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MED POL

SEA WATER DESALINATION IN THE MEDITERRANEAN

ASSESSMENT AND GUIDELINES

DESSALEMENT DE L'EAU DE MER EN MÉDITERRANEÉ

ÉVALUATION ET LIGNES DIRECTRICES

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ASSESSMENT OF SEA WATER DESALINATION ACTIVITIES IN THE MEDITERRANEAN REGION AND ENVIRONMENTAL IMPACTS

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INTRODUCTION

The need for desalting seawater is becoming more and more pressing in many parts of the world. During the period from 1950 to 1990 the worldwide consumption of water was tripled, while the population grew by 2.3 billion people.

In the Mediterranean, the present and future water needs are really increasing. It is estimated that by the year 2010 water demands will increase by 32% at least for the southern and eastern countries. There is no doubt that the above water needs can be covered and satisfied if only non-conventional resources of water are utilized, like water-recycling and desalination.

Desalination has for a long time been a major source of water in parts of the Mediterranean. Desalination plants exist in places that have hot climates, relatively low and unpredictable rainfall and where conventional water resources are unable to meet peak tourist demands.

Seawater desalination by Mediterranean countries is a steadily growing industry. This practically unlimited resource of water, requires energy consumption and results to environmental impacts. These impacts are generated mainly from the concentrate (brine) produced during the desalination, but also from the discharges of chemicals used in the desalination processes.

Although the number of scientific publications dealing with the issue is limited, the discharge of concentrate into the sea requires particular attention and scientific assessment of possible impacts on the marine environment.

There is no doubt that Mediterranean countries, which use desalination to cover their freshwater needs, should apply appropriate guidelines or procedures for the disposal of brine according to the LBS and Dumping Protocol. As a result, this document was prepared to offer a basis for discussion aiming at identifying a common management approach in line with the Barcelona Convention and its Protocols.

CHAPTER 1. - SEAWATER DESALTING

1.1 The need for seawater desalination

Agenda 21, particularly its Freshwater chapter, make it clear that water is a key to sustainable development.

An amount of 97.5% of the total global stock of water is saline and only 2.5% is fresh water. Approximately 70% of this global freshwater is locked-up in polar ice caps and a major part of the remaining 30% lies in remote underground aquifers. In effect, only a miniscule fraction of freshwater (less than 1% of the total freshwater, 0.007% of the total global water stock) is available in rivers, lakes and reservoirs and is readily accessible for direct human use. Furthermore, the spatial and temporal distribution of freshwater stock and flows is hugely uneven (Bennet *et al.*, 1999) (8).

As a result of the development of arid regions and also in the wake of intensive use of water in urban areas all over the world, freshwater is frequently not available in the quantities desired. The World Health Organization (WHO) has estimated that 1000 m^3 per person per year is the benchmark level below which chronic water scarcity is considered to impede development and harm human health.

We now witness a large drive to open arid areas of large-scale settlement. This trend is the result of the increase in world population (which has already crossed the 6 billion mark and is expected to reach 8.3 billion in 2025 and 10-12 billion in 2050), the feasibility of indoor climate control; and various military, economic and political factors.

During the period from 1950 to 1990, the worldwide consumption of water tripled. Every second of every day the earth's population increases by 2.3 people which means that water consumers are increasing by 150 per minute, 9,000 per hour, 216,000 per day or 28,8 million per year. Where will the additional two trillion cubic meters of water be found to meet the additional 2.6 billion consumers that join the present world population of over 5 billions? (Linsky, 1999) (27).

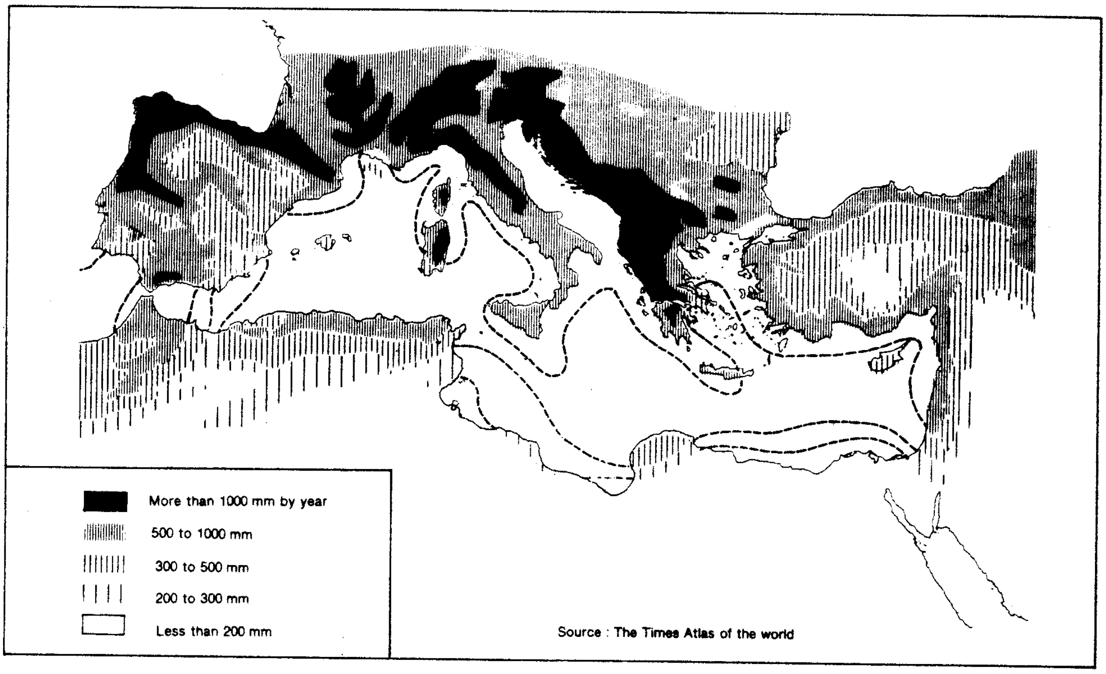
Mediterranean region water resources are limited, fragile and threatened. They are already intensively utilized, especially in the south and east where the lengthy dry seasons with low average annual rainfall is a fact (Fig. 1), (Blue Plan, 1992) (10).

In the Mediterranean region temporary droughts, which can be defined as lower than average precipitation of varying severity duration and scale, have consequences which are particularly severe for water resources. During the last few decades, most Mediterranean countries have experienced memorable long-term droughts e.g. 1980-85 in Morocco, 1982-83 in Greece, Spain, Southerly Italy and Tunisia, 1985-89 in Tunisia, 1988-90 in Greece, 1988-92 in Mediterranean France, 1989-91 in Cyprus, 1990-95 in Spain and Morocco, 1993-95 in Tunisia, 1995-2000 in Cyprus and Israel, the list being far from exhaustive.

According to United Nations (UN) estimations the total population of the region will increase from 420 million inhabitants in 1995 to 446 million in 2000, to 508-579 in 2025 (Fig. 2), (Blue Plan, 1992) (10). Within one generation the total population in the Eastern and Southern countries tripled and it was over 223 million.

FIGURE 1

AVERAGE ANNUAL RAINFALL



LENGTH OF THE DRY SEASON

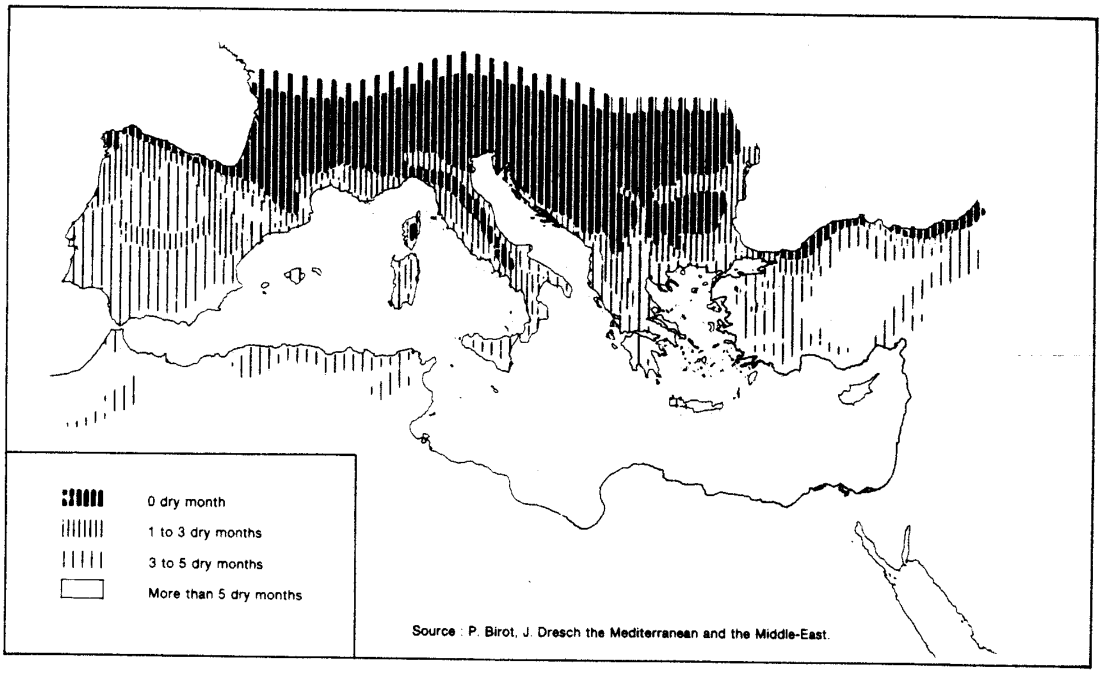
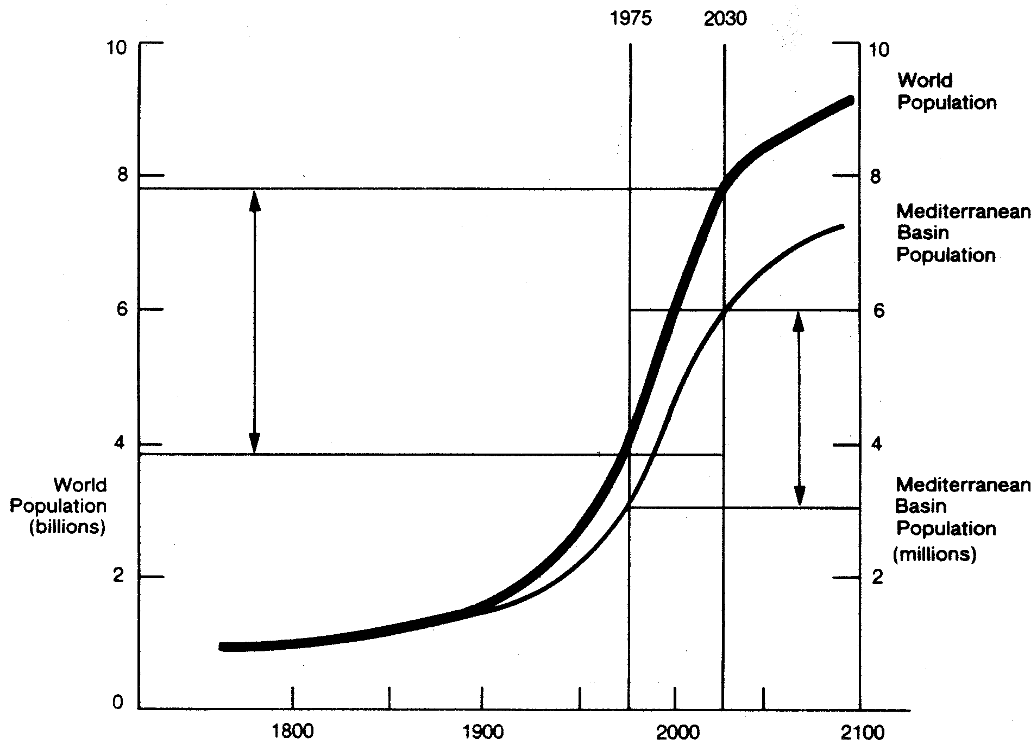


FIGURE 2

WORLD POPULATION AND MEDITERRANEAN BASIN POPULATION : PAST AND FUTURE GROWTH



Sources : I.I.A.S.A. and Blue Plan

Tourism, is steadily developing, as Mediterranean basin is the worlds No. 1 tourist destination, and in the last 15 years an increase of 64% raises the figure of visitors to about 350 million. This results to an increased demand for drinking water, especially in the summer (and especially in the islands). A telling example of this is Spain: The population of 27 municipalities on the Costa Brava swells from 150,000 in winter to 1.1 million in mid- August. (Blue Plan, 2000) (9).

Based mainly on data available in National Planning documents, the Forecast for water demand in Mediterranean countries and territories for the year 2010 and 2025 is shown in Table 1, (Blue Plan, 2000) (9). The figures in Table 1 are summarized by sub regions (Km^3/year) as show below.

Table 1

Moderate trend forecasts for water demand in
Mediterranean countries and territories for 2010 and 2025.

Countries and territories	*Sectorial demands in Km^3/year*								Total demands Km^3/year	
	Communities		Agriculture		Industry		Energy			
	2010	2025	2010	2025	2010	2025	2010	2025	2010	2025
PO	0,72	0,9	5,64	5,3	0,5	1,0	3,5	4,0	10,37	11,2
ES	6,28	7,0	27,6	25,7	2,43	3,0	4,0	5,0	40,35	40,7
FR	7,90	9,6	6,0	5,8	5,0	5,9	27,0	28,7	45,9	50,0
IT	7,60	5,2	30,7	31,7	13,3	7,0	0,5	0,5	52,1	44,37
MT	0,04	0,04	0,005	0,006	0	0	0	0	9,044	0,046
SI,HR,BA, YU,MC	2,8	3,7	1,1	1,4	6,0	8,0	10,0	12,0	19,9	25,1
AL	0,83	0,8	1,9	1,9	0,2	0,3	0	0	2,93	3,0
GR	1,50	1,8	7,7	9,0	0,18	0,2	0,12	0,2	9,50	11,2
TR	17,8	23,6	28,1	30,7	5,0	7,0	5,0	10,0	55,9	71,3
CY	0,1	0,1	0,5	0,8	0	0	0	0	0,593	0,9
SY	2,1	3	17,6	25,2	0,3	0,37	0,1	0,1	20,1	28,67
LB	0,40	0,52	0,52	1,10	0,10	0,14	0	0	1,42	1,76
IL	0,77	1,4	1,25	1,24	0,22	0,20	0	0	2,24	2,84
GZ,WE	0,32	0,53	0,30	0,42	0,04	0,06	0	0	0,66	1
JG	0,43	0,57	1,75	2,40	0,13	0,20	0	0	3,31	3,17
EG	5	6,0	75,0	95	10	14	0	0	90	115,0
LY	1,0	1,76	9	11,9	0,24	0,57	0	0	10,24	14,2
TN	0,42	0,53	3,37	4,23	0,16	0,26	0	0	3,95	5,02
DZ	4,1	6,05	3,6	4,64	0,35	1,4	0,2	0,2	8,85	12,29
MA	1,6	1,57	15,3	17,19	1,4	1,51	0	0	18,3	20,27
Total	61,71	74,67	237,335	275,626	46,15	51,11	50,42	60,7	395,657	462,036

After MEDTAC Blue Plan.

	Reference Year	Forecasts	
Sub region	**1990**	**2010**	**2025**
* North	155.5	171	186
** East	55	81	51
*** South	88.5	131	167
TOTAL	299	383	463

* Spain, France and Monaco, Italy, Malta, Bosnia-Herzegovina, Croatia, Slovenia, F.R. of Yugoslavia, Albania, Greece. (Portugal)

** Turkey, Cyprus, Syria, Lebanon, Israel, Pal. Authority (Jordan).

*** Egypt, Libya , Tunisia, Algeria, Morocco.

The demands show a 32% increase by 2010 and a 55% by 2025. The increase in the North is less than that in the South and East.

The required water production would increase by 96 billion cubic meters per year by 2010.

Figure 3, shows the projected growth of ratio demand /water resources in Southern and Eastern Mediterranean countries. Starting in 2010, eleven countries would use more than 50% of their renewable resources (Blue Plan, 2000) (9). In 2025, this index will exceed 100% in 8 countries, and more than 50% of these resources in 3 other.

In summary, present and future water needs can be covered and satisfied only if non-conventional resources (waste recycling and desalination) utilised.

1.2 Basic technology and brief description of existing desalination methods

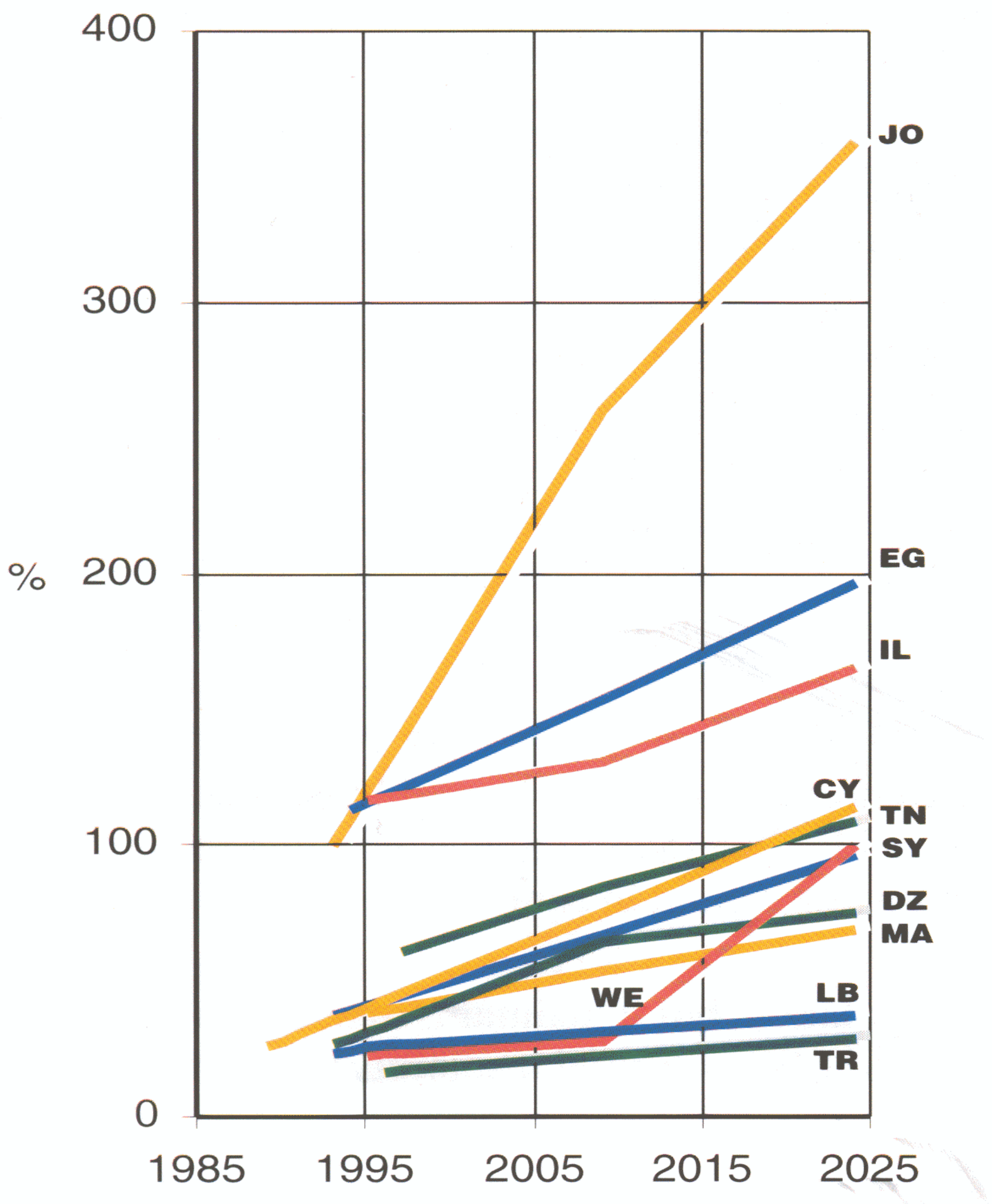
The greatest natural desalination process occurs on Earth and this is the hydrologic cycle. It is a natural machine, a constantly running distillation and pumping system. The sun supplies heat energy and this together with the force of gravity keeps the water moving from the earth to the atmosphere as evaporation and transpiration and from the atmosphere to the earth as condensation and precipitation.

