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Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia

A Review of Key issues and Experience in Six Countries

Final Report

Main Report

December 2004

This report was prepared by a consortium of consultants, consisting of DHV Water BV, Amersfoort, the Netherlands (leading partner), and BRL Ingénierie, Nîmes, France.

For the World Bank with funding from the Bank-Netherlands Water Partnership

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The Seawater and Brackish Water Desalination study in the Middle East, North Africa and Central Asia has been carried out by a consortium of consultants, consisting of DHV Water BV, Amersfoort, the Netherlands (leading partner), and BRL Ingénierie, Nîmes, France. This study was carried out for the World Bank and funded by the Bank-Netherlands Water Partnership, a facility that enhances World Bank operations to increase delivery of water supply and sanitation services to the poor (for more information see http://www.worldbank.org/watsan/bnwp).

The team of experts for the study consisted of Mr. Maarten M. Schenkeveld, Team leader and WRM expert, Mr. Richard Morris, Desalination expert, Mr. Bart Budding, Institutional expert, Mr. Jan Helmer, Economist and Mrs. Sally Innanen, Environmental expert.
The project started in November 2002 and was completed in December 2004.

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List of Abbreviations

AEC	Algerian Energy Company
ANER	National Renewable Energies Agency
AWWA	American Water Works Association
BNWPP	Bank Netherlands Water Partnership Program
BOO	Build Own Operate
BOOT	Build Own Operate Transfer
BOT	Build Operate Transfer
BRL	BRL Ingénierie, France
BSCW	Basic Support for Cooperative Work.
CA	Central Asia region
CYP	Cyprian pound
DHV	DHV Water BV, The Netherlands
DZD	Algerian dinar
EDR	Electro Dialysis Reversal
EDS	European Desalination Society
EPC	Engineering Procurement Contracting
EU	European Union
GCC	Gulf Cooperation Council
GTZ	German Technical Assistance Agency
ICZM	Integrated Coastal Zone Management
IDA	International Desalination Association
IHE	Institute for Hydraulic Engineering
IWRM	Integrated Water Resources Management
JOD	Jordanian dinar
LRMC	Long-run marginal cost
MED	Multi Effect distillation
MEDRC	Middle East Desalination Research Centre
MENA	Middle East and North Africa regions
MSF	Multi Stage Flash distillation
MTL	Maltese lira
NGO	Non-Governmental Organisation
NRW	Non Revenue Water
O&M	Operation and Maintenance
OECD	Organisation for Economic Cooperation and Development
PPP	Public Private Partnership
PPPa	Purchasing Power Parity
PSP	Private Sector Development
PWS	Public Water Supply
RO	Reverse Osmosis
TDS	Total Dissolved Solids
TND	Tunisian dinar
ToR	Terms of Reference
TVC	Thermal Vapour Compression
UfW	Unaccounted for water
UNDP	United Nations Development Program
USD	US dollar
USD-eq	Equivalent amount in USD of 2003 as compared to the amount in the original currency in the original period
UZS	Uzbek sum
VC	Vapour Compression distillation
VWS	Virtual Work Space
WB	World Bank
WWF	World Water Forum

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We sincerely hope that this report and its recommendations will be followed up by concrete actions and that the peoples of the focus countries and elsewhere will benefit from it.

Executive Summary

The study aims at providing a document, which will improve the understanding of desalination within the World Bank and among its clients in the Middle East, North Africa and Central Asia. It also tries to clarify the conditions under which desalination can help in reaching the United Nation's Millennium Development Goals (MDGs) for water supply and sanitation. The study has been funded by the Bank-Netherlands Water Partnership. The study involved visits to four countries from the region, Algeria, Jordan, Tunisia and Uzbekistan. Cyprus and Malta, serving as best-practice examples were also visited in order to gain an insight into what they have achieved in desalination and water management especially as regards involving the private sector.

A key conclusion of the study is that desalination alone cannot deliver the promise of improved water supply. The ability to make the best use of desalination is subject to a series of wider water sector related conditions. In some countries weak water utilities, politically determined low water tariffs, high water losses and poor sector policies mean that desalinated water, just like any other new source of bulk water, may not be used wisely or that desalination plants are at risk of falling into disrepair. Under these conditions, there is a risk that substantial amounts of money are used inefficiently, and that desalination cannot alleviate water scarcity nor contribute to the achievement of the MDGs. It may be preferable not to engage in desalination on a large scale unless the underlying weaknesses of the water sector are seriously addressed. A program to address these weaknesses should include a reduction of non-revenue water; appropriate cost recovery; limited use of targeted subsidies; sound investment planning; integrated water resources management; proper environmental impact assessments; and capacity building in desalination as well as in water resources management and utility management. In any case, desalination should remain the last resort, and should only be applied after cheaper alternatives in terms of supply and demand management have carefully been considered.

A second conclusion is that the private sector can play a useful and important role in funding and operating desalination plants, but only if the above conditions are met. If these conditions are absent, there is a risk that excessive investments in desalination become a drain to the national budget, either directly under public financing or indirectly through implicit or explicit guarantees under private financing.

A third conclusion is that desalination technology itself has evolved substantially, making it significantly cheaper, more reliable, less energy-intensive and more environmentally friendly than it was a few decades ago. This trend is likely to continue. It is especially true for reverse osmosis, which is gaining a large share of the market outside the Gulf countries where mainly distillation technologies continue to be used. World desalination capacity is around 30 MCM/day and growing. Desalinated water costs in recent PSP projects verges around USD 0.70 per m^3.

Desalination has the potential to contribute to the alleviation of global water scarcity. In the past century, global water consumption levels increased almost tenfold, reaching or exceeding the limits of renewable water resources in some areas, such as in the Middle East and North Africa.
This bodes well for the Southern Mediterranean countries, and indeed many other coastal countries, many of which face water shortages and have so far had limited experience with desalination. In particular, desalination can help to alleviate the pressure on coastal aquifers suffering from seawater intrusion. It can also provide an alternative to inter-basin transfers of surface water or the reallocation of water from agriculture to municipal uses whose economic and social costs have to be assessed on a case-by-case basis.

About 2.4 billion people, or 39 % of the world population, live in coastal areas.[1] Both their absolute

[1] World Resources 2002-2003, World Resources Institute, Washington 2003. Coastal areas are defined as

numbers and relative share are increasing. They include a large share of the 1.2 billion people in developing countries that lack access to clean and reliable water supply, and they overlap with the 2.7 billion poor in the world who live on less than US$ 2 per day. These numbers need to be reduced significantly according to the Millennium Development Goals.

In some water scarce and poor countries, desalination may remain unaffordable in the foreseeable future. But for hundreds of millions of people living in the water-scarce coastal areas of middle-income countries, desalination offers the prospect of a reliable, good quality drinking water supply, thus making a contribution to achieve the Millennium Development Goals.

Affordability for the poor is a key issue for sound water sector policies. The poor pay currently high prices to water vendors and they generally have a high willingness to pay for improved supply. No matter what kind of technologies is used to supply drinking water, targeted subsidies are needed to ensure a basic amount of water supply for the poor. In particular, subsidies and cross-subsidies are necessary to increase access to water supply by the poor.

Desalination is likely to provide only a portion of the total water needs alongside with existing conventional sources. Although desalination is still more expensive than most existing conventional water sources, its cost is generally lower then the incremental cost of extra bulk supply from conventional water sources, such as dams and inter-basin transfers. Also, upward pressure on tariffs due to the incremental costs of desalination is gradual and often within the ability and willingness to pay of water users.

The present study is not an assessment of desalination on a global level. It analyses the status and prospects of desalination in six water-scarce countries in the Middle East (outside the Gulf countries), the Mediterranean and Central Asia, five of which are middle-income countries. It tries to distil lessons for applicability in other middle-income countries. The lessons are not necessarily applicable to low-income countries, which generally have not embarked on desalination so far.

The study shows that sound water sector policies allow desalination to contribute to the Millennium Development Goals in some countries. Other countries still need to make major improvements. The study also outlines what steps need to be taken in these countries to gradually enable sound use of desalination.

Water resources

The demand for domestic, agricultural and industrial water is generally met through developing surface water sources, such as lakes and rivers, or through pumping of groundwater.
When the demand increases the cost of developing new sources or expanding existing ones is getting higher as most accessible water resources have largely been tapped. Saving water rather than developing new sources is often the best 'next' source of water, both from an economic and from an environmental point of view.

Once conventional water resources become scarcer or too expensive to develop further , governments turn their attention to measures to restrict water demands or to more effective use of existing resources, and also to non-conventional sources. Treated wastewater is occasionally applied for watering municipal gardens and agricultural fields, or for certain industrial processes.
Desalinated water is often the last resort for countries to overcome water shortages, which in the case of seawater is principally an unlimited source. Although the price of desalinated water has come down it still is relatively expensive and its application should be the result of thorough studies of all options available, both addressing demand management and optimisation of existing resources (supply management).

areas up to 100km away from the sea.

Desalination Processes

The most common desalination processes used today are distillation and membrane processes, each accounting for about half the installed global desalination capacity. Historically, distillation technologies have dominated the seawater desalination market, partly because they lend themselves well to co-generation of water and power, partly because energy subsidies favored these more energy-intensive technologies, and partly because of the lower reliability of earlier membrane technologies. However, most new desalination plants now use membrane technologies, in particular reverse osmosis (RO). This is mainly due to reductions in the costs and the energy intensity of reverse osmosis, as well as improvements in its reliability. Reverse osmosis of seawater requires much less energy than distillation processes. Electric energy consumption is almost the same or lower than distillation, while it does not need any thermal energy. Membrane processes have considerable advantages in desalting brackish water and are now being widely applied in this market. Another membrane technology is electrodialysis (ED). This has some advantages over reverse osmosis in the treatment of certain brackish waters and in specific environments., Finally, there is active research in new processes. Often the cost estimates for such new processes are overly optimistic and in many cases promises have failed to materialize. It is unlikely that in the near future any new process is going to challenge reverse osmosis as the main process for new desalination plants particularly seawater desalination plants. It is conceivable that in the long term, some new processes may emerge that would undercut the costs of reverse osmosis. However it is more likely that advances in RO and ED will keep these processes competitive.

Cost of desalination

The financial costs of large-scale desalination, as evidenced by recent BOT contracts, are in the order of US$ 0.45-US$ 0.52/m3. However, these figures somewhat underestimate the economic costs of desalination, because of indirect subsidies in the form of soft loans, guarantees and free land. Due to a lack of commonly accepted methodology and limited availability of commercial data it has so far not been possible to calculate the economic costs of desalination, although it is estimated to be only slightly higher than the above-quoted figures. Furthermore, the unit costs in BOT contracts are influenced by the way they are calculated (discounting and weighting). Also, changes in electricity costs are usually passed through to the price of water so that water prices are not guaranteed throughout the contract period. The unit costs for smaller plants are significantly higher.

Energy

All desalination processes use energy. Historically, desalination has been seen as a very energy intensive process. The development of reverse osmosis and more recently the improvements in energy recovery devices have changed that situation. With energy consumption on Mediterranean seawater reverse osmosis plants down to 3 kWh/m^3, it brings seawater desalination within reach of many communities. It is worth noting that all of the major plants constructed by the private sector in the non-oil rich countries (Malta, Cyprus and Israel) have used reverse osmosis technology, which requires electrical power.

Where power generation is involved high quality water may be required, or where energy prices are low, distillation technology will continue to be used either in the form of MSF or MED. However, even in the historically distillation-biased Gulf States reverse osmosis is making inroads in the market.

A number of countries using desalination, especially those in the Arabian Gulf, have significant domestic fossil energy sources. These countries usually subsidize the provision of natural gas to power plants and thus subsidize indirectly the cost of electricity and steam used for desalination. This is the case in Algeria. Energy subsidies distort the choice of desalination processes in favor of energy-inefficient technologies. In countries embarking on significant desalination investments, energy policies and energy investment planning should be revised to provide the right incentives for appropriate desalination processes and to decide whether co-generation of water and power is a suitable option or not under particular circumstances. This has become more significant for reasons ranging from integration of policies, the demand for water growing at a different rate than the demand for power, and seasonal variations between power and water demands.

Overall, given the concern for global warming and sustainable development, future development of desalination should favour low energy desalination processes. Renewable energy driven desalination plants may be applicable for small plants in remote locations.
Most of the countries visited have significant renewable energy resources (wind or solar) and have programs to develop use of renewable energy. Desalination using renewable energy is still at a very early stage of development. The most likely market for coupling renewable energy with desalination is for small communities in remote locations where there is no power grid connection or where power is expensive.

Institutional Framework and Capacity Building

Proper functioning of the water sector, and particularly the bodies that are involved in the development and implementation of desalination activities, is determined by the efficiency of the institutions themselves, by their interaction with other institutions and their ability to incorporate environment concerns in their decision-making. Important institutional aspects of facilitating desalination activities are:

- A clear water policy and strategic framework for water resources management that optimises use of water resources and clearly describes the role of desalination in the policy.
- A clearly defined institutional framework and water sector organisation. This can be laid down in a set of laws establishing various actors in the water sector, but described more in detail in policy and strategic plans for the water sector.
- A clear legal framework that leaves very limited doubt as to the legal possibilities and restriction in developing water resources, particularly desalination infrastructure, and the management thereof. The legal framework should also cater for facilitation of a clear-cut co-operation between public and private partners.

Yet, as much as the 'enabling' environment is crucial to the proper function of a sector, the quality of the actors themselves is just as important. The importance of continued, and increased capacity building in the water sector, and particularly the desalination sector, is undisputed. This should be directed not only at the operational environment, in which managers and technical staff are trained and educated to ensure a good quality of their work. It should also be aimed at strengthening the actors in the enabling environment. This means that there is a continued need for developing the skill and capabilities of people that 'set the stage' for desalination, by developing water policies, implementing new forms of contracts, and adjust the legal framework to meet the criteria described above. Capacity building may very well include support to the private sector, which are in a number of cases not yet fully equipped to work in the high-tech and competitive market of desalination.

Private Sector Participation

In a number of countries there is an apparent need for private sector participation (PSP) in the development of desalination infrastructure. The need for high-tech expertise, and operational efficiency, as well as the need for capital investments and risk-sharing are the most important drivers influencing governmental organisations to request private parties to design and build and often also operate desalination facilities.

It is, however, not always easy to attract private investors to participate 'at risk' in the development of desalination infrastructure. There are perceived country risks in some of the countries under investigation, while the absence of a clear legal framework and insufficient experience of the public sector in working with the private sector may put a brake on achieving the desired level of PSP and the subsequent risk-sharing between public and private parties. In particular cases PSP is very limited due to the fact that the market is too small, or that water consumers are unable to pay for their water and the private operator unable to gain a fair return. This is particularly the case where the local water company or local government is unable to provide sufficient guarantees to a private party.

To take away some of the restrictions in attracting private sector parties a country should be well-prepared before it enters into a process of developing PSP. Private sector parties will require a clear policy on private sector participation, embedded in a clear legal framework, that takes away a number of the perceived country risks (e.g. expropriation, rigid tariff structures, and unclear tendering procedures). From the country's perspective, it has to prepare itself for PSP as well, by determining which form of PSP is desired, and by seeing to competent staff being available to develop projects, and see to a professional tendering procedure and contract award. In brief a government has to become a competent partner to the private party.

The types of private sector participation found in the desalination market are rather limited and seem to focus strongly on design-build activities and Build-Operate-Transfer (BOT) or similar contractual arrangements. These are the types of contracts that usually meet the needs of the governments of the countries under investigation, to the 'drivers' of capital investment needs, and to private sector efficiency. The BOT approach can function as an appropriate model for desalination project development, since desalination plants are more or less 'stand-alone' facilities, for which it is relatively unproblematic to attract project financing, due to the fact that it involves the realisation of new infrastructure against, usually, rather straight-forward conditions and guarantees. However the risks associated to this type of contracts need to be carefully managed. Take-or-pay obligations by the public parties and public guarantees to cover foreign exchange risks and payment risks by the end-user need to be based on a realistic assessment of the risks and result in a fair allocation of risks between the parties. Otherwise end-users and / or taxpayers in a country may be charged for costs that could have been avoided.

In the longer term other forms of contract can be expected. In Malta, the government has taken over the operations of desalination facilities from the private sector, based on the experience and lessons learned from the private sector, which has enable the public sector to learn how to operate desalination infrastructure. In Cyprus management contracts are planned once the 10-year BOT contracts expire.

Environmental and Health aspects

The environmental footprint of desalination has been reduced through technological progress. However, some significant environmental impacts remain, in particular during the operating phase of the plants. One major impact is the discharge of brine – a concentrated salt solution that may be hot and may contain various chemicals – on coastal or marine eco-systems or, in the case of inland brackish water desalination, on rivers, aquifers and soil. Another major impact is the emission of greenhouse gases in the production of electricity and steam needed to power the desalination plants. Furthermore, abstraction of brackish groundwater for desalination can have significant environmental impacts. Other impacts of usually more limited nature include noise, visual disturbance, interference with public access and recreation, possible impacts from seawater intakes, as well as various environmental impacts during the construction phase and potential impacts from accidental spills.

There can also be positive environmental impacts from desalination, if desalination reduces the pressure on conventional water resources. In particular, seawater desalination can help to relieve the pressure on overexploited coastal aquifers and thus prevents seawater intrusion, a widespread phenomenon causing quasi-irreversible damage in coastal areas around the world. In some cases, seawater desalination can be an alternative to the use of fossil groundwater further inland or to the construction of large dams and inter-basin transfers that are usually associated with significant social and environmental costs.

Mitigation measures include preventive measures, such as the strengthening of environmental institutions and water conservation, and reactive measures, which involve physical changes to a plant or process. The latter include optimized siting in the construction phase, the use of more energy-efficient technologies, design and treatment techniques to reduce damage to the marine environment, including the appropriate design of sea outfalls and the mixing of brine with seawater before discharge, and architectural measures to reduce visual impact especially for tourism purposes.

Concerning health aspects of the use desalination, desalinated water is free from pathogens and constitutes a safe source of drinking water in terms of microbes. However, desalinated water from plants using distillation technologies is completely de-mineralized and needs to be re-mineralized before human consumption in order to include minerals that are essential for human nutrition.[2] Furthermore, if post-treatment is inadequate, desalinated water from thermal processes can corrode pipes and corrosion products may contaminate the drinking water. In addition, practically all desalination processes require chemical pre-treatment and residual chemicals need to be removed from product water through appropriate post-treatment.

There is concern about brine discharge and its environmental impacts. In seawater plants, brine is discharged into the sea. Any chemicals added to the desalination process for scale and fouling prevention, corrosion reduction and corrosion products flow back into the sea. Coastal currents should be examined to ensure that discharges are not swept back around into the intake system. If discharge occurs into a small, enclosed bay or there is no coastal current, concentrations of the substances can build up, a situation that is clearly to be avoided. There is increasing concern in the Gulf about the amount of desalination taking place and the fact that the Gulf is a small, enclosed sea.

Land-based brackish water plants can experience severe problems in disposing of the brine discharge. There are a number of options: it can be spread over the land and allowed to drain back into the ground; it can be pumped into solar ponds for evaporation, or it can be re-injected back into the ground. None of these solutions is completely sustainable.

Country experience

All visited countries are faced with structural water shortages. The countries see desalination of brackish water or seawater as an important element of their strategy to increase supply levels of potable water.

Algeria has significant indigenous energy resources and has been involved in desalination for many years but mainly in connection with oil and gas development projects for industrial use. Most of the population live near the coast, but there are also small inland towns and villages with access to brackish water. The government has recently built some small desalination plants in the vicinity of Algiers as a temporary measure pending the construction of larger seawater reverse osmosis plants.

Tunisia has gained very useful experience in brackish water desalination using both reverse osmosis and electro-dialysis. These plants are located in the south of Tunisia, which is an arid zone. Additional plants are planned; such as the first large seawater reverse osmosis desalination plant at Jerba.

Jordan is acutely short of potable water, but has brackish groundwater resources, which provide ample brackish water desalination opportunities. It has limited experience with desalination of either seawater or brackish water. This situation is changing and many reverse osmosis brackish water plants are planned, with some already under construction. Also, the falling level of the Dead Sea poses a major problem, which might be addressed through conveying seawater from the Red Sea towards the Dead Sea, meanwhile using the gravitation energy to desalinate the seawater, and discharging the brine into the Dead Sea. This may restore the water level in the Dead Sea, and will

[2] WHO drinking water guidelines currently do not specify minimum thresholds for minerals, so that de-mineralized water is technically in conformity with WHO guidelines.

meanwhile provide an opportunity to produce significant quantities of potable water.

Uzbekistan has huge regional variations. In Karakalpakstan close to the Aral Sea there are major potable water shortages. The government has purchased and installed large numbers of small electrodialysis plants of Russian manufacture. These plants are simple to operate and the newer designs are very robust. Given the local infrastructure this appears to be a good example of applying appropriate technology at scale. Installing more sophisticated reverse osmosis plants in this region is unlikely to be successful, due to a lack of skilled labour, limited financial resources, and a short supply of spare parts.

Malta and Cyprus are developed countries which are further ahead in implementing IWRM practices than the countries that are subject of this study. In parallel with the development of desalination, governments of both countries have carried out loss reduction programmes, tariff reforms and other measures to moderate water consumption. Both are heavily dependent on seawater reverse osmosis plants for a major part of their potable water supplies. This technology is proving to be very economic and reliable. In both Malta and Cyprus the private sector has had a major involvement in the construction and operation of the desalination plants.

The tables on the next pages summarize the main characteristics of desalination in the countries studied.

Seawater Desalination - Summary table

Country	Plant size (m3/day)	Total Capacity (m3/day)	Water Use	Water distributor operates plants	PSP for plants supplying municipal water	Technologies used	Number	Future Plans
Algeria	260 to 24,000	160,000	Industrial; Municipal	No (large), yes (small)	Under contract	VC/ME/MSF No RO	79	28 plants with 1,950,000 m3/day
Tunisia	100 to 1,020	7,000	Municipal	Yes	Planned	Mainly VC Some RO/ME/MSF	17	Djerba
Jordan	500 to 3,000	5,500	Mainly industrial, some municipal	Yes (for industries)	No	RO and VC	10	Aqaba Red-Dead Project
Uzbekistan	no plants since Uzbekistan has no sea border							
Malta	100 to 27,600	120,000	Municipal	Yes (through subsidiary)	No	Mainly RO Some VC/ED/MSF	45	None
Cyprus	150 to 54,000	162,000	Municipal	No	Yes	Mainly RO Some MSF and VC	27	Limassol Paphos

Brackish Water Desalination - Summary table

Country	Plant size (m3/day)	Total Capacity (m3/day)	Water Use	Operators	PSP for public water supply	Technologies used	Number	Location	Plans
Algeria	Up to 42,000	100,000	Industrial Municipal	Industry (mainly oil companies)	Under contract	Mainly RO and ED	90	Mainly Inland (Sahara), but some on the coast (Arzew)	No major plans?
Tunisia	Up to 22,500	72,800	Municipal	Sonede (public water utility); Industry	No	Mainly RO and ED	48	Coast and Inland	Rehabilitation
Jordan	Up to 1,600	5,700	Industry, Urban Municipal Agriculture	Mainly industry	Under contract	Mainly RO Some ED	21 for irrigation 9 for industry	Jordan Valley	Hisban project under PSP (40,000 cum/day?)
Uzbekistan	50 to 150	31,600	Rural Municipal	Vodokanal; Agrovodokanal	No	Mainly ED Some RO	67	Karalpakstan near Aral Sea	
Malta	Up to 4,500	8,000	Mainly industrial, some municipal	Industry and public water utility	No	Mainly RO, some ED	13	Coast	No major plans?
Cyprus	Up to 1,900	2,200	Industrial	Industry	No	RO only	10	?	No major plans

Checklist

The following is a checklist with key questions that should be considered before a decision is taken whether to construct a desalination plant.

Water resources

- Determine the required amounts of water taking into account the demands of all sectors in the region, municipal, industrial and agricultural.
- Make an analysis of the conventional water sources that are available in the area taking into account sources that may be located somewhat further away.
- Estimate the cost of conveying the water to the designated locations.
- Determine whether optimum use is already made of existing water resources
- To what extent can the extra demand be met from recycling waste water? What scope is there for increased recycling and at what cost?
- Are other non-conventional water resources a realistic option, e.g. water re-use?

Desalination process

- Assuming the conventional water sources do not provide enough water determine the source of water to be desalinated (brackish inland water or seawater).
- Determine the size and the location of the desalination plant. Does the distribution area justify more than one plant?
- Make an analysis of the most appropriate process for desalination of water
- Estimate the cost of the new plant.

Energy

- Determine the need for extra energy for the desalination plant.
- Is the energy available in the region or should additional power production capacity be installed.
- Estimate the cost of the extra power required, both for construction and for operation.

Institutional arrangements and Capacity building

- Is the development of desalination infrastructure in line with overall sector development plans and is budget available, or can this be made available?
- Determine which institution will be in charge of the new installations; has it the capacity and capability to develop the project?.
- Does the institution have sufficiently experienced staff to run the plant, both operational and managerial?
- What skills and knowledge need to be developed and how can this be achieved through training programmes and other education.

Private Sector Participation

- Determine whether it is advantageous to involve the private sector in the running of the plant;

take into account the technical skills within the government to run desalination plants, the managerial skills, the need to attract (overseas) finance, the required experience.

- Are rules and regulations sufficiently adjusted to private sector involvement in public services delivery?

- Which are the most important risks associated to including the private sector and which risk occur when the private sector is not included?

- Is competent staff available within the government to manage and support the preparation, tendering and implementation of a PPP project?

- Make a thorough comparison between the various options to for private sector involvement. Analyse the financial implications of the chosen type of contract and determine the possible need for subsidies to make the project bankable.

Economy and Affordability

- Make an analysis of the costs and benefits of the proposed desalination plant including the extra power production needed and the measures to mitigate the negative environmental impact.

- Make proposals for financing the project. Will it be through commercial loans, government budget, soft loans, international grants, private sector equity and debt funding, or through other means?

- What is the impact of the marginal cost of the desalinated water on the total water bill of consumers? Can the population afford the increased costs and are they willing to accept a price increase? Will there be government subsidy to pay for the increased cost of the water production.

Environmental Impact

- Are proper environmental laws and regulations in place?

- Carry out environmental impact assessment studies for the proposed new installations.

- Make proposals for mitigation of the negative impacts.

- Make a special study of the effects of disposal of the brine from the desalination plant.

- Are there sufficient enforcement powers when environmental impacts are prohibitive of nature and result in breach of environmental standards and regulations?

- Is the project sustainable, in terms of technical, environmental, financial, social and institutional sustainability?

1 Introduction

1.1 The Project

The World Bank has initiated the project "Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia". The objective of the project is to improve the understanding of World Bank staff and World Bank clients in the Middle-East and North Africa (MENA) and Central Asia (CA) regions of recent and ongoing changes in the Desalination Market. The project is financed by the Bank Netherlands Water Partnership Program and is managed by the World Bank.

The technical aspects of desalination are fairly well known. Comparatively little is known about how the institutional framework for desalination within the broader context of the water and power policies in the individual countries, and how various approaches for private sector participation affect the prospects for desalination. This has been assessed in the project by focussing on specific countries.

The focus countries of the project are Algeria, Tunisia, Jordan and Uzbekistan. Malta and Cyprus were added as countries having relevant experience in desalination and public private partnership.

The study builds on the knowledge gained with desalination, in particular with the recent introduction of PSP in desalination in developed countries (United States and Mediterranean Countries). The study attempted to adapt this experience to the local circumstances in the countries in MENA. In CA, with its unique setting, it focused on the analysis of the existing institutional arrangements of small-scale desalination plants.

For the purpose of this study, desalination includes any process which removes salt from sea water or brackish groundwater. The study includes small desalination plants (< 500 m3/day), medium size (500 to 20,000 m3/day) and large-scale desalination plants (20,000 m3/day or more). In addition, the study includes plants that provide water partially or fully for domestic and municipal uses. It excludes the desalination of treated industrial and municipal wastewater.

The World Bank concluded a contract for carrying out the study with DHV Water BV, Amersfoort, the Netherlands. BRL Ingénierie, Nîmes, France was a sub-consultant for a part of the study. The project started in November 2002 and was completed in June of 2004.

The study team conducted a number of visits to the focus countries of the project. The schedule of main activities including the programme of visits to the countries is presented in Appendix A. The meetings conducted in the countries are listed in Appendix B.

Two workshops were held to discuss the findings of the consultants with the World Bank and with representatives of the focus countries, one in December 2002 in Amersfoort and one in Cyprus in April 2004.

1.2 The BNWP and the poor

The project fits perfectly within the mission of the Bank-Netherlands Water Partnership, which is to improve delivery of water supply and sanitation services to the poor. The poor consistently identify safe and adequate water supply and sanitation as a critical component of their welfare. Providing desalinated water will increase the overall supply of water to the country. BNWP projects are targeted interventions that support implementation of structural changes. The BNWP operates through a number of windows. This project finds its place in most of the windows identified, such as Water supply and sanitation in rural areas and small towns, developing sustainable financing systems and capacity building.

1.3 Focus countries

The project is a regional study that covers the Middle East, North Africa and Central Asia.

The countries selected for this study are Algeria, Tunisia and Jordan in MENA and Uzbekistan in CA. These countries have limited experience with desalination be that, in some instances, it is used for special purposes related to industries. Since the focus of the project is domestic water supply, it was thought advisable to include in the study countries where considerable experience has been built up in this area. Brief visits were paid to these countries and the experience gained described in such a way that the developing countries could benefit from their experiences. Two countries in the Mediterranean were selected for this purpose: Malta and Cyprus.

Large desalination capacity has been installed in a number of countries in the Gulf region, among which is Saudi Arabia. It was however decided that this study should not include detailed studies for these countries since the economic circumstances of the developing countries that are the focus of this study are very different (from a point of view of salinity of the feed water and economy of the countries involved) from the conditions in the Gulf states. This has been further elaborated in section 3.2.

Lessons can also be drawn from other - Mediterranean - countries. A case in point here is Spain where certain regions especially in the south of the country experience severe water shortages. Several large seawater reverse osmosis desalination plants are in operation in Spain. Further alleviation of the water shortage problems was planned to come from diverting water from the north (Ebro river) to the south as part of the National Hydrological Plan. But since this project was abandoned for various reasons (among others environmental issues), it was decided to build more seawater reverse osmosis desalination plants. The water will in the first instance be used for agricultural purposes and tourism.

1.4 Contents of the report

The Final Report of the study consists of seven volumes. This is the Main Report. It discusses the main topics that have been studied, such as Water Resources, Desalination techniques, Energy and Renewable energy, Institutional framework of water resources management, Public Private Partnerships and Environmental aspects.

The six annexes to the Main Report contain reports on the status of desalination and related topics in six focus countries that have been studied in the course of this study. In four countries (Algeria, Tunisia, Jordan and Uzbekistan) desalination has not been developed at such a large scale. But governments realise that desalination is their last resort to produce enough fresh water for the population in the near future.
In two countries (Malta and Cyprus) the development of desalination has gone a long way. They could serve as reference countries for others.

The topics discussed in the annexes are: Water resources, Water resources management, Desalination, Renewable energy, Institutional capability and capacity, Environmental aspects and Future developments.

2 Water Resources

2.1 Integrated Water Resources Management

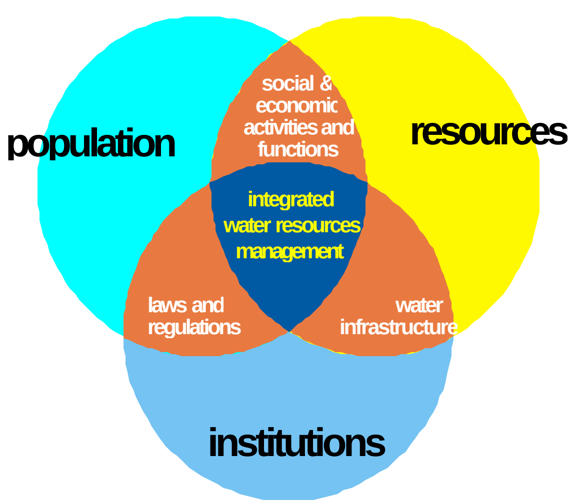
Water is essential to life. Next to oxygen, fresh water is the most important substance for sustaining human life. Access to water is considered to be a basic human right. However, the increased use and misuse of this resource by the growing population and increasing industrial activities may lead to a situation whereby countries need to reconsider their options with respect to the management of its water resources. The pressure on the available resources and stakeholders dependence on them, have made water resources management complex in nearly all countries, developed and developing alike. As a result WRM is undergoing a drastic change world-wide, moving from a supply-oriented, engineering biased approach towards a demand-oriented, multi-sectoral approach, often labelled Integrated Water Resources Management (IWRM).

In the international fora, opinions are converging to a consensus about the implications of IWRM. This is best reflected in the Dublin Principles (1992) that have been universally adopted and form a cornerstone of the chapter on water resources in Agenda 21 at the UNCED in Rio de Janeiro. The concept of IWRM makes us move away from 'water master planning', which focuses on water availability and development, towards 'comprehensive water policy planning' which addresses the interaction and possible competition between different sub-sectors, seeks to establish priorities, considers institutional requirements, and deals with the building of capacity.

Dublin principles

- Water is a finite, vulnerable and essential resource which should be managed in an integrated manner
- Water resources development and management should be based on a participatory approach, involving all relevant stakeholders
- Women play a central role in the provision, management and safeguarding of water
- Water has an economic value and should be recognised as an economic good, taking into account affordability and equity criteria

Figure 2.1 IWRM aspects



IWRM should take place through interaction with users (population), resources and institutions, as indicated in Figure 2.1. IWRM thus applied considers the use of resources in relation to social and economic activities and functions, and the water infrastructure needed. Activities and functions are also considered when laws and regulations for the sustainable use of water resources are set between institutions and users. The infrastructure made available, in relation to regulatory measures and mechanisms, will allow for effective use of the resource, taking due account of the environmental carrying capacity.

Water is becoming a scarce resource. This is especially true in the countries that are the subject of this study. In the past governments did not need to worry too much about the supply of water to the various users groups. The quantity of water was sufficient to meet the relatively small demand of the users. "There was enough for everybody", was the thinking. In the recent times the number of users has increased, as has the amount per user. This has made it necessary to look for ways of distributing the available water in an equitable, fair and efficient manner, taking into account the cost of the water.

Water does not come for free. The water as such may be considered as a free commodity, the simple fact that it should be collected, treated and transported puts a price to it. This infrastructure must be constructed and maintained. Pricing of water, however, is also used by the authorities as a means of controlling the use of the water, as is done with other economic commodities.

2.2 Water Supply

Water sources can be divided into conventional and non-conventional sources. Conventional sources are surface water and ground water; non-conventional sources are treated waste water and desalinated water. In order to distribute the available water in a correct and efficient manner hydro-geological studies must be carried out to assess the available quantities and to determine whether the demands can be met.

Conventional sources fall in the category of renewable resources. As long as a country only applies renewable resources there should be no problem in supplying water to all users, now and in the future. In a number of countries however the demand for water exceeds the supply. This is often the case where there is extensive irrigation to achieve self-sufficiently in food production and where conventional sources are insufficient to supply the demands. In some instances fossil groundwater is used to support agriculture. These countries run the risk that sooner or later they may run out of water. This problem can be addressed by resorting to non-conventional sources: treated wastewater and desalination.

Water needs are usually first of all met by developing surface water sources, such as lakes and rivers. The development of these water supplies, ranging from small diversions to large dams and reservoirs, are termed conventional water projects. Surface water was probably first used by man for domestic and small farming operations, because it was a visible and inexpensive resource. Dams and reservoirs were built later to store water flows for use by agriculture, households and the industry and for various other purposes such as water conservation, flood control, power generation, recreation, fish and wildlife enhancement, and to improve the water quality.

Ground water has always been an important source of water and is often used in the areas where it is available, eliminating the need for extensive conveyance systems. In arid areas, ground water is the traditional source of fresh water. It is used in normal recharge - extraction operation to obtain the safe yield. This has permitted growth and economic development of these areas. In some locations, during wet years, the ground water basins have been used to store imported water in lieu of surface water reservoirs. During droughts use of surface water can be reduced and the water stored underground will be released.

Treated wastewater can provide a significant source of water. Reclaimed water has several advantages, viz.:

- It can be used for irrigation, watering of parks and golf courses or stored underground for later use.
- It can reduce the strain on the available conventional water resources, i.e. reclaimed water is used for non-potable purposes to reduce the existing use of high quality potable water.
- It can stop pollution from flowing into rivers, lakes and streams which will make waterways safe for swimming and fishing.
- It can eliminate the threat to public health caused by exposure to harmful organisms present in water and consumption of fish.

There is still in some places reluctance against using treated water, however it should be perfectly safe to use it in public parks after tertiary treatment. This use of the water would free up other water for domestic use and use in the tourism sector. In Cyprus grey water is used for flushing of toilets and watering the gardens.

Desalination is also considered a non-conventional method of producing fresh water from seawater and brackish water. In 1957 when the first desalination symposium was held in Washington, several important aspects were still uncertain.

Forty years later desalination has become a proven technology for supplying fresh water with a total global capacity of over 30 MCM per day produced by more than 10,000 facilities. The most common places where desalination is used are arid areas in the Middle East, the Canary islands and the Caribbean islands, the Mediterranean basin and the United States.

Also in the countries of this study desalination is in use to a greater or smaller extent. In Malta and Cyprus all conventional water sources have been used to their full extent. Desalination is now in use to fill the gap between supply and demand. In Jordan this will be the case in the near future. In Uzbekistan desalination was applied in the regions around the Aral Sea where no other fresh water sources are available. In Algeria a number of desalination plants are in operation by the industry, plants for domestic supplies will be opened shortly. Tunisia has some desalination plants that supply water to tourist areas and some isolated communities in the south of the country.

In all of these countries (and in countries in similar conditions) the authorities are now considering the (increased) use of desalinated water. Desalinated water is often the last resort for countries to tap a new and, in the case of the use of seawater, an unlimited source for obtaining fresh water. Although the price of desalinated water has come down, its application should be the result of a thorough study of all supply options as part of integrated water management studies.

To date, the desalination of seawater and of brackish water has been considered as a technical matter. The attention of those involved has gone towards improving the processes and reducing costs. This has over the years led to more efficient and cheaper ways of desalinating water, . but too little attention was given to the fact that the water being produced forms a part of the water cycle. It seems that water resources engineers were hardly involved in the decisions whether and where desalination plants should be constructed. In deciding on the construction of desalination facilities it is important to carry out detailed water resources studies for the region concerned.

2.3 Water Demand

The main water user groups that are distinguished in almost all countries are: domestic users (households), agriculture, industries and offices and tourist facilities (resorts and hotels).

On a global scale, demand for freshwater is driven by the increase of the population and sectoral pressure for both consumptive and non-consumptive uses. The sectoral demands include agriculture (irrigation and drainage), the provision for domestic water supply and sanitation, industry, energy generation, environmental requirements and tourist facilities (hotels). On the other hand industrialization, rural/urban shifts and migration has changed the patterns of consumption which in turn has complicated the nature of these demands.

In addition to satisfying these basics needs, demand for more reliable and high quality water supply which is also of fundamental importance to fisheries, wildlife and recreational interests has exerted more pressure to protect and conserve these resources. Ground water quality has declined as result of high consumption rates and the intrusion of sea water and other contaminants into the aquifer.

The provision of adequate water supply and sanitation to the rapidly growing urban populations is increasingly becoming a problem for governments of the countries visited and throughout the world. The continuing increase of the number of people in cities who need water and sanitation services form a continuous pressure to either invest in additional production capacity or to stretch the available supplies to serve more people. At the same time, industrial activity also demands the expansion of water supply services.

2.4 Matching Supply and Demand

After having analysed the available (conventional) sources of water and the demand from the various user groups (in a certain region) one may find that the demands are higher than the available supply from conventional sources.

If after re-evaluating the demands the gap still exists, one might want to apply unconventional sources. The growing gap between supply and demand can be filled by among others re-use of waste water, fossil groundwater and desalinated water.

These waters are usually more expensive to produce, although as will be shown later in this report the costs have come down considerably in recent years. In choosing a water source it must always be ascertained that the user can afford the more expensive water.

It was found in the countries visited that agriculture is a big user of water. Sometimes irrigation schemes are even built close to desalination plants. One might then be tempted to use desalinated water for agricultural purposes.
In some instances saving of water in one sector may make free water for another sector, but a straightforward trade-off of water between urban use and irrigation can hardly be envisaged.
The costs of a water supply scheme should be worked out for each individual case taking into account the expected benefits.

The scope of the study and the time allotted to the various activities did not allow for detailed and thorough investigations regarding the quantities of water produced and used by the various demand sectors in the investigated countries.

Desalination can be applied to domestic supplies however it might be too expensive to use it for large-scale irrigation. This can only be considered if high value crops are grown or when subsidies are given. This is based upon a political decision of the government that wants to promote the agricultural activities in a certain region, such as in certain areas of Jordan and Spain. In Jordan however it is the private sector that has set-up desalination plants for irrigation.

An important aspect in choosing the right water or production process is the required water quality. It is usually not necessary to have a thorough desalination of water if it applied to agriculture.

