on whether water is conceived of as a final good, which is desired on its own right, or an input to the production of some other goods and services. If water is viewed as a final good, its user is a consumer and his demand for water is said to be a final demand. If water is viewed as an input, its user is a producer and his demand for water is said to be a derived demand – it is driven in part by the demand for the commodities which are produced through the use of water (in combination with other factors of production). In case of a final good, desired on its own right, the demand is influenced by the consumers' tastes and preferences for water versus other commodities, what economists call their utility function. For an input, demand is also influenced by the technology for producing the commodity which helps to produce, what economists call the production function for that commodity. Economic theory shows how different features of the utility function or production functions can affect the demand for water by consumers and producers. It provides a conceptual framework for thinking about the various determinants of demand and how these interact. At the same time, it can be used to generate statistical models for the empirical estimation of demand by consumers and producers. In terms of these two economic categories, residential water use should be viewed as a final demand for water by consumers while agricultural, industrial and most commercial uses should be viewed as derived demand by producers.

Tariff Structures	There is a huge variety in the types of metered tariff which can be used. The main types of tariff structure (excluding the initial connection charge) are: • flat-rate tariff; • uniform volumetric tariff; • two-part or binomial tariff (sum of a flat-rate tariffs and a uniform volumetric tariff); • block tariffs, which also usually incorporate a flat-rate charge, plus declining block tariffs and rising block tariffs. Frequently, tariffs include a basic allowance charged at zero or a low rate to allow for equity concerns. A minimum charge for a volume consumed can also be applied. The same or different tariffs may apply to different types of user. Rates and thresholds may vary over time, according to customer characteristics (property value or income) or location. Two-part, rising block and declining clock tariffs are widespread. The two former types are gaining ground due to a general shift of opinion away from consideration of water supply as a public service to its use as a commodity with a correct price. Seasonal tariffs (summer/winter) are uncommon, but are becoming more widespread. Peak tariffs (hourly or daily) have only been tested in experiments. Additionally, a connection charge may be levied separately. The existence of a connection charge, stabilized to cover one part of the fixed cost of the suppliers, is independent of water consumption, and has the result that the water of low-volume consumers is more expensive per litre than that of high-volume consumers. At the same time, it is necessary to take into account the basis of calculation of the block tariffs. If the calculation is on a unit household basis, without taking into account the number of people in the household, the water price per capita will be higher for families with more members. Sometimes, sewerage services are not charged separately from water services, and, even where they are separately identified in the bill, they are often simply calculated as percentage of the water bill.
Tariff Design	Tariffs may be designed with several aims, which may in some cases be in conflict: • efficiency (maximum net benefit for society); • raising revenue to cover the costs of supply in a fair and equitable way; • reducing environmental costs (abstraction and pollution); • understandable for customers and applicable for administration purposes. In fact, improving the fairness or efficiency of a tariff often makes it more complex and more difficult to understand. When addressing water tariffs, it is necessary to take into account vulnerable customers who may have difficulties in paying for the water used for essential

	purposes, since it is generally recognized that no one should have to compromise personal hygiene and health in order to be able to pay the water bill (Socially acceptable tariffs). Disconnection or the introduction of flow reduction devices are practices used by some water companies when customers fail to pay their bills. Different policies are established by governments to palliate this problem: free water for schools and hospitals; grants from the local authorities for vulnerable customers. They establish at the same time mechanisms to allow suppliers to recover the money (e.g. debt retrieval through the courts or through attachment of earning orders).
Price elasticity	The usual economic measure to describe the sensitivity of demand towards price changes is elasticity. This is the percentage change in consumption caused by a 1% increase in price. Therefore, a 1% fall in consumption gives an elasticity of -0.1%. Many studies of elasticity have been carried out (often in the United States) and have recorded wide ranges of values, usually form -0.1 to -1.0, but in some cases even higher (more negative). In all cases, the response is greater in the long term than in the short term, since in the first periods, leaks are fixed, habits adapt and more efficient water-saving devices are progressively installed. In practice, there are many methodological problems associated with studying this relationship. One of the main problems is that water consumption patterns are influenced by a great number of factors (e.g. network repairs/pressure variations, information campaigns and climate variations), making it very difficult to isolate price as the main factor explaining the variation of water uses. From this, it has been concluded that water price is difficult to use as a demand management tool. However, increased tariffs are often considered a useful tool to make users more responsible for their water use, when applied in conjunction with other water conservation advice and techniques.