Desalination is this paper refers only to seawater desalination, where freshwater is produced from seawater when part of inlet feed seawater flows into fresh water production. This has the inevitable result that a stream of water relatively concentrated in dissolved salts (brine) will be discharged from the plant as shown below.

FIGURE 3

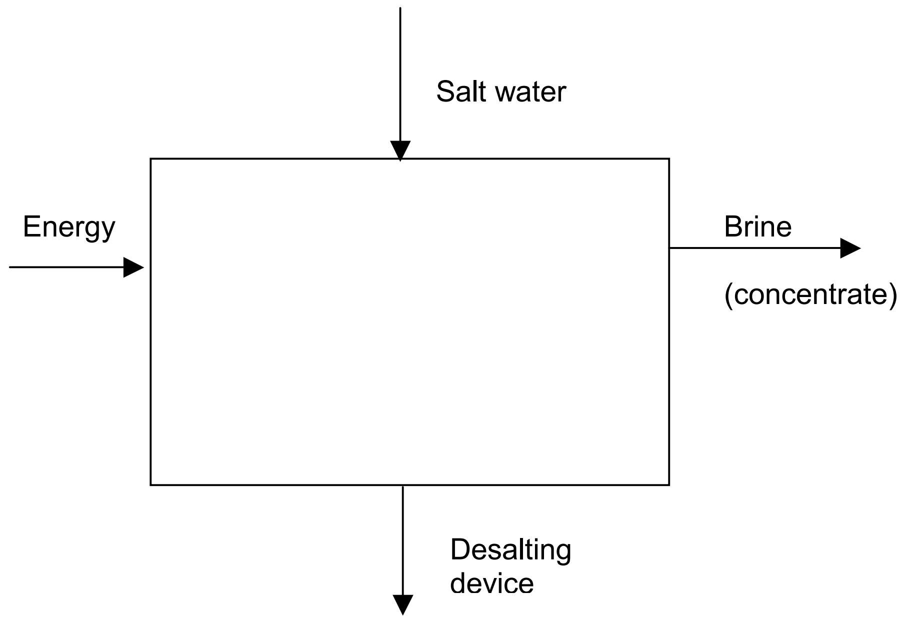
Projected growth of the ratio demand/water resources in Southern Mediterranean countries (moderate trend scenario).

(Gaza and Libya are not mentioned since their indexes, way over 100, are off the scale).



Years

After: Blue Plan Jan. 2000 Report "Mediterranean vision water, population and the environment for the 21st century".



The commercially available desalination processes are divided in two main categories, Thermal and Membrane.

a) Thermal processes

About half of the world's desalted water is produced with heat used to distill fresh water from seawater. The distillation process mimics the natural water cycle in that salt water is heated, producing water vapour that is in turn condensed to form freshwater.

In an industrial plant, water is heated to the boiling point to produce the maximum amount of vapour. To do this economically in a desalination plant, the applied pressure of the water being boiled is adjusted to control the boiling point.

i) Multistage Flash Distillation (MSF)

In the MSF process, seawater is heated in a vessel called the brine heater. This is generally done by condensing steam on a bank of tubes that carry seawater, which passes through the vessel. This heated seawater then flows into another vessel called a stage, where the ambient pressure is lower, causing the water to immediately boil. The sudden introduction of the heated water into the chamber causes it to boil rapidly, almost exploding or flashing into steam. Generally, only a small percentage of this water in converted to steam (water vapour), depending on the pressure maintained in this stage, since boiling will continue only until the water cools to the boiling point.

The concept of distilling water with a vessel operating at a reduced pressure is not new and has been used for well over a century. In the 1950´s an MFS unit that used a series of stages at increasingly lower atmospheric pressures was developed. In this unit, the feed water would pass from one stage to another and be boiled repeatedly without adding more heat. Typically an MSF plant can contain from 15 to 25 stages. Figure 4 illustrates the flow diagramme of a typical MSF plant (Bouros, 1992) (12).

ii) Multi-Effect Distillation (ME)

In multi-effect evaporators (ME) the vapour from the first evaporator condenses in the second, and the heat from its condensation services to boil the saltwater in the latter.

Therefore, the second evaporator acts as condenser for the vapour from the first, and the task of this vapour in the second evaporator is like that of the heating steam in the first. Similarly the third evaporator acts as condenser for the second and so on. This principle is illustrated in Figure 5. Each evaporator in such series is called an effect.

Some of the early water distillation plants used the MED process but MSF units, because of better resistance against scaling, displaced this process. However, starting in the 1980´s, interest in the MED process was revived, and a number of new designs have been built around the concept of operating on lower temperatures, then minimizing corrosion and scaling.

iii) Vapour Compression Distillation (VC)

The vapour compression (VC) distillation process is used for small and medium scale seawater desalting applications. The vapour compression process differs from other distillation processes, that it does not utilize an external source of heat. It makes use of the compression of water vapour (by e.g. a compressor to increase the vapour pressure and condensation temperature.

Figure 6, (Bouros, 1992) (12) illustrates a simplified method in which a mechanical compressor is used to generate the heat for evaporation. All steam is moved by a mechanical compressor from the last effect and introduced as heating steam into the first effect after compression where it condenses on the cold side of the heat transfer surface seawater is prayed or other wise distributed on the other side of the heat transfer surface, where it boils and partially evaporates, producing more vapour.

VC units are often used for resorts and industries and drilling sites where freshwater is not readily available. Their simplicity and reliability of operation make them an attractive unit for small installations.

The mechanical VC units have capacities ranging from few litres to 3,000 m^3/day.

b) Membrane Processes

In nature, membranes play an important role in the separation of salts both the process of dialysis and osmosis occur in the body.

Membranes are used in two commercially important processes. Electrodialysis (ED) and reverse osmosis (RO).

i) Electrodialysis (ED)

ED is a voltage driven process and uses an electrical potential to move salts selectively through a membrane, leaving freshwater behind.

ED was commercially introduced in the early 1960´s. The basic ED unit consist of several hundred-cell pairs bounded together with electrodes on the outside referred as the stack. Feed water passes through all cells simultaneously to provide a continuous flow of desalted water and concentrate from the stack depending on the design of the system. Chemicals may be added to the streams in the stack to reduce the potential for scaling.

The components of an electrodialysis plant are shown in the diagram Figure 7. (Bouros, 1992) (12).

FIGURE 4

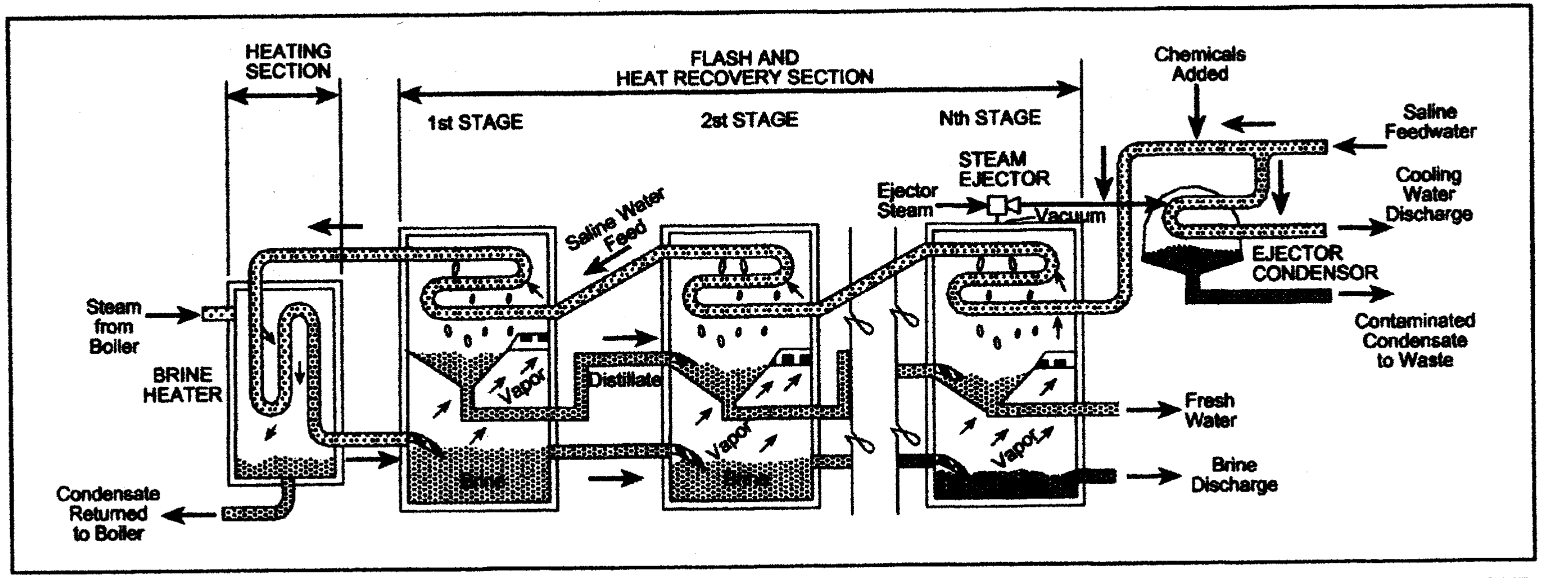


Diagram of a Multi-Stage Flash Plant *USAID*

FIGURE 5

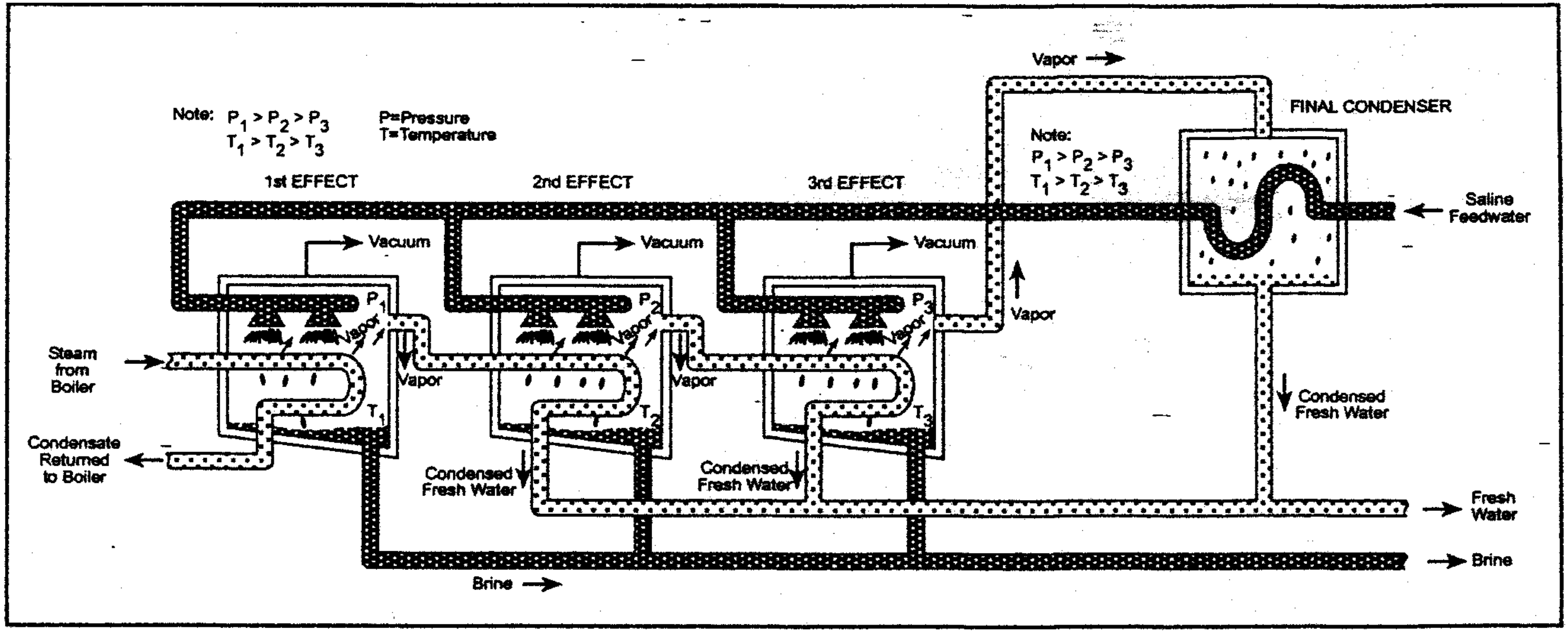


Diagram of a Multi-Effect plant with horizontal tubes. *USAID*

FIGURE 6

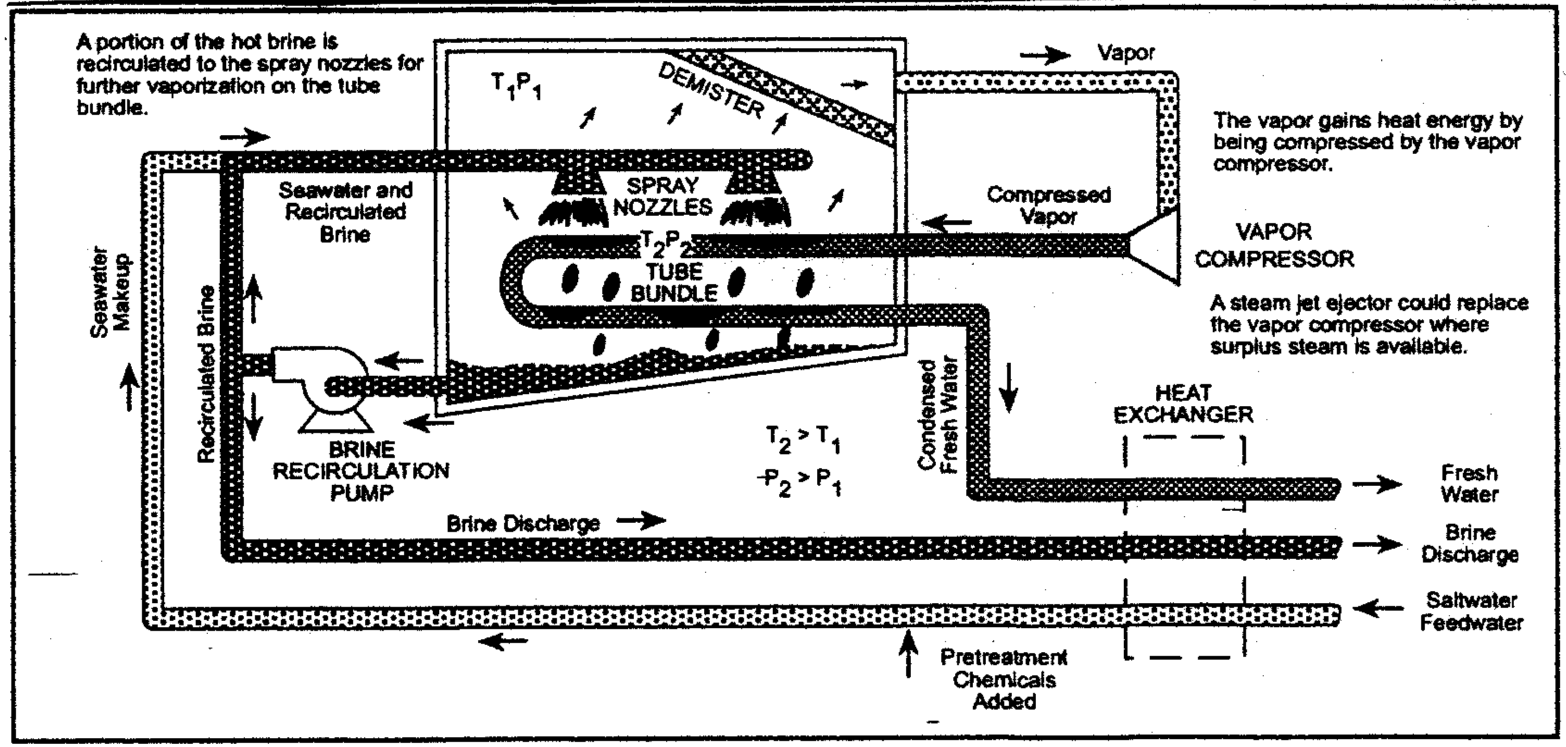


Diagram of a mechanical vapor compression unit *USAID* *ii) Reverse Osmosis (R.O)*

The RO is a membrane separation process in which the water from a pressurized saline solution is separated from the solutes (the dissolved material) by flowing through a membrane. In practice, the saline feed water is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the remaining feed water increases in salt content. At the same time, a portion of this feed water is discharged without going through the membrane.

Without this control discharge, the pressurized feed water would continue to increase in salt concentration creating problems such as precipitation of super saturated salts and increased osmotic pressure across the membranes.

The function of RO membrane is illustrated in Figure 8.
An RO system is made up of the following basic components.

- Pre-treatment
- High pressure pumps
- Membrane assembly and
- Post treatment

The above components are illustrated in detail in the flow sheet for seawater RO (Fig. 9), (Morton *et al.*, 1996) (30).

The past ten years have been significant ones for the RO process. Although the process has not fundamentally changed in concept, there have been steadily and continuous improvements in the efficiency of the membranes, energy recovery, energy reduction, membrane life control of operations and operational experiences. The result has been an overall reduction in the cost of water produced by RO in the desalting of seawater.

c) Other Processes

A number of other processes have been used to desalt saline waters. These processes have not achieved the level of commercial success that distillation and RO have, but they may prove valuable under special circumstances or with further development.

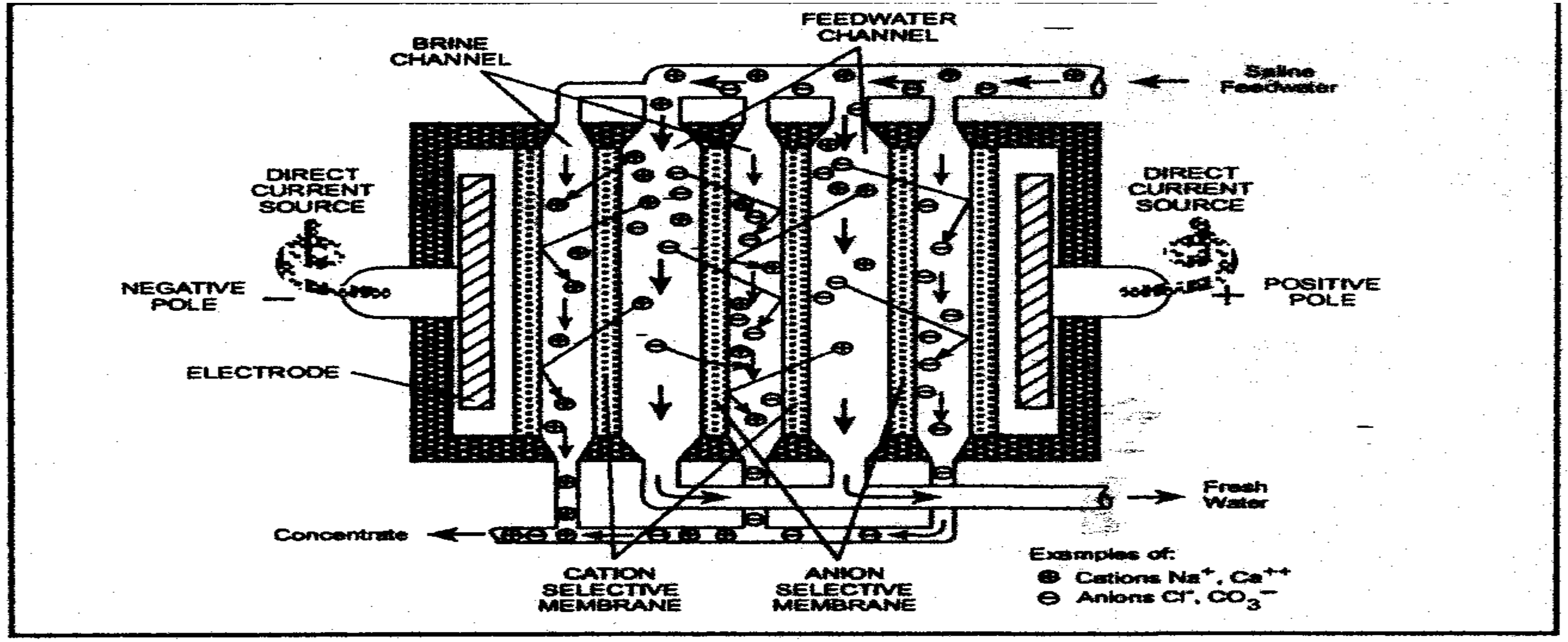
i) Freezing

During the process of freezing, dissolved salts are naturally excluded during the initial formation of ice crystals. Cooling saline water to form ice crystals under control conditions can desalinate seawater. There are several different processes that have used freezing to desalt seawater, and a few plants have been built over the past 50 years.

ii) Membrane distillation

As the name implies the process combines both the use of distillation and membranes. In the process, saline water is warmed to enhance vapour production and this vapour is exposed to a membrane that passes water vapour but not liquid water. After the vapour passes through the membrane, it is condensed on cooler surface to produce freshwater.