2.5 Water Demand Management

The predominant approach towards meeting the increasing water demands has been supply augmentation schemes. But the cost of developing new sources or expanding existing sources is getting higher and higher as the most accessible water resources have already been tapped. It has been demonstrated in many countries that saving water rather than the development of new sources is often the best 'next' source of water, both from an economic and from an environmental point of view. Water demand management therefore is seen as the preferred alternative to meet increasing water demand and can be defined as a strategy to improve efficiency and sustainable use of water resources taking into account economic, social and environmental considerations.

Water demand management measures can be divided in:
1. Water conservation measures: Leakage detection, Reduction of illegal connections, In-house retrofitting, Out-of-house water saving measures
2. Water pricing measures: Water metering, Tariff structures
3. Information and educational measures: Awareness raising, Public involvement, In-school

education
4. Legal measures: Rules and regulations that form the basis of WDM policy, Regulations on resale of water

High rates of unaccounted for water (UFW) are common in developing countries, reaching extreme levels of 40%-60% of the water produced. Of the total UFW, an estimated 50% is caused by leakage, usually the result of either lack of maintenance or failure to replace aging systems.

In many cities in the world but also in the study countries the number of leaks in the network for domestic supply is rather great. The losses that are a result of this are detrimental to the water supply situation. Losses can be distinguished in technical and administrative losses. The technical losses concern leaks from valves, holes in pipes, faulty water meters. The administrative loses are illegal connections, unpaid bills, etc. Many cities have established programmes to minimise these losses.

One of the measures that can be taken to promote water conservation and at the same time increase access and equity in water supply provision is the establishment of different forms of tariff setting. In a progressive block tariff system, the first 5 to 10 m3 have a low, subsidised tariff and the following blocks have an increasingly higher tariff. The rationale for the system is to promote water saving practices with all households and to ensure that low-income households can afford to use an amount of water that is necessary to keep themselves and their environment healthy.

People should be made aware that water is a scarce resource. This can be done through awareness campaigns that are run in the press and on television and other public fora. Awareness raising should also be made part of the curriculum at primary and secondary schools.

In all countries visited it was found that most of the water is used for agricultural purposes. It was realised that a few percent of savings in agricultural water demand would have a great impact on the water supply to domestic users. Nationwide there should also be great attention for the use of water by the agricultural sector. Proper pricing should be set up and it should be enforced. The extension service should instruct farmers how water demand can be reduced. In certain cases it is advisable to grow crops that demand less water.

2.6 Messages

2.6.1 Water Supply Management

Optimising the use of different and existing conventional water resources go hand in hand with maximising the benefits of desalination and/or other non-conventional water resources. This can be aimed both at reducing water losses and at determining the optimum ways and means of water production and delivery.

It is unusual for desalinated water to be the only water source for a community. The original community haas established itself on sustainable water from a river or an aquifer. The desalination plant is later installed to supplement the existing supply and is usually blended with the local water.

Malta is a good case study. They have an on-going programme on loss reduction coupled to improved metering and tariff re-structuring. Demand has been significantly reduced. They have published papers on this topic.
When there is a need to develop more water resources IWRM should take place through interaction with users (population), resources and institutions,

Water recovery from wastewater should also be looked at. There are various uses that can be supplied with treated wastewater, thus freeing up water for domestic and touristic uses that demand higher quality water.

2.6.2 Water Demand Management

In order to close the gap between water demand and water supply, rational use and re-use of the water available should be promoted according to a well-defined policy using legal, policy, financial and awareness raising measures, not only to increase the water available, but also to reduce demand.

The predominant approach towards meeting the increasing water demands has been towards supply augmentation schemes. It has been demonstrated however in many countries that saving water rather than the development of new sources is often the best 'next' source of water, both from an economic and from an environmental point of view. Water demand management therefore is seen as the preferred alternative to meet increasing water demand and can be defined as a strategy to improve efficiency and sustainable use of water resources taking into account economic, social and environmental considerations.

Water conservation measures can be applied, such as: Leakage detection, Reduction of illegal connections, In-house retrofitting, Out-of-house water saving measures Loss reduction programmes are a first priority before introducing relatively expensive desalinated water into the system. Losses in some parts of the system in Malta were very high and have been reduced significantly. This was done by replacing old pipes or in situ re-lining.

Water pricing measures include: Water metering, Tariff structures Imaginative tariff restructuring can be very effective. It does however demand that effective meters are installed.
Information and educational measures: Awareness raising, Public involvement, In-school education. Awareness Programmes aimed at children are used in some of the Arab countries.
Legal measures: Rules and regulations that form the basis of WDM policy, Regulations on resale of water

In many countries most of the water is used for agricultural purposes. A few percent of savings in agricultural water demand would have a great impact on the water supply to domestic users. Proper pricing should be set up for taking water for agriculture and it should be enforced. The extension service should instruct farmers how water demand can be reduced.

3 Desalination

Increased demand for water is a global problem. In many parts of the world local demand is outstripping conventional resources. More economical use of water, reducing distribution losses and increased use of recycled water can help alleviate this problem but if there is still a shortfall then desalination of seawater or brackish water may be an option..

This section of the report discusses the various technologies that can be used to desalinate seawater. These technologies are all being continuously improved in terms of economy and reliability. Development has been incremental and it is unlikely that there will be any dramatic developments in the near future.

Many areas suffering from water shortages are also short of conventional energy resources and cannot afford expensive fossil fuels. More recently (Kyoto and Johannesburg) there is increased awareness that even if fossil fuels were much cheaper, the burning of these fuels will contribute to climate change and global warming. For these reasons, the use of renewable energy for desalination is to be encouraged. Renewable energy is not a firm source of power and energy is expensive to store in large quantities. Water on the other hand is easily and cheaply stored - hence there is compatibility between renewable energy and desalination.

3.1 Background

During the last 50 years there has been a steady growth of desalination plants as shown in Figure 3.1 and Figure 3.2. The figures use data from Wangnick's Desalination Plant Inventory.2002 [1]. Most of this growth has been in the oil rich Middle East and is based on distillation technology. However alternative processes, most notably reverse osmosis (RO), have also been developed during this time. Reverse osmosis has grown spectacularly over this period and now dominates some sectors of the market.

Figure 3.1 Annually contracted desalination capacity

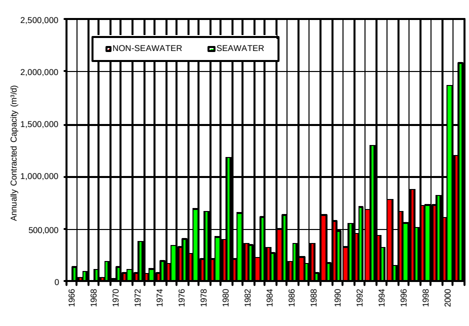
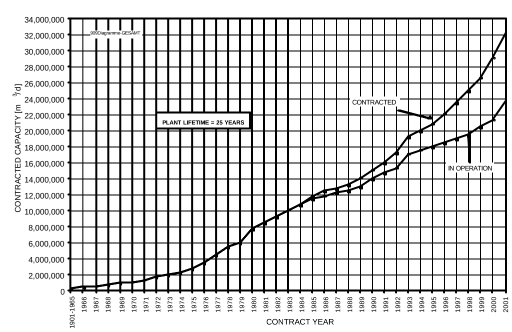


Figure 3.2 Cumulative contracted and operated desalination capacity



Source: IDA Desalting Plants Inventory. Wangnick 2002

As can be seen from Fig 3.1, the desalination market is currently very good with significantly increased orders over the last two years. Fig 3.2 shows that there is currently 24 million m3/day seawater desalination plants in operation. Of the total worldwide capacity, 20% is produced using membrane processes. Thermal processes (mainly MSF) dominate the Middle East with 90% of the installed capacity. However the membrane processes share is gaining ground in seawater desalination in general, but the proportion is increasing slowly. In the Mediterranean region the growth has been more marked with virtually all of the large plants using membrane technology. The reasons for this are discussed later in this report.

3.2 Desalination Processes

One convenient and useful way to classify desalination processes is to separate them into those which involve a change of phase to separate the pure water from the feed water and those which accomplish this separation without a change of phase. The phase-change processes include:

- Multi-Stage Flash (MSF) (a distillation process)
- Multi-Effect Boiling(MEB) or Multi-Effect Distillation (MED) (distillation processes)
- Vapour compression(VC) Thermal and Mechanical (a distillation process)
- Solar Distillation (a distillation process)
- Freezing

Those in the single-phase category include:

- Reverse Osmosis (RO) (a membrane process)
- Electrodialysis (ED) (a membrane process)

There are three other membrane processes which are not considered desalination processes but are relevant.

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)

Ion exchange is not regarded as a desalination process. It is generally used to improve water quality for some specific purpose. E.g. boiler feed water.

A detailed explanation covering the fundamentals of desalination technology is given by Spiegler & Laird [2]

Energy requirements for thermal processes are normally defined in terms of units of water produced per unit of steam consumed (or per 1,000 BTU used). This is known as the performance ratio (P.R). For power-consuming processes the energy consumptions are usually expressed in kWh/m^3. Processes involving a phase change are normally more energy intensive than those not requiring one.

3.2.1 Feed water for Desalination

Feed water for desalination plants is classified by total dissolved solids (TDS mg/l). Seawater varies considerably in concentration and more importantly there can be major local variations. The following list gives average bulk salinities:

Baltic Sea	7,000 mg/l
Open seas (oceans)	35,000 mg/l
Closed seas: Mediterranean Sea	38,000 mg/l
Red Sea	41,000 mg/l
Arabian Gulf	45,000 mg/l
Aral Sea	29,000 mg/l

Table 3.1 Feed water classified by total dissolved solids

Water	TDS (mg/l)
Potable water	< 1 000
Low salinity brackish water	1 000 – 5 000
High salinity brackish water	5 000 – 15 000
Seawater	7 000 – 50 000 (*)

Brackish waters are located in aquifers or in inland lakes. Seawater can be taken directly from the sea or from a coastal aquifer. This second alternative is preferable, as the intake water is naturally filtered by the ground. However it can be polluted with undesirable components dissolved from the ground, but usually of a more consistent quality than directly from the sea.

3.2.2 Desalination Process Comparison and Choice

Desalination of brackish or seawater can be a reliable resource for the production of fresh water. However, desalination is not an inexpensive process. A substantial capital investment is required and the operation of the system will continue to require expense for energy, labour, chemicals, replacements, etc. Thus, it is important, and prudent, to determine whether desalination is needed in the first place and, if it is, to what extent it should be used. The decision to use desalination, and the selection of the most appropriate process and its capacity depends on several parameters.

The most important parameter is the evaluation of the available water resources. This should be done in terms of quality and quantity.

The ranges of the applicability of the various desalination processes, concerning the quality of the feed water is shown in Figure 3.3. From this figure it can been seen that, in general, the phase change processes tend to be used for the treatment of high salinity waters, particularly sea water. Membrane processes are used over a wide range of salinity from brackish to sea water. The application of electrodialysis is limited to brackish water applications. In membrane processes, energy consumption is directly related to the salinity of the feed water. In distillation processes the salinity of the feed water has little impact on the overall energy consumption.

Other basic parameters that should be examined in order to select the most appropriate desalination process are as follows:

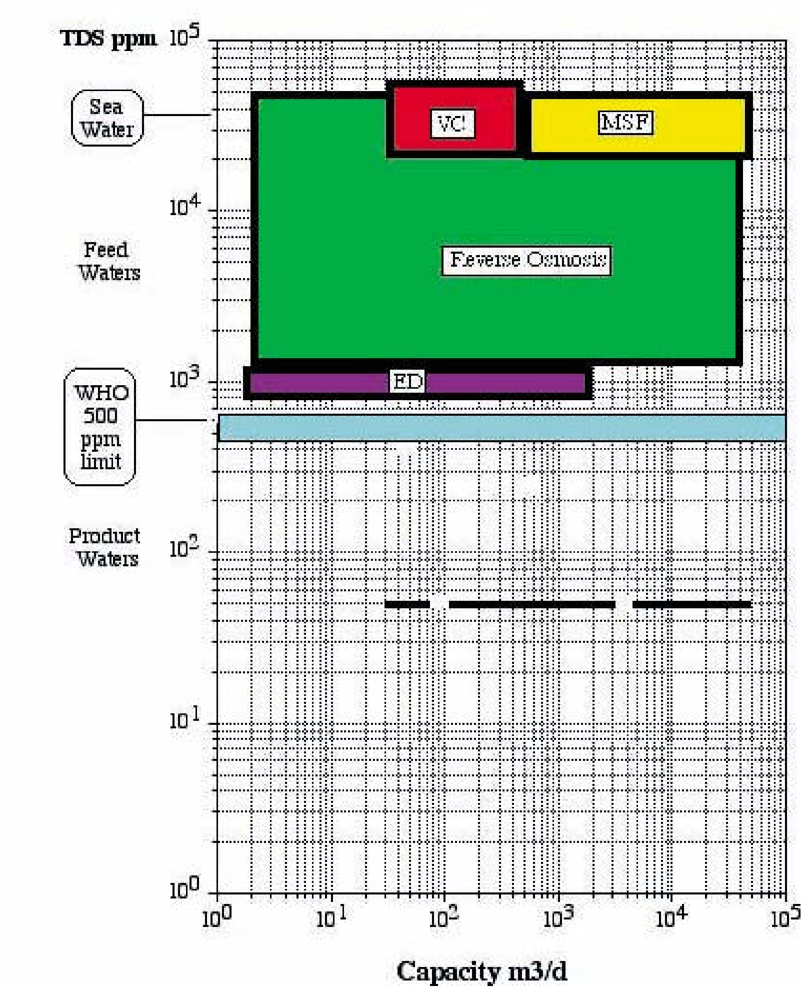
- **Co-generation:** in some instances both power and water are required. In which case a careful analysis of the various combinations of processes has to be carried out in order to optimise the cost.
- **Availability of energy resources:** a survey of all the available energy resources, conventional or renewable energy sources, as well as waste or low grade heat availability should be carried out.
- **Plant size**: the size of the desalination plant is normally dictated by the water demand. Before any decision is taken concerning the process selection, limitations on the size of each process should be considered. The MSF process has been developed and adapted to very large scale applications (10-60,000 M3/day). In recent years the size of MED and VC processes has been increased and may have some other advantages over MSF. The largest MED plant built to date is 20,000M3/day. In the case of the membrane processes, due to their modularity, there is a wide range of sizes from very small to very large scale applications.

Generally speaking, in all of the above phase separation processes there are few restrictions on the type of water which can be treated. The only effects that increased feed water salinity has on the process are:

- the boiling point elevation (or freezing point depression) is increased
- the permissible concentration ratio to avoid scale formation is reduced

Consequently, the cost of the energy to drive the separation processes at economic rates is only loosely related to feed water salinity. Whereas in the membrane processes the product water costs are very definitely related to both the feed water salinity and the desired product water purity.

Figure 3.3 Ranges of applicability for desalination processes



The most widely adopted desalination processes are examined hereafter.

With regards to thermal distillation, there are two ways in which vapour can be generated from a liquid at its boiling point:

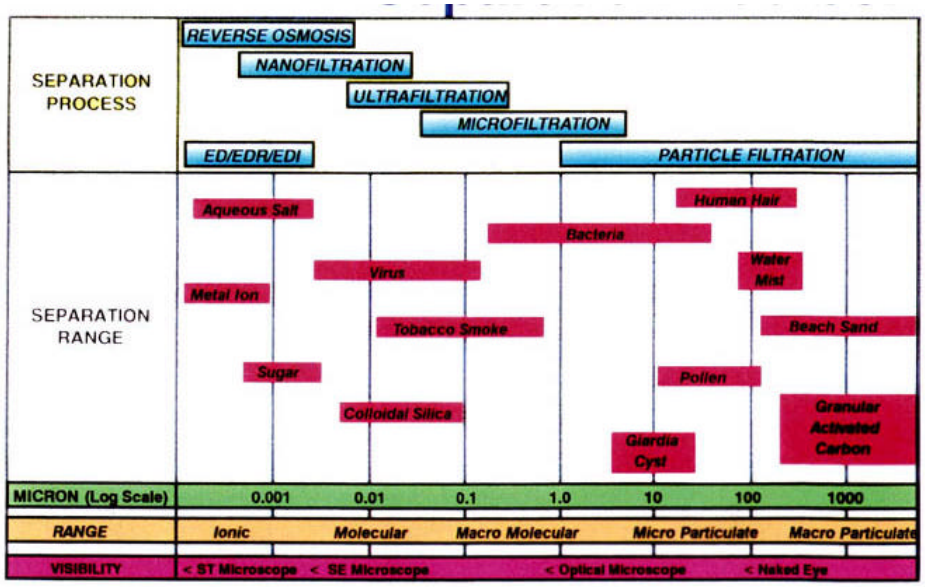
either	heat can be added	BOILING
or	pressure can be reduced	FLASHING

On this premise two types of evaporators have been developed: Multi-Stage Flash (MSF) and Multi-Effect Boiling (MEB). The thermal processes are normally driven by low pressure steam (most typically pass-out or back pressure steam from a power plant) but can equally well be operated with other hot fluids available at similar temperatures. Because of chemical scaling problems distillation processes operate up to 120°C maximum.

3.3 Membrane Processes

As can be seen from Figure 3.4, there are a wide variety of membrane processes being used to treat water. However the only processes which will remove sodium chloride are Reverse Osmosis and Electrodialysis.

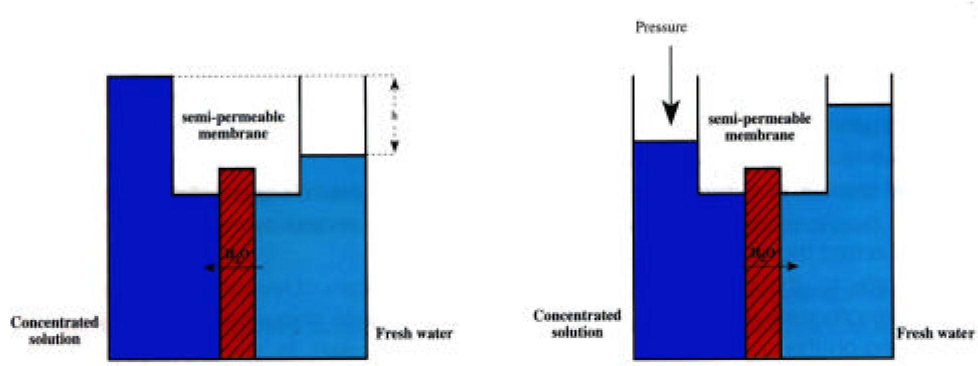
Figure 3.4 Membrane process classification.



3.3.1 Reverse Osmosis

Osmosis utilises semi-permeable membranes through which water is forced under hydraulic pressure. Water is transported through the membrane in this pressure driven process, excluding ions and most organic molecules. When one places solutions of two differing concentrations on either side of a semi-permeable membrane, water passes through the membrane toward the more concentrated side in an effort to equalise the concentrations.
The equilibrium reached is termed osmotic equilibrium. If mechanical force is applied to the more concentrated side, once the osmotic pressure is overcome, water is transported though the membrane (See Figure 3.5). This phenomenon is called 'reverse osmosis' and may be used to separate pure water from brackish or saline solutions. The energy required is directly related to the salinity of the water being treated.

Figure 3.5 Reverse Osmosis Principle



Advances in Reverse Osmosis (RO) have been directly linked to advances in membrane technology. A good membrane should be able to pass a high flow of water (high flux) and limit the amount of salt flow (good rejection). Before the formation of the Office of Saline Water in the US in 1952, membranes generally gave low fluxes and low rejections. With the aid of a large amount of sponsored research, commercial membranes were developed which could first of all desalt brackish water and then later seawater. The first commercial seawater RO plants was commissioned in the late 1970's.

As shown in Figure 3.6, purification by RO consists of placing a semi-permeable membrane in contact with a saline solution under a pressure higher than the solution osmotic pressure, typically 50 to 80 bar for seawater. The feed is pressurised by a high pressure pump and is made to flow across the membrane surface. Part of this feed, the permeate, passes through the membrane which removes the majority of the dissolved solids. The remainder together with the rejected salt emerges from the membrane modules as a concentrated reject stream, still at high pressure. In large plants, the reject brine pressure energy is recovered in a turbine or pressure exchanger. The pre-treatment required is a function of the scaling tendency of the water and the level of un-dissolved solids. The key to the successful operation of this process is in the pre-treatment section. The product water from RO is usually between 100-500 ppm NaCl which complies with WHO regulations regarding drinking water quality.

Figure 3.6 Simple Reverse Osmosis Plant

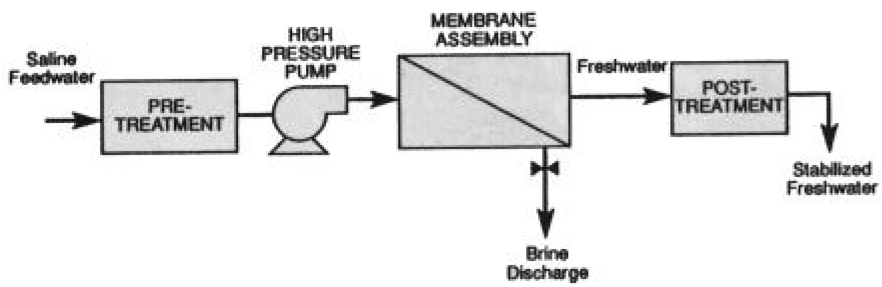
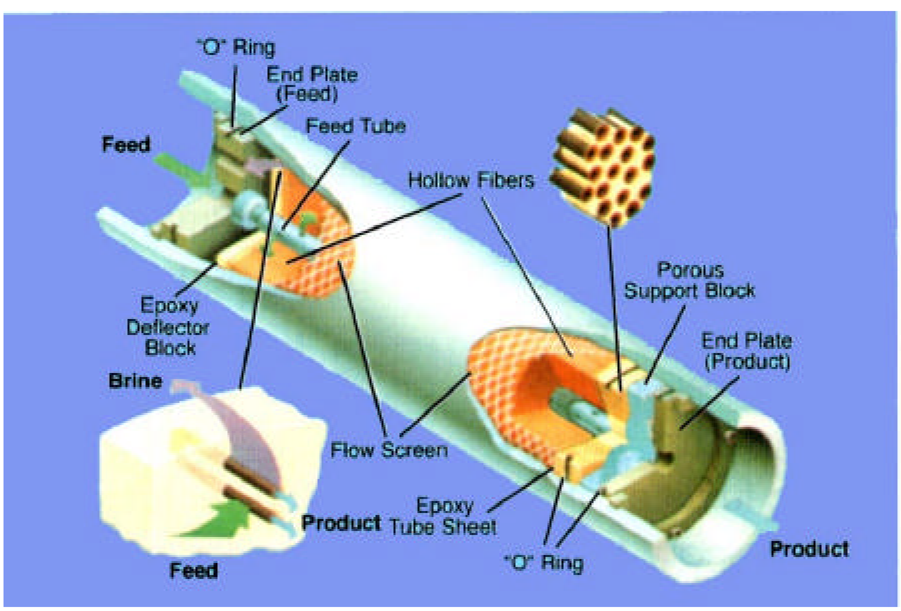


Figure 3.7 Hollow Fibre Reverse Osmosis Module Detail (Du Pont)



Important considerations in reverse osmosis are salt rejection, flux and membrane life. Usually, high salt rejection is achieved at the expense of low flux and vice versa. The membranes themselves can be purchased in a variety of forms. The major module configurations being of hollow fibre or spiral wound. Figure 3.7 illustrates the hollow filament module. This used to be made by Du Pont but currently Toyobo from Japan is the only company manufacturing this configuration. The spiral wound element is shown in Figure 3.8. This is commercially the most important configuration. The membranes, being in effect very fine filters, are very sensitive to fouling, both biological and non-biological. To avoid fouling, careful pre-treatment of the feed is necessary before it is allowed to come into contact with the membrane surface.

Figure 3.8 Spiral Wound Membrane. (Fluid Systems)

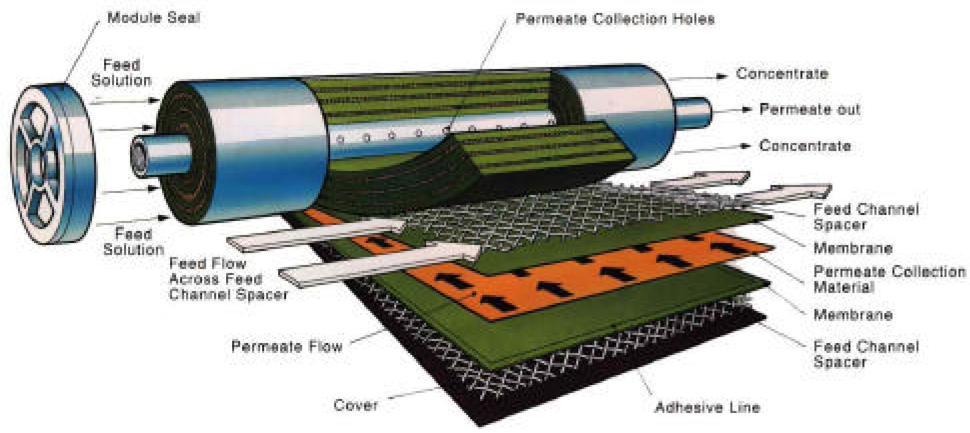


Figure 3.9 shows the process in more detail. Raw feed water, either from a seawater intake or a beach well, is filtered through a dual or multi-media filter to remove particulate matter. Acid for pH correction and/or anti-scalant are added as appropriate to prevent scale depositing on the membrane surface. A safety cartridge filter of 5-10 microns is used to further protect the membranes. The feed is then passed to the high-pressure pump, which increases the pressure to 50 – 80 bar depending on salinity and other factors. Many plants operate with 40 –45% of the feed water being recovered as potable water. The 55 –60% is rejected at very high pressure. In early designs this was discharged to atmosphere through a reducing valve as shown in Fig. 1-5. This wastes all the pressure energy, which is expensive. Later designs included various systems to recover this energy. These include, reverse running pumps, Pelton wheels and more recently pressure or work exchangers. Some of these have efficiencies of up to 96% and have resulted in plants where energy consumption has been reduced to 2.5 – 3 kWh/M3.

Figure 3.9 Seawater Reverse Osmosis

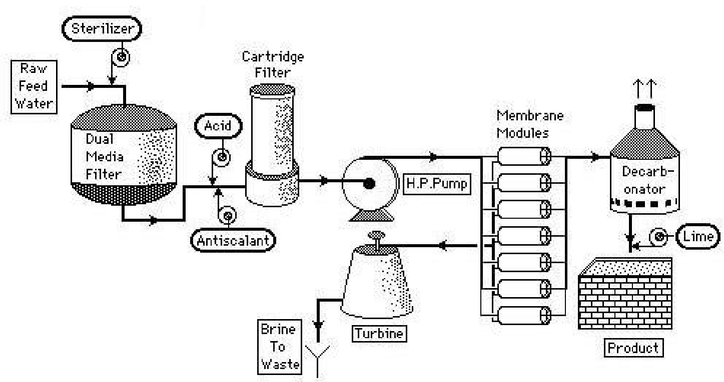


Figure 3.10 shows the interior of a large (40,000 M3/day) modern desalination plant at Dhekelia in Cyprus (1999)[3]. In this case the pre-treatment consists of flocculation followed by multi-media filtration, not shown. The cartridge filters can be seen on the left, the high pressure pump is in the centre and the membrane banks on the right. In this case the energy recovery system is a reverse running pump mounted on the same shaft as the high-pressure pump with the electric motor in between. The unit operates on a BOT basis and at a cost to the Cypriot government of around USD

1.02/m³.

Figure 3.10 Dhekelia Reverse Osmosis Plant 1999

In recent years, two companies have marketed very high efficiency energy recovery systems based on pressure or work exchange. These are Desalco (now Calder of Switzerland) and ERI.

Figure 3.11 Isobaric Chamber Technology (ERI)

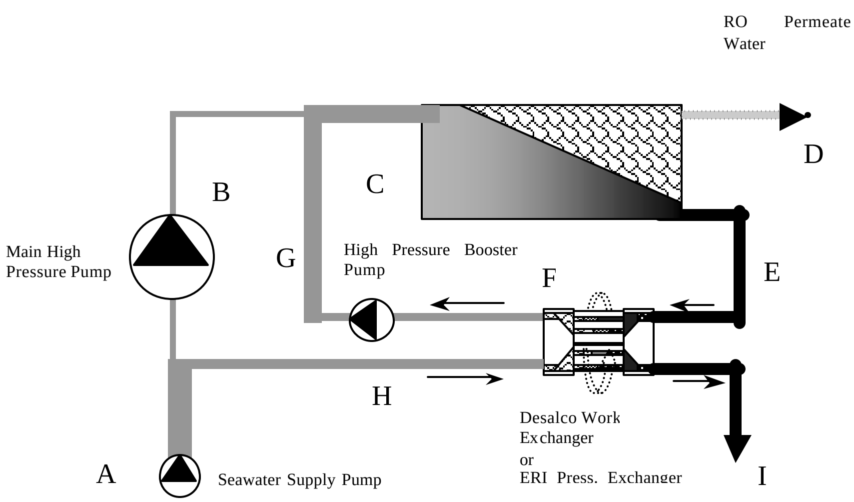


Figure 3.11 shows how the isobaric chamber technology works [4]. As can be seen from this figure, the new positive displacement energy recovery devices are applied differently in an RO system from those with conventional energy recovery devices. Energy is transmitted directly from the brine onto a large portion of the feed which is pressurized by the isobaric chamber device. A booster pump usually makes up the 2 to 4 bar needed to bring up this feed to membrane feed header pressure. One chief characteristic of the Desalco and ERI energy recovery devices is that the size of the main High pressure pump is significantly reduced so that it only has to handle the permeate flow. This has positive implications in the cost of the HP pump required and on the size of the control block the designer can work with, given HP pump, electrical motor and switchgear limitations. It also has implications on ultimate SWRO plant efficiency as the power balance

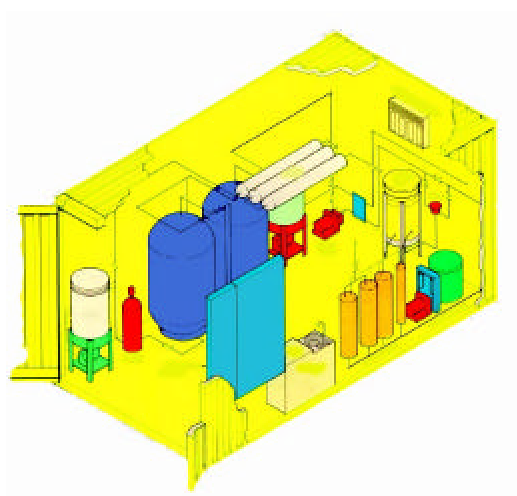
analysis shows that centrifugal HP pumps are now the major source of energy waste in a large SWRO plant.

The other major design advantage of the isobaric chamber devices is that since there is no mechanical or other connection between the HP pump and the energy recovery devices, the two devices can be designed and operated as independent units. The divorce of the energy recovery device form the HP pump skid system is considered a major design advantage. An other Design feature of the DWEER and ERI energy recovery systems, is that the SWRO system operating recovery can be changed without affecting the efficiency of the system. Normally this control of the recovery ratio is effected by putting a speed controller on the booster pump motor which allows the flow to the membranes to be increased or decreased during operation. This control of the recovery rate has major implications on operating flexibility.

When either the Desalco or ERI technology are applied properly it is possible to design and operate a SWRO plant with an overall energy consumption down to 2.5 kWh/m3 [4]. As the technology becomes more standardized, the equipment metallurgy more reliable and the membranes less prone to fouling and cleanings, the cost of operating a SWRO plant has dropped dramatically. Figure 3.12 shows a small containerised unit which contains everything necessary for the operation of the plant except an electrical supply.

Reverse Osmosis plants are of modular construction with modules being connected in parallel to give the required output. Manufacturers produce a range of module sizes. Large plants are made up of hundreds and occasionally thousands of modules which are accommodated in racks. Very small units are also available for marine purposes in small sailing craft where the output may be down to 0.1 M3/day or even smaller for household units.

Figure 3.12 Containerised R.O. Plant



Because of the modular construction, the process is very adaptable capacity wise. The development of high efficiency energy recovery systems has made the process very energy efficient. This is important where energy is expensive. This is particularly important where renewable energy sources are involved. It is important to maximise the water produced for a given quantity of electricity. The RO process is not as sensitive to stopping and starting as the thermal processes which is a distinct advantage when using renewable energy.

The process is straightforward in operation and unskilled operatives can be trained to operate such units. However satisfactory management of RO does require a knowledge of chemistry. The instrumentation is critical and requires the attention of competent personnel for maintenance. The membranes are relatively fragile and cannot be cleaned physically. They have to be cleaned chemically. Technology is improving in cleaning but some fouling conditions are difficult to overcome. Membranes can be replaced but are expensive comprising some 10% of the overall capital cost of the project. Membrane life should be in excess of 5 years. In badly maintained plants it can be a great deal shorter. The feed pump has to develop around 60-80 bar pressure when running on seawater and can require considerable maintenance.

3.3.2 Membrane Suppliers

Spiral wound membranes form standard elements (diameter 2,5",4" or 8" with 40" length), assembled themselves in pressure vessels.

Plate-and-frame is sometimes used for small scale desalination plants.
The most common configuration used nowadays is spiral wound.
There are very few reverse osmosis membrane manufacturers in the world. They all belong to important industrial groups as shown in the table hereafter.

Table 3.2 Overview of suppliers of RO membranes

			Membrane material			Membrane configuration			Application	
Manufacturer	**Owner**	**Country**	**Cellulose Triacetate**	**Cellulose Acetate**	**Polyamide**	**Hollow Fibre**	**Plate**	**Spiral Wound**	**BW**	**SW**
Dow Filmtec	Dow Chemical	USA			X			X	X	X
Fluid Systems	Koch	USA		X	X			X	X	X
Hydranautics	Nitto Denko	USA - Japan		X	X			X	X	X
Toray	Toray	Japan		X	X			X	X	X
Osmonics	General Electric Power	USA			X			X	X	
Rochem	PALL	Germany - USA			X		X			X
Toyobo	Toyobo	Japan	X			X				X

Cellulose acetate membranes have been replaced now by "thin film composite" membranes

3.3.3 Operational problems with Reverse Osmosis

RO membranes are very sensitive to fouling caused by :
- suspended solids -plugging,
- biological matter,
- chemical scaling,
- colloidal material

They require an efficient pre-treatment of the feed water by :
- filtration to decrease turbidity and fouling index,
- chemicals addition, to limit biofouling,
- acid or anti-scalant addition to increase solubility of salts of calcium (bicarbonates, sulphates), barium sulphate and strontium sulphate.

Moreover, the permeate produced needs to be equilibrated (calcium carbonate stability) and demineralised to obtain a slight scale-forming water (to protect distribution network).

To ensure a long life for membranes, one consequently needs :
- to foresee all necessary pre-treatment, depending on physical, chemical and biological characteristics of the feed water,

- to ensure a constant supply of chemicals,
- to have a very well-trained staff.

Some of these conditions can be difficult to maintain in less well developed countries.

Membrane Life

A major problem is linked to the life time of membranes. The supplier's guarantee is usually limited to 3 years, but only on the basis of the inefficient period during period of guarantee (payment of one third of the membrane price, if the membrane life was 2 years instead of 3 for example).
Membrane life time varies from plant to plant and may reflect operating conditions. Large plants tend to be well maintained owing to the large capital investment and membrane life may be much longer than 5 years. A large plant in Malta has 30% of the original membranes 20 years after commissioning. Small plants often lack the expert management to ensure trouble free operation and may have much shorter membrane life. It is unusual for membranes to fail abruptly. More often output decays with time through membrane fouling. Common practice is to add extra membranes to maintain output. Regular chemical cleaning is important to extend the life of the membrane.

Plant Life

Some RO plants have now been in continuous operation for 20 years. Because of the rapidly changing technology most of these have been modified at some point in time to improve the economics of the process by taking advantage of new developments. This trend is likely to continue. Large plants have longer life expectancy than smaller ones.

Water needs (recovery factor)

To produce 1 m3 of fresh water and depending on salinity, one needs approximately:
- 1.3 to 1.4 m3 of brackish water,
- 2 to 2.5 m3 of seawater.

These values correspond to the following recovery factors:
- 70 to 75 % for brackish water
- 40 to 50 % for seawater.

Recovery factor = (Produced water flow / Raw water flow) x 100

Energy needs (energy recovery)

Reverse osmosis units require approx. for 1 m3 of fresh water produced :
- 1.5 kW for brackish water,
- 6.0 kW for seawater, without energy recovery systems,
- 2.5-4.0 kW for seawater, with energy recovery systems.

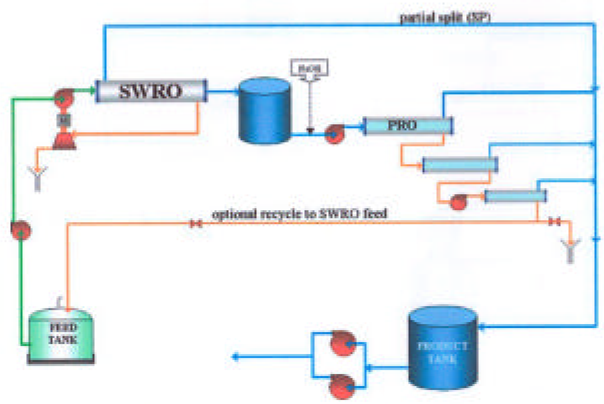
Current trends

Research and development efforts in RO desalination are concentrated on the following aspects
- decrease sensitivity of membranes regarding fouling (smoother surfaces, negative charged or neutral membranes),
- increase rejection rate of salts,
- develop new membranes that would be resistant to oxidising agents,
- improve energy recovery
- improve boron rejection.

Boron

A recently discovered problem with seawater desalination is that the levels of boron in the product water may result in the poisoning of crops where this water is used for irrigation. EC limits for boron in drinking water is 0.5mg/l. Current membranes have difficulty achieving such low levels in conventional designs. A number of solutions have been identified. These are described by Glueckstern et al [5]. One solution is shown below. In this configuration a fraction of the product from the first stage is passed through a series of further stages to reduce the boron concentration further and then the outputs blended to produce a product of acceptable quality. Clearly this extra treatment ads to the overall cost of the resulting water.

Figure 3.13 Simplified diagram of a two-pass SWRO/PRO system with split partial



Considerable research efforts are being made to develop membranes capable of dealing with this in a single pass. Other solutions involve using selective ion exchange resins.

3.3.4 Microfiltration, Ultrafiltration, Nanofiltration

As indicated earlier, the satisfactory operation of an RO plant hinges largely on the quality of the water supplied to the membranes. As shown in Figure 3.4, microfiltration, ultrafiltration and nanofiltration membranes membranes have been developed to provide different levels of filtration for particles smaller than those caught by conventional filtration systems. These systems give higher degrees of filtration than conventional multi-media filters and can be backwashed to maintain output. The boundaries between these different systems clearly overlap one and other. There is emerging a complete range of membranes which can be tailored to suit particular requirements. These are relatively new and are still being experimented with, mainly for pre-treatment. In the long run they may prove to be very useful and cost effective in regions such as the Gulf where there is a high level of biological life in the feed water.[6][7]. A seawater desalination plant using a two stage nanofiltration system has been demonstrated [8].

3.3.5 Electrodialysis

Electrodialysis (ED) is the only desalination process which uses electricity as the fundamental process energy. If a D.C. current is passed through an ionic solution, cations, positively charged ions, will migrate to the cathode and anions, negatively charged ions, will migrate to the anode. Now, if between the anode and the cathode a pair of membranes are placed one of which only allows the passage of cations and the other of which only allows the passage of anions, then a region of low salinity will be created between the membrane pair, see Figure 3.14. This is the principle of the process known as ‘electrodialysis’.

The principles of the process were known from the beginning of this century, but the membranes used were only slightly selective and so the process was only used for pH control. Developments progressed slowly with synthetic membranes being produced in 1940. With the formation of the Office of Saline water in the USA (O.S.W) and the further research into membranes, commercial plants for the treatment of brackish water began to be introduced from 1954. These were usually of standard packages up to about 1000 tons/day. These have rapidly grown in size and several plants of 40,000 tons/day have been built.