Pricing in the Urban Sector

Essential elements of water demand management programmes in urban context are measures dealing with economic incentives. Price structures are generally fixed at municipal level and can vary widely within a country. The differences in general, take into account different types of users (e.g. domestic, industrial and agricultural), and tend to reflect differences in cost structures.

Water charges are determined by a number of different factors (e.g. availability, treatment costs, social and political factors). Many studies have been carried out to analyse the effect of water price on domestic water use. However, there are few large-scale case studies where it is possible to prove that an increase in the water price has reduced water use.

The effectiveness of price as a demand-side management tool remains a matter of debate. Many studies have shown residential consumer demand for water to be price-inelastic. Some authors found high price elasticities (near – 0.57) for arid-region cities. It seems that domestic outdoor uses (garden, swimming pool) are price-elastic and domestic indoor uses price-inelastic.

Agricultural Pricing and Demand

The amount of irrigation water used in a given farming area depends on many factors. If water is not scarce, it will be used up to the point where its marginal value equals the farmer's marginal cost of acquiring and applying the water. Effective water constraints keep irrigation below the level at which marginal value equals marginal cost and the demand curve for agricultural water is truncated at by the resource constraint. It should be emphasized that in addition to water price the agricultural demand for irrigation water depends on many other factors, like, the market prices of the commercial yield of irrigated crops, the crop-mix planted in the area under consideration, prices of agricultural inputs other than water (e.g., fertilizers, insecticides), the available irrigation technology, soil types and weather conditions, and more. A "demand function" for water describes the functional relationship between the quantity of water demanded (the dependent variable) and all of the above mentioned explanatory or variables. A "demand curve" for irrigation water describes the relationships between the quantity demanded and the producer's water price, holding constant other explanatory variables.

Empirical evidences suggest that as water price increases, water use per hectare planted for a given crop may drop somewhat, but the major change will be a reduction of hectares irrigated as cultivated areas are converted to crops that demand less water and/or to dry crops. In addition, farmers may choose to switch to more efficient irrigation systems and, in more extreme cases, irrigated land might be removed completely out of production. Thus, the quantity axis of the demand curve for water should not be expressed on a quantity per-hectare basis (in contrast to the demand curve for residential water which can be expressed on a quantity per-capita or per household basis). The appropriate variable for the quantity axis is water volume for a given time period (commonly a year) for the entire agricultural area under consideration.

The two main approaches for obtaining the derived demand curves for irrigation water are (1) the econometric approach, and (2) the programming approach. In the econometric approach, data on water use are regressed on water price, prices of other inputs and of the commercial yields of the irrigated crops and quantities of inputs that are held fixed. One variant of the econometric approach involves controlled studies at experimental plots when the effect of water on the production of specific crops is carefully observed (e.g., Ayer & Hoyt, 1981; Kelly & Ayer, 1982). These studies estimate, via adequate regression analysis, production functions expressing the input-output relationships between irrigation water and crop production and then, infer the value of water (which is actually the farmers' demand for water) from the market value of the crops. Another variant is to estimate the demand for water from data on actual behaviour of farmers. This variant is commonly applied with cross-sectional (and sometimes time-series) data, representing a wide geographical area over which water prices and quantities and the level of non water inputs vary substantially (e.g., Moore et al. 1994; Ogg & Gollehon, 1989). Ogg and Gollehon for example utilized data from several Western US states, and regressed water use on water price variables using a few alternative functional forms. The most successful model was the one with a power-function that is convex to the origin.