FIGURE 7



Movement of ions in the electrodialysis process *USAID*

FIGURE 8

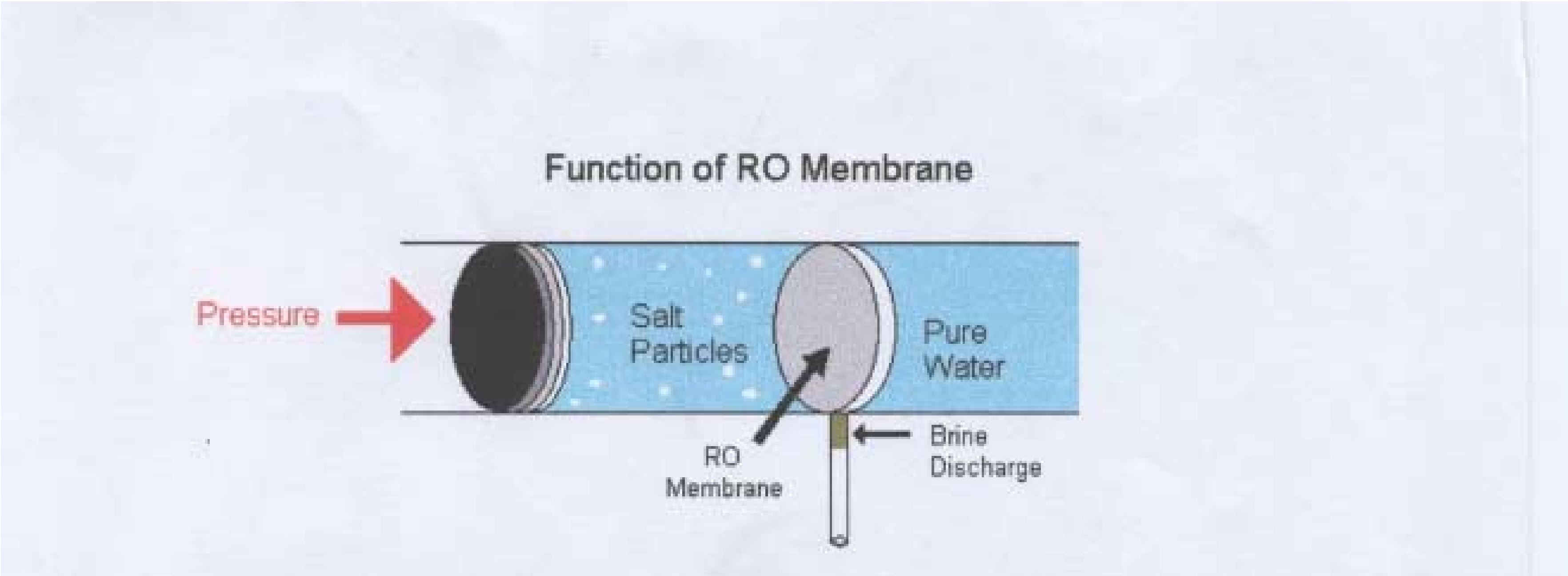
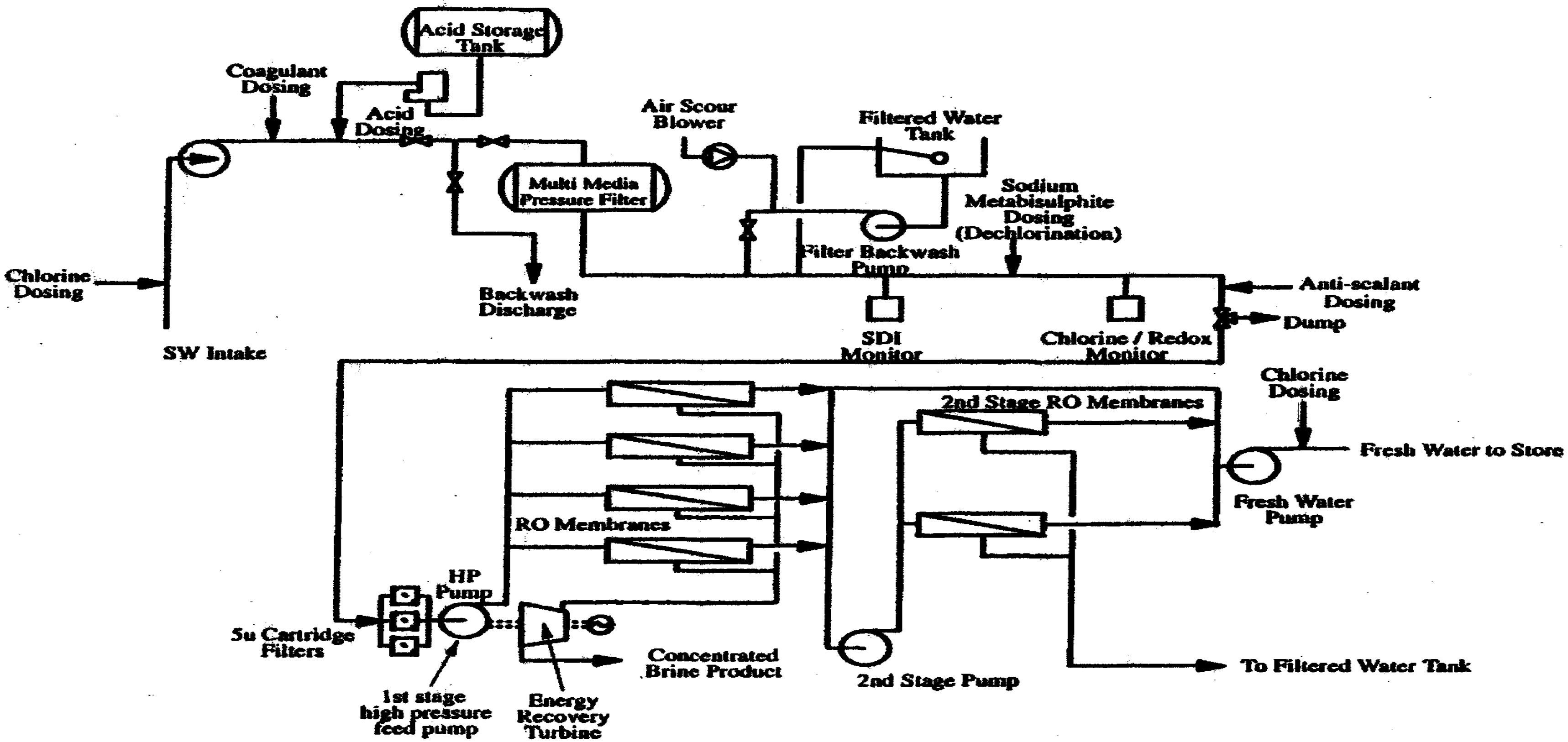

Function of RO Membrane
Pressure
Salt
Particles
Pure
Water
RO
Membrane
Brine
Discharge

FIGURE 9

Typical flow sheet – Seawater RO plant.



After: Morton *et al.*, 1996 (30)

iii) Solar Humidification

The use of direct solar energy for desalting saline water has been investigated and a variety of devices have been used. These devices generally imitate a part of the natural hydrologic cycle in that the sun's rays heat the saline water so that the production of water vapour (humidification) increases. The water vapour is then condensed on a cool surface and the condensate collected as fresh water.

An example of this type of process is the green house solar still, in which the saline water is heated in a basin on the floor and the water vapour condensed on the sloping glass roof that covers the basin. An application of this type of solar humidification units has been used for desalting saline water on small scale for small villages where solar energy and low cost of labour is abundant, but electricity is not.

d) Co-generation-Hybrid and Dual purpose plants

In certain cases it is possible to use energy so that more than one use can be obtained from it as the energy moves from a high level to ambient level. This occurs with co-generation where a single energy source can perform different functions.

Certain types of desalination processes especially the distillation process, can be structured to take advantage of a co-generation situation. Most of the distillation plants installed in the Middle East and North Africa have operated under this principle since the 1960´s, and are known in the field as dual-purpose plants (water plus power).

Dual Purpose plants use steam to drive both an electric generator (via a steam turbine) and provide thermal energy to evaporate seawater as part of the desalination process. From an energy prospective, a Dual Purpose Plant is an excellent combination. Some of the electric power can be used to operate a membrane plant and the balance sold to a local power company or the reverse. The exhaust heat from the gas turbine, or steam from a steam turbine in used to provide heat to operate a thermal desalination plant.

The virtue of the Dual Purpose Plants relies on the fact that during maximum water demand condition, the membrane plant would be operated at a maximum capacity. When water requirements subside, membrane plant water production would be reduced and more electrical power would be sold to the electric power company, while the thermal desalination plant continues to operate at rated capacity. Such an arrangement provides maximum flexibility to meet fluctuating demands.

There are estimates that for an RO plant that produces 75.10^6 m^3 /year of water that uses exhaust steam from a power plant to heat the feed water, the electricity demand could be reduced 10 to 15% (California Coastal Commission, 1991) (14).

It is difficult, to make a generalized statement that a thermal or membrane process is better than another without conducting an in-depth study for a specific application evaluating both technical and economic factors.

Even when such a study is conducted especially for a very large installation, the reviewers often consider a large thermal plant a more conservative choice than one relying solely on membranes. This is due to the fact that MSF and ME are well proven and have a greater tolerance for variable feed water conditions and maloperation changes in the cost and frequency of membrane replacement which could dramatically affect the economics and security of a water supply during the life of a plant.

An option being considered on an increasing frequent basis is a Hybrid Plant that uses both thermal and membrane processes. This alternative improves the overall process efficiency by using the warm cooling water effluent stream from the MSF/ME as RO feed water.

Hybrid Systems provide flexibility by using two different forms of energy; electricity for RO and steam for a MSF/ME and eliminate the dependence of a single technology.

e) Other options for saving energy– use of non conventional energy resources

One method for reducing energy use in all types of desalination plants is by employing energy recovery. In the case of distillation, heat in the brine and fresh water leaving the plant is used to preheat the feed water. In RO, energy is recovered by converting hydraulic pressure in the brine to electricity or by transferring this energy to the feed water.

Solar and wind energy could also be used to heat water for small distillations Plants. Solar energy is however expensive compared to other desalination technologies and normally require a larger area for the solar energy gathering and conversion devices; However this technology would not produced toxic air emissions and would not consume exhaustible resources.

At present the use of solar or wind energy by Mediterranean countries is restricted only in a few small desalination units. This technology seems to be at the stage of demonstration than commercial application.

CHAPTER 2. - THE STATE AND TRENDS OF SEAWATER DESALINATION IN THE MEDITERRANEAN REGION

Seawater distillation aboard ocean-going vessels has been standard practice for over a century and purification plants are mushrooming in many parts of the world, in particular in the countries boarding the Persian- Arabian Gulf where both the need for fresh water is great and the necessary fuel resources are readily available.

Whilst it is true that most of the very large desalination plants are sited in the Arabian peninsula, there are an impressive number of plants around the world, some in places that would not immediately be thought of likely candidates for this rather expensive water resource. By 31 December 1999, a worldwide total of 13,600 desalting plants with a total capacity of 25,909 m^3/day had been installed or contracted. (Wangnick, 2000).

In the Mediterranean, desalination has for a long time been a major source of water, with the first plant installed in Marsa Alam, Egypt with a capacity of 500 m^3/day. In 1983, Malta became one of the first places to use RO processes for seawater desalination on a large scale. In Spain and in particular in the Grand Canary Islands the first seawater plants were MSF distillers which were followed by several RO plants. Today, Spain is the country with the largest capacity of seawater desalination plants in the Mediterranean region.

2.1 Existing seawater desalination plants in the Mediterranean: their geographical distribution

The existing seawater desalination plants (capacity more than 500 m^3/day) in the Mediterranean Region are shown in Annex I, after the 2000 IDA Worldwide Desalting Plants Inventory, (Wangnick, 2000) (39). The plants appear by country, location, capacity, type of plant (process), user and year of operation.

The total capacity of existing seawater desalination plants in each Mediterranean country is shown in Table 2, and Figure 10. Spain has the highest total capacity of 648,980 m^3/day covering 33.18% of the total capacity of the Mediterranean region which by the end of 1999 was 1,955, 686 m^3/day.

Seawater desalination in Spain started in the early 70´s in places with scarcity of water near the coast where it was the only way to supplement natural water resources needed to supply domestic water to isolated highly populated territories.

Distillation technologies, MSF at the very beginning and VC later, were the only available at that time, but in recent years the desalination plants operated in Spain have increased in number and capacity. The Canary Islands is the area where most of the potable water comes from desalination.

The main desalination technology (process), which is applied in Spain, is the RO. About 82% of the total desalinated water is produced from RO plants, while the rest is equally distributed between to MSF, VC, ED and ME processes (Table 3 and Figs. 11, 12 and 13). The main users of the produced desalted water are the municipalities and tourist complexes using 580, 060 m^3/day i.e. 89.38% of the total (Table 4). About 7.5% is used for other purposes such as irrigation and military installations while only about 3% is used for electrical power stations and the industry.

Table 2

Total production capacity (m^3/day) of existing seawater desalination plants (with the percentage of the total) in each country at the end of 1999.

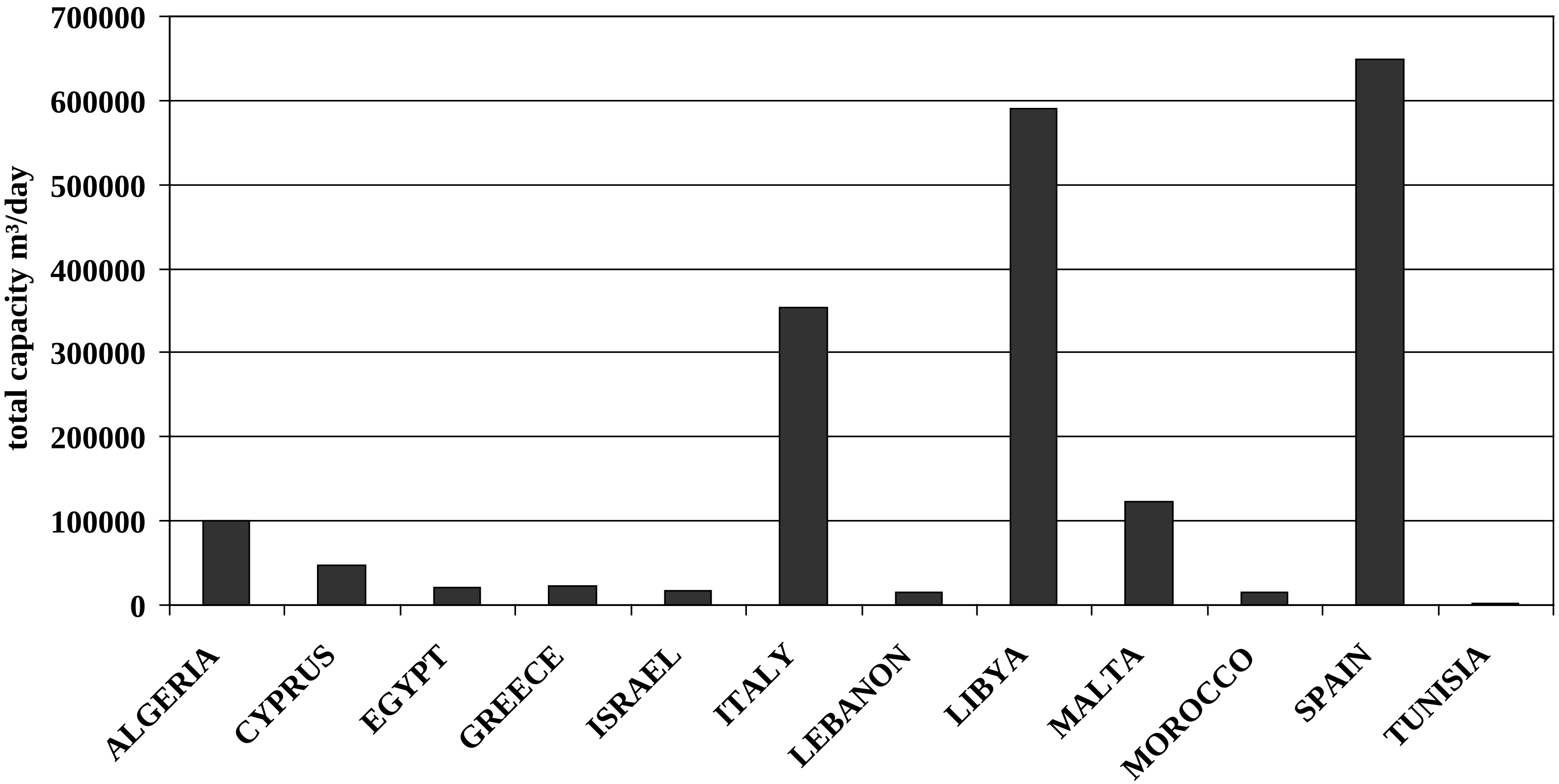
Country	TOTAL	*% of the total*
ALGERIA	100739	*5.15*
CYPRUS	46561	*2.38*
EGYPT	20860	*1.07*
GREECE	21840	*1.12*
ISRAEL	17032	*0.87*
ITALY	353990	*18.10*
LEBANON	15190	*0.78*
LIBYA	589604	*30.15*
MALTA	123868	*6.33*
MOROCCO	14802	*0.76*
SPAIN	648980	*33.18*
TUNISIA	2220	*0.11*
TOTAL	1955686	*100.00*

Libya is the second country in terms of capacity of seawater desalination plants in the Mediterranean with 30% of the total capacity. The first seawater desalination plant in Libya was installed in Port Brega in 1965 with a capacity of about 750m^3/day. In the early 70´s, Libya started operated plants of more than 10,000 m^3/day capacity and by the end of 1999 the total capacity of desalination plants was in the range of more than half a million m^3/day.

Concerning applied technology Libya has its peculiarities. Most desalted water produced is from MSF distillation plants (which is the highest from all the other countries), 72% of which is used by municipalities, which are the main users. In the other Mediterranean countries normally MSF technology is used in electrical power stations and the industry. The second user in Libya is the industry with 24.57%.

Italy is the country where most of the produced desalination water (about 60%) is used by the industry. Although desalination technology started being applied in Italy on an extensive basis, in the 70´s, only in the early 90´s, this technology (mainly VC) began to be used by the municipalities, mainly in the south of Italy and particularly in Sicily. Originally the main technology applied was the MSF for industrial and power purposes. The total capacity of seawater desalination plants in Italy is 18.1% of the total capacity for the Mediterranean region (Table 2).

Fig. 10. Total production capacity of seawater desalination plants in each country at the end of 1999.



Malta was the first Mediterranean country where in 1983 the largest RO plant was installed to produce potable water with a capacity of 20,000 m^3/day.

Table 3

Production capacity (m^3/day) of existing seawater desalination plants with the percentage of the total by type in each country by the end of 1999.