Figure 3.14 Electrodialysis Cell

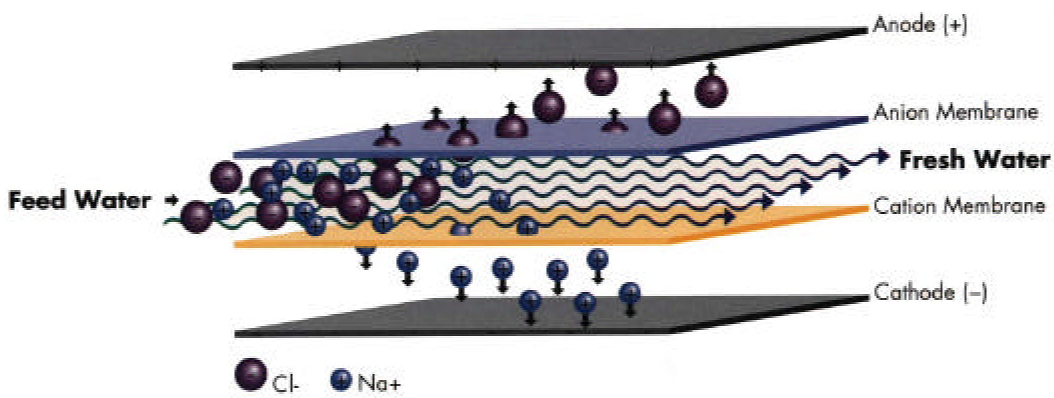
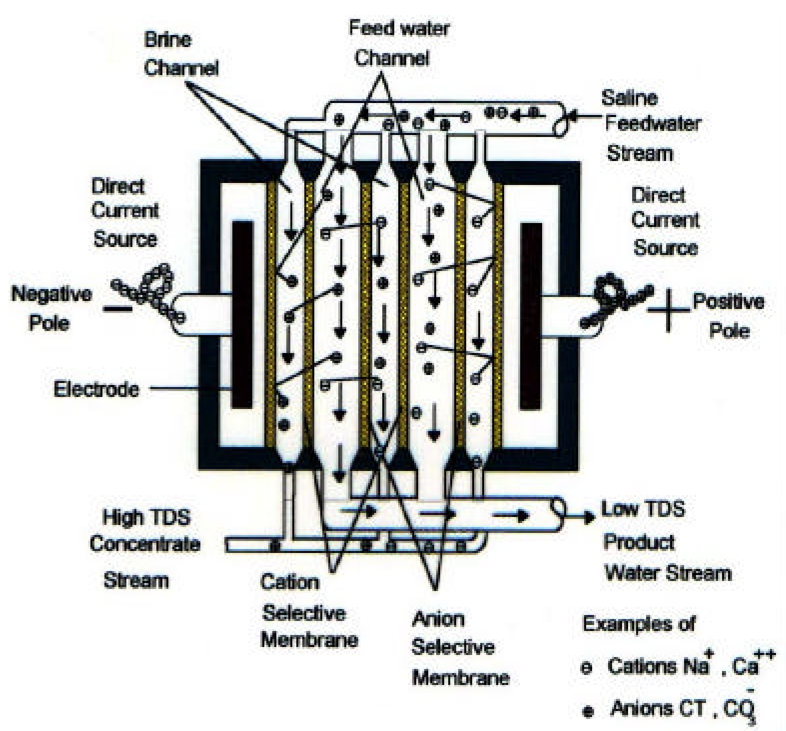


Figure 3.15 Electrodialysis Stack



The basis of any electrodialysis plant is the 'cell pair', around 300 of which may be located in a plant separated by spacers for support Figure 3.14. The membranes are normally about 1 metre square and are very thin to minimise the electrical resistance of the 'stack'. As in any membrane process the feed water has to be pre-treated before entry to the stack to minimise fouling of the membranes.

Previous limitations on this process are due to the energy cost being directly proportional to the amount of salt removed and so it is principally used for brackish water applications. Recent developments in high temperature membranes and polarity reversal, which goes a long way towards eliminating fouling, have extended the range of applicability of the process to higher salinity levels.

The viability of the process has been significantly increased with the development of EDR (Electrodialysis Reversal). In this process the polarity of the electrodes is changed after a given time period. This reverses the flow through the membrane and has the effect of negating any tendency for the membrane to foul. There is a slight loss in productivity immediately following the change but this is more than offset by the increased flow from the membranes.

Manufacture of the systems is limited to three companies, Asahi Chemical Industry Company, Japan, Ionics Incorporated from the USA and Eikoss from Russia. The process is not as widely used as RO partly because of the limitation of salinities that it can be used with and partly because of the fact that only three companies supply these membranes. Unlike RO membranes, EDR membranes are very robust and can be physically scrubbed clean. It is an attractive process for small applications treating brackish water of low salinity. Operational and maintenance requirements are similar to RO save that with EDR the membranes are much less sensitive to fouling and there is no high pressure pump to maintain. Another important factor is that with EDR no scale prevention chemicals are required. Limited scaling is allowed to develop and the process is reversed removing any scale. This is an important advantage as getting chemicals to remote locations can be expensive.

3.4 Distillation Processes

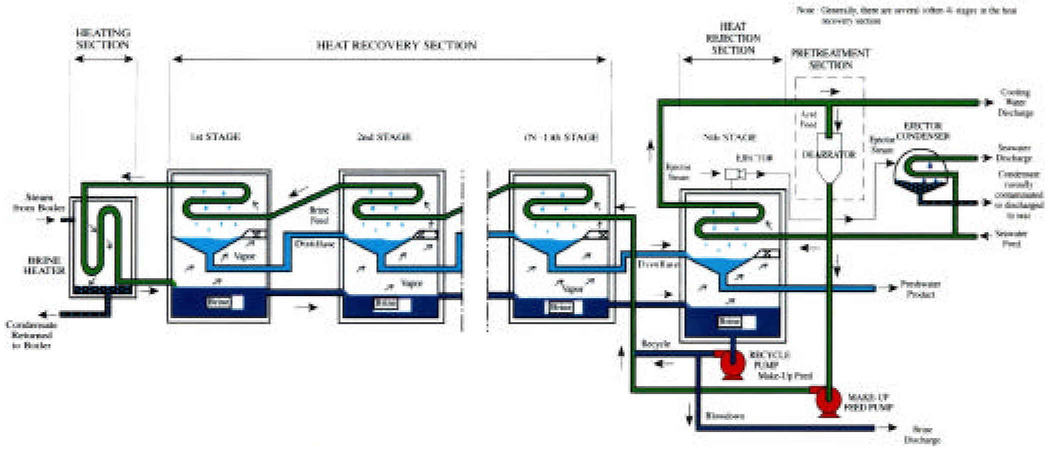
3.4.1 Multi-Stage-Flash

The principle of the Multi-Stage-Flash (MSF) process is illustrated in Figure 3.16. In this process seawater is taken into the plant and fed through a series of Heat Recovery Sections. This water is passed through a series of heat exchangers, raising its temperature. After passing through the last of these, the water enters the brine heater and is heated further, by the supply steam or heating fluid, to the top brine temperature.

The water then enters the first recovery stage through an orifice and in so doing undergoes a decompression to a pressure below its saturation pressure. As the water was already at the saturation temperature for a higher pressure, it becomes superheated and has to give off vapour to become saturated again at the lower pressure. This is known as ‘flashing’. The vapour produced passes through a wire mesh (demister) to remove any entrained brine droplets and thence into the heat exchanger where it condenses, giving up its energy to heat the upcoming brine flow. This process of decompression, flashing and condensation is then repeated all the way down the plant by both the brine and distillate streams as they flow down through the subsequent stages which are at successively lower pressures.

As shown in Figure 3.16 the process can have any number of stages. Large modern plants usually have between 14-20 heat recovery stages The process efficiency is enhanced by re-circulating some of the brine discharge and mixing it with the incoming seawater. This is done in the heat rejection section (2-4 stages) and requires a brine recirculation pump. All of the large plants are of this type. For small plants the heat rejection section can be removed. This reduces the efficiency of the system but simplifies it considerably. It is the simplest form of the MSF process and is favoured for small plants.
All evaporation distillation processes can be prone to scaling unless action is taken to prevent it. Scaling is caused by the solids in solution coming out of solution because of increased concentration or in some cases because of the increased temperature affecting compounds with inverse solubility.

Figure 3.16 Multi-Stage Flash Process



A landmark in the development of the MSF process was the development of the Taprogge ball cleaning system for scale control. With this system, large numbers of small slightly abrasive sponge balls of approximately the same diameter as the tubes are released into the circulating brine and allowed to pass through the tubes. They are then collected for re-circulation later. This is usually done once every eight hours and prevents the build up of any scale.

An important characteristic with the MSF process is that scaling does not effect plant output but does reduce thermal efficiency. With MSF the number of stages employed is not tied rigidly to the performance ratio of the plant. The minimum must just be greater than the performance ratio, while the maximum is imposed by the boiling point elevation (BPE-the increase of the boiling point due to the presence of the salt). The minimum interstage temperature drop must exceed the BPE for flashing to occur at a finite rate. Within these limits, one is free to vary the number of stages. This is advantageous because as the number of stages is increased, the terminal temperature difference over the heat exchangers increases and less heat transfer surface is required, with obvious savings in plant capital cost.

MSF is the most widely used desalination process, in terms of capacity. This is in part due to the simplicity of the process, the performance characteristics and scale control. The process is the basic workhorse of the Gulf countries where reliability and simplicity count for more than thermal efficiency. The process normally uses pass-out steam from power generation steam turbines.

The maximum performance ratio that can be obtained from this process is around 13 units of water per unit of steam. In practice this is seldom achieved. Most large plants currently in operation (10,000 - 50,000 M3/day) have performance ratios of 8-10. The performance ratio is defined as being the units of distillate produced from 1 unit of steam.

Figure 3.17 shows a battery of MSF plants installed at Jubail in Saudi Arabia in the mid eighties. The units were shipped in to site on a barge in one piece.

Technical advances and cost reductions made over the years relate mainly to improved corrosion resistance by the use of expensive alloys, increase in size and improvements in control technology and scale inhibitors.

Figure 3.17 22,500 M3/day units at Jubail, Saudi Arabia

The process is relatively simple to operate and once set up is stable in operation. Because of the thermal inertia of the plant and vacuum considerations the process is best suited for continuous operation. As seawater is corrosive to carbon steel, there is an increasing tendency to construct plants, particularly small ones, using stainless steels and copper nickel alloys. The process is not usually deemed suitable for very small capacities although some small units of 10 - 20 M3/day have been constructed to operate in conjunction with RES. Once through plants of 250 M3/day are commercially available. Small units with large numbers of stages are expensive to construct and to maintain unless made of expensive materials which drive the cost up further.

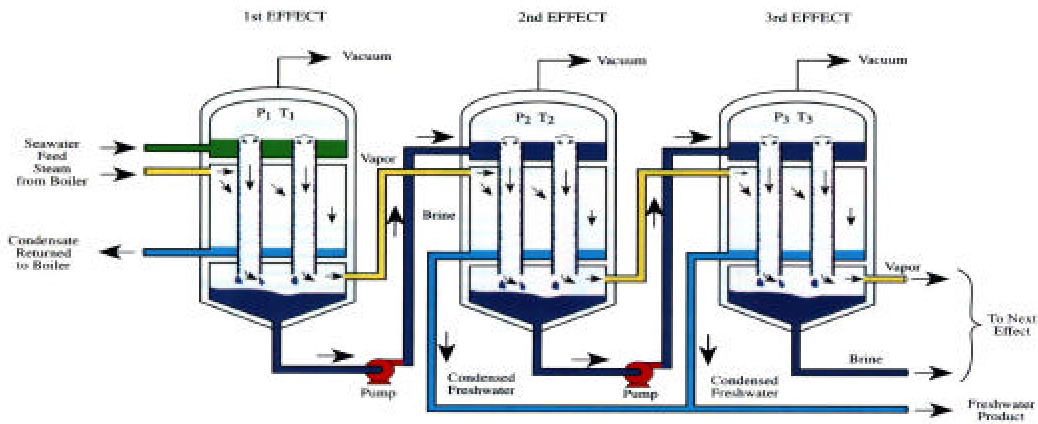
3.4.2 Multi-Effect Boiling and Multi-Effect Distillation

The Multi-Effect Boiling (MEB) process is used widely in the chemical industry where the process was originally developed. MEB was the first process to be used for seawater desalination and involved submerged tubes in which the seawater was boiled. In recent years however there has been renewed interest in Multi-Effect Distillation (MED) and plants of up to 20,000 M3/day have been built. MED is thermodynamically the same as MEB but the mechanism of heat transfer is different. In MEB the condensing steam transfers its heat through the tube to a thin film of brine where evaporation takes place. The process has the potential of giving higher performance ratios. PRs of up to 20 have been achieved. The process also uses less electrical power for pumping and the new designs are lighter in weight. A number of successful large scale plants using thermo-compression and with performance ratios of 8 have been built in the Gulf and elsewhere.

In the MED process vapour is produced by two means, by flashing and by evaporation. The majority of the distillate is produced by evaporation (Figure 3.18).

The MED process usually operates on a once through system having no large mass of brine recirculating round the plant. This reduces the pumping requirements and has a major (beneficial) effect on the scaling tendencies in the plant.

Figure 3.18 MED Evaporator 3 Effects

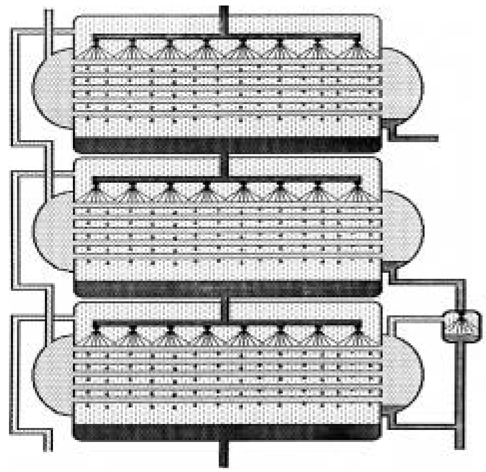


In the MED plant shown above, the incoming feed goes into the first effect where it is heated to boiling point. Some of the liquid evaporates and the resultant vapour is used to heat the liquid which passes from the first effect to the second. The feed to the second effect flashes as it enters the second effect because it is at a slightly lower pressure. This process continues down the successive stages of the plant. This is a simple MED plant. In commercial plants the incoming feed is passed to the last effect first and flows up the plant in the reverse direction. The feed is passed through a series of interstage feed heaters (feed heaters not shown above) which also serve as partial condensers for the vapour. After passing through the last of these, it enters the top "effect" where the heating steam brings it up to its boiling point and then evaporates a significant portion of it. The vapour produced is then condensed, in part, in the feed heater and in part by providing the heat supply for the second effect which is at a lower pressure and receives its feed from the brine of the first effect. This process is repeated all the way down the plant. The distillate also passes down the plant. Both the brine and the distillate flash as they travel down the plant due to the progressive reduction in pressure.

Unlike MSF, the performance ratio for an MED plant is more rigidly linked to, and cannot exceed, the number of effects in the plant. For an instance, a plant with 13 effects might typically have a performance ratio of ten. However, an MSF plant with a performance ratio of ten could have 13 to 35 stages depending on the design. There are many possible variations of MED plants, depending of the combinations of heat transfer configurations and flow sheet arrangements used. Early plants were of the submerged tube design (MEB), and only used two or three effects, and so had small performance ratios. Modern systems have got round the problem of hydrostatic head by making use of thin film designs with the feed liquid distributed on the heating surface in the form of a thin film instead of a deep pool of water. Such plants, which are known as Multi-Effect Distillation (MED) plants, may have vertical or horizontal tubes. In the long tube vertical (LTV) plants (Fig.1.16) the brine boils inside the tubes and the steam condenses outside. In the horizontal tube falling film (HFF) design the steam condenses inside the tube with the brine evaporating on the outside.

The use of horizontal tubes lends itself to a stacked design where effects are built one on top of the other with gravity providing the motive force to transfer liquid to successive effects. A typical arrangement is shown in Figure 3.19. Such designs are suitable for small capacity high performance units.

Figure 3.19 MED Evaporator 3 Effects Stacked



MED plants commonly have performance ratios as high as 12 to 14 but can be made higher. Actual performance ratios are determined by optimising capital cost against operating costs. Small single and multiple effect units are available. As with all thermal processes, it does not lend itself to intermittent use. High performance units require many effects which increases manufacturing costs. The process usually requires interstage pumps to transfer the brine through the plant. This increases the maintenance costs.

The process can give lower capital costs, lower power requirements and higher thermal performance than conventional MSF and consequently there is a revival of interest in this technology. It also can be adapted for thermal re-compression of steam.

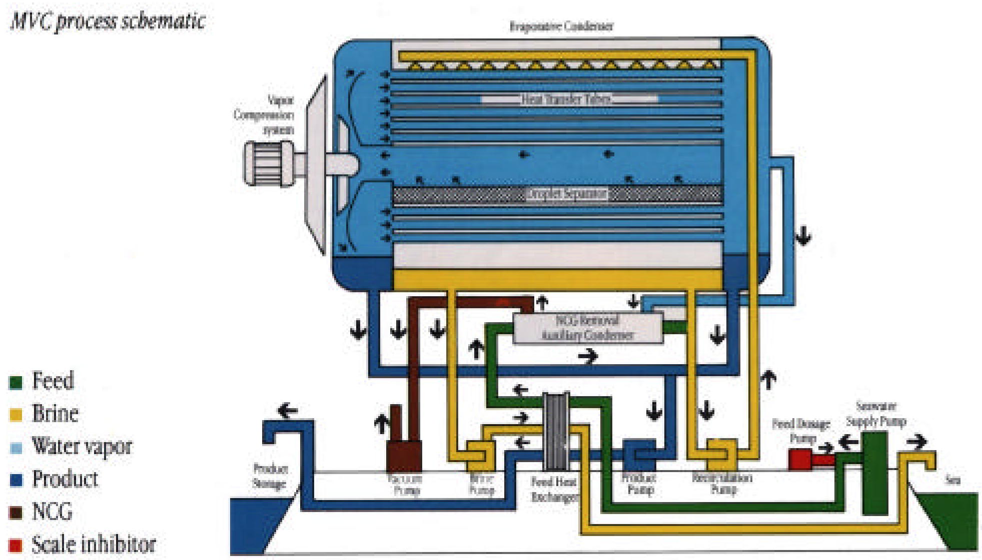
3.4.3 Vapour Compression

In the MSF and MED processes, the energy input to drive the distillation was accomplished by simply heating one end of the plant and cooling the other, whereas in the vapour compression process this input is accomplished by using a heat pump to upgrade the low-temperature energy rejected from the distiller and to recycle it back to the hot end as the energy input. The heat pump may take the form of either a mechanical compressor (see Figure 3.20) or a thermo-compressor (see Figure 3.21and Figure 1.21).

Typically the inlet feed is initially pre-heated in liquid/liquid heat exchangers by the blowdown and product streams and may be further warmed by thermal rejection from the compressor engine. It then enters the evaporator/condenser (or the top effect in a multi-effect plant). The arrangement shown is based on the Horizontal Falling Film Evaporator but any other type of boiling evaporator can be used. As in a conventional MED system, in multi-effect systems the vapour produced in the first effect is used as the heat input to the second effect which is at a lower pressure. The vapour produced in the last effect is then passed to the vapour compressor where it is compressed, its saturation temperature being raised in the process, before being returned to the first effect.

The compressor represents the major energy input to the system and as the latent heat is effectively recycled around the plant, the process has the potential for delivering high performance ratios. It is not, however, a straight-forward matter to compare the performance ratio of a vapour compression plant with that of an MSF or an MED plant. In these latter cases, the required input is ‘thermal’ energy which costs about one third of the price of the ‘mechanical’ energy used by vapour compression plant.

Figure 3.20 Mechanical Vapour Compression



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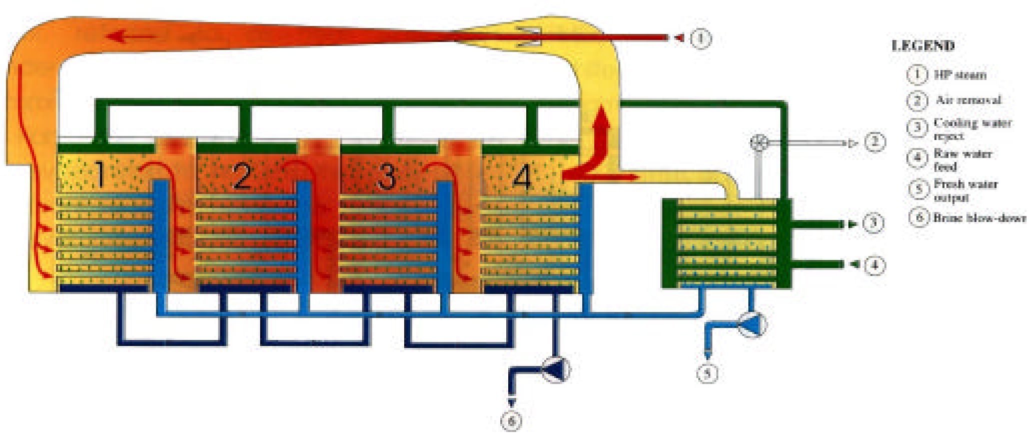
The process is particularly suited for relatively small output plants. Plants with output as low as 25M3/day are commercially available. They are widely used to produce boiler feed water for power stations.

Fig.3.21 shows a large modern 4-effect thermo-compression plant. The thermo-compressor can be seen running along the top of the plant from the last to the first effect. This uses medium pressure steam supplied from a single purpose boiler.

Figure 3.21 Schematic of 4-effect thermocompression.



Mechanical compressors are expensive but can be relatively efficient. Mechanical VC has limitations in the size of the plant due to compressor capacities. Thermo-compressors are cheaper but less efficient and require a source of steam as the motive fluid. Both types are extensively used. Large (20,000 m^3/d) thermo-compression plants [9] are now in operation in Abu Dhabi. Considerable advances in the design of such units have been made in recent years and the technology is now displacing MSF in some markets. Advantages over MSF are much lower electrical power demand, lower capital cost and lower operating top temperature. Units of 40,000 m3/day capacity have been designed.

Figure 3.22 5000 M3/day 4 - Effect Thermo Vapour Compression. (Sidem Ltd)

Small units are commercially available but usually have high energy consumptions. Energy consumption is directly proportional to the temperature difference across the heat transfer surface. Lowering this means increasing the surface area to produce the same quantity of water. Historically the compressors have been expensive and troublesome, particularly with small units where compressor speeds are often very high (8000 - 12000 rpm).

3.4.4 Distillation Limitations

Distillation is very energy intensive. MSF is more energy consuming than MED. Both processes are widely used in the Gulf states where energy is relatively cheap. This explains in part the quantity of thermal distillation units in Saudi Arabia and Arabian Gulf countries. The other reason is that the Gulf states started investing in desalination technology before membrane processes became viable. Lastly the salinity and water temperature is higher in the Gulf region. This is less of a problem today but nevertheless is an inhibiting factor in the adop tion of RO in the region.

The source of energy usually comes in the form of low grade steam (sometimes called waste heat) from thermal power plants that produce electricity. This explains the association of electricity and potable water production. The use of the term waste heat is a misnomer. The low grade steam could have been used instead to generate more electrical power by condensing at a lower temperature.
As far as operation of distillation plants is concerned, one should note the following points:

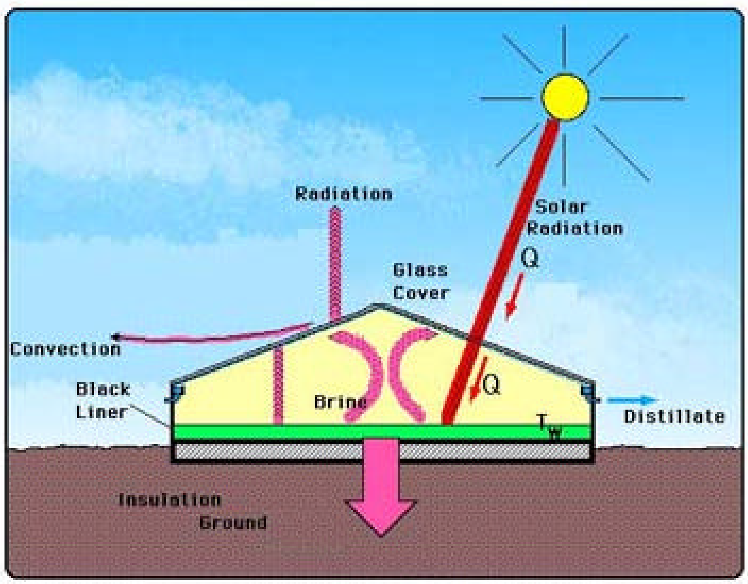
- Modern distillation plants are robust and capable of lasting 25 years or more.
- Because of the requirement for cooling water, about 4 m3 are required for MSF and 3 m3 for MED for each m3 of potable water produced.
- Low mineral content of distilled water (10 to 30 mg/l) which requires remineralisation of water before distribution to prevent corrosion in the distribution system.
- Delivery times have been reduced by nearly 50 %; plants can now be delivered in 1 to 2 years.

3.4.5 Solar Distillation

Solar distillation has been used for many years, usually for comparatively small plant outputs. Over 100 years ago a plant producing 27 t/day was built in Chile but it was not until the 1950's that substantial research was started into improving the efficiency of the process. This research work has been carried out in many parts of the world particularly Australia and the US. Solar distillation utilises, in common with all distillation processes, the evaporation and condensation modes, but unlike other processes energy consumption is not a recurrent cost but is incorporated in the capital cost of the solar collector. The solar still is basically a low "green-house" providing simplicity of construction and equally importantly, simplicity of maintenance. Obviously it is most suited for those areas of the world with high solar radiation intensities and plenty of room.

The principle of operation is based on the fact that glass and other transparent materials have the property of transmitting incident short-wave solar radiation. Thus this 'visible' radiation passes though the glass into the still and heats the water. However, the re-radiated wavelengths from the heated water surface are infra-red and very little of it is transmitted back through the glass (Figure 3.23)

Figure 3.23 Simple Solar Still



This style of desalination system is only suitable for small product rates as the output rate per unit area of the still is small. Large capacity plants, although having practically no energy running costs, would cover large areas. So capital, land and civil engineering costs would be high. Well designed units with a thermal efficiency of 50% can produce around 4.5 l/m^2/day or 222m^2 to provide 1m^3/day. The equipment is very simple to construct and to operate, which lends itself to remote installations. Consumption of electrical power is minimal. Drawbacks are the large amount of space required, high civil costs and high capital costs. Keeping the glass clean on both sides is a recurring maintenance problem. There is very little interest in this type of unit.

3.5 Capital and Operating Costs

The capital and operating costs of seawater desalination plants have decreased significantly in real terms, over the last 10 years. This is due to several factors, such as; -

a) Capital costs

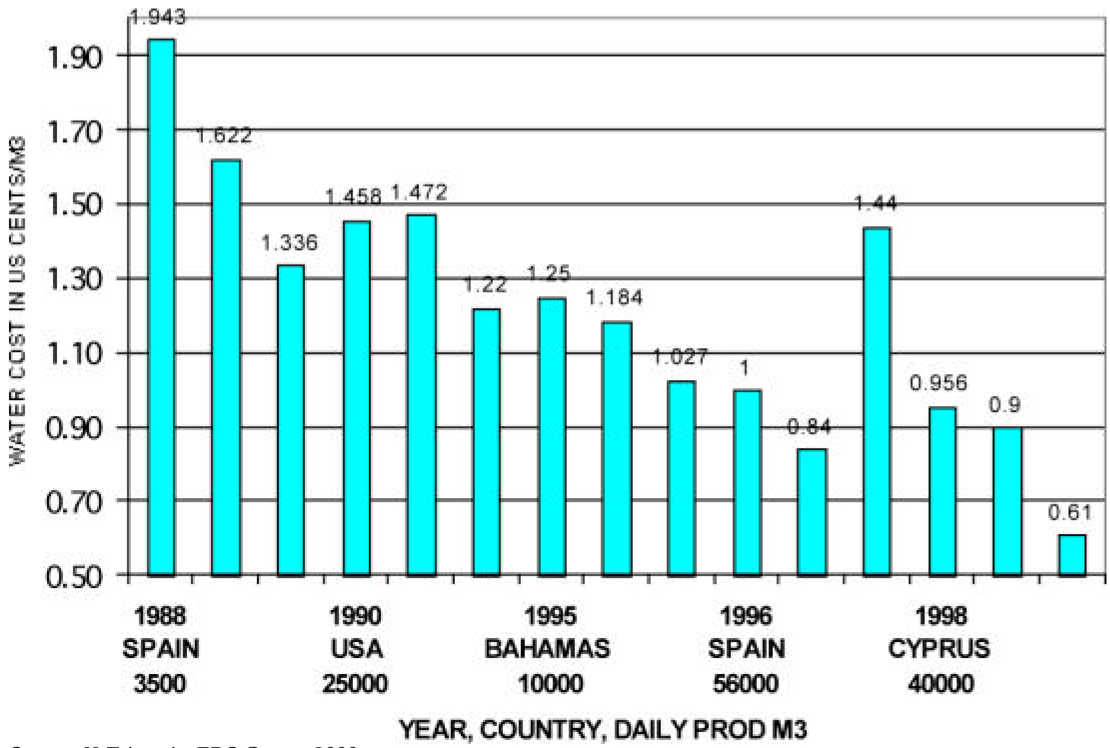
- Process design improvements,

- Membrane performance development and lower cost per m^2 (RO),
- Manufacturing methods and increased volume,
- Increased competition.

b) Operating costs
- Process performance,
- Membrane life (RO),
- Energy efficiency improvements,
- Inter-stage boost pumping (RO),
- Improved chemicals,
- Reduced corrosion,
- Privatisation.

As a consequence of this water prices for desalination have fallen consistently for many years. This is shown in Figure 3.24. The costs quoted here are all for RO plants [12].

Figure 3.24 Desalination Contract prices



Source: N Tsiourtis, EDS Cyprus 2000

3.6 Process Cost Comparison

A detailed cost comparison for the three major seawater desalination processes, MSF and MED distillation and for RO was carried out by N. Wade [13] and are shown in Table 3.2, 3-3 and 3-4. These costs refer to a plant with a capacity of 32,000 m^3/day. The MSF plant would comprise one unit, and the MED plant would be built as two units, each of 16,000 m3/day capacity. The RO plant would have a common pre-treatment section feeding 4 or 5 membrane streams. Estimated capital costs are giv en for the desalination plant, seawater intake and outfall, civil works and buildings. For the MSF and for MED distillers, steam would be supplied from the exhaust of a high efficiency CCGT power plant. For the RO plant it has been assumed that power would also be supplied from the grid, generated by high efficiency CCGT plant.

Table 3.3 Cost Parameters

Total Plant Capacity	
M3/day	32,000
Load Factor (water) %	90
Annual Production M m^3/year	10.5
CCGT rating MW	105
Reference Cycle Efficiency (average) %	52
Actual cycle efficiency%	38
Energy to power = Actual cycle efficiency/Ref. cycle efficiency	0.7308
Energy Cost$ US/GJ	1.5
Power Cost$ US/kWh	0.03
Plant Life Years	25
Discount Rate%	8
Amortisation%	9.37
RO Membrane Replacement, % pa	20

Source: N. Wade. EDS Jerba 2001

The estimates are based on Mediterranean seawater feed of around 37 000 mg/l total dissolved solids content. This gives savings in capital and energy costs compared with Arabian Gulf conditions, particularly for the RO plant. A separate estimate is shown for a "Brine booster" seawater RO plant with a second stage of brine concentrator membranes.
The costs of energy required for the distillation plants are shown separately for steam and auxiliary power. The energy needed for RO is power only and the cost is considerably lower than the distillation options.

Table 3.4 Energy Consumption for a plant of 32,000m3/day

Desalination Process	**MSF**	**MED**	**RO**	**RO+ Brine Booster**
Unit/stream capacity, MIGD	7.0	3.5	1.17	1.17
Number of units/streams	1	2	6	6
Performance Ratio	8.0	9.0	-	-
Water conversion, %	-	-	45	55
Heat consumption, MJ/m^3	290	258	0	0
Power Consumption, kWh/m	3.6	2.3	4.2	3.5
Steam flow rate, Tonne/hour	165.7	147.3	-	-
Power consumption, kW	4773.0	3050.0	5568.5	4640.4
Power plant	CCGT	CCGT	-	
Load Factor (power),%	80	80	80	80
Heat input:				
Ref. Cycle, MJ/s	161.5	161.5	161.5	161.5
Actual cycle	221.1	215.4	161.5	161.5
Energy allocated to water				
Heat consumption, MJ/m^3	161.5	146.2	0.0	0.0
Auxiliary power, MJ/m^3	24.9	15.9	29.1	24.2
Total, MJ/m^3	**186.4**	**162.1**	**29.1**	**24.2**

Source: N. Wade. EDS Jerba 2001

Table 3.5 Total water cost for a desalination plant of 32,000m3/day

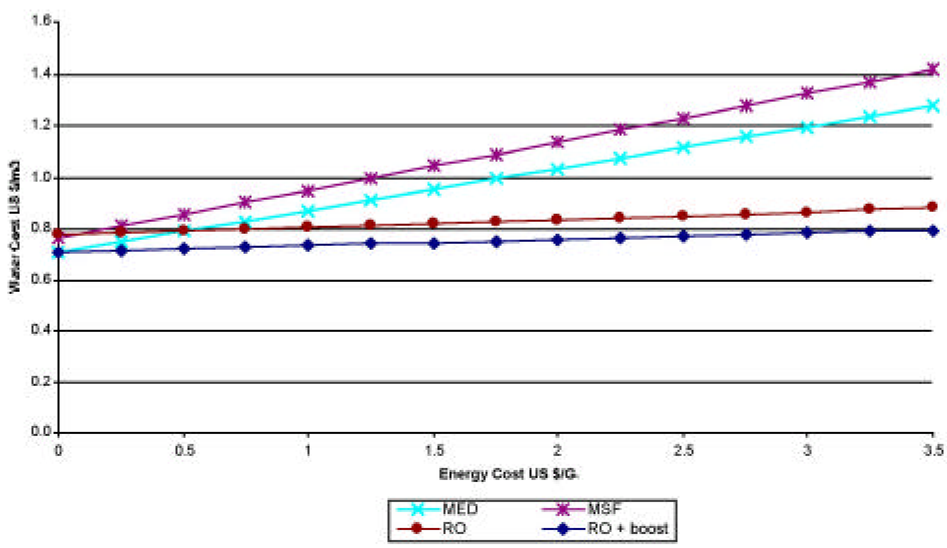
Process	MSF	MED	RO	RO+ Brine Booster
Capital Costs, in $ US (millions)				
Distillers Installed	34.5	32.4	-	-
RO plant Installed	-	-	28.7	25.5
Seawater Intake & Outfall	2.8	2.6	2.0	1.8
Foundations & B uildings, 15.0%	5.6	5.2	4.6	4.1
Financing during construction, 10%	4.3	4.0	3.5	3.1
Engineering & Contingency, 10%	4.3	4.0	3.5	3.1
Total	51.4	48.3	42.4	37.7
Unit Costs, in$ US/m				
Energy				
-heat	0.242	0.219	0.000	0.000
-power	0.109	0.070	0.128	0.106
Operation & Maintenance	0.126	0.126	0.126	0.126
Spares	0.082	0.082	0.033	0.033
Chemicals	0.024	0.024	0.047	0.047
Membranes	0	0	0.110	0.098
Capital Charges	0.461	0.433	0.380	0.338
Total $ US/m	**1.043**	**0.953**	**0.823**	**0.747**

Source: N. Wade. EDS Jerba 2001

The fuel cost of $ US 1.5 per gigajoule, used for the base case, the estimated water costs are; -

	USD per m^3
MSF	1.04
MED	0.95
RO	0.82
RO + Brine booster	0.75

Figure 3.25 Water Cost vs. Energy Cost for 32,000 m3/day total MSF, MED and RO



Source: N. Wade EDS Jerba 2001

Fig 3.25 shows the variation in water cost with energy cost for each process. At high energy costs levels the energy saving of RO is more significant in terms of water cost, usually making this process the cheapest option. The RO figures are based on a membrane life of 5 years. Large plants tend to have a membrane life in excess of this which would improve the case for RO. The assumed overall energy consumption of 4.2 kWh/m3 for RO is high for current designs.

The adoption of privatisation has made a further significant saving in water (and electricity) prices compared with previous government owned and operated plants. This trend is set to continue in the Arabian Gulf, and other MENA areas.

The above cost estimate is based on a typical medium size government owned installation. Plant size can have an appreciable effect on costs, for example in the 4 x 57500 m^3/day (50 MIGD) Taweelah A2 MSF distiller installation being built in Abu Dhabi, the water purchase price is around 0.84 US $ per m^3[13] This reduction also reflects the savings with privatisation, compared with public ownership.
In Table 3.6 a comparison is presented of the economics of the desalination processes under the following hypotheses: interest rates 7%, project life 20 years, proice electricity 0.065US$/kWh, cost of manpower 45,000US$/year. Plant capacity 30,000m3/day [14]

Table 3.6 Comparison of the economics of the desalination processes.

		MSF	MED	VC	RO
Specific Investment Cost	US$/m3/Day	1,200-1.500	900-1,000	950-1,000	700-900
Total Cost Product	US$/m3	1.10-1.25	0.75-0.85	0.87-0.95	0.68-0.82

IWACO Study 2000

Table 3.7 Comparative analysis of recent SWRO BOOT projects

	Tampa Bay	Trinidad	Larnaca	Dhekelia	Singapore	Ashkelon
Design capacity, t/d	95,000	135,000	40,000	40000	136,000	274,000
Developer	Poseidon	Ionics	IDE	Caramondani Desalination Plants Ltd	Hyflux	V.I.D. Desalination Company Ltd
Feed water	Power plant condenser discharge	Open water intake	Open water intake	Open water intake		Open water intake
Seawater salinity, ppm	26,000	38,000	40,000	40,000		40,000
Technology	RO	RO	RO	RO	RO	RO
Energy cost, $/kWh	0.04	0.04	0.057	0.053		
Contract term, y	30	23	10	10	20	25
Contract Year			2000	1996	2002	2002
Contracted water price,$/m3						
• Capital recovery	0.21	*	0.37	0.56		0.30
• Non-capital components	0.25	*	0.43	0.53		0.22
• Total first-year water price	0.46	0.71	0.80	1.09		0.52
Normalized water price for energy cost of $0.04/kWh: .				1.02		
• Reduction in water price for energy cost of $0.04/kWh .	-	-	(0.07)	0.068		
• Total first-year water price (US$/m3)	0.46	0.71	0.73	1.09	0.45	0.52

** Not reported.*

It should be noted that the desalination plant in Ashkelon, Israel, is still under construction. Therefore definite figures on energy consumption can not yet be given. Some reports say that the theoretical energy consumption would be in the order of 2 kWh/m3. This amount excludes energy needs for pumping of feed water and post-treatment.

Current trends

The Gulf states continue to invest in distillation technology for large utilities using MSF or MED processes. More and more plants nowadays use the MED process combined with thermal vapour compression (TVC). Elsewhere, where only potable water is concerned, and where higher energy costs are incurred, the trend is to reverse osmosis. Table 3.7 is a list of major BOOT contracts across the Middle East. All of these use RO technology.

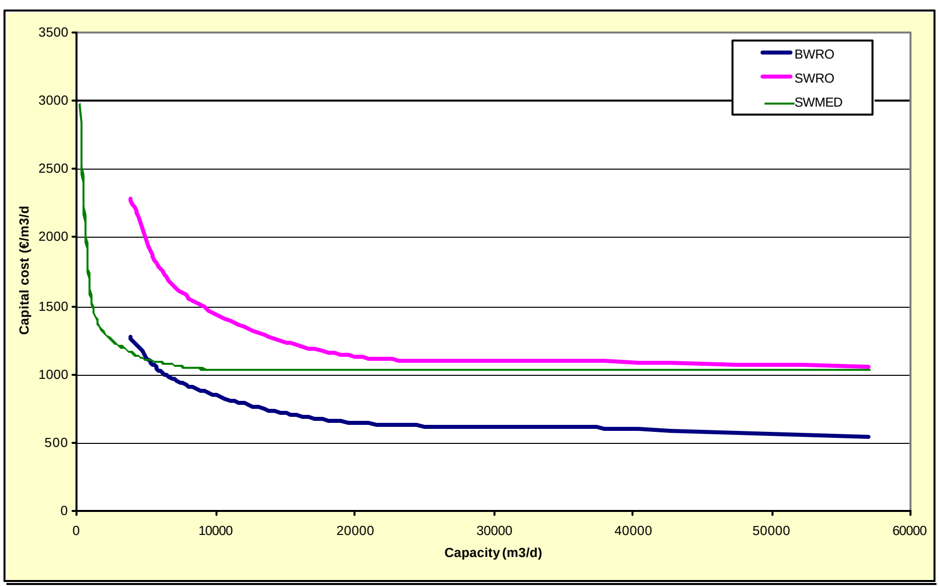
Direct capital cost

For the same production capacity, investment costs are very variable, depending on:

- For distillation:
  - Process used
  - Energy source
- For reverse osmosis:
  - Seawater quality
  - Pumping mode
  - Raw water temperature
  - Required quality for treated water
  - Equipments level of technology (automatic control systems, instrumentation)

The curves hereunder (Figure 3.26) give only average values, and are meaningful only in comparison with one another.
In addition, comparative cost for reverse osmosis for brackish water is illustrated

Figure 3.26 Comparing direct capital costs



It is interesting to notice that, for small capacities, the cost per cubic meter is very high, and above 20 000 m^3/d, it becomes rather stable. This confirms that, from a financial point of view, facilities of medium or large capacities (20 000 to 200 000 m^3/d) with water transportation to point of use, are more interesting than several smaller units.

Water cost

As for investment costs, production costs of water at the outlet of plants are very variable, depending on:

- Production capacity,
- Energy cost,
- Labour cost,
- Local charges and taxes.

The prices indicated hereunder (per cubic meter produced) are only indicative, and don't take into account financial charges and amortization. Moreover, their decreasing evolution is very fast:

SWRO	:	1 Euro/m^3
Distillation (*)	:	0.75 Euro/m^3

(*) Based on energy cost for Arabian Gulf countries.

Note : the cost for BWRO is approx. the third of SWRO's price.

Market survey
The present trend is mainly orientated towards reverse osmosis process.
Distillation can however be used in certain conditions:

- For very large capacities, coupled or not with electrical power plants,
- For very hot or with high salt content seawaters, which would require a double pass RO process, which means that a part of the first stage permeate would undergo a second RO stage, to increase potable water quality. This consequently increases investment costs, to reach investment or operating costs that would become uncompetitive with distillation.