With the programming approach, the technology of agricultural production is assumed to be known and the optimal crop production program is calculated under various resource constraints and the prevailing input-out prices. The shadow price on the water constraint constitutes the marginal value of irrigation water. The derived demand function for water can be obtained by changing parametrically the level of the water constraint and calculating the shadow prices of water at each level of the constraint (e.g. Vaux & Howitt, 1984; Booker & Young, 1994; Howitt, 1995). In other words, with enough repeated solutions of the mathematical programming (commonly linear programming) model, a water demand curve can be estimated giving the maximum amount farmers in the area under consideration could pay for increments in the available irrigation water.

All past empirical studies of demand for irrigation water found a downward sloping demand curve, commonly nonlinear and convex to the origin.

The own-price elasticity of the demand for irrigation water is defined as the ratio: [the percent change in quantity demanded]/ [the percent change in water price]. Since the demand curve is downward sloping, the price elasticity is negative. If an own price elasticity is less than unity in absolute value, the demand for water is said to be inelastic; if the elasticity is greater than unity in absolute value, the demand is said to be elastic. With the exception of a constant elasticity demand curve (a power form), the value of the pricy elasticity varies along the demand curve. If this elasticity at the specific point on the demand curve is -0.3, for example, this means that a 10% increase in the price of water results in a 3% reduction in the amount demanded, holding other non-water input prices and the scale of agricultural outputs constant. In the Table below, we present a few examples from the literature for estimated own-price elasticities of the demand for irrigation water.

Table 20 Examples of own-price elasticities for irrigation water demand

Date of Publication	Authors	Study Location	Own Price Elasticity
1973	Kelso et al.	Arizona	-0.1 to -1.2
1984	Vaux and Howitt	California	-0.1 to -10.0
1985	Nieswiadomy	Several US Western States	-0.8
1987	Harrington		-2
1989	Ogg and Gollehon	Several US Western States	-0.26
1992	Mcguckin, Gollehon and Ghosh	Nebraska	-1.095
1994	Hall, Poulter and Curtotti	Australia: Southern Murray- Darling Basin	-0.99
1994	Booker and Young	Colorado	-0.6
1995	Bhatia, Cestti and Winpenny	Industrializes Countries	-0.4 to -1.5
1999	Amir and Fisher	North of Israel (8 Districts)	-0.186 to -0.488
1999	Peretz	Israel	-0.5
2001	Nigell	Australia: Southern Murray- Darling Basin	-1.15 to -1.26

The estimates in Table 20 illustrate that demand elasticities for irrigation water may vary significantly by location, by the assumed functional form of the demand curve and the level of water use (i.e., the specific price-quantity combination along the demand curve) and, sometimes, by the estimation (econometric vs programming) procedure. Nearly all studies utilized the programming approach yielded nonlinear demand curves, convex to the origin which were inelastic (with absolute value of price elasticity lower than 0.3) at low water prices, and elastic at high water prices, that can be approximated by an exponential demand function. The econometric studies generally either assume a power demand function (a common practice in economic, partly because the exponent on the price is equal to the price elasticity, which does not vary along the curve) or find upon comparison that such a function performs better in terms of explained variance.

Unlike own-price elasticity which is always negative, cross-price elasticity related to a non-water input, given by [the percent change in quantity of water demanded]/ [the percent change in the price of the non-water input], can be positive or negative. If the price of the jth non-water agricultural input increases, the demand for the water input may either decrease or increase. If the demand for water decreases (implying negative cross price elasticity), water and input j are said to be complements; if the demand for water increases (implying positive cross-price elasticity) the two inputs are said to be substitutes. For example, fresh water and recycled waste water are substitutes while water and capital may be complements. If so, the use of fresh water rises when recycled waste water becomes more expensive, but falls when the advanced irrigation technologies become more expensive.