Country	RO	MSF	VC	ME, ED	TOTAL
	% of the total	*% of the total*	*% of the total*	*% of the total*	*% of the total*
ALGERIA		72222	27556	961	100739
		71.69	*27.35*	*0.95*	*100.00*
CYPRUS	40000	4761	1800		46561
	85.91	*10.23*	*3.87*	*0.00*	*100.00*
EGYPT	4160	12500	0	4200	20860
	19.94	*59.92*	*0.00*	*20.13*	*100.00*
GREECE	6320	5800	9720		21840
	28.94	*26.56*	*44.51*	*0.00*	*100.00*
ISRAEL	0	0	0	17032	17032
	0.00	*0.00*	*0.00*	*100.00*	*100.00*
ITALY	31771	216580	91480	14159	353990
	8.98	*61.18*	*25.84*	*4.00*	*100.00*
LEBANON	0	520	14670	0	15190
	0.00	*3.42*	*96.58*	*0.00*	*100.00*
LIBYA	59850	454716	69092	5946	589604
	10.15	*77.12*	*11.72*	*1.01*	*100.00*
MALTA	116668	3000	4200	0	123868
	94.19	*2.42*	*3.39*	*0.00*	*100.00*
MOROCCO	7800	7002	0	0	14802
	52.70	*47.30*	*0.00*	*0.00*	*100.00*
SPAIN	534160	49200	36620	29000	648980
	82.31	*5.64*	*5.64*	*4.47*	*100.00*
TUNISIA	600		1620		2220
	27.03	*0.00*	*72.97*	*0.00*	*100.00*
TOTAL	801329	826301	256758	71298	1955686
	40.97	*42.25*	*13.13*	*3.65*	*100.00*

Fig. 11. Production capacity (m³/day) of RO seawater desalination plants with the percentage of the total capacity in each country by the end of 1999.

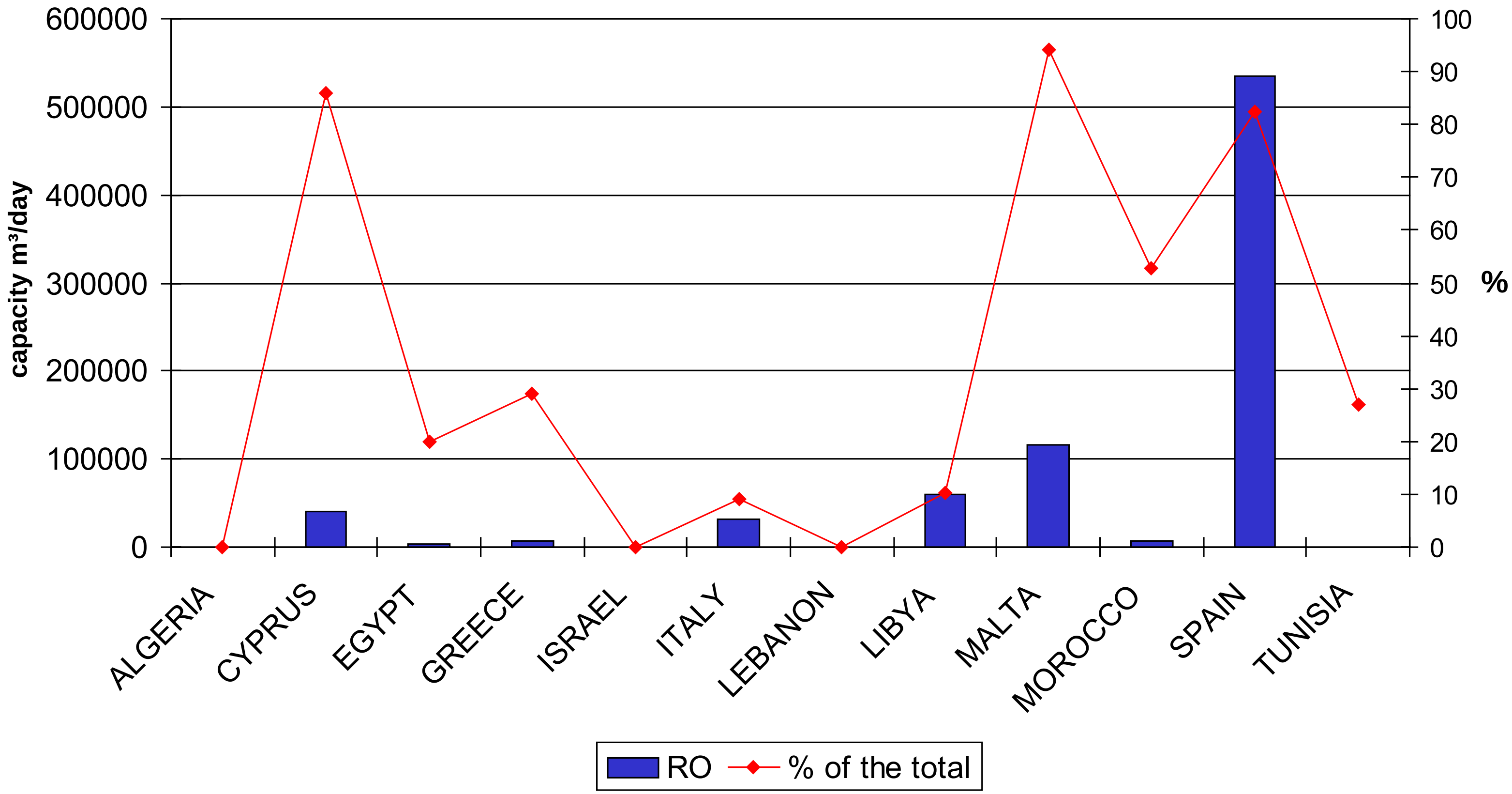


Fig. 12. Production capacity (m³/day) of MSF seawater desalination plants with the percentage of the total capacity in each country by the end of 1999.

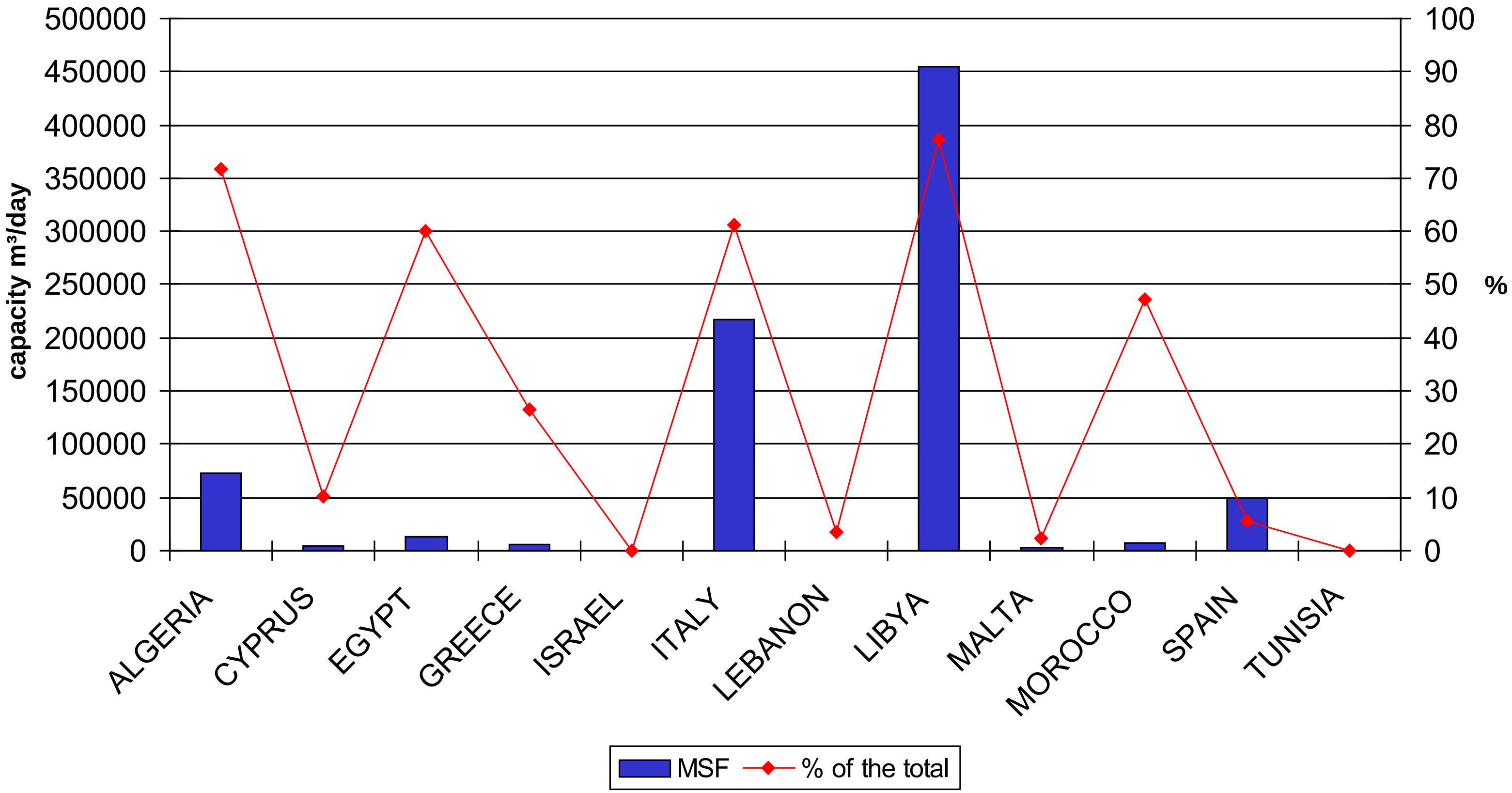


Fig. 13. Production capacity (m³/day) of VC seawater desalination plants with the percentage of the total capacity in each country, by the end of 1999.

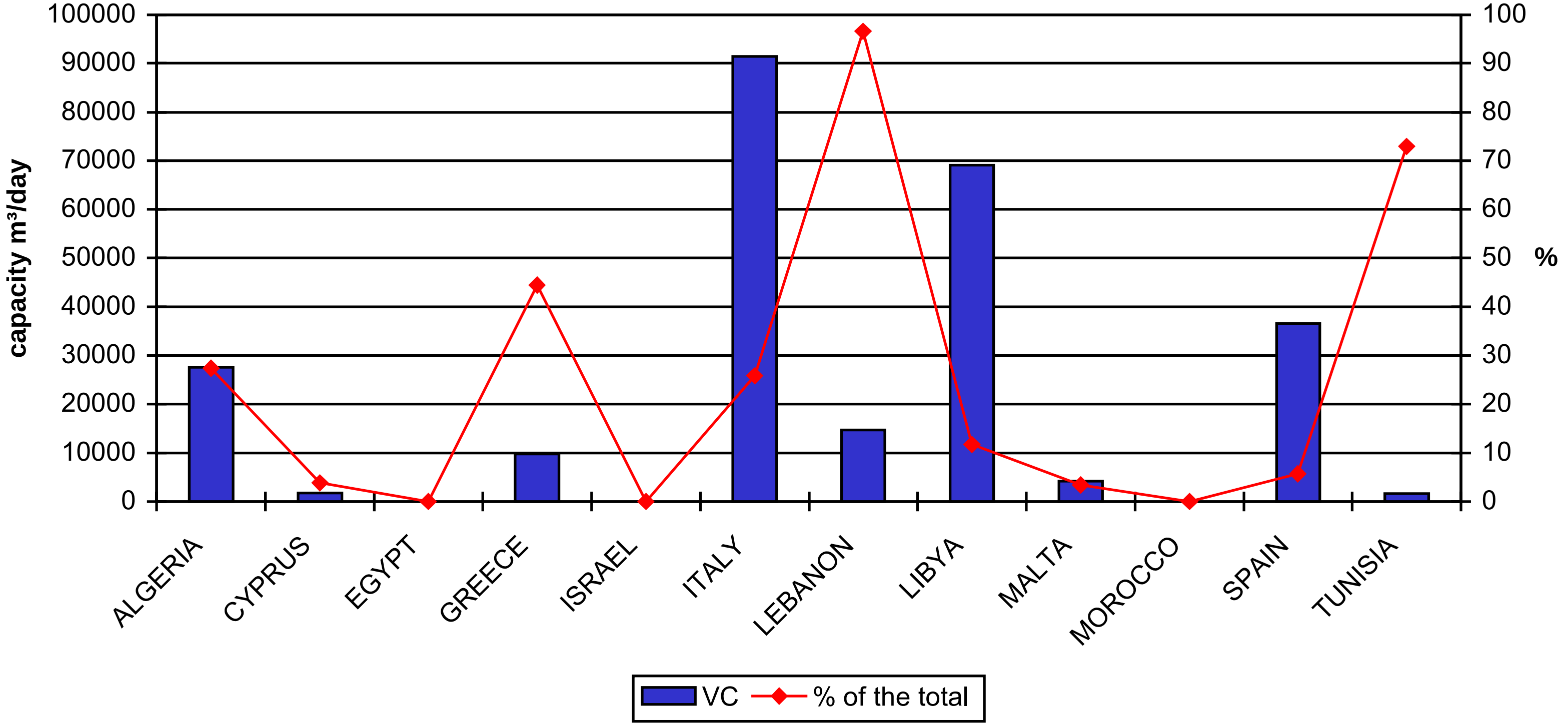


Table 4

Production capacity (m³/day) of existing seawater desalination plants with the percentage of the total by user in each country by the end of 1999.

Country	MUNI & TOUR	POWER	INDU	IRR, DEMO, MIL	TOTAL
	m³/day	m³/day	m³/day	m³/day	m³/day
	% of the total	*% of the total*	*% of the total*	*% of the total*	*% of the total*
ALGERIA		5461	95278		100739
		5.42	*94.58*	*0.00*	*100.00*
CYPRUS	40000	5880		681	46561
	85.91	*12.63*	*0.00*	*1.46*	*100.00*
EGYPT	2500	14200		4160	20860
	11.98	*68.07*	*0.00*	*19.94*	*100.00*
GREECE	5400	2400	14040		21840
	24.73	*10.99*	*64.29*	*0.00*	*100.00*
ISRAEL	17032				17032
	100.00	*0.00*	*0.00*	*0.00*	*100.00*
ITALY	102229	32499	213663	5599	353990
	28.88	*9.18*	*60.36*	*1.58*	*100.00*
LEBANON		15190			15190
	0.00	*100.00*	*0.00*	*0.00*	*100.00*
LIBYA	423509	8700	144895	12500	589604
	71.83	*1.48*	*24.57*	*2.12*	*100.00*
MALTA	119100	4200	568		123868
	96.15	*3.39*	*0.46*	*0.00*	*100.00*
MOROCCO	7800		7002		14802
	52.70	*0.00*	*47.30*	*0.00*	*100.00*
SPAIN	580060	9120	10800	49000	648980
	89.38	*1.66*	*1.66*	*7.55*	*100.00*
TUNISIA	600		1620		2220
	27.03	*0.00*	*72.97*	*0.00*	*100.00*
TOTAL	1298230	97650	487866	71940	1955686
	66.38	*4.99*	*24.95*	*3.68*	*100.00*

The total water production from desalination in Malta is 123,868m^3/day, which represents 6.3% of the total for the Mediterranean region. The basic technology applied is the RO, which accounts for 94.1% of its total desalted water production. This water is solely used for human consumption. The capacity of the MSF plants is only 4200m^3/day and it is used by power plants.

Until 1997 the only desalination units in Cyprus were those used in electrical power stations and they were of the MSF technology. It was in 1997 when the first large desalination plant of the RO type with a capacity of 20,000m^3/day started its operation. The capacity of this plant was doubled in 1998 while another RO plant of 40,000m^3/day will start its operation beginning of 2001. The total capacity of seawater desalination plants in Cyprus today is 46,561 i.e. 2.38% of the total capacity of the Mediterranean region.

Algeria is the country where seawater desalination is used basically by the industry; from the total desalination capacity of 100,739 m^3/day, 94.58% is used by industry. The process applied in Algeria is mainly the MSF (about 72%) or VC (about 27%). There are no RO desalination plants in Algeria to produce water for human consumption.

In Lebanon 100% of the total desalted water is used in electrical power units. There are no RO plants in Lebanon and the basic technology is the VC. The only desalination plant on the Mediterranean coast of Israel is of the ME type, in Ashdod of 17,032m^3/day capacity.

In Tunisia, desalination is a recent practice and is restricted only to two small plants, one RO and one VC with a very small capacity of 500 m^3/day.

In the Mediterranean coast of Morocco there are only two MSF plants of a total capacity of 6,000m^3/day used by the industry and recently (1995) one RO of capacity 7800m^3/day capacity used for human consumption.

Seawater desalination in Greece is restricted to a number of industries and power stations while very small units mainly of VC technology exist in the Aegean Islands. There are only a very small number of seawater desalination plants in the Mediterranean coast of Egypt with a total production capacity of 20,860m3/day i.e. about 1% of the total Mediterranean capacity. The main technology used is MSF (about 59%) and is applied in electrical power stations.

2.2 Evolution of seawater desalination by the Mediterranean countries in the last thirty years, 1970-1999

In the last thirty years, seawater desalination has been developing with changes in the type of process used and type of user.

Seawater desalination is a continuous and steadily growing activity in the Mediterranean. Figure 14 shows the total capacity of desalination plants operated each year by the Mediterranean countries since 1970.

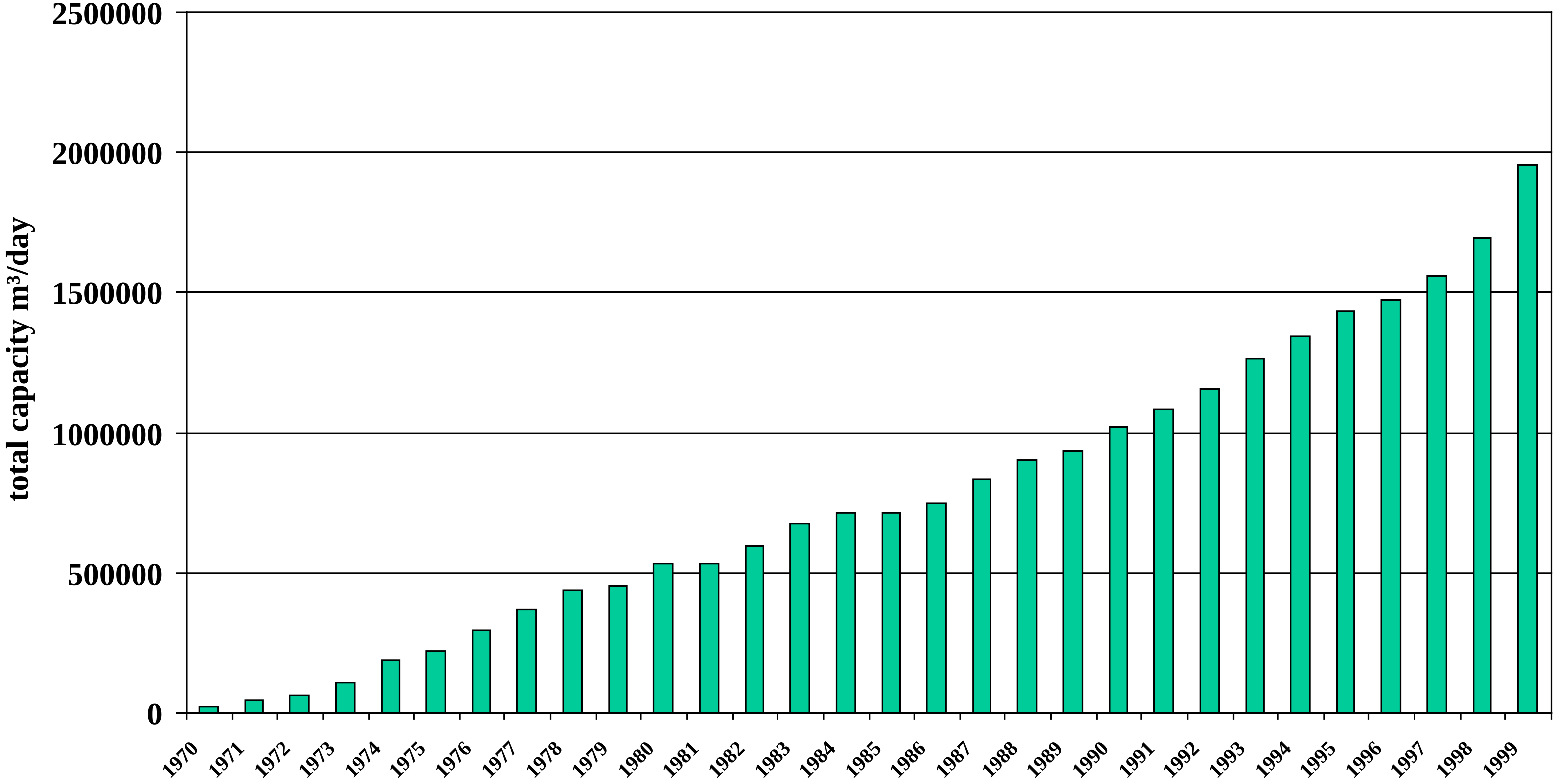
Table 5 shows the production capacities of different types of plants put in operation each year, while in Table 6 and Figure 15 the total calculated capacities of different types of plants operated by the Mediterranean countries since 1970.