3.7 Quality aspects of desalination

The produced water of desalination processes is in general free of pathogenic micro-organisms and suspended solids (except desalted water by electrodialysis reversal). However, desalinated water is not suitable for distribution and consumption, because dissolved material is reduced to such content that corrosion and potential health problems are possible. Therefore, desalination systems are always followed by a post-treatment, in order to produce a non-corrosive, healthful and pleasant-tasting water.

Quality of desalinated water
The differences in product water quality of desalination technologies are small. With distillation technologies it is possible to gain pure water, while permeate of membrane processes always contains a certain amount of dissolved solids. Depending on the used desalination technology the product water has more or less the following qualifications. The product water:

- *is very corrosive*, characterised by a low Langelier Saturation Index, due to dissolved carbon dioxide (CO_2) and low pH.
- *contains dissolved gas,* when degasification is not used as pre-treatment step.
- *is very soft (very little hardness)*, which appears to be unhealthy (and this also has a negative impact on taste).

Post treatment options
There are many options to deal with these quality problems. In general, next options are used in all kind of combinations.

Degasification
Degasification is needed to remove gases such as CO_2 and hydrogen sulphide (H_2S). A reduction of CO_2 results in a higher pH and contributes to a stabilization of the product water (for corrosion control). The removal of H_2S reduces the objectionable odour.

Remineralisation
Recalcification by dosing lime or by using marble filtration is used to remineralize the product

water, in order to increase the Langelier Saturation Index. Adding calcium also contributes to achieve a pleasant tasting and healthful product water

Residual disinfection
Chlorine can be added for disinfection. Because almost all organisms have been removed by the desalination system (except for electrodialysis reversal), the chlorine demand is rather low and generally all chlorine added produces a free chlorine residual. The use of calcium hypochlorite for disinfection will also assist in remineralisation.

Reblending
Blending the product water with pre-treated saline water is a common cost-effective remineralisation procedure, especially when the hardness of the saline water is sufficiently high.

3.8 Technology choices in the Gulf States

The Gulf States did not form part of the study area for this project, but as they are an important part of the region and as they have a major involvement in desalination, it is important to discuss what has happened there and why the route they followed is unlikely to be followed by the non-oil rich countries. The Gulf is an arid area, unique because of its oil income. In this region, oil, or its associated gas, is the energy source used to drive the desalination plants. Most other arid areas of the world have neither the indigenous fossil fuel resources nor the cash to allow them to develop in a similar manner.

The oil price hike that occurred in 1973 sparked the growth in seawater desalination in the Middle East. The inflow of funds allowed the Gulf states to invest in the development of their infrastructure on a grand scale. This included investments in power and water. For desalination the only viable technology available was Multi-Stage Flash distillation (MSF). This process was invented in 1958 by Prof. R S Silver of Weir Pumps, Glasgow. The new process was a vast improvement on the previous technology of Multiple Effect Boiling (MEB), offering improved energy efficiency coupled to ease of operation. Both processes are described later in this report. By 1975 large plants of 20,000m3/day were being built. All of the Gulf states invested heavily in this technology and have continued to invest in it to the present. The process today is much as it was then but the units are larger – up to 60,000m3/day and reliability has been improved through the use of better materials and an improved understanding of the process. Capital costs have also been reduced. The process is well understood, reliable and has served the Gulf states well. It has given the Gulf states security of supply.

To be cost effective, the MSF process has to be coupled to a power plant which can supply low grade steam. This is often referred to as waste heat. This is a misnomer. The steam used by an MSF plant could be used to generate more electrical power. By tapping of this steam at a higher temperature than necessary, the power output of the power station is reduced. This is the basis for the distillation plants installed round the Gulf.

During the eighties, the RO market for seawater desalination plants started to grow. Since then the development of this process has been spectacular. When the process was first introduced, the membranes were expensive, the pre-treatment not well understood and the energy consumption was high. Since then membrane prices have fallen, their performance improved, pre-treatment is better understood and energy consumption has dropped dramatically.

The Gulf States remains the most important market for desalination plants. Designing RO plants for operation in the Gulf presents major problems. Salinity is very high, almost double ocean water, the seawater temperature is high and there is an abundance of marine life. This affects RO plants but makes little difference to distillation plants. Early RO plants gave significant problems. All of theses factors, coupled to concern for security of supply, has made market penetration for RO in the

Gulf more difficult.

Today there is a much better understanding of scaling problems and more experience with the design and operation of the pre-treatment systems which are crucial to successful plant operation. RO plants are increasingly used in the Gulf States with some very large plants now in operation.

As stated above, the investment in desalination was coupled to a substantial investment in power plants as well. The typical ratio of power to water was 50MW: 22,500 m^3/day water. This allowed for maximum demand in the summer to be met for both water and power but has given rise to a major problem – excess generating capacity in the winter. Water demand does vary from summer to winter but not as dramatically as the variation in demand for electrical power. In summer, in the Gulf, there is a huge demand for power for air conditioning, in winter this is greatly reduced. There is therefore a surplus of generating capacity during the winter. Various ***hybrid*** schemes, usually involving building RO plants to run in parallel with the MSF plants, have been conceived, to take advantage of the surplus generating capacity, to produce more water during the winter. The economics of such schemes are complicated, controversial and beyond the scope of this study. It is unlikely that such schemes would be practical in non-oil rich countries.

MSF technology has not brought desalination within the reach of less wealthy countries. It is worth noting that virtually all the recent seawater desalination contracts placed outside the Gulf region and financed by the private sector have opted to use RO. These are discussed later in this report where a cost comparison is made which shows that for Mediterranean countries RO is cheaper in terms of both capital and operating costs.

3.9 Message

3.9.1 Reliability

Desalination is used worldwide as a very reliable source of fresh water supply, independent of climatologic conditions, well capable of tackling drought conditions and closing the supply gap.

All desalination plants are reliable if operated by competent personnel. This applies to both membrane and distillation plants. Given the fact that large plants represent significant capital investments, it would be very unusual for plant owners not to have ensured that they have provided competent management. Small plants on the other hand often suffer from neglect and mal-operation.

Small plants, and today these are mainly RO plants, do not have a good track record. Economies of scale make it difficult to justify the level of attention on a small plant and hence there are many small plants that fall into disuse through mal-operation or underfunding of spare parts. Small plants are also often located in remote areas with restricted access to technical assistance.

When considering which desalination process to select for a particular application there are many factors to be taken into account. Distillation technologies tend to be more robust than RO technology. It takes many years of mal-operation to destroy a distillation plant. An RO plant can have its membranes ruined in a day or two. The quality of staff and access to technical assistance are other factors. Obviously energy sources and capital cost are also critically important. However for sustained operations it is important to select the appropriate technology. EDR plants have a reputation for being robust. In the event the membrane fouls, it can be removed and physically cleaned. Cleaning RO membranes is possible but much more difficult.

There is a case for developing remote condition monitoring packages for small desalination plants. This would enable experts at a central location to monitor a large number of plants, identify developing problems and take action before irreversible damage is done. The developments in communications now make such systems possible. Systems of this type are used to monitor water distribution systems.

4 Energy

4.1 Theoretical Minimum Energy for Desalination

Using thermodynamics it is possible to calculate the minimum energy to separate pure water from seawater. The agreed figure is 0.7 kWh/m^3 [10].

4.2 Energy for Desalination

Table 4.1 gives a comparison of energy consumption of the main seawater desalination processes. The full analysis is already provided in Table 3.4.

Table 4.1 Estimated Energy Consumption by Desalination Processes

Process	Energy Consumption MJ/m3	Electrical Energy KWh/m3
MSF	186.4	
MED	162.1	
SWRO	29.1	4.2

From this it can be readily seen that SWRO is the most energy efficient desalination process.
Over the last 30 years the energy consumption of SWRO has been reduced due to improvements in membranes and in increased energy recovery efficiency. This process continues and further improvements can be expected although future improvements will be less spectacular. For SWRO overall energy consumption of 3 – 5kWh/m3 would now be a good estimate. The lower figure being for large plants using the most efficient technology. The wide range of this figure reflects the effects of salinity, scale of operation and energy recovery. Trends in distillation technology have in the main been increased reliability, larger plants and economies of scale with little improvement in thermal efficiency.

4.3 Energy Sources

As indicated in the previous section the different desalination processes require energy in different forms, notably electrical, mechanical or thermal. The viability of a desalination process is to a large extent dependent on energy costs. For this reason, desalination processes are often compared on their energy consumption. However this is only half the story, the 'quality' of the energy is very important. High grade energy in the form of electricity is much more valuable than the same quantity of energy in the form of low grade thermal energy. Therefore it is important to recognise that comparison of technologies or schemes based on their energy consumption is not the absolute criteria for selecting a desalination process.

Energy for desalination can come from a variety of sources. The conventional energy sources are: Grid Electricity, Diesel and Waste Heat. The renewable energy sources are: Solar, Wind, Wave, Hydro and Biomass.

4.3.1 Conventional Supplies of Energy

Grid Electricity

Grid delivered electricity can be regarded as a high grade fuel. It is usually obtained from the burning of hydrocarbons. If oil or gas is used the conversion efficiency is typically around 35%. It is usually cheaper than electricity produced from renewable sources, although this is not always the case, particularly where electricity transmission costs are high, for example in very remote locations.

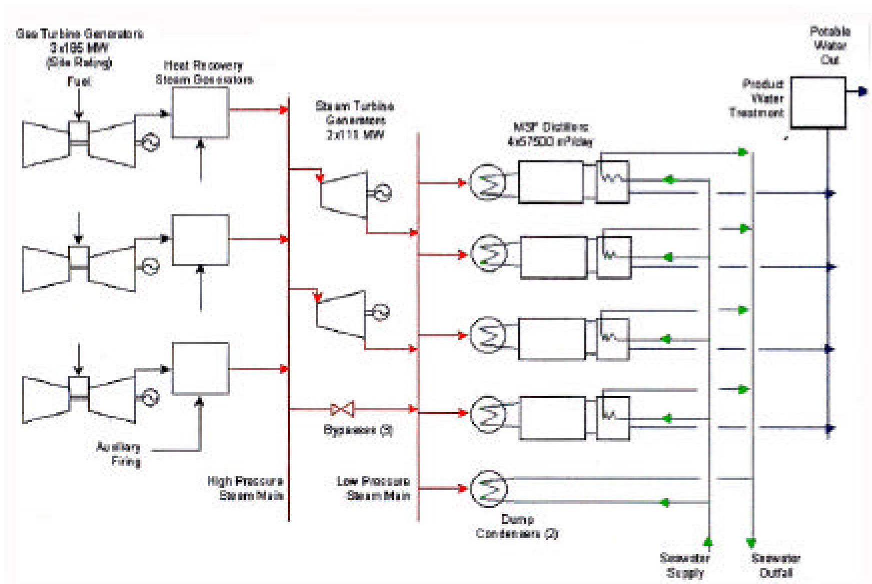
Grid electricity is presently the preferred source of energy for the desalination processes based on electrical or mechanical energy, namely RO, EDR and MVC, in that it is usually relatively cheap and it is firm, i.e. it is available constantly. The desalination plant can be sited remotely from the power plant. This gives flexibility when planning water production facilities.

Grid electricity prices vary considerably from country to country dependent upon *inter alia* the price of the fuel used to generate it. A typical cost for grid supplied electricity which is widely used as a benchmark is 5 US ¢/kWh. Grid electricity is more expensive in the case of isolated grids (e.g. islands).

Co-Generation - Low Grade Heat (Waste Heat)

Figure 4.1 shows the arrangement of the power plant and MSF plants at Taweelah in Abu Dhabi. The combined gas turbine and steam turbine in series maximises power generation. This is typical of the newer power plants being built in the Middle East. The power production unit provides the community with electricity and electrical power to run the desalination plant pumps etc. Low pressure steam is extracted from the steam turbine to supply the heat for the desalination process which is usually MSF or MED. These are often very large units.

Figure 4.1 Combined Cycle Power Plant Schematic. Abu Dhabi



If thermo-compression VC or MED is involved then this is less likely to be the case. Thermo-compression for high performance ratio MED plants requires high pressure steam. Thermo compression for low temperature MED plants can use lower grade steam. Units are in operation in the Gulf using 3 bar steam as the motive fluid.

If there is an available high grade source of waste heat and no demand for electrical power, this can be used to generate steam or a hot fluid which, dependent on quality, could be used to drive a distillation process.

In Gibraltar, municipal solid waste is burnt in an incinerator, the heat is used to produce steam which is then used to generate electricity. Pass-out steam is then used in a five effect MEB process to produce potable water. This system works well and is a useful method for disposing of waste and producing a useful product. While not suitable for village communities it can be viable in small townships.

Diesel Generators

Diesel generators can provide a continuous supply of electricity. In this sense, a desalination plant coupled to a diesel generator is equivalent to being coupled to a grid supply. i.e. it is firm power. They are therefore a perfectly acceptable source of energy for a desalination plant. As electricity is the principal output, desalination plants using electricity are appropriate. These are EDR, RO or VC.

Diesel generators normally run with an efficiency of around 33%. The rest of the energy is dissipated in the exhaust (33%) and in jacket cooling water (33%). If the generator is large enough it may be possible to run a thermal process (MSF or MEB) using this waste heat. The jacket cooling water is the easiest to use.

Diesel generators can be used in conjunction with a renewable energy driven process to supply energy during the periods that the renewable source is unavailable. An interface is required to enable the diesel to cut in and out matching supply and demand.

In remote areas, diesel fuel can be expensive because of shipping costs. Electricity generated by diesel in remote communities varies in cost from 10-20 US cents/kWh.

4.3.2 Renewable Energy Sources

The basic problem in coupling a renewable energy source (RES) to a desalination process is the variability of the power output of the RES and the availability in terms of time. This problem applies to wind, solar and wave energy but not to geothermal energy or energy from biomass which can be regarded as firm. As water can be stored relatively easily, the intermittent production of water is not a problem from a water supply point of view. If desalination technology can be run satisfactorily (technically and economically) with regular periods of shut down, then renewable energy resources can play a major role in supplying energy to desalination plant.

Solar

Solar energy can be used in two forms. Either as thermal energy by heating a fluid or by converting it into electricity using photovoltaic arrays (PV). Solar energy is a relatively diffuse source of energy. It is also available almost everywhere, unlike wind, geothermal or even conventional fuels. Depending on the energy demand of the application, it may require large areas. Yet, most solar energy conversion systems are modular and can be installed almost everywhere (e.g. house roofs) which relieves the space availability problem. Cost effectiveness is strongly influenced by the amount of solar radiation available at the site.

Solar Thermal

This is touched on in a previous section. With a simple still, it is possible to combine the energy captured with the distillation process. This is simple, relatively cheap but not particularly efficient. Alternatives have been developed to produce higher grade energy in the form of hot fluids which can then be used to drive more thermally efficient desalination processes such as MSF and MEB. These are, deep solar ponds and concentrating parabolic collectors. In all of these, the energy collected is proportional to the area of the collectors and the efficiency of the device. Solar ponds are by their nature static. Some of the other collectors can be made to track the sun which improves their efficiency but also increases their cost. Energy storage of the thermal energy is relatively cheap in the form of a hot fluid in insulated tanks or in the case of solar ponds - within the solar pond. This is important if it is connected to a continuously operating process.

Solar - Photovoltaic

In this process, the sunlight is converted into electricity using (typically silicon) PV cells. These are deployed in arrays and can be either static or tracking. Static devices are cheaper and by far the most common, but tracking devices are obviously more efficient at collecting energy. PV is widely deployed as battery charging sources for radio and telephone relay stations where the energy consumption is usually small. Typical costs are now around £3-5 per peak watt of installed capacity, however, the cost of these devices continues to fall and costs of less than the current values have been projected for the year 2010. Energy storage in batteries is really only practical for relatively small amounts of energy due to the cost of the batteries.

Solar energy in whatever form has the drawback of being only available for a fraction of the time. This means that any device using this as a source has to have back-up storage or it has to shut down. However many areas short of water have very good solar energy resources and it tends to be highly predictable.

Wind

Wind can be used to supply either electricity or mechanical power. Electricity is the usual output. Wind generators can be supplied in any capacity from a few kW to 3 MW. They come in a variety of configurations. However most designs are for horizontal axis either two or three blades. They can be deployed singly, in clusters or in farms. Good wind energy is often available on an intermittent basis in arid areas, particularly islands. As electricity is the normal output, the desalination processes suitable for use are RO, EDR and VC. For continuous operation a diesel generator is required as a back up.
The last twenty years have seen considerable developments in wind turbine technology. Wind turbines have fallen in price (now approximately $1000/kW installed capacity) and increased in size and reliability.

Wave

Several types of wave energy devices have been deployed, but none on a commercial basis. Wave energy is not yet at the stage where it can be exploited commercially either for power generation or for desalination..

Hydropower

Hydropower is unlikely to be applicable unless in exceptional circumstances. The Red-Dead hydro scheme is one such case and is described in the section dealing with Jordan.

4.4 Other Options

4.4.1 Biomass

Use of biomass is unlikely to be a common option. Availability of biomass suggests that water is available for growing the biomass and therefore a desalination plant is not required. However there may be circumstances where biomass is available and potable water is in short supply. In this event a biomass combustion based energy conversion process could be used to produce firm electrical power. Biomass tends to be seasonal but it would be possible to stockpile material for use out of season (at a cost).

4.4.2 Batteries

Commercially available battery systems have very limited capacity and are a relatively expensive way of storing energy. They are therefore not practical as a primary source of energy for desalination. However, batteries can be used on small scale units in conjunction with renewables. For example, they can be used to power the instrumentation system when the energy plant is down or may be used to smooth the power supply in small systems. In small plants they can also be used to run the system for short periods when the renewable energy source is not available.
Utilisation of Off-Peak power

4.4.3 Use of peak-hour electricity

It is usually not possible to store electrical power to any significant extent. Water on the other hand can be relatively cheaply stored in reservoirs. With most properly developed electrical power networks there are periods when power plant production is not fully utilised. For a network to be able to meet maximum demand it must have surplus capacity for some of the time. The extent to which this occurs will vary seasonally and diurnally.

When excess capacity is available it can be advantageous for the utility to sell this excess on to users at rates less than full cost recovery. This electrical power can be used to power a desalination plant whose output can be stored in a reservoir for later use. By implication this means that there has to be available excess desalination capacity and that this excess is non operational for a portion of the time. The economics of such schemes have to be examined very carefully as the cost advantage of the off-peak power has to be set against the cost of extra desalination plant capacity and water storage.

4.5 Renewable Energy Coupled Desalination

Renewable energy is generally more expensive to produce than energy from large scale power stations. However, production of fresh water using Desalination Technologies driven by RES may be a viable solution to the water scarcity at remote areas characterized by lack of potable water and lack of an electricity grid. In recent years there has been intensified R&D effort in this field. Worldwide, several RES desalination pilot plants have been installed and the majority have been successful in operation. Virtually all of them are custom designed for specific locations and utilize solar, wind or geothermal energy to produce fresh water.

In this section of the report a combination of the two technologies, RES and Desalination, is discussed. The most promising couplings such as Photo-voltaic (PV)–Reverse Osmosis (RO), Wind-RO, Wind-Mechanical-Vapour Compression will be examined. Electro dialysis (ED) and Electro dialysis reversal (EDR) are included as there are thought to be good opportunities for this process. Although RE powered desalination systems cannot compete with conventional systems in terms of the cost of water produced, they are applicable in certain areas and are likely to become more widely feasible solutions in the near future.

4.6 Technologies Combination and Selection Guidelines

The selection of the appropriate RES desalination technology depends on a number of factors [15]. These include, plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type and potential of the local renewable energy resource.

Among the several possible combinations of desalination and renewable energy technologies, some seem to be more promising in terms of economic and technological feasibility than others. However their applicability strongly depends on the local availability of renewable energy resources and the quality of water to be desalinated. In addition to that, some combinations are better suited for large size plants, whereas some others are better suited for small scale application.

Before any process selection can start, a number of basic parameters should be investigated. The first is the evaluation of the overall water resources. This should be done both in terms of quality and quantity (for brackish water resource). Should brackish water be available then this may be more attractive as the salinity is normally much lower (<10,000ppm), and hence the desalination of the brackish water should be the more attractive option. In inland sites, brackish water may be the only option.

The identification and evaluation of the renewable energy resources in the area, completes the basic steps to be performed towards the design of a RES driven desalination system. Renewable Energy driven Desalination technologies mainly fall into two categories. The first category includes distillation desalination technologies driven by heat produced by RES, while the second includes membrane and distillation desalination technologies driven by electricity or mechanical energy produced by RES. The most promising and applicable RES desalination combinations are shown in Table 4.2.

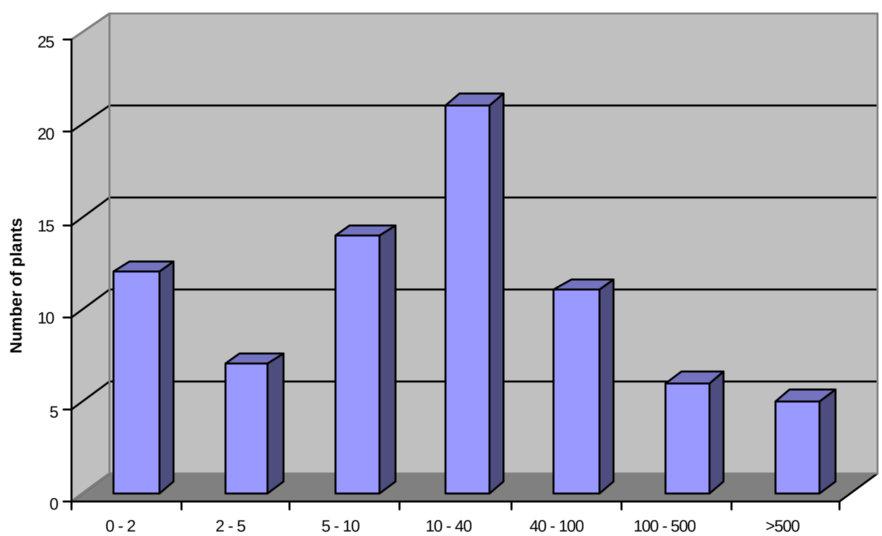
Such systems should be characterized by robustness, simplicity of operation, low maintenance, compact size, easy transportation to site, simple pre-treatment and intake system to ensure proper operation and endurance of a plant at the often difficult conditions of the remote areas. Concerning their combination, the existing experience has shown no significant technical problems. A study carried out in 1999 [16] identified 76 plants that had been constructed in the last 25 years. A breakdown of these is given in Figs 4.1, 4.2 and 4.3.

Table 4.2 Energy Sources Summary

Energy Source	Form of energy		Steady supply	Location specific	Resource Constraints
	Electricity	Heat			
Grid	✓		✓		transmission distance
Solar PV	✓			✓	solar regime
Solar Thermal		✓		✓	solar regime
Waste Heat		✓	✓*	✓	proximity to industrial plant
Batteries	✓				size
Diesel	✓		✓*		transport of diesel
Wind	✓			✓	wind regime
Wave	✓			✓	wave regime
Biomass	✓	✓	✓*	✓	availability, storage and transport of suitable biomass

* Steady supply can be achieved with resource management.

Figure 4.2 Plant Capacity m3/day



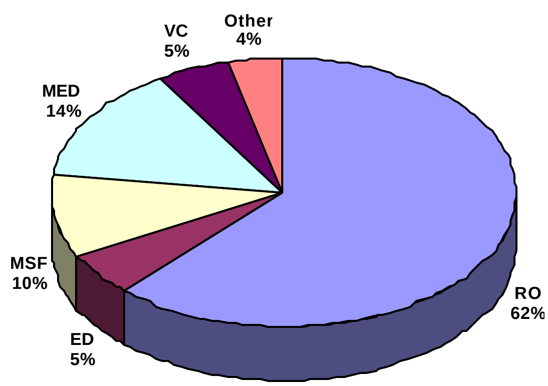
As can be seen from Fig 4.1, most of these plants have been small in capacity. The most popular combination of technologies is the use of PV with reverse osmosis. PV is particularly good for small applications in sunny areas. For large units, wind energy may be more attractive as it does not require anything like as much ground. This is often the case on islands where there is a good wind regime and often very limited flat ground.

With distillation processes, large sizes are more attractive due to the relatively high heat loss from small units.

Energy cost is one of the most important elements in determining water costs where the water is produced from desalination plants. Some energy-consumption data for traditional desalination plants using different desalination techniques are given below. These data refer to conventional plants in operation at their nominal power consumption and production.

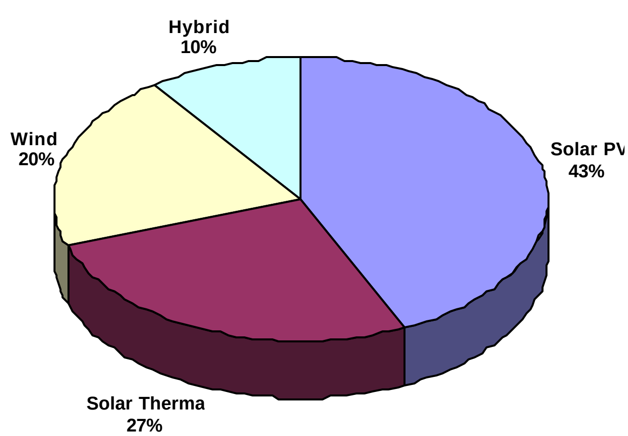
- For RO systems: 5.9 kWh/m^3 without energy recovery (large production plants), 3-4 kWh/m^3 with energy recovery
- For ED systems: 1.22 kWh/m^3 (for feed water salinity of 3000 ppm and product salinity of 500 ppm). This consumption is increased by the operation time: increment of 50% after 2.5 operation years
- For VC systems: 8.5 - 16 kWh/m^3, depending on size of plant.

Figure 4.3 Desalination processes used in conjunction with renewable energy



As can be seen from the above figures, RO, requires significantly less electrical or mechanical energy to treat seawater than any of the other processes. Hence it is the natural choice in most instances. ED or EDR plants are relatively uncommon as there are only three companies manufacturing this kind of plant and the technology is not well understood. Nevertheless there is considerable potential for this process in remote applications where brackish water is available.

Figure 4.4 Energy sources for desalination



Apart from the selection of technologies, another parameter is the type of connection of the two technologies. A renewable desalination plant can be designed to operate coupled to the grid or off-grid (stand alone - autonomous system). Where the system is grid connected, the desalination plant can operate continuously as a conventional plant and the renewable energy source merely acts as a fuel substitute. Where no electricity grid is available, autonomous systems have to be developed which allow for the intermittent nature of the renewable energy source. Due to the dispersed population that characterizes the South Mediterranean and Gulf areas, relatively small systems are used to cover the potable water needs in remote villages. The main desirable features for such systems are the low cost, low maintenance requirements, simple operation, as well as the high reliability.

The latter case poses the problem of renewable energy variability because most energy systems lack an inherent energy storage mechanism. Desalination systems have traditionally been designed to operate with a constant power input. Unpredictable and non-steady power input, force the desalination plant to operate in non-optimal conditions and may cause operational problems. Each desalination system has specific problems when it is connected to a variable power system. For instance, the reverse osmosis (RO) system has to cope with the sensitivity of the membranes regarding fouling, scaling, as well as unpredictable phenomena due to start-stop cycles and partial load operation during periods of oscillating power supply. On the other hand the vapour compression system has considerable thermal inertia and requires considerable energy to get to the nominal working point. Thus, for autonomous systems a small energy storage system, usually batteries, should be added to offer stable power to the desalination unit. Clearly this only applies to small electrically driven systems. Thermal storage can be added for thermal systems in the form of hot oil or hot water but is expensive. A further possible addition is the inclusion of a diesel generator to back-up or supplement the renewable energy source. Any candidate option resulting from the previous parameters should be further screened through constraints such a site characteristics (accessibility, land formation, etc) and financial requirements.

4.7 References

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5 Institutional Framework

The planning, development and implementation of desalination activities can play a decisive role in closing the gap between water resources availability and the demand for sweet water. Turning towards desalination is not a mere decision to extend water production capacity. It is part of a bigger picture, which includes water sector performance improvement and integrated water resources planning. In all countries that are part of this study, the consideration of desalination as a new source of water will play a role in the future planning and execution of all governments' tasks in the water sector, including resource assessment and monitoring, planning and allocation, development and distribution of water and the mobilisation of sector investments.

This Chapter does not aim at developing a water sector assessment nor at drawing up recommendations for water sector management as a whole. It rather focuses on issues related particularly to desalination.

5.1 Water Policy and Planning

As a first step towards possible development of desalination as an additional source of water, governments should develop a very clear-cut water policy. The water policy should incorporate an integrated water resources management policy, so as to be able to determine issues like real water availability and real water demand and consumption. Only after a fairly reliable picture has been drawn up about a country's water resources and the use thereof is it possible to develop a well-considered action plan for the development of additional water resources. The issue of integrated water resources management (IWRM) was addressed in a separate chapter on Water Resources.

In brief the water policy should address:

- Water consumption by different sectors;
- Water production, availability and source potential;
- Potential of non-conventional water resources;
- Cost structure of fresh water produced, treated and supplied;
- Development of indigenous resources and their infrastructure and distribution;
- Optimum management of supply;
- Stable and secure supply;
- Demand projections;
- Pricing.

Especially in cases where the further development of conventional water resources has become increasingly unsustainable, the development of non-conventional water resources and the introduction of water demand management measures are becoming interesting policy alternatives. This means that to meet increasing water demands it is essential not only to have new and more efficient ways of water purification, and to develop alternative water resources, both conventional and non-conventional, but also to introduce water conservation by preventing groundwater pollution and optimisation of water usage through better water management, and demand management in all sectors [1].

However, desalination may ultimately prove to be the best new supply option for high-valued uses of water in coastal regions where efforts to maximise efficiency are being made and where absolute supply constraints are severe. [2]. This may even include the use of desalination for irrigation for high-value cash crops such as flowers. Particularly if it is done in combination with other non-conventional water uses, such as:

- Reuse of treated wastewater;
- Water harvesting;

- Importation of water across boundaries; [3].

In theory, better water management can contribute to resolve the global water crisis through conservation, realistic pricing and some necessary regional shifts in agriculture [4]. Crucial in the respect is a shift away from water intensive irrigated agriculture. However this shift is a particularly difficult one, both from a socio-economic and from a political perspective. In Tunisia there are actually plans to increase the quantity of irrigated land, while aiming at increasing the efficiency of irrigation, to make up for the extra water needed. In Algeria there is a similar drive to rationalise water use for irrigation. Some 20-30% of irrigation water could be saved there through reduction of losses during conveyance, the application of better technologies, education of farmers and tariff increases.

Not only water management and water allocation issues are politically sensitive as are, most of the issues addressed in a country's water policy are. Possibly more sensitive even are water tariff and water pricing policies. Yet, while political and socio-economic constraints are undeniably present in most of the countries in the region, there is a serious need to address these issues. In Jordan, for example, the average cost of delivering $1m^3$ of water for domestic purposes is only recovered in the highest tariff category of the block tariff system (more than 66m3/month, a quantity only a very small group of users will consume). Water for irrigation is charged at only some 10 percent of the cost of delivery. Cost analyses suggest that the Government of Jordan has been subsidising water at some USD 50 million annually. [WB, 1997]. If relatively expensive desalinated water will be produced and pumped into systems with considerable leakage, the subsidy problem will be further aggravated.

A coordinated approach is needed to prepare water policies. Water management, purification and conservation, which require the optimisation of technical, economical and environmental aspects together with a good understanding of political and societal aspects [4] need to be coordinated.
A particularly clear and transparent water policy was found in Jordan, where clear policies for ground water management, utility management, irrigation and wastewater are clearly written down and brought together into a synergetic medium term water strategy. [5]

5.2 Water Sector Organisation

Whereas the importance of a solid water policy cannot be stressed sufficiently, another important aspect to ensure the successful implementation of desalination activities is to have a professionally organised water sector, with institutions capable of desalination policy development to project implementation. The main critical issues with regard to water sector organisation in view of the implementation of desalination activities are described in this paragraph.

5.2.1 Policy making and planning

In all countries visited the "Ministry of Water" plays a major and central role in water policy development and in the planning of desalination activities. In fact, the ministries in all 4 + 2 countries seem to play a central role in the entire process of developing desalination. This may be driven by the fact that generally there is relatively limited experience with desalination, that the projects are usually rather high-tech, and often set in complex contractual arrangements, resulting in significant risks for all parties involved. Therefore, project development and management of project implementation is often approached in a centralised manner.

Another important argument, particularly in countries that opt for a BOT or similar approach is that water boards or water companies have limited involvement with desalination project implementation from the construction or operation points of view. Rather they are the mere off-taker of water that is produced by the desalination company that was selected by a more central party, often the Ministry of Water.

Planning of desalination can only be carried out if the various water institutions involved in management of the water sector are capable of bringing together their expertise and knowledge in a co-ordinated and transparent manner. In Jordan, a major effort is ongoing to collect water resources data at central level at the Ministry of Water. Still, information and responsibilities in the water sector are spread over a number of other institutions. The Ministry of Health monitors water quality (both water resources and drinking water quality), The Ministry of Agriculture develops agricultural policies and provides (irrigation water) services to farmers outside the rift valley, and the Ministry of Municipal and Rural Affairs, and the Environment is responsible for water resources protection and for protecting the quality of water resources too. [5].

The spread of water related responsibilities over several ministries and agencies is common. In Tunisia the Ministry of Agriculture is responsible for water supply and irrigation, while the Ministry of Environment is the line ministry for wastewater issues. Similarly, in Uzbekistan, the Ministry of Agriculture and Water Resources is responsible for water resources planning and management, while the Ministry of Municipal Affairs is in charge of urban water supply and wastewater services.

Such division of responsibilities calls for close co-ordination of data collection and management, possibly by a specialist, central body, created for this particular purpose. Clear insight into national and local water balances, for example, are of crucial importance in any decision making process with regard to desalination. Issues to be taken into account are among others:

- Water consumption by different sectors;
- Water production, availability, and source potential;
- Cost structure of the fresh water produced or treated and supplied;
- Scope for water savings through UfW reductions and demand management measures.

If such information is collected and stored centrally it can be analysed to determine the trends in the composition of consumption of water, water sources and costs. [6] Based on the information collected and its subsequent analysis well considered measures can be taken to close the gap between water demand and supply. These measures can include decisions to invest in desalination capacity, but may as well give priority to water demand measures, UfW abatement or the development of other non-conventional resources.

Arguments to be taken into account when considering the development of desalination compared to, or in combination with, other measures are:

- Financial and economic arguments such as:
  - Economic optimum between cost of demand management (network leakage reduction, increased education and awareness efforts vs. cost of increased supply);
  - Development of desalination capacity vs. cost of long-distance transportation if the latter option is available;
  - Affordability and impact on utility financial performance.
- Urgency of the situation, and the speed and impact of different measures;
- Water allocation, and quality requirements for different user groups and purposes
- Technical feasibility of different measures

The choice for desalination should thus be based on a large set of criteria, which can only be correctly addressed if sufficient data are available. Therefore it is recommended to have one central body dealing with the data collection and processing with regard to water resources management.

Consequence of insufficient planning – Santa Barbara
Residents of the Californian city of Santa Barbara have saved so much water by changing their lifestyle that a new desalination plant has remained on standby since it was built. The municipal water planning department negotiated with the State of California the construction of a 230km pipeline, as well as a desalination plant, which was never put into operation. *Langford-Wood, Salter, World Water, 1998*

5.2.2 Tendering, contracting and monitoring

Tendering of desalination projects seems to be carried out in a rather centralised manner in the countries under investigation, similar to the planning and development phase. The arguments supporting this approach are similar to the planning phase: particularly when large-scale infrastructure is being tendered and complex contractual arrangements are used, a specialist commission is set up by the lead ministry, usually the Ministry of Water in the countries visited. This commission is commonly chaired by a high ranking official, who works together with a team of specialists, bringing together technical experience and expertise, knowledge of tendering procedures, and financial and legal skills. These commissions, particularly when donors are involved, are usually supported by external experts during the entire tendering procedure, from drawing up tender documents, through contract signature up to and including (contractual) monitoring of the implementation of the contract.

The issue of tendering and contracting is dealt with in more detail in the Chapter on Private Sector Participation.

The centralised approach in project planning and development calls for clear communication with and involvement of local water institutions, public bodies and other stakeholders, to ensure that the right information is being used, correct assumptions are made and to assure their commitment to the activities that are being planned in the longer term. This involvement should also assist in developing local capacities.

Regulation

Regulation by Contract
The monitoring of the implementation of a contract can typically be carried out by a 'regulator by contract', for example called a "Contract Monitoring Unit" (CMU). When a clear legal framework is absent, and a solid contract document has been drawn up, the main legal document is the contract itself, which results in the tasks of a CMU being carried out within very clear boundaries.

The tasks of a CMU may include, monitoring, sanctioning and advising on:

- Agreed technical performance standards;
- Water quality and wastewater standards;
- Implementation capital investment programme / agreed maintenance levels;
- Levels of service improvements;
- Automatic tariff adjustments;
- Extraordinary tariff adjustments to be fair and justified.

The enforcement capabilities of a CMU depend largely on the contract that was signed between the parties. It can be determined by contract that the regulator is not only the monitor, but also the body that determines possible penalties or other consequences if either of the contract parties does not fulfil its contractual obligations. Contract parties may be a public and a private party (e.g. for a BOT contract) but may as well be 2 public parties who conclude a contract to enhance performance of the service provider, and to create transparency in their co-operation.

A CMU may also act as a liaison between the parties to a contract, and act as a forum for discussion of contractual matters. In case of dispute a contract regulator is typically the mediator in first instance.

Sector Regulation
When several contracts have been concluded, or when the legal framework in a country's water sector is sufficiently developed, it may be advisable to integrate or transform the various contract regulators into a sector regulator. Regulatory bodies are often considered with regard to the development of private sector involvement, but might as well be a 'central enforcement body' monitoring public sector performance, ensuring that their operations and performance are

progressing in the right direction towards ensuring an efficient system for managing desalinated water from its inception to reuse. [7].

A regulatory authority, which thus can regulate either private or public operations, as described above could be given a wide range of monitoring tasks by which it can whether targets in water policies and/or action plans are achieved. In addition to the tasks of a contract regulator a sector regulator may have more additional tasks, such as sector benchmarking, controls over unfair trading practices, development of sector rules and regulations, and extensive arbitration and mediating powers.

The actual powers of a sector regulator depend strongly on local legal and institutional framework, particularly the level of decentralisation and the roles and responsibilities that are allocated to the various actors in the sector.

5.2.3 Operations

Contrary to the general statements about a centralised approach for planning and tendering (large) desalination projects, a number of countries apply both a centralised and de-centralised approach towards the operation of desalination plants. In three out of six countries visited local water authorities are responsible for the operations of at least part of the desalination activities in the country.

Utilities in the countries under investigation, particularly in Algeria, Jordan and Uzbekistan, are not performing in accordance with international good practice, reciprocally caused by and resulting in:

- High percentages of UfW, often exceeding 50%;
- Low tariffs, often not covering O&M, let alone capital investments;
- Inadequate O&M programmes;
- Overstaffing (also in Tunisia), but a lack of qualified staff;
- Low billing and collection rates, resulting in funding shortages.

To give an impression of utility performance in the countries under investigation, some of the main performance indicators are presented below:

Table 5.1 Performance Indicators in target countries

	Amman	Tunis	Algiers	Uzbekistan (Karakalpakstan "urban" areas)	Good Practice
UFW	52%	21%	51%	High, unknown	<20%
Water Coverage	100%	100%	100%	46%, limited house connections	100%
Continuous Supply	No	Yes	No	No	Yes
Per capita Water Use (litre/day)	~80	~80	~70	Unknown, contradictory figures	> 100
Employees/ 000 Connections	5.5	10	8.6	Unknown	< 5
O&M Cost Recovery	Yes	Yes +	No	No	Yes +

Source: WB Compilation, interviews with professionals in the field

These conditions are not conducive to the sound development and implementation of desalination infrastructure, and are -besides the requirement for capital investments- a very important reasons to include the private sector in the development and operation of desalination plants.

5.2.4 Public operation of desalination plants

The performance of public utilities is at times harmed by the institutional environment they are functioning in. Particularly in developing countries utilities sometimes face constraints in their development due to:

- The fact that limitations in tariffs, which often are below cost-recovery levels, do not cater for professional O&M and investment levels;
- Limited possibilities of recruiting qualified personnel, due to restrictions in wages under public sector operations;
- Limitations in arms' length functioning of (local) Governments, resulting in interference in operations, personnel policies and potential budgetary restrictions.

Although public utilities face potential constraints, some of them are very well capable of operating desalination infrastructure, as demonstrated below. A successful approach can be found particularly in Malta where an independent service provider was created, but which is fully Government owned. Jordan is planning similar approaches for its water supply in Aqaba and Amman, albeit not for desalination infrastructure. Sonede, the public utility in Tunisia also operates desalination infrastructure successfully.

Algeria

In Algeria, Algérienne des Eaux (ADE) is going to operate and maintain 12 medium sized desalination stations that are being built under a turn-key arrangement, as an emergency measure to abate immediate water shortages in Algiers. The first plant, with a capacity of 2500 m^3/day was inaugurated in July 2003. Linde, the supplier of the installations has also been retained to train local staff in plant operation procedures during the initial period of operations of the facilities, after which ADE will take over the operations.