It should be noted that farmers make water decisions at various times. In the long-run, all factors of production under the farmer's control are variable. For example, the choice of whether to install a drip irrigation system is variable in the long-run. Annual decisions (intermediate-run) focus largely on the choice of crop-mix, subject to various constraints and expectations, including water availability. Monthly or weekly decisions (short run) focus on responding to recent changes in prices and weather conditions. Obviously, farmers have more flexibility to make input substitution in the long run than in the short run; the farmer's ability to respond to changes in water prices decreases as the planning horizon shortens. Among other things, the demand curve for water depends partly on the degree of flexibility, implying that demand curves may vary with the length of time. The majority of studies which estimated agricultural demand for water used methods and data corresponding to intermediate or long-run planning horizon. The question of how to disaggregate an annual demand curve to monthly or weekly time steps was also investigated in the literature, but it is out of the scope of the current report.

Industrial Pricing and Demand

In the industrial sector, two different ranges of prices apply depending on whether the water supply is based on direct abstraction or there is usage of public water supply.

In countries where a permit for water abstraction is compulsory, the abstraction charges are based on the authorised volume of water that can be abstracted. For the others, the charge is simply a function of the amount of water effectively consumed. This water quantity is multiplied by coefficients according to various parameters, such as: the season of abstraction (summer, winter), the geographic zone, the type of use (cooling, industrial process, air-conditioning, etc.), and water sources (surface or ground water). It must be mentioned here, that in almost every European country, groundwater abstraction charges are much higher than surface abstraction charges. Consequently, abstraction charges are also country specific. Groundwater is regarded as an important resource which needs to be preserved. The charging policy attempts to charge more so as to preserve the source and prevent over-abstraction (Pateron, 1999). It seems that it is usually cheaper for industrial users to invest in water abstraction and treatment facilities than to pay for supplied water.

However, in most countries, little information is available on tariff structures for industrial users, since companies tend to enter into special contracts with the water supplier. A general rule in Europe is that large consumers usually benefit from decreasing block tariffs; delivering water to a large plant is cheaper than supplying the same amount to households. Such special tariffs are the result of bilateral negotiations between an entire class of industrial customers and water providers. Thus, the water price can be reduced by as much as 50%. These contracts apart from been economically beneficial to the industries, they also attract new enterprises in the region.

By reviewing the empirical literature dealing with water demand and price elasticity, it is surprising to notice that while there is a considerable number of analysis focused on the residential and agricultural users, only a few works have been devoted to industrial ones (Feres & Reynaud, 2003).

Three different studies undertaken in three different countries (India, Brazil, China) show that the average price elasticity of industrial water demand is about -1.0. This number suggests that there is a great potential for the government to use pricing policies to encourage water conservation in the industrial sector. According to these studies, increasing water prices would reduce water use substantially (Feres & Reynaud, 2003; Wang & Lall, 1999; Kumar, 2003).

Advantages & Disadvantages

Advantages	Efficient water pricing policies have a demonstrable impact on the water demand of different uses. This is particularly true for the agricultural sector, but also applies for industrial uses and for domestic outdoor uses. As the result of the direct impact of pricing on water use and pollution, pressure on water resources is reduced. However, precise information on the impact of pricing on the physical environment remains limited (Wang & Lall, 1989). Pricing policies that better account for the environment will build on: • a firmer application of the principle of recovery of costs, • a wider application of pricing structures that provide incentives and

	promotion of metering devices, • the assessment of major environmental costs and, where feasible, the internalization of these costs into prices, • a transparent policy development process with the participation of users/consumers, and • an implementation of pricing policies to integrate sound economic and environmental principles.
Disadvantages	A stricter recovery of the costs would have impact on the affordability of water services, especially for low-income groups and some rural and farming communities that pay little of the total water service costs.

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