The total capacity of all types of plants in 1970 which was 25,160m^3/day, increased to 455,000m^3/day in 1979, doubled in 1989 and more than doubled in 1999 with a total capacity of 1,955,686m^3/day.

The desalination processes applied, have changed through the period, 1970-1999. In the 1970´s the only process applied was the MSF; by 1980 the VC and ME processes were applied in very few plants with the RO starting operation in 1983. By 1999, the RO plants share with MSF 80% of the total capacity of the plants by the Mediterranean countries.

This change in the type of processes with time is clearly shown in Figure 16. As it is seen, for the period 1970-1979 the MSF was the only process actually applied (99.54%). During the decade 1980-1989 the MSF dropped down to about 75% with the RO increasing up to nearly 14% and the VC and the other process as ED and as ME about 10%. In the last ten years the MSF decreased down to 42% the RO increased to 41% and the VC doubled.

Fig. 14. Total production capacity (m³/day) of seawater desalination plants operated each year by the Mediterranean countries since 1970.



The use of the water produced from seawater desalination in the Mediterranean changed with time, since 1970. Table 7 and Figure 17 show the volume (capacity m^3/day), consumed by different users i.e. Municipalities, Industry, Power stations, Military installations and Irrigation each year since 1970.

Table 5

Production capacities (m^3/day) of different types of plants put in operation each year since 1970.

Type	R.O	MSF	V.C	ME & ED	Total
Year	**m^3/day**	**m^3/day**	**m^3/day**	**m^3/day**	**m^3/day**
1970		25160			**25160**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1971		22116			**22116**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1972		11059	1000	598	**12657**
	0.00%	***87.37%***	***7.90%***	***4.72%***	***100.00%***
1973		48819			**48819**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1974		78484			**78484**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1975		36600			**36600**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1976		70484			**70484**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1977		76010			**76010**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1978		68780			**68780**
	0.00%	***100.00%***	***0.00%***	***0.00%***	***100.00%***
1979		16140	500		**16640**
	0.00%	***97.00%***	***3.00%***	***0.00%***	***100.00%***
1980		66964	5120	4307	**76391**
	0.00%	***87.66%***	***6.70%***	***5.64%***	***100.00%***
1981		954	500		**1454**
	0.00%	***65.61%***	***34.39%***	***0.00%***	***100.00%***
1982		27489	8860	22493	**58842**
	0.00%	***46.72%***	***15.06%***	***38.23%***	***100.00%***
1983	25000	55200	500		**80700**
	30.98%	***68.40%***	***0.62%***	***0.00%***	***100.00%***
1984	22000	15801	2392		**40193**
	54.74%	***39.31%***	***5.95%***	***0.00%***	***100.00%***
1985		2500	1200		**3700**
	0.00%	***67.57%***	***32.43%***	***0.00%***	***100.00%***
1986	19211	12500	1800		**33511**
	57.33%	***37.30%***	***5.37%***	***0.00%***	***100.00%***
1987	28788	39900	14000		**82688**
	34.82%	***48.25%***	***16.93%***	***0.00%***	***100.00%***
1988	4800	32393	6600	23000	**66793**
	7.19%	***48.50%***	***9.88%***	***34.43%***	***100.00%***
1989	29600		8116		**37716**

Type	R.O	MSF	V.C	ME & ED	Total
Year	**m³/day**	**m³/day**	**m³/day**	**m³/day**	**m³/day**
	78.48%	***0.00%***	***21.52%***	***0.00%***	***100.00%***
1990	58000	14400	12500		**84900**
	68.32%	***16.96%***	***14.72%***	***0.00%***	***100.00%***
1991	56000		1900		**57900**
	96.72%	***0.00%***	***3.28%***	***0.00%***	***100.00%***
1992	58760	5000	9400	1100	**74260**
	79.13%	***6.73%***	***12.66%***	***1.48%***	***100.00%***
1993	38600	1440	68860		**108900**
	35.45%	***1.32%***	***63.23%***	***0.00%***	***100.00%***
1994	31600	39708	6200	4200	**81708**
	38.67%	***48.60%***	***7.59%***	***5.14%***	***100.00%***
1995	33420	48400	5750	1000	**88570**
	37.73%	***54.65%***	***6.49%***	***1.13%***	***100.00%***
1996	22750		15260	800	**38810**
	58.62%	***0.00%***	***39.32%***	***2.06%***	***100.00%***
1997	84600		2300	1800	**88700**
	95.38%	***0.00%***	***2.59%***	***2.03%***	***100.00%***
1998	101600		20280	12000	**133880**
	75.89%	***0.00%***	***15.15%***	***8.96%***	***100.00%***
1999	186600	10000	63720		**260320**
	71.68%	***3.84%***	***24.48%***	***0.00%***	***100.00%***
Total	**801327**	**826301**	**256758**	**71298**	**1955686**
% of the Total	***40.97***	***42.25***	***13.13***	***3.65***	***100.00***

Table 6

Yearly Capacities of different types of plants operated in the Mediterranean region since 1970.

Type	RO	MSF	VC	ME & ED	Total
Year	**m³/day**	**m³/day**	**m³/day**	**m³/day**	**m³/day**
1970		25160			**25160**
	0.00%	*100.00%*	*0.00%*	*0.00%*	*100.00%*
1971		47276			**47276**
	0.00%	*100.00%*	*0.00%*	*0.00%*	*100.00%*
1972		58335	1000	598	**59933**
	0.00%	*97.33%*	*1.67%*	*1.00%*	*100.00%*
1973		107154	1000	598	**108752**
	0.00%	*98.53%*	*0.92%*	*0.55%*	*100.00%*
1974		185638	1000	598	**187236**
	0.00%	*99.15%*	*0.53%*	*0.32%*	*100.00%*
1975		222238	1000	598	**223836**
	0.00%	*99.29%*	*0.45%*	*0.27%*	*100.00%*
1976		292722	1000	598	**294320**
	0.00%	*99.46%*	*0.34%*	*0.20%*	*100.00%*
1977		368732	1000	598	**370330**
	0.00%	*99.57%*	*0.27%*	*0.16%*	*100.00%*

Type	RO	MSF	VC	ME & ED	Total
Year	**m³/day**	**m³/day**	**m³/day**	**m³/day**	**m³/day**
1978		437512	1000	598	**439110**
	0.00%	*99.64%*	*0.23%*	*0.14%*	*100.00%*
1979		453652	1500	598	**455750**
	0.00%	*99.54%*	*0.33%*	*0.13%*	*100.00%*
1980		520616	6620	4905	**532141**
	0.00%	*97.83%*	*1.24%*	*0.92%*	*100.00%*
1981		521570	7120	4905	**533595**
	0.00%	*97.75%*	*1.33%*	*0.92%*	*100.00%*
1982		549059	15980	27398	**592437**
	0.00%	*92.68%*	*2.70%*	*4.62%*	*100.00%*
1983	25000	604259	16480	27398	**673137**
	3.71%	*89.77%*	*2.45%*	*4.07%*	*100.00%*
1984	47000	620060	18872	27398	**713330**
	6.59%	*86.92%*	*2.65%*	*3.84%*	*100.00%*
1985	47000	622560	20072	27398	**717030**
	6.55%	*86.82%*	*2.80%*	*3.82%*	*100.00%*
1986	66211	635060	21872	27398	**750541**
	8.82%	*84.61%*	*2.91%*	*3.65%*	*100.00%*
1987	94999	674960	35872	27398	**833229**
	11.40%	*81.01%*	*4.31%*	*3.29%*	*100.00%*
1988	99799	707353	42472	50398	**900022**
	11.09%	*78.59%*	*4.72%*	*5.60%*	*100.00%*
1989	129399	707353	50588	50398	**937738**
	13.80%	*75.43%*	*5.39%*	*5.37%*	*100.00%*
1990	187399	721753	63088	50398	**1022638**
	18.33%	*70.58%*	*6.17%*	*4.93%*	*100.00%*
1991	243399	721753	64988	50398	**1080538**
	22.53%	*66.80%*	*6.01%*	*4.66%*	*100.00%*
1992	302159	726753	74388	51498	**1154798**
	26.17%	*62.93%*	*6.44%*	*4.46%*	*100.00%*
1993	340759	728193	143248	51498	**1263698**
	26.97%	*57.62%*	*11.34%*	*4.08%*	*100.00%*
1994	372359	767901	149448	55698	**1345406**
	27.68%	*57.08%*	*11.11%*	*4.14%*	*100.00%*
1995	405779	816301	155198	56698	**1433976**
	28.30%	*56.93%*	*10.82%*	*3.95%*	*100.00%*
1996	428529	816301	170458	57498	**1472786**
	29.10%	*55.43%*	*11.57%*	*3.90%*	*100.00%*
1997	513129	816301	172758	59298	**1561486**
	32.86%	*52.28%*	*11.06%*	*3.80%*	*100.00%*
1998	614729	816301	193038	71298	**1695366**
	36.26%	*48.15%*	*11.39%*	*4.21%*	*100.00%*
1999	801329	826301	256758	71298	**1955686**
	40.97%	***42.25%***	***13.13%***	***3.65%***	***100.00%***

Fig. 15. Production capacity (m³/day) of different types of seawater desalination plants operated by the Mediterranean countries for the period 1970 - 1999.

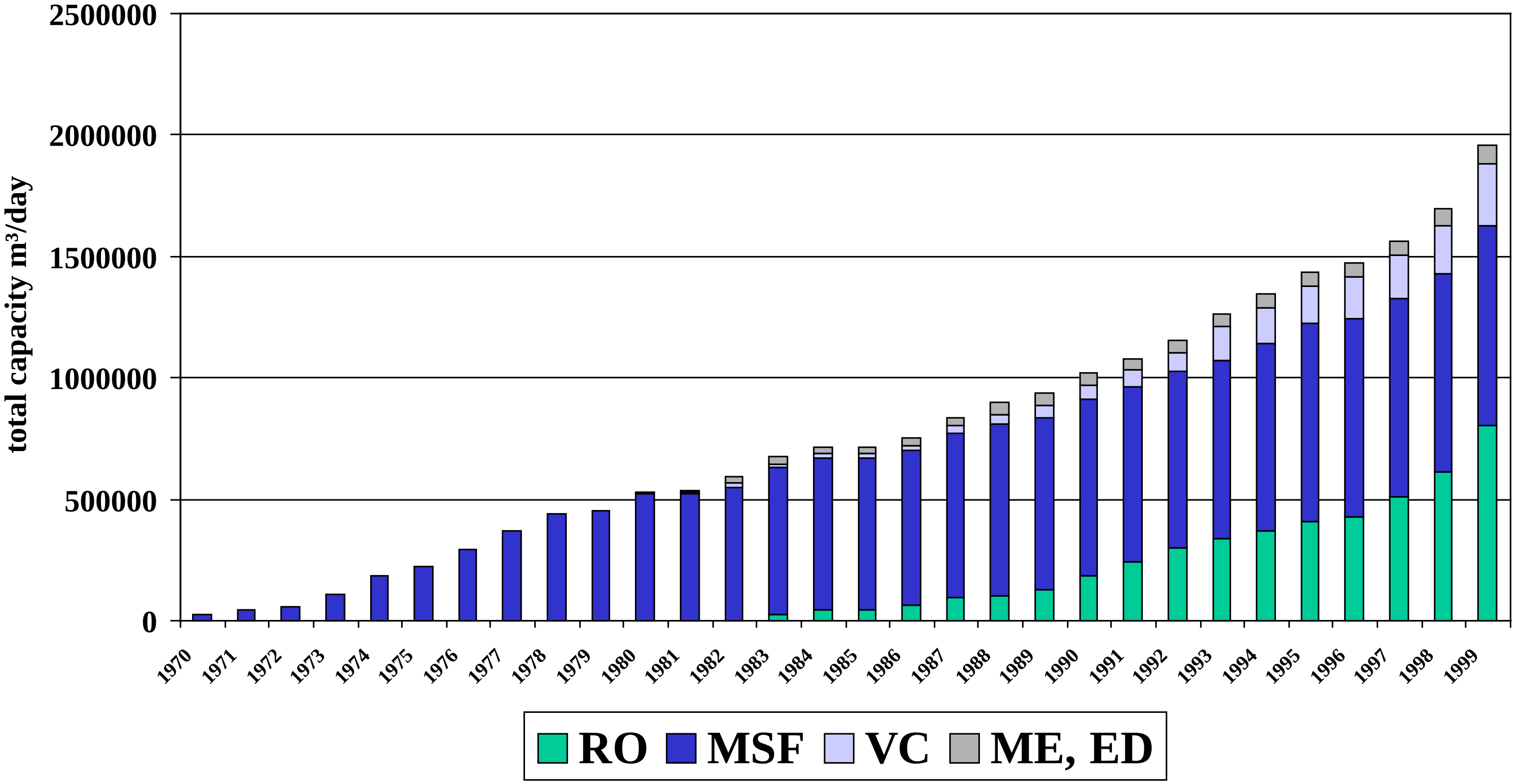
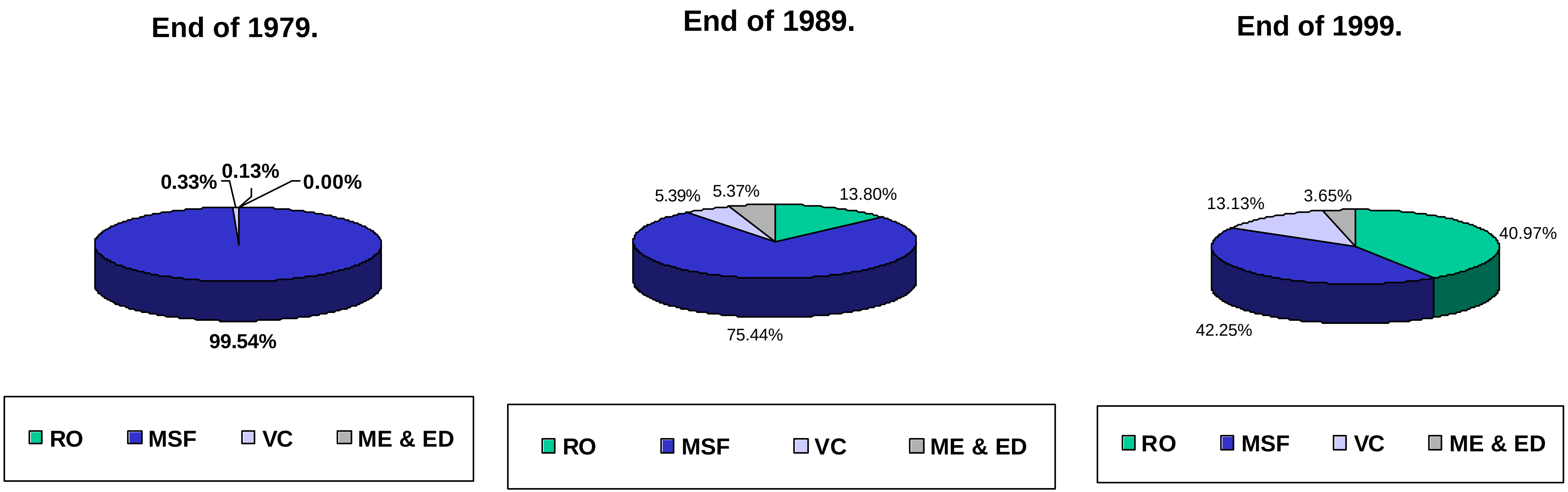


Fig. 16. The change in the type of desalination processes operated by the Mediterranean countries for the last thirty years (1970 - 1999).



As it is seen in Figure 18, from 1970 to 1979 the main users were the industry and the power stations and the municipalities to a lesser extent. During the decade 1980-1989 there was a steady increase in the use of desalted water by municipalities, which became the main user with about 58% while industry and power stations dropped down to 40%. The last decade 1990-1999 there was a further increase in the use of desalted water by municipalities reaching the 75% while the use by the industries and power stations further decreased 20%. Desalted water consumed by military installations and irrigation was at the level of about 5%.

Another important point is the change in the capacity, the size of plants with time. Figure 19 depicts are shown the capacity and the number of plants put in operation each year since 1970. In the period 1970-1979, with the MSF process fully developed, and basically the only one applied, plants were of high capacities. With the application of the not yet fully developed RO processes in the early 80´s and until the end of 1989 the units put in operation were of low capacities but the number of plants was higher.

Table 7

Volume of desalted water m³/day use by different users each year since 1970.

YEAR	MUNI	INDU & POWER	DEMO, IRR & MIL	m³/day
1970	23000	2160	0	25160
	91.41	*8.59*	*0.00*	*100.00*
1971	23000	24276	0	47276
	48.65	*51.35*	*0.00*	*100.00*
1972	31558	28375	0	59933
	52.66	*47.34*	*0.00*	*100.00*
1973	34058	73975	719	108752
	31.32	*68.02*	*0.66*	*100.00*
1974	48058	138459	719	187236
	25.67	*73.95*	*0.38*	*100.00*
1975	76458	145659	1719	223836
	34.16	*65.07*	*0.77*	*100.00*
1976	109458	183143	1719	294320
	37.19	*62.23*	*0.58*	*100.00*
1977	152408	216203	1719	370330
	41.15	*58.38*	*0.46*	*100.00*
1978	204908	232483	1719	439110
	46.66	*52.94*	*0.39*	*100.00*
1979	209448	244083	2219	455750
	45.96	*53.56*	*0.49*	*100.00*
1980	263248	265954	2939	532141
	49.47	*49.98*	*0.55*	*100.00*
1981	263248	267408	2939	533595
	49.33	*50.11*	*0.55*	*100.00*
1982	295149	292849	4439	592437
	49.82	*49.43*	*0.75*	*100.00*
1983	350649	318049	4439	673137
	52.09	*47.25*	*0.66*	*100.00*
1984	370049	326661	16620	713330
	51.88	*45.79*	*2.33*	*100.00*
1985	371249	329161	16620	717030

YEAR	MUNI	INDU & POWER	DEMO, IRR & MIL	m^3/day
	51.78	45.91	2.32	100.00
1986	403060	330861	16620	750541
	53.70	44.08	2.21	100.00
1987	450540	366069	16620	833229
	54.07	43.93	1.99	100.00
1988	510640	367962	21420	900022
	56.74	40.88	2.38	100.00
1989	539240	377078	21420	937738
	57.50	40.21	2.28	100.00
1990	598080	398978	25580	1022638
	58.48	39.01	2.50	100.00
1991	627580	407378	45580	1080538
	58.08	37.70	4.22	100.00
1992	688380	415578	50840	1154798
	59.61	35.99	4.40	100.00
1993	779980	431878	51840	1263698
	61.72	34.18	4.10	100.00
1994	811580	481986	51840	1345406
	60.32	35.82	3.85	100.00
1995	873280	508256	52440	1433976
	60.90	35.44	3.66	100.00
1996	896030	524316	52440	1472786
	60.84	35.60	3.56	100.00
1997	981430	527616	52440	1561486
	62.85	33.79	3.36	100.00
1998	1078030	559896	57440	1695366
	63.59	33.03	3.39	100.00
1999	1297730	585516	72440	1955686
	66.36	29.94	3.70	100.00

Fig. 17 Volume of desalting water m³/day different users each year since 1970.