Uzbekistan

Small-scale ED facilities in Uzbekistan are operated by the local water company "Karakalpakselkhozvodoprovod". The small containerised units do not use very advanced technology, and can be operated without too many problems by local staff with very limited technical qualifications. A specialist team of more qualified technicians is travelling around the region to service the various small stations. According to the management of the water company, it would not be possible to contract-out the O&M of these units to a private company, since the water company does not generate sufficient cash flow to guarantee payment to a possible private partner.

Malta

In Malta the government has taken over operations of a private operator at the end of a 15-year management contract. The operator was hired after the turnkey delivery of the infrastructure. After the infrastructure had been in operation for 15 years, the local staff had learned sufficiently about all aspects of plant operations, so that the government found it to be more efficient to do the operations themselves. For this purpose a commercially run company, albeit 100% owned by the Government, was created (Malta Desalination Services - MDS). MDS is successfully running and upgrading the desalination plants in Malta and is building new small plants for sale to hotles across the island. This is a step beyond private sector involvement, which for desalination projects is rather unique to the knowledge of the Consultant.

Tunisia

In Tunisia 4 desalination plants for municipal water supply are operational, using RO technology. These are operated successfully by Sonede, the national water company of Tunisia. The total production capacity of the plants is slightly over 50,000m3/day. Sonede has gained some 20 years of experience operating desalination infrastructures. The utility is pro-actively looking for performance improvement and has in this respect changed the type of membranes it uses, and has adapted their pumping process to save energy. The government of Tunisia is envisaging a large-scale desalination plant for the island of Jerba developed and operated under a BOT arrangement, and thus seems to turn towards the private sector for large scale operations

Jordan

The Minister of Water of Jordan, in contrast, has clearly stated that he is not willing to take on the risks of operating desalination facilities itself, and that he would rather prefer to transfer that 'headache' to the private sector.

5.2.5 Operational practice and water savings

Good operational practices can result in the provision of desalinated water at lower cost to the final consumer. Cost reductions can be achieved not only by addressing the production efficiency of a desalination plant, but also through reduction of UfW and the possible re-use of water.

UfW reduction

An authority, be it a central body, or a local water company, should make a clear assessment of the optimum level of unaccounted-for-water reduction. When UfW levels drop, the 'return on investment' to further abate losses reduces significantly, to a point at which it is economically unattractive to invest in order to further bring the UfW levels down. This depends on the production cost of the water, which in case of desalination may at times be significantly higher than the cost of conventional water resources. Before an investment in desalination is made, careful calculations should be made with regard to the optimum UfW level.

Water Reuse

Water reuse can help optimising the use of valuable desalinated water. However acceptance of re-used water is rather low, due to social awareness and attitudes, but also due to perceived health risks, and a lack of scientific knowledge of impact on e.g. soil and crops. The institutional framework in which water re-use is set is important, since it brings together water supply and wastewater issues. Research and development in wastewater treatment also needs to be supported, since better qualified staff will result in better effluent quality for wastewater for re-use purposes.

5.2.6 Organisational Response

The integration of water and wastewater activities based on water conservation measures may require the integration of operational bodies (mainly utilities) to integrate water delivery and wastewater collection and treatment services. A high degree of coordination is more likely to be achieved by a single authority responsible for water production, distribution and reuse. An institutional set-up is needed to control of all stages of the water supply cycle, from its inception with the production of the potable water at the desalination plant to the reuse of the sewage effluent leaving the sewage treatment plant. This overall control is necessary because the cost of desalinated water is not linked solely to efficient plant operation, but also to several other factors such as the storage capacity available, the level of unaccounted for water, and the extent of reuse of sewage effluent [7]. In addition to the necessary technical measures, acceptance of water re-use needs to be enhanced through awareness creation with farmers, final consumers of agricultural produce and other stakeholders.

5.3 Legal Framework

If a Government has the intention of embarking on desalination activities, these activities should be embedded in a well developed legal framework. The list of legal implications and potential issues of developing water supply infrastructure is extensive and will not be dealt with in their entirety in this study, but some important legal aspects will be dealt with. These include constitutional matters, the competence of governmental bodies, water legislation, environmental matters and procurement issues. The issue of procurement will be discussed more extensively in Chapter 5.

5.3.1 Constitutional matters

When a country considers the development of desalination projects, which will often involve private sector operators, a country should be able to clearly confirm that it is constitutional to transfer control over (part of the) water resources to a private party. In a number of countries water is considered as a public good per se, and the constitution does not allow private parties to have control over any water resources. The main risk of non-compliance with a country's constitution is that a contract cannot be signed after significant efforts have been put into its preparation by both public and private partners, for example because Parliament cannot ratify it. Even if a contract would be concluded between a public and a private party and it would turn out to be non-constitutional, there is a significant risk of the contract being cancelled e.g. following a change of Government.

5.3.2 Competence of Governmental Bodies

Another legal issue that needs to be transparent is the role the various institutions play in the development of the water sector. In Jordan, for example, it was carefully laid down in a set of rules and regulations that the Privatisation Committee, as a part of the Ministry of Finance is the leading party in any movement toward privatisation. Yet, if a water project is developed in cooperation with the private sector, it is clearly determined that the Ministry of Water is the competent line ministry, rather than the Ministry of Finance. A contract negotiated with a public party that turns out not to be a competent party may be cancelled by a governmental decision.

5.3.3 Water Laws

A clear set of water laws and regulations is critical for any sector development, particularly when the private sector is involved. Whereas a general water law is usually in place describing the roles and responsibilities of different actors in the water sector, a wide range of laws and by-laws may be in place in which e.g. water quality standards, treatment requirements, use of water resources for commercial purposes are laid down. Transparency in the set of rules and regulations is very important in this respect. If laws and regulations are greatly dispersed and numerous addenda and modifications are not very clearly published, it can be very time consuming to determine appropriate standards to be used as the basis for the development of newly planned infrastructure.

Additional legal options for improving water sector performance

In addition to a generic water law, rules a regulations addressing water saving, allocation, and distribution issues can be drawn up. Such regulations can include:

- Specific legislation in relation to minimum standards of efficiency for water devices in urban areas and for irrigation technologies;
- Rules to promote efficiency in water distribution networks and water use in urban areas and irrigation, establishing water use quotas;
- Legislation requiring metering in urban areas and for agriculture, certainly also metering water abstraction on private wells;
- Urban planning laws incorporating requirements for suitability of sites with regards to source availability and potential pollution;
- Regulations determining co-ordination mechanisms between various authorities and stakeholders;
- Mechanisms to enforce close resource monitoring water availability and water use. [8]

According to the GWP [8] laws specifically aimed at desalination are underdeveloped in the MENA region:

> *"Presently laws and regulations for the extraction, treatment and management of brackish water are absent. There is also no established policy for the distribution of the produced freshwater as well as the disposal of the resulting brine"*

5.3.4 Environmental Considerations

The potential environmental impacts of a desalination plant are extensively described in chapter 8. There can only be legal consequences of adverse environmental impacts if a clear set of environmental standards and rules is in place, and ways to enforce them. Enforcement of these rules is a critical matter as well. Environmental rules were by-passed under the emergency desalination programme in Algeria, but apparently also for one of the larger projects. The Ministry of Environment representatives indicated that if they were not informed about a project, there was nothing they could undertake, turning them into an institution with limited enforcement capacities.

Important guidelines for the implementation of desalination projects for the Mediterranean have been published by UNEP [17]. These guidelines are considered to be the leading environmental rules and regulations by e.g. the Ministry of Environment in Algeria.

5.3.5 Procurement laws and other commercial legislation

Transparent procurement laws and regulations are critical to the success of tenders. This can largely be managed by formulating clear tender documents and solid contracts, but there should also be a sufficient insight into the set of rules and regulations governing commercial operations in a country, such as company registration laws, tax legislation, contract laws, etc.

In the chapter on Private Sector Participation, the legal framework with regard to procurement and international investments is discussed more extensively.

5.4 Messages

5.4.1 Institutional Framework

Proper institutional frameworks, not only for desalination but for the entire water sector, including legal, policy, organisational and human resources aspects, can only be developed and sustained if sufficient capabilities are also developed.

The planning, development and implementation of desalination plants need organisational structures to manage the required activities at governmental levels as well as within the utilities, industry, research and development, and education institutes involved. The basis for all activities in the water sector, including desalination, should be a clear water policy. This policy should determine the path towards meeting the demand for water, and should also determine the roles and responsibilities of the various parties involved. To make realistic plans for desalination, close co-ordination between various governmental bodies, which in practice often have fragmented responsibilities, is essential. A central co-ordinating body for water sector data collection and data processing should be considered in many cases. If co-ordination and communication is insufficient, there is a significant risk of decisions being taken on the basis on incomplete or unreliable information with regard to investment in desalination – or rather other options to reduce the gap between water demand and water availability.

The development of institutional, legal and policy frameworks is an ongoing effort set in a rapidly evolving world. Best-practice approaches evolve rapidly and impose adjustment of skills and knowledge at all segments of the water sector. Some of the more recent developments include, but are not limited to:

- The trend towards sustainable integrated water resources management
- The tendency towards private sector involvement;
- The appreciation of water as an economic good, at the same time the paradoxical development of appreciation of water as a social good;
- The ever increasing attention for the environment;

- Rapidly evolving technologies, forcing sets of considerations and weighting thereof being permanently adjusted (e.g. environmental considerations, balance of various cost categories such as power cost vs. capital cost, desalination as an alternative to water transportation, etc.)

Whereas the implementation and operation of desalination activities is regularly carried out at de-central level, all activities leading towards project execution are often managed centrally. These often include complex tasks of policy making, water resources planning, tender activities and regulation. Given the complexity of (particularly large-scale) desalination projects, central coordination of project development seems to be a sensible approach in the countries under investigation, where local capacities and capabilities are at times under developed. At the same time central bodies should give due attention to the institutions operating at decentral level, when desalination infrastructure is planned or developed, in order to ensure a solid local embedment and commitment to the success of the project by local parties.

6 Capacity Building

6.1 Introduction

The demand for water in the Middle East and in parts of Central Asia is increasing rapidly, while water resources become increasingly scarce. Desalination will increasingly be used to fill at least part of the existing or future gap between supply and demand. The increase in desalination capacity needs to be matched by an increase of the capacity to develop, implement and operate desalination facilities. This chapter will discuss the needs for capacity building in the desalination sector.

There are many ways to define capacity building. One of the definitions is:
The process by which individuals, groups, organisations, institutions and societies increase their abilities to:
1. Perform core functions, solve problems, define and achieve objectives; and
2. Understand and deal with their development needs in a broad context and in a sustainable manner.

6.2 Capacity Building Needs

A lack of professional capacity to deal with desalination projects has in many instances during this study been mentioned as a bottleneck to the development of the sector. . Also in a broader spectrum on conferences and seminars (e.g. IDA conference in Abu Dhabi, 1995), the critical importance of capacity building is underlined. Yet, while need is recognised, little is published on how to address this problem. An active promoter of more attention for capacity building is MEDRC, a party that has developed a vision on capacity building requirements and ways to address the challenges that lie ahead.

Particular capacity problems with regard to the desalination sector in MENA countries are:
1. Inadequacy of information and data resource assessment specially related to desalination technology;
2. Lack of know-how and limited technical capabilities;
3. Lack of financial resources for research;
4. Lack of appropriate national policies regarding desalination in long-term planning and the necessity of establishing adequate institutional infrastructures for the management of the operation of desalination systems. [4]

The Consultant acknowledges these findings, particularly the first three issues described above. With regard to the fourth issue, it should be noted that desalination is receiving more and more attention in the policies of the countries under investigation. Still, it remains questionable whether appropriate policies are being developed in all countries The same applies to the second part of bullet no. 4 above; institutional structures within which desalination projects are developed and managed, but they are not yet fully mature per se. Operations of desalination infrastructure, especially large-scale infrastructure is often delegated to the private sector.

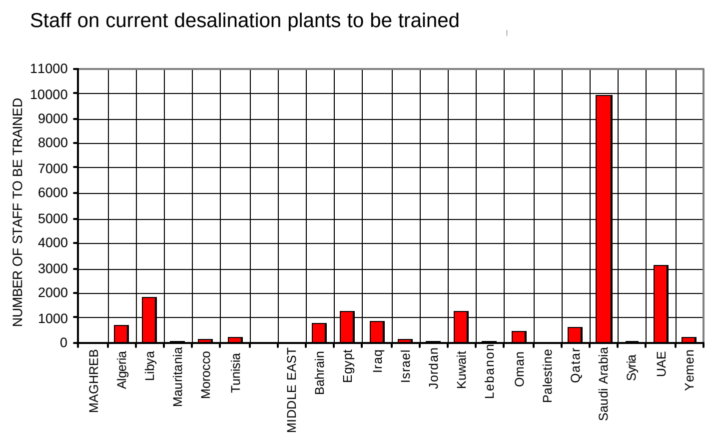
6.2.1 Training and Educational Requirements

Until very recently no structured study has been carried into the educational requirements in the desalination sector. The following paragraphs are largely based on a study carried out by K. Wangnick. (MENA Desalination Training Facility by Wangnick Consulting GmbH). This GTZ funded study was released to the Consultant in March 2004, and it provides some insight into the needs to educate and train current and future staff in the MENA region, directly related to the operation of desalination plants. The Wangnick estimations of the development of the desalination sector have been based on calculations of the development of water demand, using current demand and projected growth of the Gross National Product of countries and the projected growth of the population as most important inputs. It is assumed that the increasing gap between demand and renewable water resources is closed using desalination. Development figures for industries and irrigation have been related to the growth of domestic demand. The figures need to be used with a certain caution. For example, growth figures of the Gross National Product were set at only 2% annually. This may result in underestimation. The fact that demand management and other loss prevention measures are not taken into account may on the other hand result in somewhat high estimations of the growth of desalination capacity.

Current training needs

In the study it is estimated that there will be a need to train some 22,000 people that are currently involved with the operation of desalination plants in the MENA[3] region. Saudi Arabia has by far the largest need of current staff that needs training; some 10,000 out of the overall 22,000 in the region. In total, around 56,000 people are working at existing desalination plants.

Figure 6.1 Training needs for current staff of desalination plants



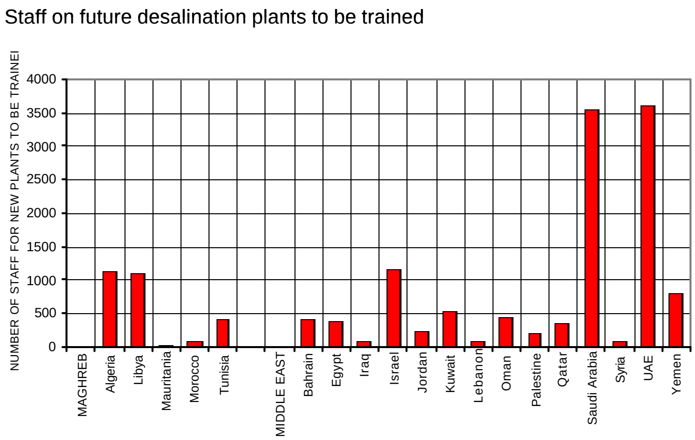
Source: Wangnick, K. MENA Desalination Training Facility, prepared by Wangnick Consulting GmbH for GTZ (2003)

Future training needs

Based on the estimated future water demand and availability, the desalination capacity, and associated number of qualified staff was estimated, taking into account the need for desalination capacity until the year 2010. It is estimated that some 36,000 staff will work in new desalination plants, of which 14,500 will require training. Out of this amount, it can be assumed that some 3,500 will be trained in Saudi Arabia, leaving still some 11,000 staff to be trained, averaging some 1,500 people annually.

[3] MENA in the Wangnick study includes the Algeria, Bahrain, Egypt, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, UAE, and Yemen.

Figure 6.2 Training needs for future staff of desalination plants



Source: Wangnick, K. MENA Desalination Training Facility,
prepared by Wangnick Consulting GmbH for GTZ (2003)

The numbers of staff that have been identified in the Wangnick study includes only staff that is directly involved with plant operation, ranging from plant managers to operators, foremen and labourers.

The educational requirements are even larger if one takes into account capacities and capabilities that are closely linked to the development of desalination infrastructure, such as:

- The plea to develop more local technical capacities and capabilities in the development of desalination infrastructure, since currently there is hardly any technological involvement in desalination projects from suppliers or manufacturers from MENA and CA region.
- The need for more professional staff at governmental level, capable of understanding desalination technologies, but also staff that is capable of contracting out the development of infrastructure and monitoring of the implementation of contracts;

Appropriate Education

The desalination options that are chosen, and the capacity building requirements that are linked to it, are to be implemented with sustainability of the solutions as a guiding principles. Al-Jayyousi states that the effectives of capacity building is strongly linked to the following aspects of sustainability:

1. Technical sustainability, which requires sound design of water systems;
2. Environmental sustainability, which guarantees that no negative long term, or irreversible effects result from interference in the water system;
3. Financial sustainability, requiring cost recovery structures, or alternative funding mechanisms taking into account the cost of service;
4. Social sustainability, meaning that society supports the activities opted for, bringing along willingness to pay for services;
5. Institutional sustainability, implying that the respective bodies involved with planning, operation and management of system is capable of taking on these tasks in a sustainable manner.

Various authors [9, 11] identify 4 levels at which desalination education should take place:

- Undergraduate engineering;
- Graduate engineering
- Training and short courses for field engineers and technicians and
- Research at MSc and PhD levels.

The main objective of the application of desalination education, aimed at different levels, and to different groups of people, is to provide comprehensive theoretical and practical aspects in desalination to the manpower at all levels required to design, develop, construct and operate different desalination processes in an efficient and safe way, from hands-on plant operation, to advanced research, optimising desalination technologies.

The benefits of this are the following:

- Reduce the time and costs for training of newly hired staff, due to a quick understanding of the working environment;
- Provide the necessary theoretical basis for better understanding of different aspects of water desalination;
- Learn about elements of other related industries, which include wastewater treatment, power plants, and air pollution.
- Gain knowledge and better understanding of new technologies adopted by various sectors of the desalination industry.
- Gain knowledge of recent data on market status, new projects, current production volumes, and future projections.
- Discuss trends, developments, and research in desalination.
- Reduce the gap between the industry, research centres, and universities. [11]

All in all, courses comprising technical aspects of desalination technology alone are not enough. If desalination is to be successfully implemented in the region, undergraduate and postgraduate programmes involving an integrated approach to sustainable water management are needed and desalination, wastewater reuse and irrigation management should be part of these programmes. [9] These programmes should result in better functioning staff in the sector both in the public sector and in the private sector, at operational, and management of operations level, as well as with governments and other public bodies at planning level.

6.2.2 Formal Education

There are a number of universities in the region that have a desalination curriculum, but this is generally part of a more general study in chemical, civil or mechanical engineering. A degree in desalination may be too much of a ‘niche’ education, so a desalination specialist coming from the universities that are currently active in the field of desalination would have one of the before mentioned degrees, and would write a thesis on desalination. Some of the universities in the region with considerable contributions to desalination education are:

- Kuwait University – Kuwait
- King Abdul-Aziz University – Saudi Arabia
- King Fahd University – Saudi Arabia
- King Saud University – Saudi Arabia
- Alexandria University – Egypt

The only compulsory undergraduate course offered in desalination, is at the Chemical Engineering Department of Kuwait University. [11] Other mechanical or chemical engineering departments offer the water desalination course as an elective only. Despite the above-described restriction of ‘hyper-specialist’ niche education, in two of the countries under investigation, there are plans for developing a curriculum that leads to a degree in desalination. In Jordan this is the Jordan University of Science and Technology, and in Tunisia this is the Ecole Nationale d’Ingénieurs de Tunis.

Other universities and institutions with attention for desalination in their curriculum, are the following:

- Al-Azhar University - Gaza
- Ben-Gurion University of the Negev - Israel

- Hashemite University - Jordan
- Hydraulic Research Institute - Egypt
- Kuwait Institute for Scientific Research - Kuwait
- Royal Scientific Society - Jordan
- The University of Qatar
- University of Sfax - Tunisia
- Technion-Israel Institute of Technology - Israel

6.2.3 Research and Development

In spite of the widely acknowledged importance of desalination for the region and compared with the capacity of existing installations, relatively little desalination R&D is carried out in the region's universities and relatively few provide related post-graduate courses.

Conditions vary considerably from one country to the other, but the lack of desalination research in the MENA region's universities can generally be attributed to a combination of commonly observed factors:

- Many universities have limited financial resources for research facilities and assisting staff.
- There is often a shortage of staff positions and of opportunities for advanced qualification between the graduate and the professorial level. This affects the capability to do research at a university since, classically, much of the research at universities is done in the context of MSc, ME and PhD programs.
- Researchers in the MENA countries often lack contacts with manufacturers and have little access to the actual development needs, both of which provide much of the stimulus for R&D. [12]

A number of institutes and organisations, other than universities, that support or enhance capacity building in the desalination sector are described below.

- MEDRC, the Middle East Desalination Research Centre is an organisation aimed at dissemination of desalination technology and know-how, aimed decreasing the price of desalination and increasing the acceptance of desalination. The Centre supports desalination research by third parties financially and is aiming at developing in-house research facilities as well. Capacity building in the region is enhanced by the provision of training programmes and academic interchange.
- Dar Al-Taqniya Institute, part of the Bushnak group, which is a private technology co-operative of scientists and engineers, providing not only design, engineering and other technical services, it also provides a wide range of training and education programmes to Arab professionals in the water sector. The Institute’s activities are largely aimed at advanced water treatment technology, including desalination.
- Mohammed Bin Rashid Technology Park, Dubai, which has the objective of providing a regional platform for the transfer of technology and makes it actual ‘local knowledge’ through the attraction of foreign technology. It is also a platform for the commercialisation of innovation and aimed at enhancing a knowledge-based economy. One of the high-tech clusters announced by the technology park is desalination and water resources. The Park was announced on May 21 2002 and is under development.
- Saline Water Conversion Corporation is the Saudi operator for water desalination. It does not only desalinate water, but also participates in developing this industry through its own research and studies centre. Its efforts resulted in the invention of a new method of desalination by using micro filtration membranes (Nano) which helped overcome many problems mainly scaling and contamination of desalination equipment. Further, SWCC constructed a training centre and trained thousands of Saudi manpower for the technical skills required in this industry.

Outside the region there are numerous institutions with extensive water curricula and specialist courses in the field of desalination. One of the leading institutions is UNESCO-IHE Institute for Water Education, which was founded (initially as IHE) in 1957. The Institute delivers some 250 international water and environment specialists annually, and provides a wide range of post graduate courses and training programmes in the fields of water, environment and infrastructure. Education and research is carried out in the field of institutional development, capacity building and education, HRM development, and applied research. The Institute holds internationally recognised expertise and experience in the field of desalination, and provides a specialist desalination course..

Besides well-known organisations, there are numerous research institutions and universities specialising in desalination research, or offering courses in desalination, literally all over the world. A rather random sample of these institutions is presented below:

- Sea Water Desalination Research Centre of the University of Tianjin – China
- Long Beach Seawater Desalination Research and Development Facility, under construction, to be the largest seawater desalination research facility in the country – USA
- NED University of Technology and Engineering offers a course in desalination in Karachi – Pakistan
- Las Palmas University (Gran Canaria) offering courses in desalination – Spain
- Nanyang University which has carried out various research projects in the field of desalination – Singapore
- The university of New South Wales, School of Chemical Engineering and Industrial Chemistry, courses in desalination, and home of the Australasian Desalination Association - Australia

Many international organisations that are active in desalination research and education can be found in membership directories or organisations like the European Desalination Society and the International Desalination Association.

6.2.4 Knowledge and Information Exchange

Training, Informal education and information exchange

A restraint in capacity building for many countries receiving international support is that many studies such as technical studies and feasibility studies are often done by foreign agencies as external support while executions of these projects are implemented with little involvement of the national experiences. Many of the external supports are spent on studies whereas very little are allocated to capacity building and human resources development. [10].

Whereas there seems to be a quite active exchange of knowledge and experience in the desalination sector, with active knowledge exchange platforms like IDA and EDS, it is remarkable that there is no library well resourced with desalination material freely open to researchers, students and industry professionals in the Middle East and North Africa. MEDRC is however preparing to establish such a library in Muscat. Moreover, there seems to be limited information exchange between operators and utilities about their experiences. This can partly be attributed to the fact that much of the state-of-the-art expertise and experience gained in the desalination sector, be it design, construction or operations is related to commercial interests.

Utilities and Operators (Public and Private)

The development and strengthening of the operational environment can be aimed at strengthening public water companies that are being prepared for their new role in a private sector arrangement, or technicians who are taught to work with new, high-tech technologies. This process starts with recruiting qualified and motivated staff, and keep them motivated. Most of the water sector agencies in the Arab World are staffed with a large number employees. For the countries under investigation, this is particularly the case in Tunisia, which has a very high number of staff per 1000 connections. Qualifications of staff are usually low. In many cases the proportion the University graduate is less than 10% and roughly more than 70% of the employees have less than a high school certificate. [10]. Jordan is good case example. The government has great difficulties attracting qualified staff for their water operations in Aqaba. The town is rather isolated from the rest of the country and expensive to live in. Yet, since employees of the water company are civil servants they cannot be offered competitive salaries, and it is therefore difficult to attract qualified employees. But attracting qualified people by paying a competitive salary alone is not enough. Continuous learning and motivation, through classroom education or on-the-job training is equally, if not more, important.

Ian Watson, in an article for Watermark [12] highlights some possibilities for staff motivation and education, which can be used either in combination or as separate measures:

- Develop and incentive programmes for staff who find ways of more efficient operation and promote active interchange of ideas and discussion;
- Provide possibilities of attending seminars and formal training, but do not underestimate the value of possibilities and benefits of on-the-job learning;
- Encourage staff by ensuring progressive management that promotes staff innovation and continued education;
- Involve senior operating staff in management meetings;
- Promote the free exchange of information between operating companies / utilities.

Insufficiently developed capacities and capabilities can lead to erroneous decisions and quick deterioration of infrastructure. The example of Algeria is described by Salim Kehal. In the eighties already some desalination capacity was developed in the country. Due to poor administration, hardly any reliable data are available for these plants, but some trends can be recognised, related the sector being immature. After the first few years of functioning the plants started operating below their optimum capacities and this for several reasons:

- Inappropriate choice and design of the process
- Lack of maintenance and spare parts
- Unavailability of skilled labour. (Salim Kehal, 2002).

The local market for desalination related activities is still under developed, since the majority of activities related to desalination, be it design and engineering, construction, or operation are being carried out by foreign parties will little involvement of national companies. An exception to this rule is the recently created and publicly owned Algerian Electricity Company, which acts as a promoter of desalination plants, upon the instigation of the Algerian government.

In the utilities and particularly in desalination facilities it is crucial to have sufficiently motivated and educated staff at all levels, including operational technical staff, since decisions that are based on insufficient knowledge can have a quite destructive effects on the operation of a high-tech as a desalination plant. Since the start of desalination in the MENA region, the manufacturers of desalination plants have called for more efforts in training, partly because many of the desalination plants were deteriorating faster than their design lifetime. This vision is shared by regional plant owners and policy makers. [13]. Also the Wangnick study [14] underlines the adverse impact of insufficiently skilled labour operating desalination plants. Desalination plants in Abu Dhabi, for example, are running significantly below their designed availability of 90-95%. Wangnick attributes this to the very limited training of staff working at the plants. This is illustrated by a very low spending on training, as compared to the total investment on desalination infrastructure. Training programs in desalination for practicing engineers and technicians are not fully defined or well developed. Elements and duration of field training for starting engineers/technicians differ considerably from one plant to another. [11]

In the countries under investigation (Algeria, Jordan, Tunisia and Uzbekistan) no official desalination training facilities are known.

6.2.5 Capacity Building for the Private Sector

One of the strong pleas of parties like MEDRC is to not only enhance the skills of people involved in desalination from a operational or planning perspective, but to rather also aim at developing capacities and capabilities of the commercial sector in the MENA region and Central Asia. It is a fact that in the two regions there is hardly any production capacity of high-tech components of a desalination plant. This is dominated by companies from the for example the USA, Europe and Japan. The small units in Uzbekistan were partially of Russian make, so one could consider these containerised units a regional product. Areas requiring strengthening thus could include localising design, fabrication and construction of desalination plants and the development of desalination business incubator centres. [15]. While one can question the commercial viability of such an initiative (taking into account regional trade restrictions, limitations in knowledge and fierce international competition), there are local political arguments in favour of this, primarily to make the region less dependent of foreign assistance.

Consultancy and engineering activities should be more localised where possible. Various authors identify limitations in knowledge and skills transfer to local parties when (large) projects are developed. International companies are often hired to provide engineering services, as well as advisory services in the field of technical, legal, organisational, financial and environmental matters. These services are often provided with only limited local involvement, and insufficient attention of 'on the job' training of local partners.

A very limited number of companies active in the field of desalination (design and engineering, construction and O&M) are based in the countries under investigation. The ones that are based in the region, are mainly from Gulf countries. A selection of firms is presented below:

- AquaTreat is regional company, active in the Gulf countries, and Jordan. The company offers engineering, procurement, assembly and construction services. It has the ambition of expanding its services with O&M services.
- Dar Al Taqniya is part of the Bushnak Group of Saudi Arabia. It has some 50 years of experience in the field of desalination, offering process design and detailed engineering services, extensive advisory services, and construction management services.
- IDE Technologies of Israel develops, designs, installs state of the art desalination technologies. It is one of the very few specialist operators of desalination plants in the region, and operates among others the Lmaca desalination plant in Cyprus.
- SOGEX of Oman is a general contracting company active as electromechanical contractor for erection of power and desalination plants. It is also active in operation, maintenance and management of power and desalination plants since 27 years. It operates some 6 major plants, including the Arzew desalination plant which is under construction in Algeria.

6.2.6 Capacity building for the Public Sector

In the countries visited there are some limitations in the capacity of governments to deal with the development of desalination infrastructure. While in many of the technical departments there are skilled engineers, specialist knowledge of desalination is often centred around a small number of individuals. At the same time, it is clear that not only technical skills but also knowledge and experience of integrated water resources management, sector development planning, tender procedures, and legal issues are very important.

There seems to be a general requirement for strengthening the capacities of central public bodies. This need was recognised in all 4 countries that are under investigation. A number of measures that can be taken are the following:

- Give priority to human resources development through continuous education, in-service training, career development, and short-and long -term training. This includes the necessity of paying structural attention to 'learning by doing', for example in relation to the development, tendering and implementation of projects. Particularly in large-scale projects, very much foreign expertise is used. This expertise should be built upon in a structured way, and more attention should be paid to knowledge transfer. A very good case-example is found in Jordan, where the development of a large BOT project has been a very interactive process between the Government, its advisors and the potential bidders for the project, resulting in a very steep learning curve for the government officials that are involved in the process.

- Strengthen or develop a national water training centre and provide it with the necessary support in order to identify, encourage, promote, and organize human resources activities and training needs. This training centre should preferably have a broad portfolio of courses; a curriculum that goes beyond technical matters, but includes the issues mentioned above.
- Ensure that recruitment of new staff is based on sound criteria and meeting clear qualifications and provide job security and longevity to qualified personnel, while at the same time seeing to qualified and particularly valuable staff receiving competitive wages, so as to increase chances of them remaining with the Government.; and
- Encourage coordination between universities and public sector to review their curriculum according to the needs. [10]

A potential general challenge when it comes to public sector strengthening is that 'hire and fire' policies are commonly restricted. There may be general limitations in the wages that are paid in governmental departments, while job security is very high. Thus it may be difficult for Governments to attract the most highly qualified people, and equally difficult to re-deploy under performers.

6.2.7 Desalination Training facility

The study carried out by Wangnick [14], funded by GTZ addresses the need and feasibility of creating a regional desalination facility for the MENA region. In previous paragraphs the need for this facility is addressed already, indicating that some 36,500 staff will need training for current and future desalination plants. (until 2010). This includes a total of 13,500 people from Saudi Arabia, which will likely be trained at national facilities. This still leaves a large demand of 23,000 people in need of training in the MENA region.

While the study recognises the enormous need for training of staff, it also paints a rather modest, and probably realistic, picture of the capacity of the training facility to be developed. Based on calculations of realistic costing and investments, and limited durations of the training, it is estimated that some 300 people can be trained in the proposed location, annually. This is only 1/5 of the estimated need of 1,500 staff that needs to be trained annually for new facilities only. However, if one would calculate the need from 2005 until 2010 based on the above mentioned figure of 23,000 staff that needs training, a need of almost 4,000 people to be trained annually arises.

It is thus very clear that urgent action is required with regard to the creation of a training facility for desalination in the region, since there is already a large shortage of skilled staff, resulting in under-performance of a number of desalination plants.

At the same time it is obvious that a regional desalination centre, as studied by Wangnick is not sufficient to address the needs of many of the individual countries. So, in addition to the proposed regional centre the respective countries will need to develop their own education and training centres in the field of desalination. This can be achieved through the development of the previously discussed academic curricula, or through development of training facilities. One approach towards addressing short-term needs can be that training capacity is developed on-site in countries with already existing desalination infrastructure.

6.2.8 Capacity building

Research, training, and capacity building needs to be enhanced to be commensurate with the anticipated growth in the desalination market.

There is a very large need for training of staff that works at desalination plants, and to staff future desalination plants. The current quality of staff limits the performance of the sector. Recent studies show that until 2010 some 36,500 staff needs to be trained to improve sector performance, and to facilitate the growth of the desalination market in the MENA region alone, just to cover the technical and operational aspects of desalination. Saudi Arabia may be able to address its own training needs, while the rest of the MENA region with an estimated training need of 23,000 staff until 2010 faces a serious constraint in training facilities. A regional training facility is under investigation, with an estimated capacity of some 300 trainees annually. This is not sufficient to address current and future needs. Therefore national governments will need to invest in training capacity in the short run as well.

The educational requirements are even larger if one takes into account capacities and capabilities that are closely linked to the development of desalination infrastructure, such as:

- The plea to develop more local technical capacities and capabilities in the development of desalination infrastructure.
- The need for more professional staff at governmental level, capable of understanding desalination technologies, but also staff that is capable of contracting out the development of infrastructure and monitoring of the implementation of contracts;

Increasingly it is perceived that training in technical and operational aspects of desalination technology alone are not sufficient, and should be complemented with subjects like integrated approach to sustainable water management, water conservation, wastewater reuse and irrigation management.

A restraint in capacity building for many countries receiving international support is that many studies such as technical studies and feasibility studies are often done by foreign agencies as external support while executions of these projects are implemented with little involvement of the national experiences. Many of the external supports are spent on studies whereas very little are allocated to capacity building and human resources development. [10]. On top of this there are limited investments in R&D in the public sector or at institutes and universities in the MENA and CA region, except in the Gulf region.

If desalination is to be successful and widely adopted there will be an increased demand for competent people at all levels. Crucial in this respect are the decision makers. Decisions on water are usually long term and can involve significant capital expenditure. It is therefore important that those making the decisions are well informed and can take all of the factors involved into consideration. Currently there are very few places where managers can acquire these skills. This is an issue that needs to be examined. At the other end of the scale there will be a need for operatives and technicians. Most of the Gulf States established national training facilities to satisfy local demand, MENA and possibly CA countries should learn from the best practices in the Gulf region in this respect.

The development of regional or local centres for desalination education is highly recommendable to ‘localise’ capacities and capabilities. Plans are in place to develop a regional centre for desalination education. But such regional centre will not be sufficient to meet the expected needs of the market. Therefore MEDRC is giving urgent attention to raising awareness at universities, trying to motivate them to include desalination as a an important aspect of their curriculum in for example mechanical or civil engineering degrees. Tunisia and Jordan are considering the development of such curricula.

It is also recognised that the MENA region uses desalination but has made no real contribution to the development of the technology. MEDRC, rightly, believes this should be changed so that the MENA region is less dependent on outside assistance. With regard to consulting, design and engineering, and plant operations, as well as construction of "generic" civil, mechanical and electric parts of a plant the aim should indeed be to develop strong local and regional expertise and skills. However, the call for local production capacity of high-tech modules, such as membranes, might be difficult to achieve based on commercial arguments. From a local and regional political perspective this call for more local production is understandable and possibly justified.

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7 Private Sector Participation

Planning is the key word in developing the desalination sector in a country. As described in other chapters, any desalination activity should fit within a larger picture of optimising the use of existing water resources, reducing losses, managing demand properly, allocating the limited resources wisely and re-using water efficiently to the extent that it is feasible.

Once a government has determined that it is necessary to develop desalination capacity, the main issue is how this can be realised. Desalination plants are capital intensive, and require specific high-tech knowledge, both of which are scarce in the four countries that are subject of this study. Therefore a realistic option might be to turn towards the private sector as a provider of both capital and knowledge.

In Appendix A the rationale for Private Sector Participation the various options for Private Sector Participation in the provision of water services is discussed more extensively.

7.1 Rationale for Private Sector Participation (General)

The most important reasons to include the private sector in public services provisions, the so-called 'drivers' for PSP can be summarised as follows:

- Increased access to (private) capital investments, and effective use of capital;
- Increased technical and managerial capabilities in the water sector;
- Increased operating efficiency;
- Increased customer focus;
- Reduced need for, but, more transparent subsidies.

For PSP in desalination projects, which usually is aimed at bulk water supply only, the increased customer focus argument does not apply. However, the issue of reduced needs for subsidies and more transparency in the allocation thereof, and the lack of public investment funds have been reasons for many governments around the world to attract private sector companies to enter into long-term contracts, preferably with an investment obligation for the often international private water company.

Ever since the start of the tendency towards contracting-out water and wastewater services under long-term management contracts, leases, concessions and full privatisations, opponents have argued that this should be a publicly managed sector per se. A common argument is that the private sector's profit objective outweighs possible efficiency gains achieved through private sector involvement. Efficiency gains after the introduction of the private sector in utility sectors amount to some 10-30% on average. [1]. The upper scale of this average is well above the profit a private sector party should (be allowed to) gain on the provision of public services.

With regard to impact on tariffs this means that if water tariffs are set at or near cost-recovery levels, a tariff increase is not necessarily needed. Unfortunately, in many countries in MENA and CA tariff levels are not set at below cost-recovery levels.

7.2 Types of Private Sector Participation

Although there is a multitude of types of contracts for private sector operations of water and wastewater systems, a brief description of the various options for private sector participation in the water services delivery is given below.

Service Contracts

Service contracts include supply and civil work contracts, technical assistance contracts, plus sub-contracting or contracting out aspects of the water supply service. These sub-contracts can address a wide range of activities, ranging from meter reading, billing and invoicing and customer service management, to design activities, O&M support and construction activities. In cases of political and/or social opposition against PSP in the water sector, service contracts can be a good means to introduce the efficiency of the private sector to the public sector. At the same time it can be a first careful step towards further private sector involvement.

Management Contracts

A management contract resembles a service contract, to the extent that only services are provided and no capital investments are made and very limited commercial risks are transferred from the utility or public authority to a private party. The main difference is that rather than contracting out various 'bits and pieces' the authority or utility contracts out its operations in full, or at least a significant part of it. Investment responsibilities remain with the public sector, so consequently management contracts particularly address the improvement of service standards to existing customers. Since there are no private sector investments, service area expansion or increasing treatment and production capacities are not facilitated by a management contract.

Lease Contracts

Lease contracts include the transfer of the entire operation of a utility in a certain area to a private party. The utility leases its infrastructure to an operator against a lease fee, while the operator, in exchange, gets the right to collect water charges from consumers for its own account. Typical tasks of an operator under a lease contract include the optimisation of billing and collection rates, bringing down operational costs, increasing customer focus, and improving the overall quality of the infrastructure by seeing to professional maintenance

BOT Type Contracts

BOT, build-own-operate-transfer (BOOT), and Rehabilitate-own-Transfer (ROT) schemes come in a wide variety, and are similar to lease contracts. However, BOT contracts are particularly aimed at bulk supply, rather than at retail services. BOT and alike contracts are typically used for new infrastructure to be built (or: 'green field' projects). In the water sector this type of contract is used particularly for water and wastewater treatment infrastructure. BOT contracts are usually concluded for a duration between 10 and 30 years.

Concession Contracts (full utility / retail)

A concession contract leaves the entire commercial and capital investment risks to a private operator, which is typically allowed to use already existing infrastructure to supply customers with water and wastewater services. A concession contract thus combines the BOT characteristic of large-scale investments and the lease characteristics of taking on the responsibility for an entire system and its operation. The typical duration for a Concession contract is around 25 years.

Divestiture / Full privatisation (retail)

Under a divestiture arrangement the assets of a utility are transferred to a private (or public -private) party or joint venture. In a full divestiture, the private sector has full responsibility for operations, maintenance, and investment in a utility. The private party thus becomes the owner of the infrastructure.

A brief overview of the main characteristics of the most common types of private sector participation is given in Table 7.1.

Table 7.1 Types of PSP

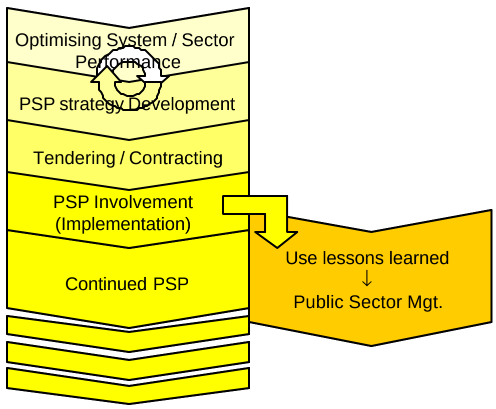
	Management Contract	Lease contract	BOOT / BOT / BOO / concession	Full utility concession	Asset sale / Full Privatisation
Time Horizon	2-5 yrs, up to 10	10-15 yrs, up to 25	10-30 yrs, up to 95 yrs.	20-30 years	In perpetuity, may be limited by licence
Customer	Government/ Municipality	Retail customer	Government/ Municipality	Retail customer	Retail customer
Ownership	**Public**	**Public**	**Private, then Public**	**Public**	Private, or public and private
Investment	**Public**	**Public, limited private**	Private	Private	Private
Tariff collection	**Public/Private**	Private	Public	Private	Private
Cash flow profile	**Fixed-fee for service paid directly by government, may include performance payments**	**O&M fee paid directly from retail customers and thus subject to market risk**	**Post-construction purchase contract, typically with a (public) utility**	**Subject to market and regulatory risk**	**Subject to market and regulatory risk**
Construction risk (private party)	None	None	High	Low	Very low
Operational Risk	**Public**	Private	Private	Private	Private
Commercial risk	**Public**	Shared	Private	Private	Private
Regulatory risk	None	Medium	Low	High if politics volatile	Very high
Security interest	Not relevant	Right to part of cash flows generated by assets. Usually no right to own or pledge assets	Right to cash flows generated by assets; usually no right to own or pledge assets	Right to cash flows generated by assets; usually no right to own or pledge assets	Ownership rights to pledge as security; shares are tradable

Source: Adjusted from Masons Water Yearbook 2001-2002, Tapping the private sector, Haarmeyer and Mody, 1998, World Bank Toolkits for PSP in water supply and sanitation, 1997

7.3 Process towards Private Sector Participation

In Figure 7.1 an overview is given of the ideal process towards private sector participation. The process is described in the following paragraphs.

Figure 7.1 Path towards Private Sector Involvement



7.3.1 Determine clear PSP / PPP policy

A very first step towards PSP is the development of a policy framework. This policy should be a clear statement regarding a government's commitment to implementing a PPP policy in a professional and sustainable manner. The policy should demonstrate a "partnering friendly" culture, and provide a systematic approach to conducting PPP for different market segments or services. It should complement existing policies with regard to planning, procurement and other areas, and ensure that the PSP / PPP contracting and execution process is fair, transparent and in the public interest.

The goals of a PSP policy are the following:

- Define PPP / PSP as seen by the host country, and identifies potential partners;
- Ensure that PSP is explored as an option for service delivery or attracting investments;
- Ensure PSP is used only if and when appropriate;
- Communicate the approach to PSP to all stakeholders and potential stakeholders;
- Define codes of conduct;
- Indicate the various possibilities of tendering, ranging from unsolicited bids to international competitive bidding;
- Identify risk, concerns, and responses to these risks and concerns. [2]

Jordan is rather advanced in this respect. The country has a clear-cut privatisation policy, with a transparent set of rules and regulation to support private sector involvement.

The trends with regard to PSP in desalination in the study countries are summarised in Table 7.2:

Table 7.2 Status and strategy of PSP in desalination in the study countries

Algeria	
Current status PSP in Desalination	*Strategy and future*
In Algeria, a number of desalination plants which have been developed under a BOT arragment is operational or under development. The Arzew	The Algerian Government has ambitious plans for the development of 10-12 large-scale desalination plants. Some of them will be developed as BOTs,

plant is already operational, and has Black and Veatch as main investor. This is a IWPP, using MFS technology, with a 90,000m3/day capacity. In Oran a BOT, with Degremont as main promoter is under construction. (estimated capacity of 100,000 m3/day). The Hamma RO plant (planned capacity of 200,000m3/day) has been developed as a BOT and is under negotiation. Besides the large scale desalination plants, 12 small scale plants have been provided under a turn-key arrangement by a German supplier. (Linde).	others will be funded with government budget. No clear strategy seems to be in place. Algerian Energy Company is the main promoter of BOTs in Algeria. It started of with energy projects, but is now also developing IWPPs, including the Hamma plant, which is to be the largest desalination plant in Algeria, and possibly the largest RO plant in the world. No clear PSP strategy has been found.
Jordan	
Current status PSP in Desalination	*Strategy and future*
There is no private sector involvement in desalination plants in Jordan. Currently a WWTP is being tendered under a BOT arrangement. More BOT projects are planned, but no concrete plans are yet in place to develop a desalination plant with private sector participation.	In an unofficial statement the Minister of Water stated that if Jordan is going to develop large-scale desalination, this will be done under a BOO arrangement, transferring the responsibility for the infrastructure to a commercial operator in 'perpetuity', so as to avoid public sector risk in the operation of a desalination plant. IN order to facilitate private sector involvement, the national water law was amended.
Tunisia	
Current status PSP in Desalination	*Strategy and future*
Sonede, the public utility, currently operates the medium-sized desalination infrastructure in the country, without private sector involvement	PSP is an option in desalination in Tunisia. The planned Jerba desalination plant (15,000 m3/day) is to be developed under a BOT arrangement. Furthermore, 10 medium sized brackish water treatment plants may be developed under a private sector arrangement in the future.
Uzbekistan	
Current status PSP in Desalination	*Strategy and future*
Although there is limited private sector participation in the water sector in Uzbekistan, there is no PSP in the desalination sector. In Karakalpakstan, where the majority of desalination capacity is installed, a law has been adopted that allows PSP (management contracts). Private ownership of water infrastructure in not allowed in Karakalpakstan.	The relatively small scale of the desalination operations and the lack of cash revenues of the water utility makes private sector involvement not very likely in the short run. Currently not even service contracts are envisaged. In terms of more more advanced PSP, a concession is under development in Charesm region, but this concerns a water supply system as a whole, without desalination.
Cyprus	
Current status PSP in Desalination	*Strategy and future*
In Dhekelia and Larnaca there are two large-scale plants operated under a BOT contract. The government is satisfied with this approach, which is working quite well.	The current contracts are relatively short-term BOT's with a contractual term of 10 years. Once the contracts expire, it is likely that management contracts will be tendered for the operation of the infrastructure. If there would be a need for rehabilitation or extension of the plant capacity, a lease contract (actually further BOT or ROT) might be considered. The development of two more desalination plants is envisaged. (Limassol, already under preparation, and Pafos, long-term plan). There is no reason to assume that the Cypriot government would not contract out a BOT contract for these two plants.
Malta	
Current status PSP in Desalination	*Strategy and future*
Currently no PSP, and no PSP planned. Government took over private sector management of desalination infrastructure. It is now operated by a government owned, independent company, MDS.	PSP not likely in the near future in Malta

7.3.2 Identify strengths and weaknesses of the water sector

If PSP is opted for, it is important to choose a clear path towards PSP. It might be advisable to first restructure the water sector, start making water tariff adjustments, before introducing a private sector party. If the private sector party is made responsible for both internal and external performance improvement of a utility, it may be turned into a scapegoat who is blamed for the loss of employment, increasing water tariffs and possible other perceived negative side-effects of commercialisation of water supply. Reality is, however, that private sector involvement in such cases is merely uncovering sector weaknesses that have remained hidden under public service provision. [1] Strengthening the water sector may very well require a 'light' form of private sector involvement. A good example is the approach opted for by the Ministry of Water in Amman. A management contract is currently under execution, which should prepare the water company for further commercialisation in a later stage. Even though this cannot be stated with certainty, this will most likely be under a hybrid 'corporatisation' model, that will turn the utility into an independent company, with commercial operations, while the utility remains in state ownership. Adequate arrangements and preparations are essential in advance of the date that the present management contract expires.

7.3.3 Determine the right form of PSP

If a government intends to pursue improvement of the quality of water service delivery through PSP, it should consider carefully what type of PSP is required for the particular needs within the service area. Criteria for determining the right option include the following considerations:

- What are current stakeholders attitudes;
- Are capital investments required;
- Should assets remain publicly owned;
- To what extent does the government want to keep control over the operations;
- Which risks are to be transferred to the private sector.

Table 7.3 Conditions for successful implementation of private sector options

Option	Service contract	Management contract	Lease	BOT	Concession	Divestiture
Stakeholder support and political commitment	Unimportant	Low to moderate levels needed	Moderate to high levels needed	Moderate to high levels needed	High levels needed	High levels needed
Cost recovering tariffs	Not necessary in the short term	Preferred but not necessary in the short term	Necessary	Preferred	Necessary	Necessary
Good system information	Possible to proceed with only limited information	Sufficient information required to set incentives	Good information required	Good information required	Good information required	Good information required
Developed regulatory framework	Minimal monitoring capacity needed	Moderate monitoring capacity needed	Strong capacity for regulation and coordination needed	Strong capacity for regulation and coordination needed	Strong regulatory capacity needed	Strong regulatory capacity needed
Good country credit rating	Not necessary	Not necessary	Not necessary	Higher rating will reduce costs	Higher rating will reduce costs	Higher rating will reduce costs
Potential benefits of the option	Low →					High

Source: World Bank, Saghir, Schiffler, Woldu, – Water and Sanitation in MENA – the way forward, 2000

Not only is it important for a government to know what exactly it wants to achieve by involving the private sector, and realise which criteria it will use for determining their preferred option of PSP, it is also important to determine what types of PSP can be ‘absorbed’ by the government, and whether it can meet common conditions for successful implementation of the various options for private sector involvement. A concise overview of these conditions is provided in Table 7.3.

7.3.4 Tendering and Contracting: Ensure clarity, transparency and stability

Once the decision has been taken to involve the private sector in the provision of services in the water sector, or the realisation of water supply infrastructure, a country should see to being prepared for private sector involvement. This means that for the particular topic of PSP a set of rules and regulations needs to be adopted, defining the roles and responsibilities of various actors in the process and transparent processes for award of contracts to service providers. Whereas governments design this process, it is to be enforced by a regulator, which can be an independent institution or a governmental body. A stable environment enables a private party to operate efficiently and effectively, which is beneficial for all parties involved. [3]. In theory the legal environment should be well developed before the initiation of any PSP activity. In reality however this process often runs in parallel with a tendering process for private sector involvement. Yet in theory, the following issues should be in place before any steps towards tendering are taken:

- Clearly defined tendering and contracting procedures;
- Solid set of rules and regulations, including a sufficiently developed regulatory mechanism;
- Clear position on the role the public party is going play;
- Sufficient political commitment;
- Sufficient governmental guarantees and fair risk allocation principles;
- Sufficient knowledge of PSP and tendering and contracting at the government level to be a reliable and competent partner in tendering and negotiating with the private sector.

Tendering procedure

A tendering procedure for a PSP project, particularly with regard to the models that bring about private sector investments should ideally contain the following steps:

Phase 1

- Appointment of professional advisers (legal, financial, technical).
- Preparation of a strategy report for the implementation of the proposed project including the following:
  - Engineering aspects, including scope of contracts, performance criteria and standards, costing;
  - Preliminary environmental analysis;
  - Legislative analysis and recommendations for a new regulatory framework (if not already sufficiently in place);
  - Financial analysis and preparation of a financial model exhibiting appropriate discount rate;
  - Analysis of budget implications and likely availability of project finance;
  - Risk transfer analysis;
  - Possibly some market sounding with potential investors/developers;
  - Preparation of an indicative financing plan;
  - Preparation of an outline tendering plan including the determination of the criteria for technical and financial evaluation criteria of tenders.
- Preparation of public sector comparator, which forms the basis of the benchmark against which the private sector bids will be evaluated. The public sector comparator enables a government to determine the extent of the benefits private sector participation brings about.

Phase 2

- Pre-qualification of bidders;
- Management of the tender process with pre-qualified bidders including the following:

- Preparation of detailed tender documentation;
- Comparison of the bids according to the evaluation criteria;
- Selection of preferred bidder.

Phase 3

- Negotiation with preferred bidder up to Financial Close [4]

Defining the technology

The procedure for tendering a desalination plant is usually a process of international competitive bidding. There is ongoing debate about whether or not technology should be defined in the tender documents. It is argued that leaving the choice of technology up to the bidders, has significantly brought down cost, because bidders needed to consider all possible technical solutions. This argument is supported by the fact that during the tendering procedures for Tampa Bay BOT and the Ashkelon BOT, considered to be two of the most competitive BOT desalination contracts in the world no technology was defined. If no technology is determined, competitors will at all times try to apply the most suitable technology, and optimise the technology opted for.

Particularly in cases of PSP where investments and operations are to be the private sector's responsibility it seems logical to leave the choice of technology to the private sector.

There are some risks associated to not defining the desired technology:

1. Whereas the tariffs offered by the bidder are easily compared, additional factors, such as quality or technology are difficult to assess when different technologies are offered by the bidders;
2. Unfamiliarity with one technology may result in a client being biased towards another technology. The result may be that the most appropriate technology is not opted for during tender evaluation;
3. A very clear set of design criteria regarding water quality, pollutants, energy availability and cost, etc. needs to be drawn up, to allow bidders to determine the optimum technical solution, taking into all account local circumstances.
4. The most competitive offers may use a technology the client does not like. This can be either an unproven technology, or a technology that is environmentally undesirable. (for example very energy intensive, but competitive due to very low energy prices in a country)
5. Preparing a bid is expensive. Bidders may not like the uncertainty of non-specified technology. The Hamma desalination plant in Algiers had to be re-tendered, after no tenders were received during the first tender procedure in which no technology was defined. According to AEC (Algerian Energy Company) potential tenderers stated they preferred a technology to be determined prior to bidding for the plant.

The above demonstrates that the pros and cons with regard to the decision to include a preferred technology in tender documents depends much on local circumstances. Therefore prior to tendering a 'market sounding' should take place to determine potential bidders perceptions and preferences.

7.4 BOT Contracts in Desalination

As described in the introductory paragraphs of this chapter, there are many forms of private sector involvement. Desalination usually is aimed at the realisation of a water treatment facility, rather than at the development or management of an entire water supply system. The most opted for solution with regard to PSP in the desalination sector in the countries under investigation is the BOT or a similar approach.

7.4.1 BOT and similar contracts

Examples of BOT and similar contracts can be found in Ashkelon (Israel), Singapore, Cyprus, Antigua, and Tampa Bay. Tunisia is developing a project using a BOT approach for a desalination plant in Jerba.

As described before, BOTs are often used for the realisation of 'stand alone' parts of infrastructure, such as water production facilities. BOTs are particularly interesting when a utility or government generates sufficient cash-flow to run and maintain its operations, but lacks investment funds, and when it lacks the skills to run a facility itself, or take responsibility for it. BOTs are typically applied for greenfield projects, or major rehabilitation activities (ROT: Rehabilitate-Operate-Transfer). Under a BOT arrangement a private sector party is attracted to develop, design, construct and operate a facility, against a fixed amount per period, or for example against a fixed amount per m^3 of water produced or treated. After a predetermined period (usually between some 10 to 30 years), the infrastructure is handed over to the client, typically at no cost.

Desalination requires substantial investments. Under a BOT structure, the private party has sufficient control and guarantees to assure this financing. Many international operators are willing and able to deliver a project in an integrated manner, taking care of Engineering, Procurement and Contracting, followed by operations of the plant that was built, as proven in recent international bids. It speaks for itself that specialist operators / investors can run a plant very efficiently, bringing along state of the art technology and O&M experience. Proof of private sector efficiency can be found in the fact that desalination plants in Cyprus, Ashkelon and Tampa Bay at their time of contracting were each described as being the 'cheapest plant ever built'. All these plants are or will be run under a BOT agreement.

BOT aims at bulk-water supply, rather than retail water delivery. In other words, water is supplied to one main off-taker, usually the water utility, who distributes the water the consumers. This means that payment risks lie entirely with the utility, or with another public body ("the government" as a guarantor. The utility will have to collect its funds from the end-users, and transfer part of it, the full amount, or possibly even the full amount plus a subsidy to the BOT contractor. The latter will usually demand guarantees for payment, and a guaranteed minimum periodic payment, under a take-or-pay or similar arrangement. Herein lies one of the most important draw-backs of BOT contracts. This problem is accentuated further in water supply systems in which there are high percentages of physical and administrative water losses, and where tariff structures do not sufficiently reflect the 'cost of service' incurred by the utility. This topic is further discussed in section 6.5.3 on 'Limitations and drawbacks of BOT'.

Desalination plants make good candidates for project financing, for which it is usually possible to raise sufficient equity and debt to be able to develop a project. The most important reasons for this are:

- It concerns (often) large fixed assets with a specified construction period;
- It involves production of a product (potable water) sold to a monopoly which requires, in most cases, a long term contractual off take;
- Private sectors investors are providing either equipment/Engineering Procurement and Contracting (EPC) expertise or operational skills and are therefore keen to minimise their equity investment and maximise equity returns;
- It attracts traditional public sector interest in relieving capital burden, transferring construction and operational risk to private sector and attracting foreign investment and technology. [5]

From an private operator's perspective, BOT is interesting since it generates a long-term and steady cash-flow, contrary to the more 'hit-and-run' character of EPC (Engineering, Procurement and Contracting) or turn-key delivery of a plant. AEC of Algeria stressed this point repeatedly during discussions, as did the operators during discussions in Cyprus.

7.4.2 Rationale for BOT in desalination

Since desalination is a high-tech, and capital intensive activity, the particular advantages of the private sector involvement can be summarized as follows:

- Implement appropriate technologies, and take on technological risks.
- Capability of raising finance, both equity and debt;
- Utilize efficient management skills (limited extent)

These are three aspects BOT can bring along. In addition, BOT schemes, because they do not involve management of distribution systems down to the tap, are easier to implement than more comprehensive private sector models such as retail concessions, which require more extensive negotiation of contracts. In economies with poorly defined regulatory and legal structures and emerging capital markets, BOT schemes can be implemented relatively quickly and provide a building block for subsequent PSP in the rest of the distribution system [6].

The fact that BOT bulk water projects can potentially be implemented more quickly than PSP models that are aimed at retail water delivery, is very relevant for governments in countries with a significant and acute water shortage, who are turning to desalination as a solution to fill the gap between supply and demand.

The parties concerned have to be very aware of the risks that are brought along by turning towards a BOT model, including the risk of insufficient attention for network performance improvement, once the water flow increases and more water becomes available. An alternative in this respect could be to contract out a concession for the operation of a system, including the obligation to develop desalination capacity. A potential drawback is that this may have a significant disadvantage in terms of delay of the expansion of water production capacity, and it may result in a more complex tendering process. A parallel approach may represent the best alternative in this case.

Governments that are turning to BOT as a short-track solution to their water shortage should not decide too hastily for this solution, but should first consider carefully how the gap between supply and demand can be closed, at least partially, by demand management measures, network rehabilitation and water re-use.

7.4.3 Limitations and drawbacks of BOT

Whereas the BOT-model seems to be the most applied PSP model for the development of desalination infrastructure, it has some potential drawbacks and risks for the public sector. The BOT contract model, if applied to stand-alone infrastructure such as a desalination plant, is aimed at increasing the quantity of water produced. This may take away some focus on more comprehensive measures such as demand management, improvements to the transportation and distribution network and overall utility performance improvement.

Once network improvements have been made, and efficiency gains are achieved, the BOT contract may turn out to be based on too high a production capacity, resulting in over-capacity. Under a BOT contract it is likely that the utility or government will have to pay this overcapacity, whether it uses the water or not.

Some of the potential drawbacks are listed below:

- Contracts for private sector investment in bulk water supply may lead to an increase in the retail utility's costs. Overall cost of service may increase, since potentially expensive water is pumped into a distribution system with a sub optimum performance.
- Bulk water contracts have only limited potential for facilitating improvements in the efficiency of retail distribution systems. These contracts, unlike concession contracts, produce no direct incentives for the retail distribution utility to reduce or minimize sources of inefficiency associated with the general operation and management of the utility, other than the loss of water that has already been paid for. Increased water flows and pressure on the system may even aggravate leakage and losses.
- Demand management is an important element of the water market which can be easily

dismissed in favour of increasing supply. Demand management is usually not part of a BOT contract.

- Income risks are at times allocated largely to the public sector, potentially putting a significant claim on public income, particularly when the water supply system is under developed and when political and economic environments are volatile.

The drawbacks of a BOT-approach are reflected in some of the private sector contracts that were awarded in developing countries during the period between 1990 and 2001. Despite BOT's apparent benefits, full utility concessions which are much more complex were the most opted for solution, followed by BOT projects. The problems in many countries are not a water shortage in absolute terms, but rather serious transportation, distribution, and administrative problems. An integrated project, like a concession, can address these issues. [7]

Government commitment to projects is of crucial importance to private investors. Commitment may come in the form of governmental guarantees, or financial participation in projects. However, these risks are likely to materialise at times when a government can least afford it, like during financial crises or political unrest. [8]

The two main risks for a government related to BOT contracts are described below.

Take-or-pay risks

Particularly when large-scale desalination capacity is tendered and contracted under BOT or similar arrangements, there is a risk of burdening the public budget, and discouraging network rehabilitation. In one of the countries under investigation this risk may occur. The Government is planning installation of significant desalination capacity., under BOT arrangements. Once this capacity is installed, the government will likely be up for a take-or-pay agreement with BOT operators for some 25 years. Network rehabilitation does currently not seem to have the highest priority in country's policy, and may end up even lower on the agenda, once sufficient water arrives at the consumers' taps. According to the estimations of some officials in the country, the proposed installed capacity will result in 1/3 overcapacity, if a basic network rehabilitation programme is carried out.

If this is indeed the case it means that if further network improvements are carried out, and the full capacity is installed, the government will invest into network rehabilitation, and pay for the overcapacity of water produced too.

In one of the countries covered in this study the Government seems willing to take on a large part of the income risk. Without a solid governmental guarantee for payment of the sums due to the BOT contractor no private party would be willing to invest in the infrastructure, since water tariffs (retail tariffs) are very low and are heavily subsidized. Therefore the burden of a take-or-pay agreement will be heavy. If one assumes that the Government will pay around USD 0.8/m3 for the newly installed capacity, and charges on average USD 0.25/m3 to consumers, using a distribution system with some 50% losses (including administrative losses), governmental subsidy amounts to USD 1.425/m3 delivered.
To limit the impact on the state budget, tariff mechanisms will have to be rationalised and adjusted to reflect at least some level of cost-recovery focus. This applies to any country or region where privately produced water is going to be part of the total quantity of water sold, but also when a public party remains to be the service provider.

If a government ends up accepting high-risk take-or-pay agreements, this agreement may effectively be an expensive way of substituting private debt for public debt, due to the quasi-permanent public funding of the project, through the provision of a stable guaranteed payment to the project.
It should be noted that take-or-pay arrangements come in many shades of grey and usually do not impose a straight forward obligation for a government to buy the full quantity of water that

represents the design capacity of a plant against the full tariff. Rather, the actual amount paid periodically can be based on a payment for availability of the infrastructure (fixed cost) and an flexible amount for the quantity of water actually used, on top of the guaranteed quantity of water paid for whether it is used or not. In Cyprus, for example, there is a contractual mechanism, which determines different tariffs for a m^3 that is actually produced and purchased (full cost + reasonable profit) and the tariff for the quantity of water paid under the take-or pay agreement, but not actually produced by the BOT contractor. (Variable costs excluded).

Foreign Exchange risks

A major risk for the public sector entering into a BOT-like arrangement is the foreign exchange risk. Whereas the aim of a government will be do to as much business as possible in their own currency, private operators in desalination, particularly in the countries that are subject of this study and other developing countries, will often require payments in a 'hard' currency. This is because both investments and international expertise will often be sourced from outside the host-country. The private operator will thus be doing business, and take on loans, at least partially in hard currency. If a local currency is very volatile, the private operator will ask for guarantees ensuring that he will earn sufficient local currency to fulfil his hard currency obligations, which means that payments in local currencies will be indexed to a hard currency.

The apparent risk for the public sector was painfully shown in the power generation sector, where take-or-pay contracts, backed by foreign exchange guarantees to the private sector led to major financial problems for (Asian) public utilities during the Asian economic crisis. Significant devaluation of e.g. the Indonesian Rupiah (80%) resulted in the Independent Power Provider (IPP) solution being very expensive to the public utilities that had contracted IPPs with significant foreign exchange guarantees and inflation correction mechanisms. Extreme escalations of exchange rates and inflation cannot easily be recovered from customers, particularly not during times of economic crises. [8]

With regard to this risk there is a tension between the private sector and the public sector's objectives. The private party will usually seek to optimise the 'leverage' in a project by maximising debt financing, and limiting his equity involvement. However, the larger the debt financing, which in developing countries where capital markets are usually under developed will usually largely be based on international loans, the larger the risk for the local government or utility if it takes on exchange risks in part or in full.

This risk is, however, not only important in the case of BOT development of projects. Also in concession-like arrangements, large sums of debt funding are very common. While the government may have limited immediate responsibility for the currency risks under a concession agreement, it may have provided certain income guarantees to the operator. Alternatively, the operator may try to claim increased tariffs, or (in case of a severe crisis) go bankrupt.

To link back into the example of Algeria, the currency risk here is significant, assuming that payments are made in USD. Over the past 4 years, the devaluation of the Algerian Dinar compared to the USD has been some 20%. Although the contract conditions of the Hamma plant are unknown to the Consultant, it is rather obvious that if the Algerian government would enter into a 25 years agreement with full currency indexation risks allocated to the state, the potential burden on the state budget and thus the taxpayers is quite significant, taking into account the historic devaluation of the Algerian Dinar.

The only real way to off-set some or all of the foreign exchange risks is to develop local capital markets, but this is feasible only as a very long-term solution in many countries in MENA and CA.

7.5 Other Private Sector Participation in Desalination

Besides BOT and similar contracts there can be other forms of PSP in the desalination markets. Limited evidence of other types of contract was found. Projects in which a private sector party invests ‘at risk’ in infrastructure have usually a long contractual period. These periods have not ended yet. However, in Cyprus it is envisaged that once the BOT contracts expire, management contracts will be tendered to run the plants that are transferred to the government. These contracts may even be tendered as lease contracts (as per the terminology of Cypriot officials – this would rather be a BOT/ROT-type of contract) if it is envisaged that substantial investments are required for upgrading or expanding the plants.

7.5.1 Build-Own-Operate

Besides BOT, which has a project duration of between (for desalination) some 10 and 25 years, BOO (Build-Own-Operate) is an option to ensure long-term private sector involvement. BOO is very similar to a divesture, in terms of it being a transfer of ownership and execution of water production from the public to the private sector, in principle in perpetuity. A BOO, however, is usually aimed at the construction and operation of greenfield bulk water supply infrastructure, rather the divestiture of a retail water supply system.

The Minister of Water of Jordan stated recently that BOT is not the preferred contractual arrangement for desalination plants. He would rather see Build-Own-Operate agreement, where the private party remains to be the party responsible for operation of the plant. He stated that the public sector does not want the risk of operating a desalination plant, for which very specific technological expertise is required, and would therefore opt for the private sector to remain in charge of this type of water production.

An advantage of BOO for governments is that the responsibility for investments and re-investments in desalination infrastructure remains with the private sector. Although BOT contracts are usually structured in such a way that at the end of the contract period the facilities have to be in good operating condition, taking ownership of a facility constitutes a certain risk. This risk is eliminated under the BOO model, where a government has no obligation to take ownership at the end of a pre-determined period.

If BOO is opted for, but a government wishes not to hand over the entire control over a water resource to a private party, a BOO can be set up in a Public-Private-Partnership arrangement, in which the government can be a (strategic) shareholder in the venture.

7.5.2 Design-Build-Operate

The term DBO is used in many different ways. For the purpose of this report, DBO is assumed to be a PSP scheme in which the government participates as an investor.
DBO schemes are very similar to BOT schemes, with the exception that a considerable part, or the entire capital investment responsibility is taken on by the public party. In cases where governments have sufficient funds to invest in desalination infrastructure, Design-Build-Operate may be an appropriate option for the realization of infrastructure. In such case, the government itself takes on significant commercial risks, but does not have to pay a commercial water rate for possible over capacity, and may be less sensitive to exchange risks, if it can raise sufficient capital on national capital markets. Like any investor, a government can take on investment responsibilities, through equity and debt funding, up to different levels of involvement, including full investment responsibility.

DBO may be particularly advantageous in countries with a high perceived country risk, and where private equity and private debt may thus be expensive to acquire. The advantage over a management contract is that the DBO approach leaves the operation of the new infrastructure to the consortium that has built it, and is thus familiar with it. Under a DBO arrangement it is possible to determine a very clear set of performance indicators for the operation of a desalination plant, based on the assumption that the DBO contractor knows exactly what performance can be realistically expected during the operational period, since the contractor is in control of the entire process from design up to and including operation[4]. If the performance indicators cannot be attained this will be largely the risk of the private operator who has been responsible for the realization of the infrastructure.

The timing of investment by the government may vary from case to case. It is not uncommon that a government buys the facilities at a pre-agreed price upon commissioning of the infrastructure, leaving it up to the DBO consortium to pre-finance the construction period.

An advantage of DBO is that model streamlines a government's procurement steps and saves money by eliminating the separate stages and selection procedures for engineering, construction, procurement, and operations disciplines. [9]

A possible disadvantage of the DBO option is that the commitment of a private party to a facility it operates with limited risks of losing significant capital investments may be less than under a BOT arrangement.

7.5.3 Management Contracts

The Consultant has found no evidence in the studied countries of any ongoing management contracts for the operation of desalination infrastructure. The management contracts in Malta were finished after 15 years, and the government took over the operation of the desalination plants in the country, since public utility staff had learned sufficiently to operate the plants themselves.

Cyprus has the intention of contracting out their desalination infrastructure once the BOT contracts in Larnaca and Dhekelia have ended.

A management contract after the finalisation of a BOT contract is a potentially good mechanism to end any take-or-pay risks from the government. However, the real risk related to the plant's capacity will be for the account of the respective government. Basically, if the path of management contracts is chosen, virtually all commercial risks are passed on to the government.

Also reinvestments in the plant, for possible upgrading, refurbishment or capacity expansion will have to be made by the government. In the particular case of Cyprus, this issue is of limited relevance for the medium-term, since the BOT contracts were awarded for the duration of 10 years only. This means that ownership of the plants is transferred to the government at a point in time that may well be before the end of the plant's useful and economic life. This will depend among other things on the speed of further cost reductions in desalination, by which it is partially determined whether it is economically interesting to continue operations with an existing plant, to refurbish it, or to replace it.

At the same time also full risks for the physical infrastructure, that fall outside the operational risks to be taken on by the management contractor will be allocated to the government.

Yet, a (performance based) management contract can be a good way to ensure professional operation of a desalination plant. With sufficient performance incentives for the operator to promote operating efficiency, cost of water production may go down during the management contract, resulting in either a lower tax pressure, or lower water tariffs for the end user.

Particularly in countries where the level of technical advancement and professional skills of utility staff is limited, and risks of plant operation failures due to human errors are significant management contracts can be a valuable approach to successful plant operation.

[4] This applies to BOT as well.

7.5.4 Service contracts for small units

In areas where small scale desalination is taking place, and particularly in remote areas where numerous smaller units are installed it could be advantageous to contract out the operation and maintenance of desalination units. This was suggested to the water company in Nukus, Uzbekistan. The concept was considered as a reasonable option, however, the company stated it is not generating sufficient cash-flow to guarantee payment to a private party. Contracting out part of the specialist O&M could also be applied to the small-scale turn-key plants in Algeria, once they become operational. An alternative way of financing private sector involvement is to offer them a share in the efficiency gains achieved through their involvement. Whereas such an approach can be applied in many situations, it may be particularly conducive to PSP in circumstances where cash flows are limited or insecure.

7.5.5 Turn-key delivery (Algeria case example)

A form of PSP that is rather a 'classic' market approach is the turn-key delivery of infrastructure. In Algeria 12 plants are being delivered on a turn-key basis. These plants are part of an emergency measure to increase water supply to the city of Algiers. Whereas the success of this measure can be disputed (see also Country Report on Algeria, Annex 1) the approach to the development of desalination is rather unique. German company Linde was awarded the turn-key supply of 12 small-scale RO plants. During the initial period of operation, Linde is to teach and train local operators of Algérienne des Eaux on how to operate the plants. As soon as the period of instructions has ended, Linde's at-risk involvement ends and the government of Algeria will run the plants themselves.

A similar example is the Zara'a Main desalination plant in Jordan where the supplier will operate the plant for a certain period of time.

7.5.6 Post-PSP

As shown in Figure 7.1 there is a possibility of turning back to publicly run infrastructure. The case-example of Malta is striking. The government decided that it could operate a desalination plant just as well as the private operator, who was awarded a management contract. Malta thus turned away from PSP, due to a lack of typical drivers for PSP in desalination, in particular the fact that currently no heavy investments are required and the added value of private sector efficiency and knowledge does not seem to weigh against the price needed to deliver this extra efficiency. It should be noted, however, that much was learned from the private sector. It is likely that without private sector participation over a significant period of time, the Maltese public sector would not have been as capable as it is now to operate desalination infrastructure as it is now.

7.5.7 Role of the Private Sector in the Distribution of Desalinated Water

If the government is not in a position to distribute the water to the public by means of a water supply network the private sector might step in. Three types of small scale service providers are discussed here: mobile distributors, retail outlets and piped sub-networks. The options discussed below are based on a generic distribution models and are not based on actual desalination case-examples.

Mobile Distributors

A private company can enter into an agreement with an operator of a desalination plant to distribute the water through tanker trucks, or through the sale of water through large bottles or plastic containers delivered at the consumers address. They can provide water at times and places that water utilities are unable to serve. This service model can cater for very quick access to water in areas where no service infrastructure is available. Yet, although bottled water sales are increasingly important, it may not be a sustainable or desirable long-term substitute for municipal / piped water supply. Bottled water is expensive, and will thus primarily be used as drinking water. Bottled water can be a valuable addition to municipal systems where potable water quality is too low, and can be used as a short-term to medium-term solution to create greater access to desalinated water to all levels of society.

Retail Outlets

Retail outlets can be shaped along two main lines. In one model, similar to the one of the mobile distributors, a private company buys water in bulk from the desalination plant or the utility, and sells it at his shop. This can be either through bottled or containered units, or through a stand-pipe at the shop. When the latter solution is opted for, the retail seller may very well have a more or less permanent relationship with the operator or utility, constituting the second model. If such model is applied, a private vendor represents the utility in an area where the utility has no service coverage, acting as a sort of "franchise taker". The private party distributes the utility's water at kiosks or standpipes, which are property of the utility. In both models, the private party does not receive a salary, nor does it invest in infrastructure to improve the service provided by the utility. Rather they earn their money with the margin they earn from the sale of water.

Piped sub-networks

In some cases a small scale private operator may invest in the development of a sub-network, serving an area outside the service area of the utility. In case of desalination, water may be delivered to a local network or reservoir in bulk to serve the sub-network. The level of investment and thus the financial risk taken by these various typologies of water providers are higher than in the two other models. The small scale operators invest higher amounts of money for permanent equipment and may provide a higher quality of service than vendors or partners of water utilities. The owner of a sub-network may develop a fully-fledged system with house connections or rather opt for a system with public standpipes. A system with house connections can be made feasible even in a poor area for example by using low-cost technologies, community labour and alternative approaches to payment for the one-time connection fee.

7.6 Incentives for PSP in Desalination

An important reason for contracting the private sector to carry out public tasks is performance improvement. This can be higher operational efficiency, better value for money for customers, or better quality of service. The intrinsic motivation of a private party is to optimise its profit, which is not always in the best interest of the client or the end-user. To ensure that a private operator, either as a management contractor or as a BOT contractor of a desalination plant, delivers his services to the agreed standards, clear contractual arrangements need to be put in place to provide incentives for optimum performance. Performance indicators can be used to measure performance, and determine a flexible part of the compensation to the contractor. Performance indicators for a desalination plant can include:
From the above it can be seen that internal costs are relevant to utility or government under a management contract only. Under a BOT or similar arrangement this risk typically lies with the contractor.

7.7 Output Based Aid

Traditionally financial aid is provided to projects on the basis of the input requirements, such as the construction of water supply systems, health clinics or telecom networks. The aid is given by local governments from its own funds or from the proceeds of loans or grants given by international donors. The service provider would construct the needed facilities and start the operation thereof in order to meet the objectives of the development project. The loan or grant is repaid from the benefits of the project. In order to obtain the loan or grant the only guarantee is the solvability of the service provider. However often there are disappointing results. More often than not the objectives of the project are not met. The population does not receive the expected services and the project cannot repay the funds that have been put at the disposal of the service provider.

Later other means of providing financial assistance were devised. One such measure was the setting up of performance contracts. This new approach would increase the efficiency of the operation of the service provider. It leads, as experience has shown, to lower costs, better quality of service and greater innovation. However preparing and managing performance contracts is rather costly, particularly if there are no precedents. In addition checking the performance was not always easy.

Many governments are faced with a lack of funds for financing new schemes; hence there is a need to involve the private sectors more often, not only to execute the project but also to provide financing. This approach has proven successful in a wide range of sectors and countries. The delivery of the services has improved dramatically.

A further step is to tie the aid given to the promised output.
In this arrangement the (private) service provider provides the funds that are needed for the construction and the initial operation of the facilities. Public finance (whether from the government or from donors) will be made available to the service provider under certain conditions that are tied to the performance of the service delivery while the project is in operation.

The World Bank has already some experience with Output Based Aid. In the examples given this approach is applied to water supply projects in Chile for low-income groups, to primary health care schemes in Haiti and Romania and rural telecommunication schemes in Peru. In these cases the service provider would receive financial aid from the government if it could be shown that the recipients had paid their bills. In many cases these bills would not cover all costs. Subsidies from the Government may be involved here.

Desalination projects seem perfect projects to apply this method. There is a well-defined objective for these projects: the delivery of water to the (urban) population and there is a well-defined geographical area where the operations take place.
The private operator would construct the plant and produce the water, treat it, deliver it to the households, initially using private funds. It would collect the fees from the consumers. The contract with the government would stipulate that the service provider receives a certain payment to cover the costs that cannot be met by the proceeds from the consumers. This arrangement would put a burden on the service provider to guarantee a good service.

It is our understanding, however, that a system of output-based aid would apply only to stand-alone or self-contained facilities. If more service providers are involved in the delivery of (parts of) the services, it may prove to be difficult to measure the share and the responsibility of each one of them.

In the desalination schemes that are in operation in the six countries of this study the water is not sent directly from the plant to the consumers. It is rather fed into the existing network and then delivered. Thus several service providers are involved.
In Cyprus the desalination plants are owned and run by private enterprises. They feed the water in the national network. After that it is the task of the government (through the Water Boards) to deliver the water to the consumers. The service provider who owns and operates the desalination plant receives payment based upon the quantity delivered. But this is not a delivery according to the OBA principles directly to the ultimate user.
The desalination plants in Karakalpakstan in Uzbekistan are rather small. They are owned and operated by the Government. Water is provided free of charge to the population.
In Algeria there are a number of small desalination plants that are meant to supply water to villages and suburbs without receiving water from elsewhere. Unfortunately these plants, although completed, do not yet deliver water due to technical problems.

All in all a clear-cut case for OBA was not found in the six countries studied.

7.8 Message

7.8.1 Private Sector Involvement

The Private Sector can play a crucial role in providing reliable production of freshwater through desalination, in increasing efficiency of operations, and in catering for badly needed investments in the desalination sector, as long as the potential risks associated with PSP are sufficiently recognised and managed.

Private sector involvement in desalination is rapidly evolving and an option that is being used or considered for desalination in all countries visited, except Uzbekistan, where Private Sector Participation is already in use as a means of project delivery, but not yet for desalination projects. The scope for private sector involvement in desalination in Uzbekistan seems to be limited due to the very small size of projects.

For the other countries under investigation the statement seems to apply in full. With regard to efficiency as the most important aspect with regard to desalination projects the private sector is always looking for more efficient ways of delivering their services, so as to be more competitive than the rest of the market and thus to be able to win projects. Once a contract has been awarded the main driver for more efficiency is profit. It is very common to have performance related incentives in a programme. While a contract between the public and a private party may contain a profit ceiling for the private party, there may be space for additional profits if for example power consumption is below the projected consumption. The benefits resulting from a lower consumption may be shared in a profit-sharing arrangement.

Another driver to strive for efficiency is contract related. Once the infrastructure gets older over the period of a contract the risks of operating failures increase. Increased attention for operational matters will be required to avoid being penalized for not meeting the obligations put forward in the contract. Contrary to publicly operated infrastructure where such threats are not commonplace the private party will at all times be motivated to perform as good as possible. The strive for efficiency has lead to a number of ‘cheapest plants ever' being constructed, including the plants in Cyprus, the Tampa Bay plant in the USA and the desalination plant in Ashkelon, Israel that is currently under construction.

In Malta the government has turned away from private sector involvement in desalination, due to a lack of ‘drivers' for private sector participation. After a long period of private sector involvement, the public utility has become sufficiently knowledgeable about desalination that to operate the infrastructure as efficiently as the private operator – without having to pay a commercial tariff for it. The principle of an independent firm operating the infrastructure was adhered to. A specialised and independent company, fully Government owned was created and is now successfully operating the infrastructure.