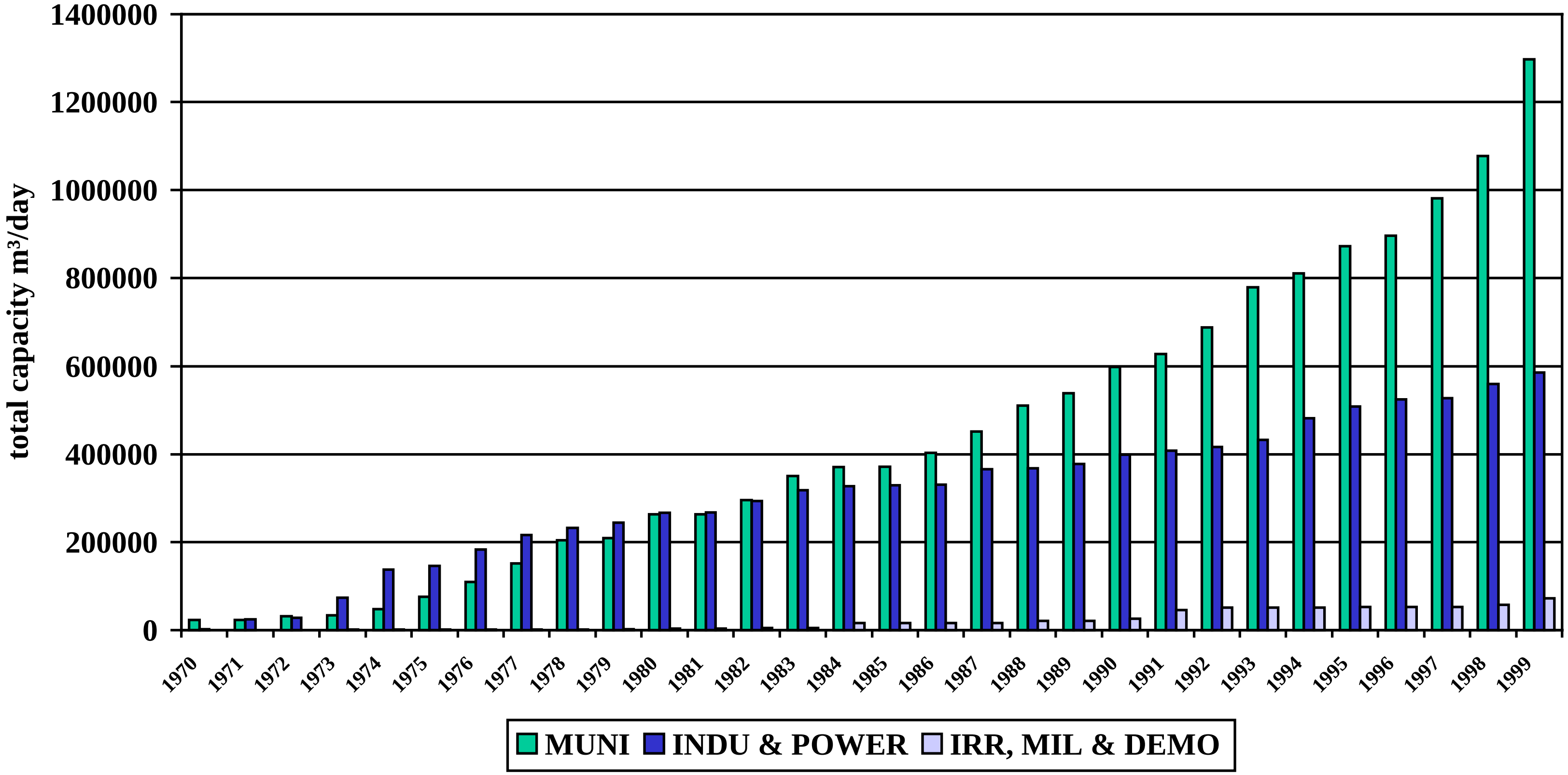


Fig. 18. The change in use of desalted water for the last thirty years by the Mediterranean countries

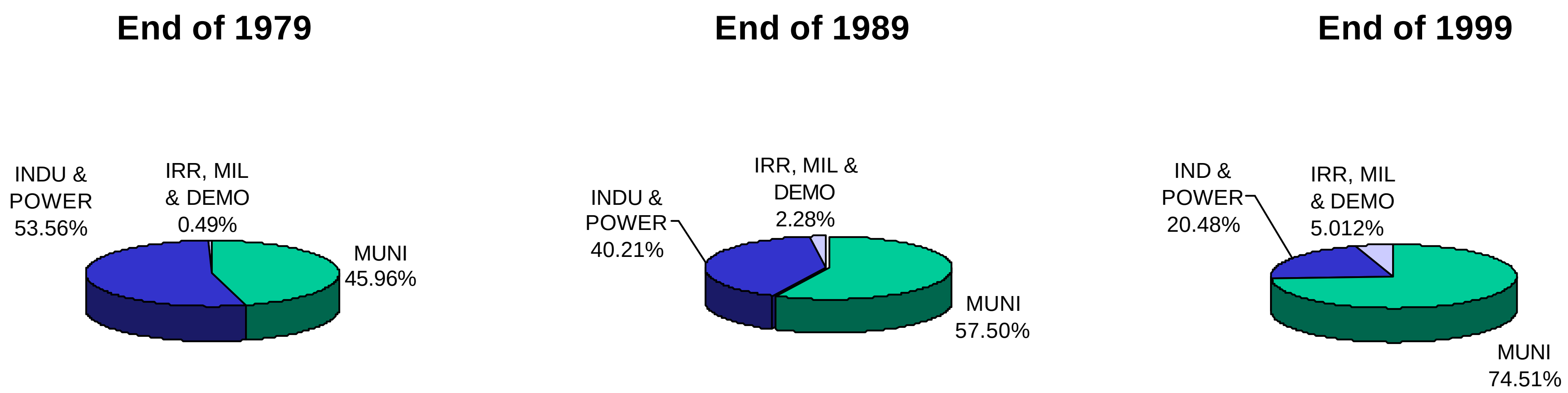
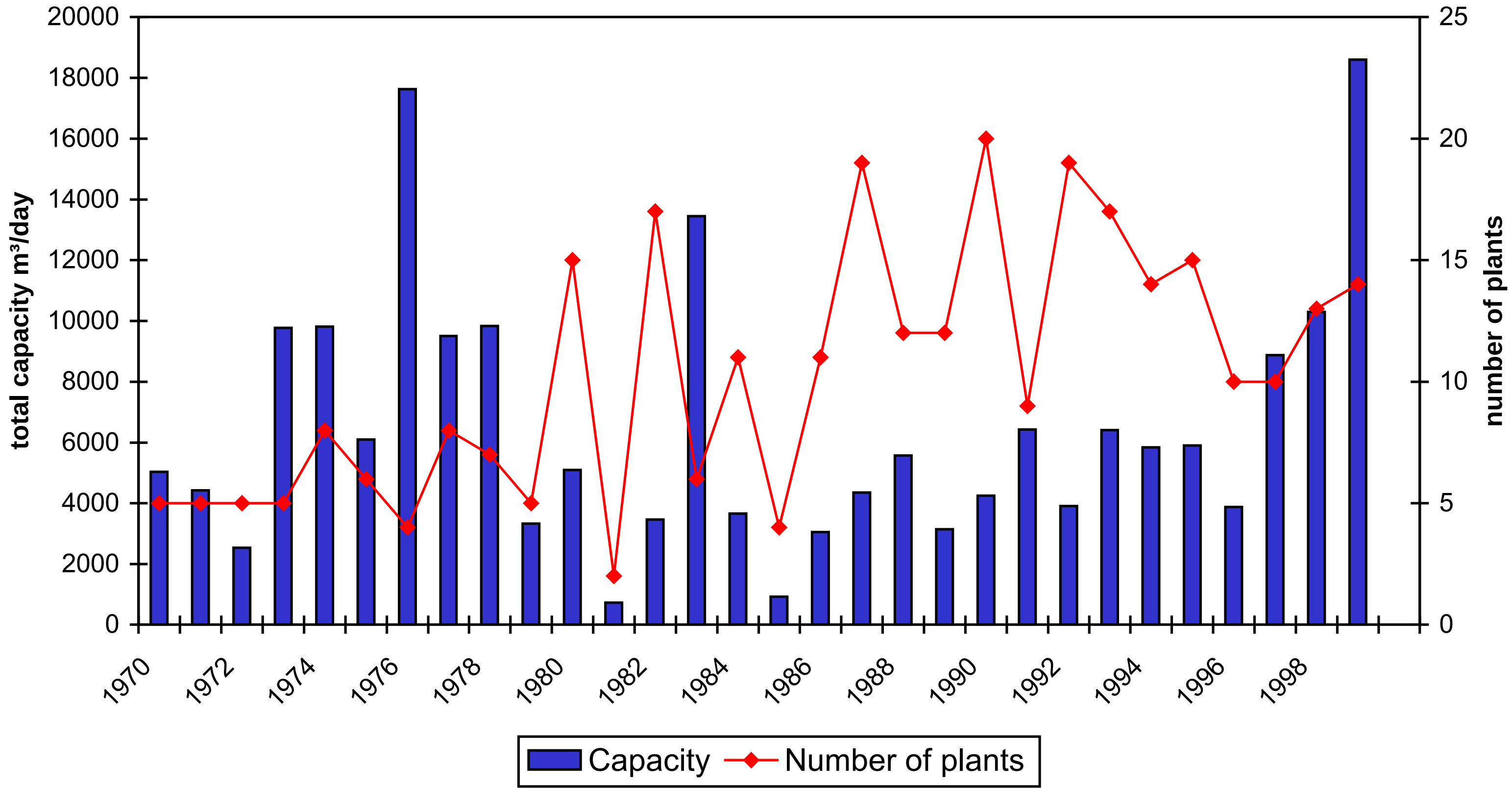


Fig. 19. Capacities and number of plants put in operation each year since 1970.



In the 1990´s with the RO technology better developed, and the change in use (mostly for municipal purposes), that is still a large number of plants with relatively higher capacities especially in the last 3-4 years.

It is expected that this will continue in the future. Table 8, shows the plants rated at 4000 (m^3/day) or more which have been contracted in 1998, 1999 and early 2000. As it is seen these plants have a very high capacity with the biggest in Murcia (Spain) with a capacity of 65,000 m^3/day. It is also envisaged that a new seawater desalted plant will be built in Israel with a capacity of 50 million m^3/year i.e. 140,000 m^3/day.

Table 8

Seawater desalination plants with capacity more than 4000 m^3/day
contracted in 1998, 1999 and early 2000

Country	**Location**	**Capacity m^3/day**	**Type/Units**	**User**	**Op. Year**
Algeria	Arzew	50000	MSF/2	MUNI	2002
Cyprus	Larnaca	40000	RO/5	MUNI	2000
Cyprus	Larnaca	20000	RO/4	POWER	2002
Cyprus	Limassol	20000	RO/4	POWER	2001
Italy	Gela	14400	MSF/1	INDU	2000
Italy	Gela	17280	MSF/1	MUNI	2001
Morocco	Boujdour	8000	Project/2	MUNI	2001
Spain	Alicante	50000	RO/7	MUNI	2001
Spain	Almarosa	10000	RO/1	MUNI	1998
Spain	Almeria	50000	RO/7	MUNI	2001
Spain	Murcia	65000	RO/9	MUNI	2000
Spain	BI Palma de Mal	43200	RO/5	MUNI	1999
Spain	CI Gran Canaria	5000	RO/1	IRR	1998
Spain	CI Gran Canaria	5000	RO/1	MUNI	2001
Spain	CI Las Palmas	6700	RO/1	MUNI	2001
Spain	CI Las Palmas	35000	ME/2	MUNI	2000

CHAPTER 3. - ENVIRONMENTAL IMPACTS OF SEAWATER DESALINATION WITH PARTICULAR REFERENCE TO THE MARINE ENVIRONMENT

Among the impacts originating from a desalination plant are those restricted to the construction phase and those related to the operation phase. Impacts start with the change of land-use, proceed to visual and acoustic disturbance and extend to emissions to water and atmosphere and to the potential damages of the recipient environment.

Construction and operation activities could result in a variety of coastal zone impacts including impacts to air quality, to water quality, to marine life, disturbance of ecological important ecosystems (sand-dunes, seagrass beds and other important habitats by the siting of pipelines route), dredging and disposal of dredged material, noise, interference with public access and recreation. The most significant of these impacts are to air quality and water quality, which subsequently, the latter has adverse impacts on marine life and ecosystems.

Despite the fact that different technologies have been developed for desalination, which include reverse osmosis, distillation, electrodialysis, vacuum freezing etc., the common element in all of these desalination processes is the removal of dissolved minerals (including but not limited to salt) from seawater. The result is then a stream of water (concentrate), which has a chemical composition similar to the source water but with concentrations 1.2-3.0 times higher than the source water (Vanhems, 1998), combined with chemicals used during post and pre-treatments processes. A variety of chemicals and additives is used in desalination, to control the formation of mineral scale and biological growth that would otherwise interfere with the process.

The constituents of the by-product water, discharged from desalination plants, depend largely on the quality of the intake water, the quality of water produced and the desalination technology used. However, the desalination plants´ discharges are not only the concentrate, the disinfectants and de-fouling agents (Abu Qdais, 1999) (1), but also warm water and aqueous effluents such as rejected distillate and ejector condensates.

The other main characteristic of desalination processes is that they require an input of thermal or mechanical energy in order to achieve separation of freshwater from the saline feed. The main consequences of such an input of energy are an increase in the temperature of the brine discharged and the rejection of heat and atmospheric emissions associated with power generation.

3.1 Source and type of emissions and discharges

3.1.1 Air emissions

In general, desalination plants´ air emissions consist only of discharges of nitrogen and oxygen from distillation plants that use de-aeration processes to reduce corrosion, discharge of the air ejector system (MSF Plants) or discharge of the degasified (RO Plants).

In addition to the above, the production of energy for use in desalination plants will increase air emissions. Substantial increases in air emissions could also occur if a new power plant or co-generation facility is built for a desalination project.

A method of evaluating energy for desalination presented by Wade and Fletcher (1995) (38) gives the following head inputs for typical plants, per kilogram of water produced, shown in Table 9.

Table 9

Method of evaluating energy for desalination giving the following heat inputs for typical plants, per kg of water produced (Wade and Fletcher, 1995) (38)

Desalination process		
Associated power plant	MSF combined cycle	RO combined cycle
Heat consumption of desalination process kj/kg	282	-
Power consumption of desalination process, kWh/m3	3.6	7.5
Prime energy from fuel for water production, KJ/Kg	149	75.0

This comparison of relative energy requirements of these desalination techniques illustrates that RO has a smaller equivalent energy consumption than MSF.

As the atmospheric emissions associated with a desalination process are directly related to its relative energy requirement, it is evident that the atmospheric impacts associated with RO are less than those associated with MSF. Afgan *et al.* (1999) (2) analysis, which is based on desalination plants in Gulf countries, resulted to sustainability indicators, which confirmed the above as shown in the following Tables 10 and 11.

Table 10

Sustainability indicators for single purpose MSF plant

Fuel resource indicator, Kg Fuel /m^3	11
Environmental indicator for CO_2 Kg CO_2/m^3	37
Environmental indicator for SO_2, Kg SO_2/m^3	0.09
Environmental indicator for NO_x Kg NOx/m^3	0.06

Table 11

Sustainability for RO plant with local electric energy source

Fuel resource indicator, Kg fuel /m^3	1.8
Environmental indicator for CO_2 Kg CO_2/m^3	6
Environmental indicator for SO_2, Kg SO_2/m^3	0.005
Environmental indicator for NO_x Kg NO_x/m^3	0.009

3.1.2 Chemical discharges

All desalination plants use chemicals as part of the pre- treatment process of the feedwater or source water, as well as for the post- treatment process of the product water. Most chemicals are mainly used as biocides, antiscalants, antifoulants and antifoaming agents and ultimately affect the concentrate composition. The presence of certain metals, which are derived as corrosion products from the system, also affects the concentrate composition.

These chemicals are not the same for the main desalination processes i.e. the thermal MSF and the Reverse Osmosis. The pre- and post- treatments taking part in the process of producing potable water are described in Table 12.

The chemicals discharged into the marine environment fall in the following categories:

i) Corrosion products

Thermal desalination plants discharge copper, nickel, iron, chromium, zinc and other heavy metals depending on the alloys present in the process line e.g. titanium. (Schippers, 2000) (34). In terms of concentrations, those of copper and iron are the highest (Hoepner, 1999) (21). For example, the lowest copper concentration value measured in the effluent of Al-Khobar desalination plant was 20ppb (Oldfield, 1996) (31), as compared with natural background concentrations in seawater of 0.12 ppb (Kennish, 1999 and 0.07ppb Laane, 1992) (24). For the Mediterranean, copper levels in seawater cover a wide range of values: the range of concentrations for open sea is 0.04-0.70 ppb, while for coastal waters the range is 0.01-50 ppb (UNEP, 1995) (37). Assuming 20 ppb copper in the brine of a desalination plant with a capacity of 50,000 m^3 product per day and a water conversion of 10% then more than 10 kg of copper will be discharged with the 500,000 m^3 brine every day at the site.

Table 12

A summary of pre-(a) and post-(b) treatment processes employed during potable water production by desalination (Mickley *et al.*, 1993) (39)

(a) Pre-treatment step	**Purpose**	**Chemicals Added**	**Fate of Chemicals**
pH-Adjustment to 7	Decrease Carbonate Concentration (and Carbonate Precipitation). Protect Membrane from Hydrolysis	Acid (H_2SO_4)	Affect pH of both produced water and concentrate, sulphate stays in the concentrate
Antiscalants	Prevent Formation of Scaling on the Membranes	Sequestering Agent dispersants	Complexes formed stay in concentrate
Coagulation-filtration	Prevent Fouling and Clogging of the Membranes	Coagulants-flocculants	Flocullants formed settle out and are removed by filtration
Desinfection	Prevent Biological Fouling and Remove Microorganisms that feed on Membranes Material	Chlorine (or Biocides, UV)	Chlorine distributed equally in permeate and concentrate
Dechlorination	Protect Chlorine-Sensitive Membranes	Sodium Bisulfate or Granular Activated Carbon (GAC)	Reacts with Chlorine to form sulphate and chloride that stay in concentrate

(b) Pre-treatment step	Purpose	Chemicals Added or Method Used	Fate of Chemicals
Removal Dissolved Gases	Remove Objectionable Gases, CO_2, Radon and H_2S	Aeration, Degasification	Oxidize H_2S and NH_4 in both produced water and concentrate
pH Adjustment to 7	Prevent Corrosion in Distribution System, Protect Aquatic Life in case of Surface Discharge	NaOH, soda ash, lime	Increase sodium level in both produced water and concentrate
Desinfection	Prevent Bacterial Growth in Distribution System, Protect Aquatic Life if necessary	Chlorine (or Chloramination)	Chlorine stays in produced water and concentrate
Reduction of Chlorine Level	Eliminate Chlorine and other Oxidizers	Sodium Bisulfite or GAC	Increase sulphate and chloride levels in both produced water and concentrate if necessary
Oxygenation	Increase Dissolved Oxygen to Level Supporting Aquatic Life	Aeration	Increase DO in Concentrate
Removal of other Species	Decrease any Pollutants that may be present in Produced Water and Concentrate	Depends on Species	

This is of great concern, since, in the Mediterranean the member of MSF Desalination Plants of 40,000 and 50,000 m^3/day production capacity increases rapidly.

Corrosion products are not so important in the RO process since it operates at ambient temperatures and the metallic parts of the system are mainly stainless steel. For example, at Dhekelia (Cyprus) SWDP, copper concentration measured in seawater, close to the brine outfall, was found to be less than 1 ppb (Zimmerman, 1999) (41).

ii) Antiscalants

Scale deposits are formed on surfaces in industrial equipment for desalination. The presence of scale invariably leads to operating difficulties and/or loss of efficiency. In distillation, scale reduces the rate of heat transfer through the affected surfaces and restrict the flow of fluids in tubes.