The second argument in the statement in support of PSP is the attraction of badly needed investments in desalination. This argument particularly applies to the countries that are subject of this study. All countries under investigation are in need of private sector capital to support the development of desalination infrastructure. The approach towards this goal varies from country to country. In Jordan, for example, no desalination infrastructure has yet been built with the involvement of private capital. The country is however negotiating a large WWTP under a BOT arrangement. This project is made feasible not only by attracting private capital, but also by a significant USAID grant. Without these funding sources, the infrastructure may not be realized. In Algeria private capital is attracted for BOT project development as well, providing significant relief to the state budget, in terms of capital investments, thus leaving space for investment in other priority sectors for which no private sector capital can be attracted.

There is a limit to the extent the private sector can be involved. In most countries water is heavily subsidized. Desalinated water is still a relatively expensive source if it is regarded as an independent source of water. Consequently, if water sector management in general is under developed, and revenues from water are limited the privately developed projects may have a significant impact on the cash flow of the public party responsible for paying the private operator or operators.

The revenue or cash-flow risk for governments is further enhanced under BOT and similar contracts, which will often contain clauses that address take-or-pay contracts, and foreign currency exchange guarantees to be provided by the government.

BOT is the most opted-for solution with regard to private sector participation aimed at the realisation of desalination infrastructure. Whereas this model indeed caters for investment, commitment of the private party, and expertise, it brings along significant risks for the public sector.

Besides the financial risks mentioned in the previous paragraph, BOT may adversely affect overall utility and system performance. Due to the increase in bulk water production, realised under a BOT contract, focus of a utility or government on further system performance improvement may diminish, since there is an instant increase in water availability. Leakage reduction programmes and demand management measures may consequently end up lower on the agenda. In fact, leakages may increase due to increased system pressure following the addition of a new water flow, resulting in much of the added capacity lost before it reaches the end users.

To reduce the risks associated with BOT project development, it should as much as possible be linked to water supply system performance improvement, such as UfW reduction programmes, tariff adjustments to a realistic level, and other water conservation and demand management measures.

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8 Environmental aspects of desalination

The following chapter addresses the environmental aspects of desalination for drinking water production in the Middle East (Malta, Cyprus, Algeria, Tunisia, Jordan) and in Uzbekistan. In the Annexes, more concise analyses of the situations currently experienced in these countries are provided; in this chapter, environmental aspects of desalination in general are discussed, and a brief comparison is made of the main (expected) environmental impacts in these countries and their similarities and differences are examined.

8.1 Environmental Impacts

8.1.1 General Environmental Impacts

Generally speaking, the main local environmental impacts that arise from the desalination process are from brine concentrates and from discharges of chemicals in the desalination process. Energy intensity is also considerable, although resulting emissions of greenhouse gases should be examined on the international level (in relation to the Kyoto Protocol; refer to UNFCC, 2003). Local impacts are acute in comparison to global impacts and could thus be seen to be more "significant".

Unless otherwise stated, the following paragraphs are amended from UNEP/MAP (2003) and Lattemann and Höpner (2003). These impacts have been classified as "minor" or "major" on a qualitative basis.

8.1.2 Local Impacts

Plant Siting (may be major or minor depending upon chosen site)

A new desalination facility changes the properties of a coastal site and can permanently alter land use options. Potential impacts can be expected during plant construction and operation, but also from the building itself, including intakes, outfalls, pumping stations, and supporting infrastructure like roads, pipelines or power transmission lines. Construction activity could result in soil disturbance (dunes, beaches, seafloor), erosion, and damage to archaeological sites; heavy machinery produces air emissions and noise, obstructs views and disturbs terrestrial and marine organisms. Plant operation causes atmospheric and marine emissions or noise from pumping stations, while the building complex and supporting infrastructure alter the visual properties (and thus attractiveness to tourists) of a landscape permanently. As a consequence, altered air, water and sediment quality, in addition to auditory and visual effects, have potential impacts on human activities and the coastal environment (including loss of habitat). Values of adjacent properties could be reduced in an urban environment.

Sea Water Intake and Outfall (may be minor or major depending upon siting)

Maritime structures such as intakes or outfalls could interfere with navigation, access to harbours or other activities such as fishing, as well as on water currents and sediment transport. Open seawater intake usually results in the loss of marine organisms when these collide with screens at the intake (impingement) or are drawn into the plant with the seawater (entrainment). An open intake requires an above-ground intake structure that can affect surface currents and sediment transport, interfere with shipping or other maritime uses, and provides a surface for the attachment of marine organisms. Pre-treatment is generally higher than for beach wells and infiltration galleries to cope with insufficient and more variable surface water quality. Optimal chemical dosage may be difficult to establish and overdosing might ensure safe operation in the case of deteriorating feedwater quality, in turn increasing the risk of chemical discharges to the marine environment. Besides requiring minimal chemical pre-treatment, underground intake structures eliminate impacts from entrainment and impingement. However, initial disturbance during construction is higher as sediments have to be replaced or become re-suspended. Beach wells may also interfere with aquifers, e.g. by changing groundwater flow or causing saltwater intrusion into freshwater aquifers.

Impacts of Brine Production and Release to Sea Sources (major)

Most substances in the desalination discharge have a limited dispersal range so that associated environmental effects will be restricted to the discharge site and its immediate vicinity. Their environmental fate is characterized by processes such as self-decomposition (e.g. chlorine) and transport into sediments (e.g. copper, coagulants) in addition to dilution. Local effects may be significant, especially in desalination 'hot spots' where installed capacities are high. Residual chemical concentrations in the desalination discharge are relatively low but may eventually amount to heavy loads due to the large effluent volumes produced.

The waste stream resulting from the desalination process consists of highly concentrated saline brine that may be increased in temperature, contain residual chemicals from the pre-treatment process, heavy metals from corrosion or intermittently used cleaning agents. Emission of this multi-component waste into the sea, either directly through coastal outfalls or disposal by ships, might therefore have potential adverse effects on water and sediment quality or impair marine ecosystems. The physical and chemical properties of seawater are modified during desalination, depending on the pre-treatment methods and desalination process used. Similar pre-treatment steps in distillation and reverse osmosis plants include scale and biofouling control, whereas differences exist in the removal of suspended material (RO only) or the control of corrosion and foaming in distillation plants. The process has a significant influence on effluent salinity, which is typically higher in the RO brine, whereas elevated temperature is characteristic of distillation effluents. In addition to pre-treatment chemicals, the effluent may contain intermittently used cleaning solutions if these are blended with the brine. The single effluent properties have potential impacts on the marine environment and their combined discharge might result in additive or synergistic effects.

It is important to note that, in the case of seawater desalination plants, the environmental impact of brine discharge is often minimal, especially if there are no sensitive environmental eco-systems near the outfall, if mitigation measures are taken and/or the plant is only of small or medium size. However, if there are cumulative impacts from several large plants discharging to a sensitive eco-system in an area without currents and without sufficient mitigation measures, the impacts may be great.

Salinity is one environmental factor controlling the distribution of marine organisms. Although most organisms can adapt to minor changes or might temporarily cope with strongly deviating salinities, the continuous discharge of highly saline effluents will be harmful to marine life and cause a change in species composition and abundance.

The *thermal discharge* may change variable localized temperature distribution and seasonal variability in the outfall site with potential impacts on biological activity, species abundance and distribution. While warmer seawater temperatures may enhance biological processes in winter, increased summer values could result in stress or cause an abrupt decline in activity when a critical value is exceeded. Marine organisms could be attracted or repelled by the plume, and species more adapted to the higher temperatures could eventually predominate in the discharge site.

Oxygen solubility declines because of physical de-aeration in distillation plants to prevent corrosion. In RO plants, reducing agents such as sodium bisulfite are used for dechlorination, which also depletes oxygen as a side effect. The effluent might cause an oxygen deficiency in the discharge site, possibly harmful to marine life.

Chlorine is a highly effective biocide and residual concentrations may be hazardous to marine life.

Although environmental concentrations are decreased by rapid self-degradation and dilution, the potential for adverse effects on the marine environment is high. An initial decrease of 90 % can be expected in warm sunlit seawater, resulting in environmental levels of 20-50 µg/l in the mixing zone of the effluent, which is consistent with observed concentrations in discharge sites of desalination plants. For comparison, the U.S. EPA recommends a quality criterion for seawater of 7.5 µg/l for long-term exposure, which is based on toxicological results from a wide spectrum of species. Residual chlorine levels in seawater increase the risk that organohalogen by-products are produced, of which a major part will contain bromine in addition to chlorine. Bromide ions are naturally present in seawater and transformed into highly reactive bromine in the presence of chlorine.

Organohalogen compounds may be formed from precursors of natural or anthropogenic origin. For example, trihalomethanes (THMs) originate from naturally-occurring organics and have been detected as major by-products in desalination plant discharge sites, or chlorophenols and chlorobenzenes may arise in the presence of petroleum compounds. The number of by-products is difficult to quantify due to many possible reactions with organic seawater constituents. While the different organohalogen compounds may not be present in acutely toxic concentrations, sufficient evidence exists that some of them have carcinogenic properties or may cause chronic effects during long-term exposure.

Coagulants: Filter backwash is non-toxic, but marine disposal increases the amount of suspended material in the discharge site. A potential adverse effect of higher turbidity and lower light penetration is a decline in primary production, while increased sedimentation rates could cause a burial of sessile organisms.

Antiscalants: Organic polymers are non-hazardous to marine life as toxicity values ($L_{C5}0$) exceed required dosage levels by several orders of magnitude. However, biodegradation is relatively slow with half-lives of one month or longer and it must be expected that organic polymers are persistent in the marine environment. As these substances control scale formation by dispersing and complexing calcium and magnesium ions in the desalination plant, they could influence natural processes of other divalent metals in the marine environment. Phosphonates are organophosphorus compounds characterized by a stable carbon to phosphorus (C-P) bond, which is resistant to biological, chemical and physical degradation. The environmental fate of phosphonate antiscalants primarily depends on processes such as dilution or adsorption to suspended material. Similar to organic polymers, toxic effects are not to be expected due to relatively high L_{C50} values of commercial products. Polyphosphate antiscalants are easily hydrolysed to orthophosphate, especially at high temperatures, which lowers their efficiency in distillation plants. Orthophosphate is an essential nutrient for primary producers, with the potential to cause eutrophication and oxygen depletion in the discharge site. Algal mat formation has been observed at the outlets of some desalination plants that used polyphosphates for scale control.

Heavy metals: Trace amounts of stainless steel alloys pose relatively little risk to the marine environment, but copper is highly toxic to most marine organisms. Concentrations as low as 10 µg/l in seawater may have significant effects, but toxicity generally depends on bioavailability and species sensitivity. Background copper levels in the Mediterranean are low and range between 0.04-0.70 µg/l in open water and <0.01-50 µg/l in coastal areas (UNEP, 1996). Dissolved copper levels are decreased by chemical and physical processes in seawater (precipitation, complex formation, adsorption), while the element is enriched in suspended material and finally in sediments. The risk of copper accumulation is potentially high for soft bottom habitats and areas of restricted water exchange, where sedimentation rates are high. Many benthic invertebrates (including shellfish) feed on suspended or deposited material, with the risk that heavy metals are enriched in their bodies (bioconcentration) and passed on to higher trophic levels.

Antifoamings: Antifoaming agents such as polyethylene- and polypropylene glycol are added to the intake seawater of distillation plants to disperse foam-causing organics and to reduce surface tension in the water-air interface. Polyglycols are not toxic but can be highly polymerised, which reduces their biodegradability. Potential adverse effects are not to be expected at a significant level as dosage levels are low and discharge concentrations are further decreased by dilution in the environment.

Cleaning solutions: Seawater has a good buffering capacity, i.e. the natural pH of about 8 is usually not affected by slightly alkaline or acidic discharges. The discharge of highly acidic or alkaline cleaning solutions, however, may become toxic to aquatic life if dilution in the discharge site is insufficient. Detergents such as dodecylbenzene sulfonate are hazardous to aquatic life as they have the potential to disturb the intracellular membrane system of organisms. Similarly, the oxidizing potential of some chemicals (e.g. sodium perborate) may affect marine organisms by oxidizing their organic tissue. If complexing agents are released into seawater, they could interact with dissolved metal ions and interfere with natural processes of these elements in the environment. Complexing agents, e.g. EDTA, are typically used in cleaning solutions, which is persistent in the marine environment. Oxidizing or non-oxidizing biocides (e.g. chlorine or formaldehyde) are used for membrane disinfection, which are particularly hazardous and may be toxic to marine life if released to the environment. Membrane storage solutions containing sodium bisulfite could also have detrimental effects on marine life by causing oxygen deficiency in the discharge site.

Oceanographic Conditions and Behaviour of Water Mass
A distinct water mass may be formed under limited mixing conditions, characterized by effluent properties such as increased salinity or residual chemical concentrations. The spreading of this discharge plume could affect marine organisms. The RO brine is negatively buoyant as a result of its high salinity, with the potential to sink to the bottom and spread over the ocean floor, where it could have detrimental effects on benthic habitats. While the high density can be primarily attributed to brine salinity in RO plants, the influence of temperature must be considered in addition to salinity for the distillation process. As both parameters have contrary effects on density, the distillation discharge may either be positively, neutrally or negatively buoyant depending on ambient density stratification. Surface spreading or trapping of the plume in intermediate water masses affects the pelagic community, while sinking and spreading along the seafloor is comparable to RO discharges that affect benthic organisms.

Impacts of Brine Production and Release to Land Sources (minor to moderate)

Land-based brackish water plants can experience mild to moderate problems in disposing of the brine discharge. The most significant impact is the contribution of this brine to the salinisation process, which is taking place on a wide scale because of poor agricultural practices, especially in Uzbekistan.

Socio-Economic Impacts of Desalination (may be major or minor depending upon location and land-use plans)

Possible positive socio-economic impacts of desalination include:

- ensuring access to sufficient and safe drinking water for domestic use
- creating wealth through tourism, industrial and agricultural development, or even new employment opportunities in the desalination industry
- decreasing the pressure on natural resources, protecting freshwater ecosystems, preventing desertification or ground-water salinisation
- aiding in attaining stability and peace in the region.

Possible negative socio-economic impacts of desalination include:

- changed consumption patterns or even misuse of water due to the impression that water is readily available
- a further concentration of development and activity in the coastal zone, migration of people from inland/rural regions to coastal/suburban areas

- dependency on a technology that may in turn depend on the import of know-how or energy, that is vulnerable to deteriorating seawater quality (e.g. oil spills), and is probably centralized in a few locations requiring the transport of water over large distances.

The magnitude of socio-economic impacts depends on the future development of desalination activity in the Mediterranean region. Trend scenarios range from a restricted use in developed countries to a widespread applicability in the whole region if costs can be further reduced.

Increased Development (may be major or minor depending upon the location)

Related to the above-mentioned socio-economic impacts, the construction of desalination plants to meet water supply needs may result in growth-inducing impacts. Limited water is often the major constraint to development. Therefore, new desalination projects could lead directly to new development and a resulting increase in population migration, possibly interfering with long-term regional goals for growth control. For example, desalination plants built in rural areas could lead to growth in these areas rather than those within existing urban boundaries; desalination plants built in urban areas may also change the character of these areas. Potential growth-inducing impacts should be considered for those communities that receive the water, as well as those where the desalination plants will be located. The pros and cons of building a larger number of small plants versus a few larger ones should be carefully considered. Growth-inducing impacts may be more significant for projects that operate for many years, as compared to those that are short-term projects.

Water Balance Issues (may be major or minor depending on water balance in area and mitigation measures taken)

The addition of water into the local and regional water balances, and into an urban water supply system that has a design capacity for smaller amounts of water, may cause some major impacts. In the urban setting, the water treatment systems, if existing, may not be capable of handling the new fresh water provided. Therefore, when new water is introduced into a supply system, corresponding water treatment capacity must be developed. When new water is added into a water basin which has always had the same water balance, physical impacts such as rising of the water table and possible water logging may take place. These physical impacts may have further-reaching consequences.

8.1.3 Global Impacts

Energy Use and Global Warming (minor impact except for Malta)

Desalination of seawater consumes a significant amount of energy, which is mostly required for the process itself (about 90%) in the form of thermal energy (distillation processes) or mechanical energy usually obtained by electricity (RO process). Electrical energy is furthermore needed in all plants to operate auxiliary equipment like pumps or dosing systems. A major impact is the emission of greenhouse (mainly CO_2) and acid rain gases (NO_x, SO_x) into the atmosphere, if fossil fuels are used as primary energy source. However, desalination plants also emit gases that do not originate from fossil fuel combustion, but were formerly dissolved in seawater. In thermal plants, the feed water is usually de-aerated and gases evolve from the evaporating brine in flashing chambers. Both processes increase carbon dioxide (CO_2) emissions, which is stored in the oceans in the form of bicarbonate, and cause the release of other atmospheric gases (mainly O_2 and N_2) from seawater.

Table 2 provides an overview of the tot al power consumed by the countries on an annual basis (as in 2001) in comparison to the amount of power used by the desalination process. It can be seen that Malta uses the most power for the purpose of desalination at 22% of total consumption.

Table 8.1 Power consumption in the six countries relative to the desalination process

Country	Power Consumed Annually (billion kWh, 2001 est.)	Population (2003 est.)	Power Consumed Annually (kWh per capita)	Capacity of Desalination plants (m^3/day) *)	Power Consumed by Desalination Annually (billion kWh)	Percentage of total annual power consumption
Algeria	22.9	32,818,500	698	100,739	100739m ^{3}x8x365 = 0.29 billion kWh	1.3%
Cyprus	3.163	771,657	4099	46,561	46561m ^{3}x8x365 = 0.14 billion kWh	4.4%
Jordan	6.86	5,460,265	1256	11,000	11000m ^{3}x8x365 = 0.03 billion kWh	0.4%
Malta	1.644	400,420	4106	123,868	123868m ^{3}x8x365 = 0.36 billion kWh	22.0%
Tunisia	9.748	9,924,742	982	2,220	2220m ^{3}x8x365 = 0.006 billion kWh	0.06%
Uzbekistan	47.08	25,981,647	1812	17,500	17500m ^{3}x4x365 = 0.026 billion kWh	0.06%

*) Total estimates for daily capacity in Jordan and Uzbekistan are taken from country annexes; the other capacities are 1999 estimates taken from UNEP (2002). The statistics on power consumption and population estimates have been taken from the CIA World Factbook (http://www.odci.gov/cia/publications/factbook/index.html).
Power consumption for desalination is estimated at 8 kWh/m^3, except for Uzbekistan: 4 kWh/m^3

Transboundary Impacts (minor)

Pollutants transported by currents may affect areas distant from the origin. Potential impacts beyond the territorial waters or exclusive economic zone of a contracting state should consequently be considered for substances that are persistent and easily dispersed in the marine environment. The degradation of local environments may also have transboundary implications. Intact coastal and marine ecosystems throughout the region are essential for high biodiversity in the Mediterranean Sea and provide habitats for migratory, endangered or endemic species. Persistent and mobile substances may be dispersed by currents, and dilution will cause a further decline of already low discharge concentrations.

Earthquake Risk (potential for major impacts)

A regional problem, especially in the Mediterranean countries of the study, is the risk of earthquake. Possible environmental impacts could occur as the result of an earthquake damaging one or more of the desalination plants. Damage by earthquake of the pipelines or facilities themselves could cause spillage of harmful chemicals or wastes, thus causing worker health issues or problems in the surrounding environment. Additionally, stoppage of production as a result of damage could result in drinking/ industrial water supply shortages.

8.2 The Practice of EIA regarding desalination projects in the core countries

Information on the practice of EIA in the core countries as regards desalination was not available for each country. Only in the case of Cyprus was there an example of an EIA (incomplete) available for work done in Larnaca. This EIA report showed concerns that are similar to those shown further in this chapter. Because of imminent accession, the laws of Cyprus are now almost completely in line with European Union laws; this statement is also valid for the EIA Directive. Many of the core countries have developed EIA legislation as well; however, little information is available on how EIAs regarding desalination plant development are actually carried out.

As addressed in section 5.4, capacity building for the development and staffing of desalination plants is an important topic area to examine further. In that section a statement was made to the effect of the need for capacity building to address the need for sustainability in such projects, including environmental sustainability. Indeed, capacity building for specialists to be trained specifically in the field of the environmental impacts and mitigation measures for desalination plants in these countries is also required, in order to aid in the overall environmental sustainability of these projects.

8.3 Environmental Standards for Desalination

8.3.1 General

There do not appear to be any specific desalination environmental standards existing at Barcelona Convention, European Union or U.S. EPA levels. However, there are specific environmental standards for all chemicals discussed in section 8.1 for ambient water at European Union and U.S. EPA levels, as well as standards for effluent from various types of industry to receiving waters. It appears that these standards have not been amalgamated into a separate law, Directive or regulation to specifically control desalination plants.

8.3.2 Barcelona Convention

In the Barcelona Convention (Annex I), thirty land-based pollution sources are controlled. However, desalination practices are not among these (Box 8.1). However, desalination may be categorised into the section "Works which cause physical alteration of the natural state of the coastline", for example. In Annex I, types of activity, characteristics of substances in the environment (including persistence, toxicity and bioaccumulative nature) and categories of substances (including heavy metals, polycyclic organic compounds, etc.) are controlled. In Annex II, "Elements To Be Taken Into Account In The Issue Of The Authorizations For Discharges Of Wastes", characteristics and composition of the discharges, characteristics of the discharge constituents with regard to their harmfulness, characteristics of receiving environment, availability of waste technologies and potential impairment of marine ecosystems and seawater uses, are controlled. Again, desalination is not mentioned, but many of the aspects and impacts of concern regarding brine production and chemical release, as well as the receiving environment, are addressed.

The Barcelona Convention also puts forth the need to use Best Available Techniques and Best Environmental Practice.

Box 8.1 Land-based sources of pollution controlled under the Barcelona Convention (Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources and Activities, 1996)

1. Energy production;
2. Fertilizer production;
3. Production and formulation of biocides;
4. The pharmaceutical industry;
5. Petroleum refining;
6. The paper and paper-pulp industry;
7. Cement production;
8. The tanning industry;
9. The metal industry;
10. Mining;
11. The shipbuilding and repairing industry;
12. Harbor operations;
13. The textile industry;
14. The electronic industry;
15. The recycling industry;
16. Other sectors of the organic chemical industry;

17. Other sectors of the inorganic chemical industry;
18. Tourism;
19. Agriculture;
20. Animal husbandry;
21. Food processing;
22. Aquaculture;
23. Treatment and disposal of hazardous wastes;
24. Treatment and disposal of domestic waste water;
25. Management of municipal solid waste;
26. Disposal of sewage sludge;
27. The waste management industry;
28. Incineration of waste and management of its residues;
29. Works which cause physical alteration of the natural state of the coastline;
30. Transport.

8.3.3 European Union standards

In the European Union, water policy is governed through the Water Framework Directive for inland waters, but for marine purposes, the EU takes the Barcelona Convention and other such Conventions governing marine outfalls and implements it directly into its own legislation. In 2002, the EU took some initial steps towards developing an overall thematic strategy for marine environment policy when it published the Communication from the Commission to the Council and the European Parliament of 2 October 2002 "Towards a strategy to protect and conserve the marine environment" (COM 2002-539 final). The overarching objective proposed for the strategy to protect the marine environment is to promote sustainable use of the seas and conservation of marine ecosystems, particularly sites of high biodiversity value. Other sectoral objectives are also set for this strategy, covering biodiversity loss, habitat destruction, discharges of hazardous substances, eutrophication, radioactive substances, oil pollution, litter, maritime transport, health, climate change, research and closer coordination.

Where a large part of the regulatory effort of marine Conventions attempts to control chemical products and industrial installations which are also covered by Community legislation, there is a large duplication of effort as well as confusion given the divergent positions taken by the same countries in different fora. Usefully, there have recently been some efforts to co-ordinate the respective work programmes and work according to common methodology. Further afield, international action in the context of the POPs Convention and the LRTAP Protocols will be of relevance.

Once again, there is also no specific Regulation or Directive addressing desalination plants. However, “desalination plants” are listed in Annex IV of Directive 2000/60/EC, which addresses establishing a framework for Community action in the field of water policy. However, in this case, the desalination plant is listed only as a measure to be taken in order to protect a river basin district from environmental damage.

EU measures for controlling pollution with hazardous substances include as the most significant the Directives on new and existing substances, the Integrated Industrial Pollution Prevention and Control (IPPC), the Water Framework Directive and the New Chemicals Policy. Again, these do not mention desalination, but do regulate release of substances that form part of the pollution caused by desalination plants. A listing of substance release controlled by the IPPC Directive is seen in Box 8.2.

Box 8.2 List of controlled release substances by the IPPC Directive

1. Organohalogen compounds and substances which may form such compounds in the aquatic environment
2. Organophosphorus compounds
3. Organotin compounds
4. Substances and preparations which have been proved to possess carcinogenic or mutagenic properties or

properties which may affect reproduction in or via the aquatic environment
5. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances
6. Cyanides
7. Metals and their compounds
8. Arsenic and its compounds
9. Biocides and plant health products
10. Materials in suspension
11. Substances which contribute to eutrophication (in particular, nitrates and phosphates)
12. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.).

8.3.4 American and EPA standards

EPA environmental standards for desalination could not be found. However, a law was recently passed in California, where desalination has been increasingly in use. The Cobey-Porter Saline Water Conversion Law authorizes the Department of Water Resources, either independently or in cooperation with public or private entities to conduct a program of investigation, study, and evaluation in the field of saline water conversion, to provide assistance to persons or entities seeking to construct desalination facilities, and after submission of a written report and upon appropriation from the Legislature, to finance, construct, and operate saline water conversion facilities. Assembly Bill No. 2717, Chapter 957, passed September 26, 2002, adds a new section to the Water Code, which among others demands a study into the environmental impacts of desalination processes (Box 8.3). Presumably, further regulations will arise from this work after July 2004.

Box 8.3 Section 12949.6, an addition to the Water Code

Section 12949.6 is added to the Water Code, to read: 12949.6. (a) Not later that July 1, 2004, the Department of Water Resources shall report to the Legislature on potential opportunities for the use of seawater and brackish water desalination in California. The report shall evaluate impediments to the use of desalination technology and shall examine what role, if any, the state should play in furthering the use of desalination in California.
(b) The department shall convene a task force, to be known as the Water Desalination Task Force, to advise the department in implementation of subdivision (a), including making recommendations to the Legislature regarding the following:
(1) The need for research, development and demonstration projects for more cost effective and technologically efficient desalination processes.
(2) The environmental impacts of brine disposal, energy use related to desalination, and large-scale ocean water desalination.
(3) An evaluation of the current regulatory framework of state and local rules, regulations, ordinances, and permits to identify the obstacles and methods to creating an efficient siting and permitting system.
(4) Determining a relationship between existing electricity generation facilities and potential desalination facilities, including an examination of issues related to the amounts of electricity required to maintain a desalination facility.
(5) Ensuring desalinated water meets state water quality standards.
(6) Impediments or constraints, other than water rights, to increasing the use of desalinated water both in coastal and inland regions.
(7) The economic impact and potential impacts of the desalination industry on state revenues.
(8) The role that the state should play in furthering the use of desalination technology in California.
(9) An evaluation of a potential relationship between desalination technology and alternative energy sources, including photovoltaic energy and desalination.
(c) (1) The task force shall be convened by the department and be comprised of one representative from each of the following agencies:
(A) The department.
(B) The California Coastal Commission.
(C) The State Energy Resources Conservation and Development
Commission.
(D) The California Environmental Protection Agency.
(E) The State Department of Health Services.

(F) The Resources Agency.
(G) The State Water Resources Control Board.
(H) The CALFED Bay-Delta Program.
(I) The Department of Food and Agriculture.
(J) The University of California.
(K) The United States Department of Interior, if that agency wishes to participate.
(2) The task force shall also include, as determined by the department, one representative from a recognized environmental advocacy group, one representative from a consumer advocacy group, one representative of local agency health officers, one representative of a municipal water supply agency, one representative of urban water wholesalers, one representative from a regional water control board, one representative from a groundwater management entity, one representative of water districts, one representative from a nonprofit association of public and private members created to further the use of desalinated water, one representative of land development, and one representative of industrial interests.
(d) The sum of $600,000 is hereby appropriated from the Bosco-Keene Renewable Resources Investment Fund to the department for the purpose of establishing the task force and preparing the report required in subdivision (a).

8.4 Mitigation Measures

The below sections described general mitigation measures that may be applied to prevent or reduce the impacts described above. In a more general sense, mitigation of local impacts of desalination plants involves institutional development, and included under this subject is proper enforcement of any existing environmental or water laws or regulations, effective water resources management planning with environmental aspects, and further awareness-raising for water conservation.

8.4.1 Local Impacts

Construction

Construction should be scheduled for time periods that guarantee a low interference with recreation and tourism or breeding and migration of coastal animals. Preventive actions further include noise buffering, visual screening and spatially restricted construction corridors. The desalination plant can be designed to minimize visual and auditory impacts (sound-proofing of complexes where pumps are housed, limited height of the facility and blending into the surrounding landscape). Impairment of water and air quality should be minimized by implementing best available techniques (BAT/BATNEEC) to limit emissions. Desalination plants should be located near other facilities with similar consequences. Existing infrastructure such as roads or seawater intakes should be used to the extent possible, where visual or noise disturbance is an acceptable circumstance or where marine waters have been classified for industrial use. If new infrastructure is unavoidable, siting should be optimised to reduce land use and to avoid impacts on sensitive marine areas and protected species. Pipelines should be placed underground and/or their number and length minimized without accessing sensitive areas. The different interests and activities in the coastal site should be regulated by the coastal development plan to avoid conflicts.

Seawater Intake

Screens should be used to avoid intake of larger marine organisms. Intakes should be sited where less productivity is taking place to avoid intake of eggs or larvae; as a result, somewhat less fouling should take place and chemical use may be reduced. Intakes should further be designed to avoid impingement and flows should be optimised to avoid same. Generally, beach wells should be used in preference to intakes. Cooling water may be reused from the desalination plant, thus avoiding extra impingement and entrainment, and reducing chemical use as it is likely to have already been treated. Co-location should be encouraged to use existing infrastructure to the extent possible.

Mitigation for Impacts of Brine Discharge to Sea Sources

Salinity: To minimize impacts from elevated salinity levels, desalination effluents should be within 10% of the ambient value, achieved by blending desalination effluents with power plant cooling water in adequate mixing ratios. Options that improve mixing in the discharge site should further be considered.

Thermal Discharges: Temperature increase in discharged water should be limited to 10% above normal. Power plant cooling water is recommended for diluting brine salinity, but does not cause a decline in effluent temperature. However, the power plant cooling water could serve as feed water to the desalination plant, thereby lowering the total intake and discharge of heated seawater. Adequate mixing of the effluent plume with surrounding seawater should be ensured to mitigate impacts from elevated temperature.

Oxygen Content: To prevent oxygen deficiency, the effluent can be aerated or blended with other waste streams of higher oxygen content prior to discharge. Oceanographic conditions in the discharge site should provide for good mixing of effluent and seawater to adjust oxygen contents to ambient levels within close distance from the outfall.

Biocides: Neutralization of residual chlorine levels is of importance regarding the desalination process. Several chemical treatment options exist: dosing of sodium bisulfite (used in RO) or sulphur dioxide. Alternative treatment methods should be considered where feasible, such as ultraviolet light in small, automated systems. Major advantages of UV-light are that storage and handling of chemicals is not required, physical and chemical seawater parameters are not altered and no toxic by-products are formed. Other non-chemical pre-treatment options include prefiltration with fine-pored membranes (microfiltration or ultrafiltration) or the use of beach-wells, so that continuous biocide dosing is replaced by intermittent treatment for disinfection and cleaning.

Coagulants: The filter backwash should be sufficiently diluted, e.g. by continuous blending with the brine, or be removed from the filters and transported to a landfill. The disposal option will also depend on the amount of material produced. Deposition in a landfill should be considered for large plants, where more material accumulates and potential impacts are more likely. The plant would further have to include a process for removal and means of transportation to the landfill.

Antiscalants: Organic polymers may be used to mitigate potential impacts from increased nutrient levels in the discharge site. Although these substances are relatively non-toxic, their environmental fate and potential impact on dissolved metals in seawater should be addressed. Pre-treatment with sulphuric acid might be considered for RO plants, where piping is usually made from plastic or stainless steel, which is more resistant to corrosion than copper alloys. The intake water can further be pre-treated by nanofiltration, a membrane softening process that partially removes divalent cations such as calcium or magnesium from seawater.

Heavy Metals: Expected discharge levels of copper should be well below an established discharge limit of 500 µg/l (Barcelona Convention), but may exceed the water quality objective of 8 µg/l. The outfall should be placed and configured as to achieve sufficient dilution of copper, so that the quality objective can be met at the edge of the mixing zone. To lower the risk of toxic effects in the mixing zone, it is desirable to decrease copper concentrations in the effluent as far as possible. Sediments and organisms should be monitored with regard to quality criteria. Discharge concentrations can be influenced by controlling corrosion, which is usually achieved by pre-treatment of the intake seawater, the choice of corrosion-resistant construction materials, and the use of corrosion inhibitors. Non-metallic equipment should be used where possible, e.g. for intakes and outfall pipes or in RO plants. To mitigate impacts from copper contamination, copper-nickel alloys should be replaced by titanium in distillation plants where feasible.

Cleaning Solutions: Prior to discharge, cleaning and storage solutions should be recovered to remove any potential toxicity. This requires neutralization of the alkaline or acidic pH values and specific treatment for detergents, oxidants, complexing agents, biocides or other compounds with detrimental effects on marine life and the coastal water body. A wastewater treatment section should be implemented in the desalination plant, while substances for which existing treatment methods are inadequate should be avoided or replaced by alternative chemicals.

Combining waste with other discharges: As regards mixing with sewage effluent, UNEP Guidelines do not recommend undertaking this step in the Mediterranean area. Options for waste stream blending should be evaluated in the planning phase of a new project, especially for RO plants with highly saline discharges. Distillation effluents have generally lower salinity values due to the mixing of brine with cooling water from the heat rejection section of the desalination plant. Further dilution with other waste streams is not essentially necessary but may be considered for co-located power and distillation plants to bring effluent salinities as close as possible to ambient values. It is notable that pre-treatment chemicals that are toxic, such as residual biocides and heavy metals, should not be diluted in this manner and disposed of. These substances require further specific treatments.

Mixture of effluent in receiving waters: Mixing of the effluent in the receiving water body should be optimised by making use of favourable oceanographic conditions and discharging at appropriate intervals. Good mixing results can be achieved on high-energy coasts, where turbulence is high and strong currents cause a rapid water exchange; sheltered sites may trap effluents, resulting in long residence times of pollutants. In this case, the outfall can be located further offshore. Similarly, outfalls near the surface prevent attachment of negatively buoyant plumes to the sea floor (or vice versa for positively buoyant plumes). The outfall can further be technically improved, for example by using multi-port diffusers or increasing the discharge velocity. Different discharge scenarios should be analysed for a proposed desalination plant to determine the best method of disposal.

Brine Production and Release to Land Sources

Although local discharges of brine are of themselves not very significant, more sustainable approaches should probably be taken in future to the disposal of brine. There are a number of options: it can be spread over the land and allowed to drain back into the ground; it can be pumped into solar ponds for evaporation, or it can be re-injected back into the ground. It can also be transported by pipeline to a suitable disposal site. However all of these methods add to the cost of the project.

Socio-Economic Impacts and Increased Development

In order to mitigate for impacts related to increased development, siting of plants near existing fresh water distribution mains to distribute the product water should be encouraged in order to avoid further construction. As well, sizing of plant capacity should be commensurate with the planned level of development for the area, and assessment of the long-term growth-inducing impacts of proposals for long-term projects and for projects that are intended to be temporary, but may become permanent in the future should be undertaken. Co-ordination of project approval should be in accordance with (eventual) regional growth management goals.

Water Balance Issues

The water balance of the given area should be properly researched, so that the exact effects of the increased water in the basin can be calculated within a reasonable error margin. Wastewater treatment capacity would have to be increased to compensate for the extra water so that water logging and excessive water table increases do not take place to an extreme level.

8.4.2 Global Impacts

Global Warming Issues

To mitigate impacts related to energy consumption, national authorities should encourage the use of energy saving technologies and processes, including energy recovery systems in RO, which can be used in systems that produce more than 50 m^3/day. Furthermore, implementation of co-generation processes and the use of the same infrastructure for both desalination and power generating plants should be recommended where feasible. However, efficient operation of the desalination plant requires that the steam turbine for electricity production is operated simultaneously. Water and electricity production must therefore be matched to each other and adjusted to the actual demand. National authorities should also promote the use of renewable energy sources (solar, wind, geothermal energy) where the potential for renewable energy use exists. If fossil fuels are used as primary energy source, air emissions should comply with national air pollution control standards.

Transboundary Impacts

Effective planning to reduce local emissions according to remarks made above should be undertaken in order to reduce potential transboundary impacts. Planning and agreements to uphold applicable Conventions to generally Mediterranean should be honoured by all countries involved.

Earthquake Risks

Construction should be made earthquake proof to the extent possible by observing modern architectural practices.

8.5 The Environmental Impact of Various Technologies

Noise may originate from construction activities and from pumps and other plant equipment during operation, regardless of plant type. Water effluents include physical releases of brine to surrounding waters (heightened salinity and thermal discharge). The release of toxic materials, such as chlorine, heavy metals, cleaning solutions (antiscalants and antifoamings are not toxic, but are persistent in the environment) to waters and possibly to air, is an issue for all three plant types (RO, MSF, E.D.). Air pollution arises from construction activities and from the production of electricity for the energy requirements of any plant (mainly associated with global impacts).

The most significant impact from RO plants is noise in comparison with the other types of installations. However, in the larger environmental scheme (in the main text of Chapter 8), noise is not seen as highly important and is therefore not covered. The Multi-Stage Flash method causes, from a relative perspective, the most effluents, the most toxic material, the most air pollution and the most industrial risk of the three. It is important to note that generally speaking, the effluents represent the most significant impact of any given plant. RO plants generally have the least impact on the environment in the relative sense.

8.6 Comparison of the Different Countries

The countries, aside from the case of Uzbekistan, would not have mitigation programmes that would be very different from one another. However. Cyprus and Malta appear to be much further advanced from a legislative and institutional viewpoint than Tunisia, Algeria or Jordan, even though most of the countries appear to have at least the beginnings of environmental policy in place. In the case of all countries, methods by which enforcement of this policy and legislation can occur have been suggested, as this is often the main issue even in countries where environmental policy and legislation is highly developed. However, as Cyprus and Malta are candidates for accession to the European Union in 2004, their environmental policy and infrastructure would have to have reached a certain qualifying level by now, as determined by the environmental *acquis*.

Uzbekistan is a slightly different case, as it applies a different technology, has multiple installations rather than only a few large ones, and desalinates only brackish water, as it is landlocked (according to the CIA website, it is one of two countries in the world that is “doubly landlocked”). One of the world’s great ecological disasters is also involved here as well: the Aral Sea and its gradual disappearance. Here, options for good quality drinking water are more bleak than in some other countries; the one that is in a somewhat similar situation is Jordan, with its plans for bringing water from the Red Sea to the Dead Sea and its limited sea access. In Uzbekistan, the environmental impacts of desalination are much less significant in the larger picture than they would be in the Mediterranean countries.

8.7 Recommendations

Mitigation with respect to the methodologies described above should be undertaken to the extent feasible in the countries in question. Mitigation should be undertaken in respect of the Mediterranean Action Programme under UNEP in the countries where the policy applies. Additionally, it is highly recommended in general – that is, also to Uzbekistan to the extent possible – that the useful Checklist as provided in UNEP/MAP 2003, for use in preparing EIA studies for desalination projects, is used systematically. Ideally, each country that uses desalination should develop its own policy for sustainable management of its new water resource, respecting the national and transboundary environmental issues that it experiences.

In terms of mitigating the impacts before they occur, EIA should be used for each planned facility for desalination. Generally the EIA should be carried out according to the guidelines in UNEP/MAP (2003), and addressing at least those issues described above, and including specific issues related to the site and surroundings at hand. The sample EIA method to use proposed in Hoepner (1999) and in UNEP/MAP (2003) should be used to set up the EIA reporting and to aid in discerning the most important impacts.

In order to effectively address environmental problems already caused by desalination activities, in Figure 4 (*Ibid*, addressing both RO and MSF plants), a number of hotspots in the Mediterranean coastal area are identified in terms of copper contamination, chlorine loads and antiscalant loads. It is recommended that these areas be addressed immediately in terms of cleaning measures.

The fact that desalination plant environmental impacts will likely only become more pronounced in coming years, especially in the Mediterranean basin, may eventually call for the use of Strategic Environment Assessment (SEA) in order to examine desalination in more detail and from a regional perspective. SEA ensures that environmental consequences of certain plans and programmes are identified and assessed during their preparation and before their adoption. The public and environmental authorities provide opinions and all results are integrated and taken into account in the course of the planning procedure. After the adoption of the plan or programme the public is informed about the decision and the way in which it was made. In the case of transboundary impacts that are likely significant, the affected country and its public are informed and have the possibility to make comments which are also integrated into the national decision making process. SEA would contribute to more transparent planning by involving the public and by integrating environmental considerations, thus helping to achieve the goal of sustainable development. However, the use of SEA before the completely functional use of the more concrete methods involved in EIA would not be recommended.

More detailed studies and more time allowed are recommended for the current project, in terms of developing a more concrete vision of how to deal effectively with environmental problems resulting from desalination, especially in the Mediterranean.