Different methods are applied for the prevention of scale in distillation processes. Polyphosphates, which retard scale deposition, is an early antiscaling agent. It is cheap, but of limited effectiveness, and its disadvantage is that it is temperature sensitive: it is hydrolyzed to orthophosphate at temperatures above 90°C . In recent years, the use of this chemical has been significantly restricted.

The most widely used antiscaling additive seems to be a polymer of maleic acid (Finan *et al*., 1989) (18). These polymers prevent the dissolved material from precipitating, settling and baking on surfaces and impair crystal growth by distorting the lattice structure so that soft sludge may be formed that does not adhere to or grow on metal surfaces. (Al Gobaisi, 1999) (5). Although the application rate of this acid used is 1 to 3 ppm, the typical discharge concentration is 0.53 ppm (Morton *et al.*, 1996) (30). In RO plants, sulphuric acid is used together with polymeric additives to prevent scale formation.

iii) Antifouling additives

Fouling is a multistage process in which many groups of organisms are involved. It starts with the adsorption of polymeric matter from the raw water to solid surfaces, which allows film-forming pioneer-bacteria to settle. This first biofilm is then joined by periphytes and later by microalgae, protozoa and fungi and finally by adhesion of debris, detritus and inorganic particles.

Traditionally, chlorine or chlorine compounds have been used to disinfect seawater intake systems and the associate downstream plant, in order to prevent biofouling. A typical chlorine addition is 2ppm. Good process guidance aims at a chlorine concentration of zero at the outlet. At the Sitra, (Phase I), Plant in Bahrain hypochloride is continuously added to give a content equivalent of 2 ppm chlorine. The injection rate is controlled in order to maintain a residual chlorine of 0.2 ppm at the outfall (Burashid, 1992) (13).

In the Dhekelia (Cyprus) desalination plant the level of chlorine in the brine is actually nil. When backwash water is rejected with the brine, chlorine is at the level of 0.23 ppm.

Alternative biocides such as copper salts have been tried with varying success and in many areas the discharges of copper in the brine are much lower than 1ppm. However, this is still unsatisfactory because of the environmental damage, which can arise through the accumulation of the metal. (Morton *et al.*, 1996) (30).

iv) Antifoaming additives

Foaming of seawater in the flash stages of the distillation plant is unpredictable but tends to be more severe where the demisters are close to the surface of the brine stream, allowing only a small volume for separation of aqueous and vapour.

Antifoaming agents are usually alkylated polyglycols, fatty acids and fatty acid esters. The agents exhibit surface activity at the water-steam interface and prevent foam formation. Typical addition rates are at 0.1 ppm, but overdose is observed frequently. Foaming is a function of organic seawater constituents, which are mainly excretion and degradation products of planktonic algae. In the case of RO there is no need for antifoaming additives.

3.1.3 The concentrate

The desalination plants discharge actually the same load of seawater constituents as taken in, but in much less volume of water.

In the MSF, a typical recovery rate based on feed, is 10% and thus the salinity of the concentrate is 1.1 times higher than the feed salinity. The concentrate is usually diluted twice with cooling water before being discharged, and therefore the concentration factor is 1.05 reducing impacts to the environment.

In the RO the conversion factor can vary from 30% to 70%. In this case the concentrate is 1.3 to 1.7 times higher than the raw salinity. Assuming a typical salinity of 39 psu for the Eastern Mediterranean this means that the concentrate from RO plants average from about 51 to 66 psu. Performance and environmental data from an RO plant with an output of 10,000 m^3/day at Fujarirah in UAE are provided by Morton *et al.* (1996) and appears in Table 13. The table illustrates the significantly higher brine concentration compared with the MSF plant.

The chemical composition of the rejected brine relative to that of feed seawater in the case of the Canary Islands RODP samples is shown in Table 14 (Zimmerman, 1999) (41). The total salinity of the brine is 63.8 compared to 38.95 of the feed water with a brine/feed ratio of 1.64. Recent advances in RO with much higher recovery rates result in concentrates with much higher salinity (exceeding 70 psu).

Table 13

RO plant performance and environmental data for Fujarah SWRO, UAE
and comparison plant

	Fujairah SWRO	**Comparison plant**
Rated capacity, m^3/d	9.000	30.000
Product water TDS, mg/l	450	450
Water conversion, %	35	35
Membrane supplier	Dow Filmtec	
Membrane configuration	Spiral wound	Spiral wound
Seawater temperature, °C	27	27
Energy consumpt., kWh/m^3	7.75	7.75
Seawater temperature rise, K	0.65	0.65
Inlet seawater flow, kg/s	306.5	1.022
Seawater TDS, %	4.2	4.2
Brine flow, kg/s	199.3	664.2
Brine TDS, %	6.46	6.46
Density: Inlet 1.027.5 Discharge 1.048.8 Relative 1.021		
Chemical dosing. mg/l		
Sulphuric acid	30	30
Chlorine	2	2
Sodium bisulphite	9	9
Sodium hexametaphosphate	0	0

After Morton *et al.*, 1996 (30)

Table 14

Chemical composition of the brine in relation to the seawater
(Data analysed in samples from Canary Islands RODP)

Analysis	**Feed Water mg/l**	**Brine mg/l**	**Ratio (Brine/feed water)**
Ca++	962	1.583	1.64
Mg++	1,021	1.909	1.87
Na+	11,781	19,346	1.64
K +	514	830	1.61
NH_4 +	0.004	0.005	1.25
HCO_3^-	195	256	1.31
CO_3^-	nil	nil mg/l	
So_4	3,162	5,548	1.75
Cl^-	21,312	43,362	2.03
F^-	1.5	1.9	1.26
NO_3^-	2.6	4	1.54
PO_4^-	0-08	0.4	5
NO_2^-	0.03	0.05	1.67
Total Hardness in $CaCO_3$	6.600	11,800	1.78
Total Salinity (TDS)	38.951	63,840	1.64
Fe***	0.04	0.05	1.25
Al+++	0.001	0.007	7
pH	6.33	6.26	NA
Conductivity	46.200 µS	75,300 µS	NA

(After Zimmerman, 1999) (41)

The analysis of feed water and brine for the Dhekelia S.W.D.P. is provided in Table 15 (Zimmerman, 1999) (41). A concentration of chlorides in feed water of 22,099 mg/l results in a brine chloride concentration of 43,661 mg/l and therefore, to a brine/feed water ratio of 1.976.

Likewise, in Larnaca (Cyprus) desalination plant (RO) which is planned to start operation in early 2001, chloride concentrations are expected to be the same as Dhekelia, since, it is designed to produce a concentrate of a salinity of about 72 psu.

3.1.4 Backwash of membranes discharges in RO plants

In RO plants, cleaning and storage of the membranes can produce potentially hazardous waters. The membranes must be cleaned at intervals from three to six months depending on feed water quality and plant operation. The membrane cleaning formulations are usually dilute alkaline or acid aqueous solutions. In addition, a chemical preservation solution (usually sodium bisulphite) must be used if the membranes are stored while a plant unit is shut down. These chemicals are normally treated before their discharge into the sea. (Californian Coastal Commission, 1991) (14).

3.2 Environmental impacts

The different types of pollutants resulting from different processes taking place in desalination plants (Distillation and Reverse Osmosis) have already been identified and described.

A matrix of adverse environmental impacts associated with desalination processes is shown in Table 16. According to this Table chemicals, which enhance to eutrophication of receiving waters as well as disinfectants have the higher impact.

Table 15

Analysis of S.W.D.P. brine and feed water at Dekhelia, Cyprus

Analysis	**Feed water mg/l**	**Brine mg/l**	**Ratio (brine/feed water)**
Ca~	450.0	891.2	1.98
Mg++	1,4523.0	2,877.7	1.98
Na	12,480.0	24,649.2	1.975
K	450.0	888.0	1.973
NH_4	0.0	0.0	-
HCO_3	160.0	315.3	1.97
CO_3	0.2	0.4	2
So_4	3,406.0	6,745.1	1.98
Bα	0.0	0.0	-
Sr	0.0	0.0	-

Analysis	Feed water mg/l	Brine mg/l	Ratio (brine/feed water)
Cl	22,099.0	43,661.5	1.976
F	0.0	0.0	-
NO_3	0.0	0.0	-
P	0.0	0.0	-
SiO_2	0.0	0.0	-
TDS	40,498.2	80,028.4	1.976
pH	8.1	7.8	-

(After Zimmerman, 1999) (41)

Table 16

Matrix of adverse environmental impacts associated with desalination processes

Adverse Impact	Impact Level	Source of Impact	Mitigation Techniques
Thermal pollution Reduction of dissolved oxygen in receiving waters. harmful effects to thermal tolerant species	M M	-hot brine	Mixing of brine with cold water before discharge retention ponds
Increased Salinity Harmful effects to salt tolerant species.	M	- concentrated brine	dilution of brine before discharge salts recovery Proper selection of the plant outfall location to allow for maximum mixing and dispersion
Disinfectants	H	Chlorine and its compounds reaction of chlorine with organic compounds, mainly hydrocarbons	use of other disinfectants such as UV protecting measures to the plant intake from pollutant
Heavy metals - toxicity	M	corrosion of plant equipment	proper design and selection of plant equipment by using materials resistant to corrosion
Chemicals eutrophication of receiving waters toxicity pH increase	H L L	anticorrosion and antiscalant additives	reduce the use of chemicals to minimum level use of environmentally friend additives.

Adverse Impact	Impact Level	Source of Impact	Mitigation Techniques
Air pollution acid rain green house effect dust	 L M M	 combustion of fuel and contraction activities	 use of clean and renewable energy wherever possible apply cogeneration and hybrid systems scrubbing the gases before release to the atmosphere
Sediments Turbidity and Limitation of photosynthesis Difficulties in respiration of aquatic animals	 M M	 disturbance of sands by excavation and dredging activities	 minimize and control the cut and fill activities proper management of runoff within the site area.
Noise	L	constriction activities pumps and other plant equipment during operation	limit the construction activities to working hours select plant equipment with low noise level

H- high-level impact, M-middle level impact, L-low level impact.
(After Abu Qdais, 1999) (1)

Reduction of dissolved oxygen in receiving waters as a result of the hot brine discharge and the harmful effects to salt tolerant species are characterised as being of medium level impact. Increased turbidity and limitation of photosynthesis as a result of disturbance of sand by excavation and dredging activities are characterized also as of a medium level impact.

Toxicity due to chemicals is characterized as having a low level impact.

Sabri *et al.* (1980) (32) evaluated the safety, health, and environment (SHE) considerations for RO, MSF and ED technologies using value impact analysis techniques. They utilized a pseudo quantitative scale where high (H = 3), medium (M = 2) and low (L = 1). Their results are shown in Table 17. It appears that RO and ED had a lesser impact on the environment.

It is true that the main desalination processes, the MSF, RO and ED due to their different technologies applied, they differ to their impact to the environment.

Table 17

Rating of various desalination plants

Type of plant / Effect	RO	MSF	E.D.
Noise	H	M	L
Water effluent	M	H	M
Product water impurity			
Microelement	L	H	L
Toxic material	M	H	M
Air Pollution	L	H	M
Industrial Risk	L	H	M
Total Score	10	17	10

3.2.1 Effects from corrosion products

As already mentioned, metals like copper, nickel, iron, chromium and zinc are discharged into the marine environment from distillation plants.

These metals do not occur as free ions but form inorganic and organic complexes, which are adsorbed to, suspended matter and sink accumulating in the sediments. Since the problem in this case is not the actual concentration of the metal but the total load reaching the environment the consequences cannot be mitigated by dilution of the discharge.

An environmental impact study which was conducted for the discharges of an MSF desalination plant that operated in Key West, Florida during the 1960´s and mid-1970´s showed that copper concentrations, which were often 5 to 10 times higher than the ambient levels, were found to be toxic to marine organisms (California Coastal Commission, 1991) (14). Similarly, heavy metal contamination of sediments has been documented in the vicinity of a concentrate discharged site from a Saudi Arabia SWRO water treatment plant (Sadiq, 1995).

It must be stated clearly that it is still difficult to build a bridge between heavy metal concentrations in seawater and sediments on the one hand and ecological consequences on the other. In general, however, concentration of metals exceeding the natural backgrounds significantly, are considered as environmental pollution even if biological consequences have not been proven. It is still not possible to set a standard up to which metal pollution is harmless and from which it is harmful (Hoepner, 1999) (21).

3.2.2 Effects from antiscaling additives

Early scale control is achieved through the use of polymeric phosphates. Orthophosphate, the product of polyphosphate hydrolysis, is a macronutrient enhancing primary productivity. In an oligotrophic sea area such as the Mediterranean Sea, discharge of a macronutrient may have drastic consequences such as algal blooms, macroalgae proliferation etc. In recent years, the most widely used antiscaling additives have been the polymers of maleic acid. The use of these products eliminates the possibility of eutrophication problems.

The use of sulphuric acid to facilitate action of antiscalants on the membranes of RO plants must be considered. An environmental Impact study of the effluent from the TIGNE RO plant in Malta (Aguis, 1988) (3) showed that pH values of the brine were lower (7.3) than the pH of ambient seawater (8.28).

3.2.3 Effects of Antifouling additives

Chlorination is a good servant but a bad master in the sense that it is very economical and effective but it is not controlled properly; it forms by-products (DBPS) such as thiolomethanes, which are regulated due to their carcinogenic effects.

If chlorine is a broad effect antifouling agent, it exhibits also broad effects on the marine environment when it is discharged with the brine. It causes biological effects. by its sterilizing activity itself, and chemical effects by halogenating the organic seawater constituents (Hoepner, 1999) (21).

Alternative antifouling agents such as copper salts result in the discharge of copper in the brine which even at very low concentrations (less than 1ppm), may have environmental effects due to its accumulation in the environment.

3.2.4 Effects of Antifoaming additives

Antifoaming agents are detergents. Detergents have adverse effects on organisms disturbing the intracellular membrane system. Effects on the marine ecosystem have not been examined but are likely to be negligible.

3.2.5 Effects of the concentrate (brine)

There is no doubt that the brine has the greatest impact on the marine environment. The total volume of brine being released is critical for environmental damage. Discharge of concentrated brine in large amounts requires more careful consideration of potential environmental impacts than do smaller brine discharges volumes.

Apart from the volume itself, the way brine is discharged and the discharge site characteristics are critical for the resulting environmental impacts. The length of the outfall pipe, its distance from the shore, its level from the seafloor, existence of diffuser or not, along with water depth combined with hydrological features (currents, waves) can determine the brine dispersion and the dilution efficiency at the discharge site and therefore, the potential impact to the environment.

For instance, in the Dhekelia (Cyprus) SWDP, which has a production capacity of 40,000 m^3/day, brine of a salinity of about 72 ‰ is discharged into the sea, through an outfall which ends to a multi-point diffuser, at a depth of about 5 m and at a distance of 250 m from the shore, resulted in an increase in salinity within a distance of 200 m from the part of discharge. In fact, the highest (≈ 54 ‰) salinity were always found at the discharge site, while, salinity higher than those of seawater (≈ 39 ‰) were traced up to a distance of 200 m from the outfall.

The impacted high salinity area varies seasonally, with the most prominent impact during summer months (Argyrou, 2000) (7).

The discharge of 2.5 million gallons of brine salinity (62‰) from TIGNE RO plant (Malta) at a trench of soft lime stone of about 30 meter depth results in a salinity of up to 58 at the area of its discharge (Falzon and Gingeil, 1990) (19).

In the new RO plant at Larnaca (Cyprus) of 40,000m^3/day, (to start operation in early 2001) the brine pipe of 32 inch diameter is approximately 1500m long. The location of the discharge point is at a depth of about 15 meters. The results of an investigation for the dispersion of the brine with the application of a three dimensional convection-diffuse model showed that the maximum salinity at the bottom will be about 42.7‰ (Zodiatis and Lardner, 1999) (42).

Operating plants in Spain like the one in Ceuta, an RO plant of 16,000 m3 /day capacity discharges its brine with an outfall pipe of 450m from the shore and the other in Suresta a RO plant of 10,000m3/day, discharges its brine with an outfall brine of 500m from the shore. The new, under construction plants with higher capacity, are designed so that the brine is discharged far away from the coast. The RO plant of 50,000m3/day in Almeira, will discharge its brine at a distance of 1200 meters from the shore while the RO plant in Cartagena will discharge its brine at a distance of 4,650 meters from the shore, (Chimarides, 2000) (15).

The discharge of the concentrate into the sea leads to the formation of a stratified system with the concentrate flow at the bottom layer, since, it contains higher salt concentrations than the ambient seawater. The bottom flow of the higher salinity water can affect seriously the marine environment and particularly the benthic biota.
(Argyrou, 2000) (7).

The way that increased salinity affect marine organisms is mainly through the process of osmosis, which is the movement of pure water across a membrane, which is permeable to water, but not to solute (dissolved ions in the water). Therefore, if the salt content differs on either side of the membrane, pure water will move across the membrane from the compartment with low dissolved ions to the compartment with higher concentration of dissolved ions. When marine organisms are exposed to a change in salinity (higher salt content in the external environment than the body fluids) then they will suffer osmotic stress which will be detrimental for most of them depending upon their tolerance to salinity (Levinton, 1996) (26).

In the case of Dhekelia (Cyprus) SWDP, a three years study on the impact of concentrate on marine macrobenthos showed that the observed high salinities caused significant degradation on *Cystoseira barbata* macroalgal communities in the vicinity of the concentrate outfall, while, some other macroalgae species disappeared from the proximity area (within the distance of 100 m from the outfall site). Furthermore, it also resulted in significant decreases of benthic macrofaunal diversity and abundance at the concentrate discharge site, in comparison with those found prior to the operation of the Desalination Plant. Overall, the changes of water salinity induced compositional changes of macrofauna assemblages in the vicinity of the discharge point. While the benthic community prior to the outfall construction consisted of 27% polychaetes, 27% echinoderms, 26% scaphopods and 20% gastropods, after the three years operation of the Plant the only observed taxa were the polychaetes and crustaceans representing 80% and 20% respectively of the total macrofauna (Argyrou, 2000) (7).

Impacts were also reported at the TIGNE plant (Malta), where the effluent from the plant has affected the algal growth in the vicinity of the brine outfall (Fatzon and Gingell, 1990) (19).

A variety of organisms were adversely affected by the effluent of the MSF desalination plant in Key West in Florida during the 1960´s and mid-1970s (California coastal Commission, 1998) (14).

From the international literature many scientific publications have been published in specialized periodics. For the purpose of this report we mention some of them.

Altayaran and Madany (1992) (6) explored the impact of the discharge of brine from a desalination plant on the physical and chemical properties of seawater in Bahrain. They found that the heat dissipation is a direct function of the amount by which the effluent temperature is above the ambient water temperature. The average temperature reaches 7.5c higher than the ambient in a shallow coastline. The brine discharge system causes its spreading over the surface and avoid excessive mixing. The effluents change the water temperature, salinity and water circulation. The salinity reaches an average of 52 g/l at 50 m from the discharge point.

The increase of the seawater salinity would enhance the intake of dissolved trace metals by marine animals. Blust (1992) (11) mentioned that the rate of Cadmium uptake by brine shrimp *Artemia franciscana* would increase with water salinity.

Del Bebe *et al.* (1994) (16) investigates several brine discharge scenarios using an EPA CORMIX computer simulation programme. They concluded that:

- dense brine discharges can impact the benthic environment
- an effluent dilution to 1ppt above ambient salinity is a conservative guideline for initial studies to limit the impact, however site specific impact evaluations should be performed
- dilution of dense brine effluents to 1ppt in reasonable distances can be achieved
- the co-discharge of brine with wastewater appear beneficial.

Hon-machi and Sibuya-ka (1977) (22) investigated the pollution problems in a seawater distillation process. They concluded that the impacts of waste brine in Tokyo bay could be reduced by a wise design of the discharge device.

Mabrook (1994) (28) showed the marine life in Hurghada region (Egyptian Red Sea region) is highly damaged by the discharge of brine waste from a desalination plants. Most of the coal has disappeared from the coastal areas, many planktons organisms have disappeared from the area around the plant, populations of many fish species have declined and even disappeared and marine forms from other areas have not been able to become established in the Hurghada area.