A table addressing the main differences between the six countries is provided on the following pages.

Table 8.2 Environmental issues in the countries under investigation

Country	Main Desalination Method	Main Expected Environmental Impacts		Possible Mitigation Measures		
		Construction Phase	***Operational Phase***	***Institutional***	***Water Conservation***	***Physical – Construction, Operational Phases***
Algeria	RO	• expected impacts from construction of power plants • impacts on tourism and landscape NB	• energy is from natural gas; relatively "clean" emissions; perhaps problems re. Kyoto Protocol	• proper implementation of Littoral Law • possible extension of EIA to public utilities • integration of environmental issues into water planning • development of environmental institutions • improved public awareness	• emphasise the use of drip irrigation (Sectoral Strategy for Water stresses it) • improved wastewater treatment • proper disposal of hazardous waste, esp. oil	• special care as regards any species that may be protected by the Littoral Law
Cyprus	RO	• plants to be refurbished may cause construction impacts • nature impacts may not offend re. the Bird and Habitat Directives • Visual and landscape impacts NB for tourism	• Larnaca could be used as an example for ongoing operational impacts • Energy uses contribute 2.2% more greenhouse gases from Cyprus, against Kyoto Protocol • Spills of hazardous chemicals highlighted in a past EIA report • Water may infiltrate back in pipe in water shortage periods causing system and health problems	• Enforcement of environmental legislation should be emphasised • Reduce subsidies on irrigation water • Piece together the fragmented water sector to a more integrated whole • Further awareness raising among farmers	• Control saltwater intrusion • Use of drip irrigation in order to reduce farmers' w ater use further • Increase appeal of re-use of wastewater for crops • Carry out planned wastewater treatment capacity increase	• Increase use of alternative energy sources such as wind and solar • Use economic incentives to encourage desalination plants to run energy - efficiently • Monitoring near Larnaca to avoid regulation problems in waste stream mixing • System should stay in use; fix leaks in system immediately

Country	Main Desalination Method	Main Expected Environmental Impacts		Possible Mitigation Measures		
		Construction Phase	***Operational Phase***	***Institutional***	***Water Conservation***	***Physical – Construction, Operational Phases***
Jordan	RO	• Any construction at Aqaba must protect the coastal zone	• energy use may contribute to greenhouse gas emissions; Kyoto not signed but ratified • operations must respect the protected coastal zone • brine release and other operational activities may impact the delicate semi-desert ecosystem • water balance around Dead Sea is delicate and could be impacted by brackish water removal	• carry out highly stringent EIAs for planned Red-Dead project • complete environmental legislation must be developed and put in place, especially EIA • continued and deepened good work with water resources management strategy • cooperat ion between Water Authority, new Ministry of Environment, and Ministry of Irrigation	• WRM Strategy indicates agriculture as a main polluter: use drip irrigation and use only needed chemicals • Improve wastewater treatment capacity • Regulations may be difficult to enforce in Aqaba if waste streams are mixed; monitoring is NB	As in above text.
Malta	RO	As in main text. No new desalination capacity is planned for Malta.	• Desalination uses 8.8% of energy from Enemalta; problems with Kyoto Protocol promises • Chemicals and brine release as well as spillage risk could affect sea ecosystem; it is not believed brine would have a large impact • Desalination is meant to help increase tourism and speed development	• Full environmental legislation incl. EIA in place; enforcement is now key • Mandates in each organisation for public awareness raising; any further awareness raising will happen as needed	• Drip irrigation in full use; overuse in chemicals should be completely mitigated in Malta now	• Planned refurbishments should take construction impacts/mitigation measures into consideration • Continued use of Pelton wheel and other methodologies for energy efficiency • Continued phaseout of chemicals such as formaldehyde

Country	Main Desalination Method	Main Expected Environmental Impacts		Possible Mitigation Measures		
		Construction Phase	***Operational Phase***	***Institutional***	***Water Conservation***	***Physical – Construction, Operational Phases***
Tunisia	RO	• General construction impacts should be expected for planned plants • Visual and landscape impacts NB	• Energy releases may affect Kyoto Protocol implementation • Impacts on marine environment doubtful: contradicting reports; however, several endangered species that are delicate	• Full enforcement of all environmental legislation including 1991 EIA legislation • Full implementation of the Strategy for Potable Water • Effective cooperation of SONEDE and the MoEP • Full implementation of planned awareness raising activities	• Avoidance/mitigation of present saltwater intrusion problems • Improved wastewater treatment capacity	• Routes and planned locations must respect protected areas • Use of energy recovery technology • Full knowledge of water balance issues
Uzbekistan	ED	• General impacts as in main text	• High power usage in comparison to RO plants (however on much smaller scales); Kyoto breaches possible • Brine release in small amounts not expected to much damage environment; some further soil salinisation and mineralization of waters • Most impacts will be felt from inherited pollution from So viet era and Aral Sea issues	• Proper execution of the environmental legislation – which should be made realistic and not acc. to Gosstandard • Implement screening process to streamline EIA • Effective cooperation and division of responsibilities for the water-related organisations and effective implementation of WRM strategy • Improved awareness-raising efforts	• Implementation of aquifer protection schemes • Use of drip irrigation if applicable • Improved wastewater treatment capacity • Proper/safe disposal of hazardous waste to avoid aquifer contamination\	• all activities should respect Uzbekistan's Biodiversity Conservation Plan • possible improved use of solar energy (not wind energy) to increase energy efficiency

8.8 Message

8.8.1 Environment and Energy

While desalination plants often have the reputation of being highly energy intensive, this is not always warranted; potentially, more adverse environmental impacts occur particularly through brine release, especially in situations where several large plants discharge into an environmentally sensitive area with few currents.

Desalination plants do have potentially significant environmental impacts. They all use energy in a fairly intensive manner, though the most significant impacts result from brine discharges on a more local basis. Environmental Impact Studies are now carried out for all large installations.

Gaseous Emissions
Distillation plants use both heat and electrical power. If it is a large plant, such as those installed in the Gulf, the generation of power using fossil fuel is usually coupled to the production of water using MSF or MED distillation plants. Such plants use more total energy than RO plants, which use only electrical power; however, their advantage lies in the fact that the technology is very well proven and robust. Large MSF plants are predicted to have an operating life of 25-50 years if well maintained. The Gulf States are familiar with the technology and it is easier to understand and manage. There are lower CO_2 emissions with RO than distillation. In some areas high-sulphur fossil fuels are being used to generate electrical power; therefore, SO_2 as well as CO_2 emissions may occur.

Brine Discharges
There is concern about brine discharge and its environmental impacts. However, the level of the impact depends heavily on the situation (low impact in a non-sensitive environment with no currents; high impact in a sensitive environment with no currents, for example). In seawater plants, brine is discharged into the sea. Any chemicals added to the desalination process for scale and fouling prevention, corrosion reduction and corrosion products flow back into the sea. Coastal currents should be examined to ensure that discharges are not swept back around into the intake system. If discharge occurs into a small, enclosed bay or there is no coastal current, concentrations of the substances can build up, a situation that is clearly to be avoided. There is increasing concern in the Gulf about the amount of desalination taking place and the fact that the Gulf is a small, enclosed sea.

Land-based brackish water plants can experience mild to moderate problems in disposing of the brine discharge. There are a number of options: it can be spread over the land and allowed to drain back into the ground; it can be pumped into solar ponds for evaporation, or it can be re-injected back into the ground. None of these solutions is completely sustainable.

Renewable Energy
The energy requirements for small plants can be met through renewable energy sources, which produce no CO_2 directly. This technology is currently at an early stage. Wind and photovoltaic energy are the most commonly used; wave power is possible in the future. Plant sizes are small and the cost of water is high. However, if the sole use of the water is for potable purposes, this is not an insurmountable barrier as the quantities being consumed are low (RM, UNESCO, 2000).

Visual Intrusion
Desalination plants can be visually intrusive. Seawater plants are usually built on the coast. In areas where tourism is important this can create problems. In Cyprus, the Dhekalia and the Larnaca plant were located some 500 meters from the shore in order to keep the shoreline clear.

Noise Emissions

Desalination plants can also be noisy. RO plants have high-speed pumps, which are noisy. These pumps are normally housed in buildings to reduce the noise. Problems have arisen when, during the summer, doors have been left open to reduce building temperatures and allow the noise to escape.

8.9 References

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9 Country reports

9.1 Algeria

Water Resources. Algeria is one of the countries in the world with water resources that are well below the threshold adopted by the World Bank. The situation is aggravated by the fact that there is a wrong spatial distribution of the water, seasonal and inter-annual irregularities of the rainfall, filling up of the reservoirs with sediment, vast losses of water due to the aging of the municipal distribution networks, bad management of the resources, pollution, insufficient infrastructure, and a lack of maintenance.
The shortage of water affects both the drinking water supplies for the population and the supply of irrigation water for the farmers.

Energy. Algeria is totally self-sufficient in energy and has a very high renewable energies potential. Despite this, the application of renewable energy is considered modest when compared to the neighbouring countries of Morocco and Tunisia.

Institutions. The Ministry of Water Resources is responsible for the management of the water resources in the country, including the municipal water supply. The Algerienne des Eau (ADE) which is a pat of the Ministry is responsible for the supply of water to the public.

Water Supply Sector Performance.
Currently some 40% of the water is lost in the distribution system. The aim is to reduce this to 25%. Combating water losses is considered a priority action; therefore 11 towns will be addressed under an Unaccounted for Water (UfW) programme. The technical losses are around 32%. 8% is lost due to illegal connections.
The World Bank is presently funding a project for the rehabilitation of the water supply network in a number of major cities, among which Algiers, Oran and Constantine.
There used to be a fixed-fee for water supply, but this system is being abandoned. Now people can choose between a fixed fee, which is set rather high, and a bill against a metered supply.

Current Status of Desalination. In order to alleviate the water problems Algeria started investing in desalination plants during the sixties. They have been built to support the development of the oil and steel industry,. Many of the plants are owned by Sonatrach, the Algerian national oil company. Another major player in this field is Sonelgaz, an Algerian utility company.
The Ministry of Water has recently started the construction of 21 small-scale RO desalination plants with a capacity of less than 5,000 m^3/day, to supply towns along the Mediterranean coast, 14 of those plants are located in the central region, the rest in the eastern and western regions. Initially it was planned that all 21 plants would be operational by July 2002. However these plants are only now coming on stream (July 2003).

Private Sector Participation. Private Sector Participation in the field of desalination is being encouraged by the Government's plans to develop a large number of desalination plants, some of which will be developed under BOT arrangements. The Ministry of Water Resources stated that although Algeria is open to BOT, the plants may as well be funded by international financiers (e.g. World Bank) or by the Algerian State Budget. The main promoter of desalination BOTs in Algeria is the Algerian Energy Company (AEC), which is owned by Sonatrach and Sonelgaz.

Capacity Building.
After the first few years of functioning the desalination plants began to operate below their optimum capacities mainly due to the unavailability of skilled labour.
The most important recommendation in this respect is to set up training and education of staff

working in the sector, but also to increase attention for desalination at the universities in the country.

Environmental Impact.
There are no guidelines in Algeria for EIA, The Programme d'Action pour la Mediterranée (PAM) as part of the Barcelona Convention has issued guidelines for assessing desalination projects. No EIA studies have been carried out for the twenty-one emergency monobloc installations. In the littoral zone, there are strict rules about which construction and economic activities are permissible.

Future Plans for Desalination. The AEC recently awarded a BOT contract for an 80,000 m^3/day desalination plant in Arzew to a consortium called Kahrame. The water will partly be used by Sonatrach for the industrial complex of Arzew. Another part of the water is destined for municipal water supply.
The Ministry of Water Resources plans the construction of a total of 28 large-scale desalination plants all along the 1,300 km coast line of Algeria within the next few years, under BOT contracts. The combined capacity of the plants is about 1,950,000 m^3/day. The capacities, locations and technologies of these plants will be further assessed under the on-going national desalination study by the French engineering firm Safege.

9.2 Tunisia

Water Resources. The bulk of the potential conventional water resources of Tunisia lie in the northern region of the country and amount to 4,600 MCM/yr of which 54% has a salinity less than 1.5 g/l. These comprise 2,700 MCM from surface water and 1,900 MCM from ground water. Potential per capita supply is 450 m3/yr. Given the concentration of the natural resource is in the north, the southern part of the country is the area where water is in short supply. This is exacerbated by the growth in tourism in the southern region.

Energy. Tunisia is currently self-sufficient in (conventional) energy, provided from petroleum (72%), natural gas - principally from Algeria (26%), coke (1.6%) and hydo-power (0.3%). In terms of renewable energy, wind and solar are the main focus and have potential application with desalination in rural areas.

Institutions. The Ministere de l'Agriculture, de l'Environnement et des Ressources Hydrauliques (Ministry of Agriculture, Environment and Water Resources) is by law in charge of the management of the water resources as well as drinking water supply and sanitation in Tunisia.
The Societe Nationale d'Exploitation et de Distribution des Eaux (Sonede) is responsible for domestic and industrial water supply in all urban areas of Tunisia. It is a so-called Etablissement Public a Caractere Industriel et Commercial (EPIC), a public entity with an industrial and commercial character. It operates within the Ministry as an industrial organisation.
The national company STEG is in charge of electricity and gas distribution in the whole country. The National Agency of Renewable Energies is active in most fields of renewable energy

Water Supply Sector Performance. Coverage, cost recovery, unaccounted-for water
The population is mainly served through the networks of Sonede. An estimated 75 % of the population is connected. A further 1.22 million people are served by local organisations (Associations d'interets collectifs). In this way about 88 % of the population of Tunisia is connected to the water supply system. The rest takes its water from rainfall collectors, shallow wells and other means.
The potable water demand is estimated at 290 MCM per year in 1996, of which Sonede distributes 256 million m3. Of this amount 134 million m3 comes from surface water sources, 156 million m3 from ground water sources and 7 million m3 from desalination plants. Only the cities of Kerkenah and Gabes are supplied by these desalination plants.

Current status of desalination. Because of the lack of adequate good quality water resources in the southern part of Tunisia it has resorted to building desalination plants using brackish water.
In Tunisia there are some 48 desalination plants with a total capacity of 130,000 m^3/day of potable water. Most of them are run by industries for their own water supply. The majority of the plants are operating with brackish water as the feed source. Except for a few these plants are located along the coast. The small number operating on seawater are mainly VC plants where the product water is being used as boiler feed water make –up in power generation plants. Of the 48 plants, 22 use the electro-dialysis (EDR) process to treat the brackish water. Only four plants are owned and operated by Sonede. They are all brackish water plants and are located in coastal areas in the southern part of Tunisia which is particularly short of potable water and where there has been huge growth in tourism. The plants are located in Kerkennah, Gabes, Zarzis and Djerba. The latter two locations are major destinations for international tourists.

Future plans for desalination. Sonede are currently considering building a large seawater desalination plant at Djerba to cope with the increasing (touristic) demand. The output of the plant will be about 25,000 m^3/day. Although the process and the contractual option still needs to be decided upon it is hoped that the plant will be operational by 2006.
Sonede is also looking at 13 sites in southern Tunisia (inland?) where it is considering installing equipment to improve the quality of the water. The feed water in these cases is brackish water. This will involve building water treatment plants at these sites and in the further development of the pipe network.

Private sector participation. The private sector operates a number of small plants for industrial self-supply. So far it has not participated in financing or operating desalinaiton plants supplying water to the network, although a new plant in Djerba (see above) is likely to be implemented with private sector participation in its design, operation and possibly financing. A recent amendment to the Water Law has allowed PSP in non-conventional water supply, including desalination.

Environment
Proper implementation of EIA guidelines under a more basic environmental law would also be of great use; in Tunisia. According to decree no. 91-362, dated 13 March 1991, an EIA study is required for public and private projects likely to have effects on the environment. The legislation is there, but level of enforcement should be investigated. In the Water Strategy Tunisia is planning, however, a number of mechanisms for monitoring progress for water savings are built in, such as periodic assessments for major consumers, assessments of water provision equipment, development of bodies specialising in water saving assessment and expertise, and plans for development of economic incentives for water saving.

Capacity Building. Regarding the involvement of the private sector in the development ofdesalination , there is a need to invest in education of Sonede staff with regard to BOT tendering, contracting and monitoring skills.

9.3 Jordan

Water Resources. All conventional water resources are being used at their maximum capacity. In order to estimate the future water demand two growth scenarios have been drafted. Whatever the growth scenario adopted, there will be a big gap between supply and demand. In addition to demand management options this gap can only be closed by applying more desalination.

Energy. Jordan is almost totally dependent upon imported fuels to meet its energy demands, principally oil and gas. A major programme of exploration for oil and gas is underway, and natural gas is already being produced for power generation.
The National Energy Research Centre (NERC) was established for the purposes of research, development and training in the fields of new and renewable energy.

Institutions. The Ministry of Water and Irrigation (MWI) is responsible for the management of the water resources in Jordan. It was established in 1992 to integrate various policies carried out thus far by a number of government agencies including the Water Authority of Jordan (WAJ), the Jordan Valley Authority (JVA), Ministry of Agriculture and Ministry of Health.
The Water Authority of Jordan (WAJ) is among others responsible for the municipal water supply and the Jordan Valley Authority (JVA) for irrigation.

Water Supply Sector Performance. Jordan is working hard on water demand reduction, awareness creation, education, etc. Measures include re-use of water, and brackish water desalination.

Current Status of Desalination. In the Jordan Valley there is small-scale brackish water desalination. Twenty-one stations deliver water destined largely for irrigation use. These stations are located north of the Dead Sea and are privately owned. WRM studies indicate that there is a maximum of 80 million m^3 of water that can be used in the Jordan Valley. Salinity in the valley is maximum 7000-8000 ppm, but on average it is some 3000 ppm. The Hisban project could be implemented by 2015. This project should deliver some 9 to 15 MCM/year.
There is a groundwater desalination plant at Zarqa, operating at 600 m^3/hr. This plant was inaugurated by the King in 2001.

Public Sector Participation. In Jordan various types of PSP are underway, or being planned. The most well known example is the management contract for water supply that is being carried out in Amman.
Another important PSP contract is the BOT contract for the Asamra WWTP near Zarqa.
The private sector has been involved with the construction of private RO plants for industrial and agricultural use since the late eighties. Governmental plans for desalination came into being much later during the late nineties. The Ministry of Water has been investing in the local industry by promoting local manufacturers and contractors to get involved with desalination.
There are two companies in Jordan with the capability of designing and constructing RO plants. These are Aqua Treat and Irishaidat. Both companies have still limited experience

Capacity Building.
In Jordan it is difficult for water companies to recruit qualified staff, since water supply services are generally provided by the public sector, which has a quite restrictive salary system. Particularly with regard to desalination, the absence of well-qualified and experienced personnel in the field of water desalination science and technology is experienced.
It is recommended to start programs for capacity building, which can be achieved through cooperation between the academic and research communities with the MWI.

Environmental Impact. The Ministry of Environment has only recently been set up. Therefore, regarding institutional aspects of environment, the first steps have been made, but it is an area that is as yet in its infancy. Proper implementation of an EIA law or EIA as guidelines under a more basic environmental law would be of great use in further development of water resources in this country.

Future plans for Desalination. In order to meet the growing water demand the Government has drawn up a number of major water development plans.

- The exploitation of fossil non-renewable groundwater in the Disi aquifer.
- The construction of the Al Wahda dam on the Yarmouk river in the north of the country.
- Use of treated waste water will increase.
- Desalination of seawater and brackish water; this remains the only solution to solve the water shortage problems in the long run.

9.4 Uzbekistan

Water Resources. Special attention is given in this study to the Republic of Karakalpakstan, situated in the north-western part of Uzbekistan. It includes the Amu Darya River delta. The Republic's total area covers 165,600 square kilometres (37 % of Uzbekistan). The climate is typically continental, with very hot summers and cold winters without snow. The area is experiencing severe environmental problems as a result of the shrinking of the Aral Sea.
There are several reservoirs in the Amu Darya basin, the largest of which is the Tuya Muyun with a storage capacity of 7,800 MCM, consisting of four separate reservoirs. In the future one reservoir of this system (Kaparas) will be used to provide drinking water for Karakalpakstan.

Energy. Access to the electric power and gas is available in the whole territory of the Republic of Uzbekistan. The only energy source used in all desalination plants is the public power supply network. Uzbekistan has very little experience in the use of wind or solar energy and has no experience of using renewable energy with desalination.

Institutions. In Karakalpakstan there are three main water supply organisations.
- Tuya Muyun - Regional organisation for water transportation mains.
- Agrovodokanal, - Water Company for the rural area.
- Vodokanal - Regional water company

Water Supply Sector Performance. At present, the drinking water supply for this zone comes from groundwater which is too saline. For communities in this region, the following water supply schemes are possible:
- Supply from local fresh groundwater sources;
- Connection to the group system of Tuya Muyun-Nukus trunk mains
- Truck water supply (supply of water in water trailers)
- Desalination of ground water, which is rather brackish.

Current Status of Desalination. Since 1987, 200 desalination stations have been constructed in the region. Only 63 are operational at present however. They are run by the Agrovodokanal. These stations are known as EKOS plants and were assembled and built by the "Tambovmash" factory from Tambov in Russia. Feed water is usually obtained from deep wells, ranging between 400 and 600 meters deep. The distribution system basically only has public tapping points. These desalination plants use the electro dialysis process. They are rather basic and robust installations very suitable for the local circumstances.
The Vodokanal has two sites where it applies desalination using reverse osmosis. There is one plant in Takhtakupir of 2400m^3/day, and there are five small plants in Muynak of 15m3/day each.

Private Sector Involvement. In Karakalpakstan private sector involvement has been made possible by law. Management contracts of up to 5 years can be granted, however, no private ownership of water infrastructure is allowed, other than community ownership.

Capacity Building. Little is known about capacity and capabilities in the water sector in Uzbekistan. With regard to desalination in particular, proof of underdeveloped skills and expertise can be found in Karakalpakstan particularly with regard to the state of the infrastructure operated. The fact that 63 plants are still running is mainly due to the fact that robust, appropriate technology was chosen, rather than this being a result of qualified operators on-site.

Environmental Impact. Brine that derives from the many ED desalination plants is discharged to general collectors. From an ecological point of view this is not correct; brine should be treated instead. This is considered not to be an environmental threat since the quantities of desalinated water are so small and very local. Moreover, there are no chemicals used in the treatment process, so the composition of the water does not really change.
It should be noted that, although these local discharges of brine are of themselves not very

significant, that more sustainable approaches should probably be taken in future to the disposal of brine. The brine should eventually be neutralised.

Future plans for Desalination. Besides Karakalpakstan there might be potential for desalination in other regions as well. These include Navai region, Bukhara region, Fergana region and Kashkadaria region.

9.5 Malta

Water Resources. There are no rivers of any significance in Malta. The rainfall mostly infiltrates into the groundwater aquifers. The groundwater is taken from 95 boreholes in Malta and 43 boreholes in Gozo. Some water is recovered from the sewage treatment plant and used for irrigation and industrial activities.
There is a water deficit in Malta. It occurs especially in summer when there is a great demand from the farmers for their irrigation, but also from the tourism sector to satisfy the needs of the many tourists that flock to the island. In order to bridge the gap between supply and demand has Malta has long ago started desalination of seawater.
The increased availability of more potable water (due to desalination) has greatly facilitated the development of the island in recent years. Tourism and industry have developed and at the same time, the quality of life of the population has been enhanced by allowing a bigger per caput water use.

Energy. Malta has no fossil fuel resources of its own and to date imports heavy fuel oil, coal and gas oil to generate electrical power. Moreover, Malta is not connected to any existing electricity grid in Europe or Africa. Harvesting of renewable energy, though not directly for desalination is receiving attention, not least by the country's obligation as a new EU member. There is no great potential in the application of renewable energy to desalination in Malta.

Institutions. The Water Services Corporation (WSC) is responsible for the supply of water to the population. It is an independent body wholly owned by the government.
The WSC has over the years carried out a rigorous programme of reducing water losses. This has been very successful. The program started with establishing exactly where the network was located. Existing drawings were found to be totally inadequate. Following this, a leakage reduction programme was instituted. This is on going.
Malta Desalination Services Ltd. (MDS), which was set up in 1997 as a subsidiary to the Water Services Corporation, is charged with the design, construction, operation and maintenance of the desalination plants.

Water Supply Sector Performance.
Water conservation is high up on the agenda in Malta. Education programmes were started at primary schools. Tariffs were set in different ways; the subsidy that was given in the past was almost scrapped. Rather now water is subsidised with a view to the social needs of certain groups in the community. There is an effective programme for leakage control. The greatest emphasis was placed the control of losses but an understanding of metering accuracy was also obtained through investigations. The population is encouraged to use private wells and to apply that water for toilet flushing and gardening, so that first class water can be freed from that.

Current Status of Desalination. There are three desalination plants in operation: Lapsi and Cirkewwa, Pembroke. They are all run by the Malta Desalination Services. All are reverse osmosis plants using sea water from beach wells. The first two seawater plants were initially operated by the company that constructed them under a management contract with the WSC. By the time the last plant was being considered, the Maltese decided to take over the running of the plants themselves.
Up until the Pembroke plant was commissioned demand was racing ahead of supply and the island had a permanent water crisis. This was due to the continuing success of the tourist industry and the

associated prosperity which it brought to the citizens of Malta. The building of Pembroke provided the government with some breathing space and the opportunity of taking stock. Water demand was continuing to increase. The government was faced with the possibility of having to install more desalination capacity or of attempting to modify consumption. The leakage control programme paid of and no new desalination plant was needed for the time being.

Private Sector Participation.
After completion of the construction of the desalination plant the government awarded a management contract to the company that built the plants. This contract ran for 15 years from 1982. Upon expiration of the contract the government felt that the local staff had learned sufficient about all aspects of plant operations and decided it was more economic to manage the plants themselves. A government owned company was set up for this purpose. Thus there is at present no private sector involvement in the desalination sector in Malta.

Capacity Building.
The Malta Desalination Services successfully runs the desalination plants in Malta. It also designs, manufactures and maintains plants for some of the larger hotels on the island. It also has undertaken major plant refurbishment and modifications. MDS has also undertaken major development projects to reduce energy costs and improve operational efficiency. All training and capacity building is done in-house.

Environmental Impact.
Malta has in place comprehensive environmental legislation. It has an Environmental Protection Act, issued in 2001, with a further 74 associated legal notices. Enforcement of this legislation is now of utmost importance. EIA is fully operational in Malta.

Future Plans for Desalination. There are no current plans for any new seawater desalination plants in the immediate future. Upgrading and improvement of existing plants will continue. The leakage control programme is ongoing and success here will in part match increase in consumption. The government is also pursuing other initiatives to reduce or moderate water consumption.

9.6 Cyprus

Water Resources. For the last fifty years the water demand in Cyprus was mostly satisfied from groundwater. The annual extraction was 45 MCM beyond the safe yield. This resulted in saline intrusion and quality deterioration of all coastal aquifers and spoiling valuable underground water storage. Overpumping caused depletion of inland aquifers and variable increase of their boron content. Intensive irrigated agriculture and over-fertilization increase nitrate content, particularly in the coastal areas.
To increase the water resources of Government embarked in an ambitious program of tapping the surface water, which was lost to the sea. To further increase the water resources and especially to relieve the domestic water supply from the vagaries of the weather, the Government signed contracts for the construction and operation of two desalination plants of the reverse osmosis type built in Dhekelia and Larnaca.
Recycled wastewater is an additional source of water that is applied in Cyprus.

Energy. Cyprus has no indigenous energy resources and is therefore completely dependent on imported energy, particularly oil
There is some scope to develop hydroelectric power and other renewable energy sources such as solar-powered heating, which is already well established in the domestic sector.

Institutions. The Water Development Department was established in 1896 as a Section of the Public Works Department, with responsibility for domestic water supply and irrigation.
As regards the provision of potable water the WDD is responsible for the collection and storage of water in reservoirs, the treatment of the water and its conveyance to the cities and villages in

Cyprus. It is also responsible for obtaining the water from the two desalination plants. The WDD makes sure that the water is delivered at the agreed quantities and that the water quality is in order.
The water is supplied to the people by the Water Boards, the Municipal Boards and the Village Boards. There are four water boards in Cyprus: at Nicosia, Limasol Larnaca and Famagusta (this board is currently inactive).

Current Status of Desalination. Since 1970 some 37 desalination units, on 18 different sites, have been installed in Cyprus. Desalination of seawater was first introduced in Cyprus on a large-scale in 1997 with the operation of the 20,000 m^3/day RO Dhekelia plant. The plant was soon expanded to 40,000 m^3/day. The Dhekelia plant uses a seawater intake. A second seawater desalination plant of 40,000 m^3/day was opened in 1999 in Larnaca.
The two large plants in Cyprus are of particular interest and importance in that they are the only large desalination plants operating on a purely commercial basis in a non-oil rich economy. They are therefore excellent case studies.
The desalinated water is sold to the Government at source and in bulk at US$ 1.00 at the time of concluding the contract in 1997 for Dhekelia and US$ 0.74 at the time of contracting for Larnaca. At present, these unit prices are raised by more than 25 percent due to an increase in the price of oil.

Private Sector Participation. The two plants in Dhekelia and Larnaca are run under a BOOT type of contact. The contracts run for 10 years. Once the contracts expire, it is very likely that the government will float management contracts for the operation of the plants. The initial operators (of the BOT contract) may be retained to carry out those management contracts.

Environmental Impact.
In Cyprus most of the harmonisation with the environmental acquis has taken place. This harmonisation would mean that at least on paper, environmental legislation should exist up to approximately the level of the EU Directives. Enforcement of the legislation is often another issue. EIA is certainly carried out on a regular basis. It appears as if this legislation is being properly enforced, though the Consultant has seen only a small example of an EIA report.

Future Plans for Desalination. The Government of Cyprus is currently considering building two further desalination plants, one at Limassol and another at Pafos. Each plant will produce 20,000 m3/day.

Appendix A Schedule of Main activities

This table lists the main activities carried out by the Consultant in the course of the study.

Date	Activity
18 - 19 December 2002	Inception Workshop, Amersfoort, the Netherlands
4 - 6 March 2003, 14 - 15 March 2003	Visit to Malta
7 - 13 March 2003	Visit to Tunisia
9 - 17April 2003	Visit to Uzbekistan
12 - 19 June 2003 11 - 14 August 2003	Visit to Algeria Visit to Cyprus
15 - 25 August 2003	Visit to Jordan
25 - 26 August 2003	EDS - WSTA Workshop, Amsterdam, the Netherlands
28 October 2003	Mini workshop in Washington, USA
TBA	Workshop in Larnaca Cyprus

Appendix B Country visits

Schedule of meetings

Tunisia and Malta

Date, time	Agency	Persons met
04 Mar,		Travel from Amsterdam / Glasgow to Malta
05 Mar, 10.00	Malta Resources Authority	Mr. Antoine Riolo, Malta Resources Authority Mr. George Cassar
05 Mar, 12.00	Water Services Corporation	Mr. Lino Spiteri, Chairman of WSC Malta Mr. Anthony Rizzo, Chief Executive of WSC Malta Mr. David Sacco, Malta Water Services, manager Pembroke plant
06 Mar, 10.00		Travel from Malta to Tunisia
06 Mar, 14.30	DHV Tunisie	Mr. Sami Abid
06 Mar, 16.00	Sonede	Mr. Mohammed Zaara
07 Mar, 09.00	DHV Tunisie	Mrs. Nozha Charfi, DG Adjoint Mr. Hedi Ben Mohammed, Dir. Technique
07 Mar, 11.00	Sonede	Mr. Abdelaziz Limam, Dir. Planification
07 Mar, 16.00	INRST	Mr. Raouf Bennaceur, Directeur Général de l'INRST, Mr. Ezzaoua Hatem, Directeur du Laboratoire des Applications Solaires, Dr. Bessais Brahim, Maître des Conférences, Mr. Mohamed Limam, Directeur du UGPAO et Directeur du Technopole Tunisien, Mr. Balghouthi Moncef, Ingénieur Chercheur a l'INRST.
08 Mar. 11.00	Min. Agriculture	Mr. Mojammed El Hedi Louati, Directeur des Grands Ouvrages Hydarauliques
10 Mar, 10.00	ANER	Mr. Mohammed Naceur, Directeur Renewable Energy
11 Mar, 10.00	Min. Developpement et Coop. Internationale	Mr. Mabrouk Mejeri, DG Evaluation et Suivi
11 Mar, 16.00	Sonede	Mr. Mohammed Zaara
12 Mar, 14.00	Sonede	Mr. Abdelaziz Limam, Dir. Planification
12 Mar, 16.00	Sonede	Mr. Mohammed Zaara
13 Mar, 09.00	DHV Tunisie	Mr. Hedi Ben Mohammed, Dir. Technique Mr. Sami Abid
13 Mar, 13.00		Travel from Tunis to Malta
14 Mar, 09.00 15 Mar, 07.00	Malta Resources Authority	Mr. Antoine Riolo Mr. George Cassar Travel from Malta to Amsterdam / Glasgow

Uzbekistan

Date, time	Agency	Persons met
09 Apr, 04.00		Travel from Amsterdam / Glasgow to Tashkent, Uzbekistan
10 Apr, 12.00	Min. Economics	Mr. Takhir Mamadvaliev, deputy Head PIU, "Uzbekistan: Water Supply, Sanitation and Health Project" Mr. Nikolay Kochnev, PIU, Rural water supply engineer Mr. Sergey M. Galtsev, Deputy Head of the Department of the Ministry of Economy Mr. Rinat Iskhakov, World Bank, Operations officer
10 Apr, 14.30	Hydrogeology Institute	Mr. Tariel V. Kuchekhidze, Director Mr. Vladimir Krasnikov, Chief engineer Mr. Nikolay Kochnev, PIU, Rural water supply engineer
11 Apr, 10.00	Design Institute "Suv Taminoti"	Mr. Pavel Tertychny, Director Mr. Timur A. Amirsaidov, Dep. Team leader Mr. Iskander Mirsabekov, Deputy Chief Engineer Mrs. Larisa I. Tsirkina, head of department Mrs. Elena V. Antonyn, head of department Mr. Nikolay Kochnev, PIU, Rural water supply engineer
11 Apr, 11.30	Obi Khayet	Mr. Bakhtiyor Nosirov, Chairman of the Board
11 Apr, 14.30	Min. Economics	Mr. Nikolay Kochnev, PIU, Rural water supply engineer
11 Apr, 17.00	State Com. on Environment	Mr. Halilulla S. Sherembetov, President "Goscompriroda" Mr. Rahmatulla Khabirov, Director research institute "Vodgeo" Mrs. Natalya Kasymova, Chief of the International Co-operation and Program Department "Goscompriroda" Mr. Nikolay Kochnev, PIU, Rural water supply engineer
14 Apr, 09.00	PIU Nukus	Mr. Rasbergen K. Kamalov, Head PIU Nukus
14 Apr, 11.00	Council of Ministers	Mr. Burkitbay T. Kdirniyazov, First Vice chairman of Advice of Ministers
14 Apr, 12.00	Vodokanal ("Su akkaba")	Mt. Sabit T. Yusupov, Chief Engineer
14 Apr. 12.30	Agrovodokanal (Trust "Karakalpakselkhozvodoprovod")	Mr. Joldasbay O. Otegenov, Director Mr. Urazbay Ishmuradov, Chief engineer
14 Apr, 14.00	Fieldvist to desalination plants	Kegeily region: Boklitay village, Ishankala village, Altinpishak village
15 Apr, 09.00	Fieldvist to desalination plants	Karauzyak region: Akpetkey village, Temirkhan village
16 Apr, 10.00	Min. Economics, PIU	Mr. Nikolay Kochnev, PIU, Rural water supply engineer
16 Apr, 14.00	Technology Transfer Agency	Mrs. Prof. Svetalana D. Gusakova, Director Mrs. Gulnara Sh. Rashidova, Deputy Director Mr. Kahima, expert
16 Apr. 16.00	World Bank	Mr. Rinat Iskhakov, Operations officer
17 Apr. 07.00		Travel from Tashkent, Uzbekistan to Amsterdam / Glasgow

Algeria

Date, time	Agency	Persons met
12 Jun, 14.00		Travel from Amsterdam / Glasgow to Algiers
13 Jun		Work in hotel
14 Jun, 10.00	UNDP	M. Ivon Morasse
14 Jun, 16.00	BRLi	M. Jacques Cambon (no meeting due to illness of M. Cambon)
15 Jun, 10.00	MRE	M. Moussa Yalaoui
15 Jun, 19.30	GTZ	M. Dieter Gomer
16 Jun, 10.00	AEC	M. Kamel Sid, Ms Amel Nour
16 Jun, 15.00	SEM	M. Jaen Luc Lafarge
17 Jun, 09.00	MRE, Ionics	M. Moussa Yalaoui, M. Maged Kasem
17 Jun, 11.00	ADE	
17 Jun, 14.30	DHW - Algiers	M. Amourouche
17 Jun, 17.00	ADE	Visit of Desalination plant at Zeralda
18 Jun, 10.00	MRE	M. Moussa Yalaoui, M. Abdelmadjid Demmak
18 Jun, 14.00	MRE, Safege	M. Moussa Yalaoui, M. Jean Marie Batterel
18 Jun, 15.00	Min. Environment	M. Abdelkarim Larech, Ms. Samira Nateche
19.Jun, 10.00	GTZ	M. Dieter Gomer
19 Jun, 15 .45		Travel from Algiers to Amsterdam / Glasgow

Cyprus

Date, time	Agency	Persons met
11 Aug, 19.00		Travel from Amsterdam / Glasgow to Larnaca, Cyprus, met by Dr. C A. Kambanellas of WDD
12 Aug, 09.00	Water Development Department	Mr. C. Artemis, Director Dr. C. Kambanellas, Executive Engineer Mr. Charlambos Kritiotis, Principal Water Engineer Mr. Andreas Manoli, Electrical Engineer, Desalination expert
12 Aug., 11.00	Caramondani Desalination Plant	Mr. Tasos Anastasi, Chief Electrical Engineer Mr. Georgios Psaltis, Plant Chemist Ms. Olga Sallangos, Plant Manager
13 Aug., 08.30	WDD	Dr. C. Kambanellas, Executive Engineer
13 Aug., 09.00	Planing Bureau	Mr. Costas Iacovou, Director of Planning Ms. Litsa Kastanou, Senior Planning Officer
13 Aug., 10.00	Water Board of Nicosia	Mr. Panayotis Theodolides, Technical Manager
13 Aug, 12.00	Larnaca Water partners	Dr. Erineos Koutsakos, Plant Manager
13 Aug, 14.00	Water Board of Lemesos	Mr. Bambos Charalambos, Head of Technical Services
13 Aug, 17.00	Hotels in Limassol	Mirabelle Hotel Four Seasons Hotel Hawaii Grand hotel
14 Aug, 09.00	WDD	Dr. C. Kambanellas, Executive Engineer
14 Aug, 18.00	Hotels in Larnaca	Lordos Beach hotel The Golden Bay hotel
14 Aug, 22.15		Travel from Larnaca, Cyprus to Amman, Jordan

Jordan

Date, time	Agency	Persons met
14 Aug, 23.30		Travel from Larnaca, Jordan to Amman, Jordan
15 Aug, 11.00	DHV	Mr. Rik Dierx
16 Aug, 09.00	MWI	Mr. Nazir Abu Arqoub Mr. Fayez Batainah, Ass. Secretary General
17 Aug, 08.45	MWI	Mr. Nazir Abu Arqoub
17 Aug, 09.45	MWI	Mr. Ibrahim Alkam, WAJ water tariffs
17 Aug, 10.30	MWI	Ms. Suzan Taha, National Water Masterplan
17 Aug, 11.45	Marriott hotel	Mr. Koussai Quteishat, Director MEDRC
17 Aug, 12.45	MWI	Mr. Edward Qunqar, Director Water Resources Planning Directorate
17 Aug, 13.30	MWI	Mr. Sa'ad Bakri, Secretary General of the Ministry
18 Aug, 09.00	USAID Workshop, Dead Sea, Movenpick	Mr. Harold Gillam, CDM Mr. Malek Kabariti, President National Energy Research Centre
19 Aug, 09.00	Nat. Privatisation Commission	Mr. Nazih Wafiq Barqawi, Secretary General
19 Aug, 10.30	Min. of Planning	Dr. Kamal M. Khdier, Director Water, Environment and Tourism Directorate
19 Aug, 12.00	PMU, BOT	Mr. Mohammad Najjar Mr. Sultan Mashakbeh, Engineer
19 Aug, 13.30	PMU	Mr. Joseph Kefaya, Director Management Contract Mr. Rik Dierx, Co-director
20 Aug,	EU	Mr. Mario Rizos
20 Aug, 13.00		Trip to Aqaba
21	Aseza	Mr. Bilal Bashir, Commissioner for Environment
21 Aug, 10.30	Water Authority	Mr. Imad Zuraikat, Asst. Secr. General
24 Aug, 09.00	MWI	Mr. Rateb Al Adwan, Director Water treatment and Desalination Department Mr. Nazir Abu Arqoub
24 Aug, 11.30	Aqua Treat	Mr. Tarik S. A. Dehays
24 Aug, 11.45	MWI	Mr. Nazir Abu Arqoub Mr. Fayez Batainah, Ass. Secretary General
25 Aug, 02.00		Travel from Amman to Amsterdam / Glasgow

Appendix C Private Sector Participation