It should be mentioned that Hurghada area is classified into 5 biological zones: 1) shore, 2) stylophoro, 3) red-alga-sea grass, 4) pocillopora, 5) millepora and aeropora zones. This classification ere done according to the types of coral reefs existing at each area.

Shunya *et al.* (1994) (35) investigated *in vitro* (laboratory experiments) the lethal effect of a hypertonic solution on the marine organisms with the aim of simulating the brine impact on the marine life. They concluded that the incipient lethal salinity and sensitivity in each organism are different from species to species.

The following table shows summary of the effects of hypertonic salt solutions on marine coastal organisms:

Survivorship and Hatchability	No effect ‰	Sensitivity ‰	Incipient lethal Salinity ‰
Sea bream juvenile Survivorship	<45	50; change of body colour	50
Flouder larvae Survivorship	<50		55
Flouder egg Hatchability	<40(45?)	50-55;slight delay of development 60; delay of development	70
Soft clam Survivorship	<50	60-70; siphon not protruded	60
Sea bream juveniles	<40	45; enter rather often 50;stay only several tens of seconds	70

Concerning the coral reef, the authors found that coral (*Porites lutea, P. australienses, Goniastrea pectinata* and *Galaxea fascicularis*) died within 24h of exposure to a salinity of 52.5‰; 48% of them died before 1 week. The critical salinity was found to be between 40-45‰.

Endean (1978) (17) outlines the results of a literature review regarding the impacts of brine discharge on coral reefs. The author mentioned that corals and other invertebrates have been killed to a distance of 200m from the discharge pointing Virgin Islands. In Florida, brine effluents appear to have caused marked changes in the population densities of many species in the discharge area. The paper stress on that the damages were caused by the high salinity of the brine effluents and the presence of trace metals.

Hammond *et al.* (1998) (20) investigates the effects of seawater reverse osmosis concentrate on marine benthic community in two locations: Florida and the Caribbean (Antigua).

The results suggested that there is no discernable toxicity to the sea grass *Thalassia testudium* near the Antigua plant. The discharge plume did not affect the grazing rate of a major sea grass consumer, the bucktooth parrot fish (*Sparisoma radians*). The results, also, indicate that the discharge had no detectable effect on the chlorophyll concentration (biomass) and the numerical abundance of the benthic micro algae community in the area. No obvious or statistically significant effects were observed on the micro-epifauna or pelagic fish. Corals showed no apparent stress as a result of the maximum salinity increase of 45‰.

3.2.6 Effects of Heat

Normally, distillation plants discharge the brine with a temperature of about 10 to 15°C above the seawater temperature. The 1°C above ambient is reached as soon as the concentrate is diluted 10 fold by water of the receiving sea area. The 1°C above ambient temperature is neither of ecological importance nor significantly provable (Hoepner, 1999)

(21). This situation occurs when an adequate mixing and exchange with the ambient seawater of the concentrate exists.

In the TIGNE RO plant in Malta the temperature of the effluent was quite high compared to that of the seawater and the change in temperature of the brine effluent did not follow the pattern of temperature variation of seawater (Falzon and Gingell, 1990) (19).

3.2.7 Effects of water abstraction

Seawater desalting plants have intake structures located offshore from where large quantities of water are abstracted in close proximity to certain marine habitats. This process has potential impacts to existing marine flora and fauna of the area.

For instance drum screens are often provided between the intake structure and feed water pumps in order to prevent flotsam, large marine organisms and other matter entering the desalination plant pre-treatment system.

Generally the mesh provided on such screens is of the order of 5 mm, to prevent the intake of most fish and other aquatic organisms. However, the abstraction represents two potential sources of impact with these consisting of impingement of fish upon the screens, and entrainment of biota in the feed water system.

The abstraction and screening of relatively large volumes of cooling water is known to cause fish and other organism to collide with the drum screens leading to physical damage as descaling and stress such as disorientation. This phenomenon leads to subsequent increase mortality through disease and increased vulnerability to predation.

Secondly, although the mesh prevents the intake of larger fish and invertebrate entrainment is known to pose significant threat to phytoplankton and zooplankton. The principal impacts associated with passage through the pre-treatment and desalination processes, largely related to technology adopted for both RO and MSF producing impacts associated with activities such as chlorination and shear stresses and rapid pressure through the system. The overall effect of the entrainment of organisms is a reduction in the recruitment to existing habitat and a fall in overall productivity of the ecosystem.

CHAPTER 4. - THE LEGAL ASPECTS OF CONCENTRATE (BRINE) DISPOSAL, IN RELATION TO THE LBS AND DUMPING PROTOCOLS

The desalination industry is a steadily growing industry in certain countries of the Mediterranean. The estimated total desalination capacity of about one million cubic meters per day in 1990 has nearly doubled nowadays with trends for a further rapid increase in the near future.

This coastal land-based activity is unique as there is a mutual interaction between the desalination plants and the marine coast environment. A clean marine environment is a prerequisite for the production of clean water. On the other hand, the effluent and emissions produced by the desalination plants are affecting the fragile environment of the Mediterranean Sea.

It is therefore essential to address and document all discharges from these desalination plants in order to control them through the provisions of existing legal instruments such as the Dumping and LBS protocols of the Barcelona Convention.

4.1 Substances or energy discharged related to the LBS Protocol

Table 18, shows the different types of discharges from the RO and MSF desalination plants, their effects on the marine environment and how they are related to the LBS Protocol provisions.

Article 5 para 1 of the LBS Protocol states that “The Parties undertake to eliminate pollution deriving from land-based sources and activities in particular to phase out inputs of substances that are toxic, persistent and liable to bio-accumulate, listed in Annex I.”

Seawater desalination is not included in the sectors of activity (Part A of annex I) which should be primarily considered when setting priorities for the preparation of action plants, programmes and measures for the elimination of the pollution from land-based sources and activities. However heavy metals which are discharged into the marine environment from MSF systems are included in the categories of substance (Part C of Annex I) which will serve as a guidance in the preparation of action plans, programmes and measures for the elimination of pollution.

Article 6 para 1 of the LBS defines that: “Point source discharges into the Protocol Area, and releases into water or air that reach and may affect the Mediterranean area, as defined in article 3(a), 3(c) and 3(d) of this Protocol, shall be strictly subject to authorization or regulation by the competent authorities of the Parties, taking due to account of the provisions of this Protocol and Annex II thereto, as well as the relevant decisions or recommendations of the meetings of the contracting Parties”.

Table 18 indicates the discharged substances, which must be regulated in accordance with the above article and Annex II.

Air emissions such CO_2, SO_2 and NO_x which are the result of the required energy for the desalination process, which are transported by the atmosphere to the Mediterranean sea area are deal with in Art. 4 of the Protocol and Annex III. These emissions should be regulated or eliminated according to their properties on the basic of articles 5 and 6.

Table 18

Matrix of chemical and other discharges from RO and MSF plants, their impacts to the Marine environment and their relation to LBS Protocol

Process/source of impact/effect	Chemicals added or produced	Fate of chemicals or products	Adverse Impacts on Marine Environment	Relation to LBS Protocol Provisions
Brine	Brine		Changes in the chemical and physical characteristics of the seawater and damage to the biota	Discharge must be regulated (Article 5, Annex I)
RO				
a) Pretreatment step				
pH adjustment and prevention of membrane from hydrolysis	Acid addition	Effect on pH of concentrate Sulphate stays in the concentrate.	Normally none, if addition is regulated	Discharge must be regulated (Article 6, Annex II)
- Prevention of membrane scaling	Antiscallants Polyphospates, maleic acid	Complexes formed stay in concentrate	Normally none, if addition is controlled	Discharge must be regulated (Article 6, Annex II)
Disinfection to prevent of biological fouling and remove microorganisms that feed on membranes material.	Chlorine or other Biocides or UV	Chlorine is regulated to be at very low level in the concentrate	Normally none if their addition are regulated	Discharge must be regulated (Article 6, Annex II)
b) Treatment step Removal of salts from feed water		Concentrate -brine with 1.2 to 3 times higher than feed water	Increase salinity. Harmful effects to salt tolerant species	Discharge must be regulated (Article 6, Annex II)

c) Post treatment step				
-pH adjacent to 7.0 of produced water	NaOH, Soda Ash or Lime	Increase sodium level in concentrate	Normally none, if addition is regulated	Discharge must be regulated (Article 6, Annex II)
- Disinfection produced water	Chlorine	Chlorine stays in concentrate but at low levels	Normally none, if addition is regulated	Discharge must be regulated (Article 6, Annex II)
MSF				
a) Treatment process				
-removal of salts from feed water		Concentrate with 1.1 to 0 1.2 times higher than feed water	Relative increase of salinity harmful effects to salt tolerant species	Discharge must be regulated (Article 6, Annex II)
Temperature rise up to 100-110°C		Concentrate with temperature rise 10 to 15°C higher than the ambient	Effect due to increase temperature of temperature sensitive species.	Discharge must be regulated (Article 6, Annex II)
- Corrosion of system pipes		Heavy metals like Cu, Ti, Zn depending on tubing construction	Potential toxic effects of these metal, to marine organisms.	Discharge must be regulated (Article 5, Annex I)
Prevention of scale of distiller heat transfer surfaces.	Polymer additives such as Polyphosphates or maleic acid polymers.	Regulated to be very low about 0.33mg/l in concentrate	Normally none, if addition is regulated	Discharge must be regulated (Article 6, Annex II)
RO & MSF				
a) Energy- consumption of fuel	air emission	SO_2, NO_x CO_2	Transfer to adjustment marine environment through the atmosphere	Discharge must be regulated (Art. 4, Annex III)

4.2 Dumping of dredged material and its relation to the Dumping Protocol

The siting of long, several hundred meters, intake and outtake pipes which should be buried, to a large extent in a desalination plant, result to the need for dumping of dredged material.

According to article 6 of the Dumping Protocol "The dumping of the wastes or matter listed in article 4.2(a) i.e. Dredged material, requires special permit from the competent authorities. In this respect dumping of dredged material during construction of desalination plants will require licencing from the national component authorities.

CHAPTER 5. - CONCLUSIONS

The recent development of arid areas and the intensive use of water in urban areas result to an increased demand of freshwater by the Mediterranean countries where water resources are limited, fragile and threatened, especially in the south and east where the lengthy dry seasons with low average rainfall is a fact.

Freshwater demands by Mediterranean countries are estimated to increase by 32% by the year 2010 and 55% by the year 2025 and so present and future water needs in the region can be covered and satisfied only if non-conventional sources i.e. waste water recycling and seawater desalination will be utilized.

Seawater desalination started being applied in Mediterranean countries on a commercial basis, in the early 70´s and the basic processes used fall into two categories: the thermal processes i.e. MSF, ME and VC and the Membrane Processes i.e. RO, ED. The application of non-conventional resources for seawater desalination i.e. solar or wind is of very limited application and is restricted to very small units. Co-generation Hibryd and Dual purpose plants with an aim to save energy is a practice which has recently started been applied in the Mediterranean region on a trial basis.

Although seawater desalination has been a major source of freshwater for the Mediterranean countries since the 1970´s, this technology has been applied for the production of potable water only in mid 80´s.

Seawater desalination is a practice applied in a number of Mediterranean countries with Spain sharing about one-third of the total freshwater production, Libya about 25% and Italy about 18%. Other Mediterranean countries where desalination is applied are Cyprus, Greece, Malta, Egypt, Israel, Algeria, Lebanon and very recently Morocco and Tunisia.

Applied desalination technology has changed with time during the last thirty years. In the 1970´s the only process applied was the MSF, in the year 1980, VC and ME processes were applied in very few plants, with the RO starting operation in 1983. Today, the RO plants share with MSF 82% of the total production capacity of the plants operated by Mediterranean countries.

Water uses of the desalinated seawater have also changed with time. The period from 1970 to 1979 the main users were the industry and the power stations and the municipalities to a much lesser extent. During the decade 1980-89 there was a steady increase in the use of desalted water by municipalities, which became the main user. In the last ten years the use of desalted water by municipalities reached two-thirds of the total production capacity of the Mediterranean countries. Regarding size of plants, the last 3-4 years, with RO process fully developed there are very large plants with a production capacity up to 50,000 –60,000 m^3/day. This trend will continue in the future.

Although seawater desalination is a steadily growing industry in many Mediterranean countries, there are only very few studies on the impacts of this activity to the marine environment. Impacts from desalination plants start with the change of land-use, proceeds to visual and acoustic disturbance and extend to emission to water and atmosphere and to potential damages of the recipient environment. The basic seawater desalination processes, the MSF and RO, differ in the type of their impacts. In the case of MSF the main impact is heat, thermal effluents and metals like Cu and Zn, while in the case of RO it is the high salinity of the concentrate (1.2 to 3 times higher than the feed water).

Seawater desalination is a unique as there is a mutual interaction between desalination plant and the adjacent marine environment. A clean marine environment is a prerequisite for clean water production. On the other hand, the effluent and emissions produced by the plant are affecting the marine environment.

Desalination process requires an input of thermal or mechanical energy, which in turn results to an increase in the temperature of the concentrate discharges, the rejection of heat and atmospheric emissions associated with power generation. During pre-treatment, treatment and post-treatment in the desalination process a number of chemicals i.e. antiscalants, disinfectants, anticorrosion and antifoaming additives, are added. A part of these chemicals or their by-products may discharge with the concentrate. Their addition should be controlled to avoid so having an impact to the marine environment.

The impact of SWDP on marine macrobethos in the coastal waters of the Dhekelia area, Cyprus, is one of the few studies conducted in the Mediterranean. The concentrate of salinity 72, result to increases the salinity in the area of 200 meter radius from the point of discharge. Noticeable changes on the macrobenthos were observed in the vicinity of the concentrate discharge. Effect on the algal growth was also observed in the vicinity of the TIGNE RO plant in Malta.

During the very recent years there is a trend for constructing very large desalination plants of the RO type. Having in mind the continuous improvement in desalination with a conversion ratio of about 70%, the concentrates of about three times higher salinity than the feed water, should be properly disposed.

Dredged material from the construction of and installations of lengthy submarine intake and outtake pipes, must be dumped, according to the specific provisions of the Dumping Protocol. The concentrate from a desalination plant should be regulated prior to its discharge to the marine environment according to the relevant provisions of the LBS Protocol. Metal discharge i.e. copper from desalination plants should be eliminated according to the relevant provisions of the LBS Protocol.

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ANNEX I

EXISTING SEAWATER DESALINATION PLANTS WITH CAPACITY MORE THAN 500 M³/DAY IN THE MEDITERRANEAN COUNTRIES

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
ALGERIA	Mers el Hadjiari	500	VC/1	POWER	1987
ALGERIA	Arzew	500	VC/1	INDU	1990
ALGERIA	Arzew	720	MSF/1	INDU	1970
ALGERIA	Arzew	960	MSF/1	INDU	1971
ALGERIA	Arzew	961	OTHER/1	POWER	1982
ALGERIA	Arzew	1100	MSF/1	INDU	1977
ALGERIA	Arzew	1200	VC/1	INDU	1982
ALGERIA	Shikda	1440	MSF/1	INDU	1970
ALGERIA	Arzew	1440	VC/1	INDU	1989
ALGERIA	Arzew	1560	VC/1	INDU	1989
ALGERIA	Arzew	1720	VC/1	INDU	1989
ALGERIA	Arzew	1920	MSF/1	INDU	1977
ALGERIA	Algeria DZ	2000	MSF/2	INDU	1979
ALGERIA	Ras Djinet	2000	MSF/1	INDU	1985
ALGERIA	Jijel	2000	MSF/4	POWER	1992
ALGERIA	Arsew	2000	VC/1	INDU	1993
ALGERIA	Bethioua	2000	MSF/2	INDU	1994
ALGERIA	Cazaouet	2000	VC/1	INDU	1994
ALGERIA	Mers el Hadjiari	2000	MSF/4	POWER	1994
ALGERIA	Arzew	2200	MSF/2	INDU	1977
ALGERIA	Algeria DZ	2400	VC/1	INDU	2000
ALGERIA	Shidka	2896	VC/2	INDU	1989
ALGERIA	Arzew	2980	VC/2	INDU	1982
ALGERIA	Arzew	3000	MSF/2	INDU	1969
ALGERIA	Bethioua	3000	MSF/3	INDU	1994
ALGERIA	Arzew	3264	MFS/3	INDU	1980
ALGERIA	Arzew	3840	MSF/2	INDU	1977
ALGERIA	Annaba	5000	VC/1	INDU	1990
ALGERIA	Arsew	5678	MSF/5	INDU	1994
ALGERIA	Shidka	5760	VC/4	INDU	1993
ALGERIA	Annaba	14100	MFS/3	INDU-PETROCH	1978
ALGERIA	Shidka	24000	MSF/3	INDU	1977
CYPRUS	Dhekelia	681	MSF/1	MIL	1984
CYPRUS	Dhekelia	840	MSF/1	POWER	1992
CYPRUS	Dhekelia	1440	MSF/2	POWER	1982
CYPRUS	Dhekelia	1514	MSF/2	MIL	1964
CYPRUS	Dhekelia	1800	MSF/2	POWER	1982
CYPRUS	Dhekelia	20000	RO/4	MUNI	1997
CYPRUS	Dhekelia	20000	RO/8	MUNI	1998
CYPRUS	Larnaca	40000	RO/5	MUNI	2000
CYPRUS	Vassilikos	1800	VC/2	POWER	1999
EGYPT	Alexandria	600	RO/1	MIL	1995

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
EGYPT	El Arish	4200	ME	POWER	1994
EGYPT	Marsa Alam	500	RO/1	MUNI	1955
EGYPT	Matrouh	2000	MSF/4	MUNI	1973
EGYPT	Matrouh	500	MSF/2	MUNI	1988
EGYPT	Varwina	3560	RO/1	MIL	1992
EGYPT	Sidi KRIT	10000	MSF/2	POWER	1999
GREECE	Greece GR	600	RO/1	MUNI	1996
GREECE	Aspropyrgos	3600	VC/3	INDU	1993
GREECE	Aspropyrgos	1920	VC/2	INDU	1999
GREECE	Chios Island	1920	RO/1	INDU (fish farm)	1995
GREECE	Corinth	2400	MSF/1	INDU	1980
GREECE	Corinth	2400	MSF/1	INDU	1984
GREECE	Lavrion	2400	VC/2	POWER	1998
GREECE	Mykonos	1200	RO/1	MUNI	1989
GREECE	Offhore Rig	1800	VC/3	INDU	1980
GREECE	Syros	1000	MSF/1	MUNI	1970
GREECE	Syros	600	RO/1	MUNI	1997
GREECE	Syros Island	1200	RO/1	MUNI	1989
GREECE	Syros Island	800	RO/1	MUNI	1993
ISRAEL	Ashold	17032	ME/1	MUNI	1982
ITALY	Bari	1680	MSF/1	POWER	1978
ITALY	Brindisi	590	MSF/1	INDU	1967
ITALY	Brindisi	9600	MSF/2	INDU	1969
ITALY	Brindisi	598	ME/1	INDU	1972
ITALY	Brindisi	9600	MSF/1	INDU	1973
ITALY	Brindisi	5760	MSF/4	MUNI	1987
ITALY	Brindisi	954	MSF/1	POWER	1971
ITALY	Brindisi	954	MSF/1	POWER	1981
ITALY	Brindisi	960	MSF/1	POWER	1992
ITALY	Cabri	4558	MF/2	MUNI	1972
ITALY	Cagliari	6000	RO/1	INDU	1991
ITALY	Cagliari	1000	RO/1	POWER	1991
ITALY	Carloforte	1000	RO/1	MIL	1990
ITALY	Gela	14400	MSF/1	MUNI	2000
ITALY	Gela	17280	MSF/1	MUNI	2001
ITALY	Gela	30000	MSF/2	INDU	1974
ITALY	Gela	14400	MSF/1	INDU	1974
ITALY	Gela	14483	MSF/1	INDU	1974
ITALY	Gela	14400	MSF/1	INDU	1976
ITALY	Gela	14400	MSF/1	INDU	1990
ITALY	Fuime Santo	2880	MSF/2	POWER	1971
ITALY	Italy I	511	RO/1	MUNI	1986
ITALY	Italy I	1900	RO/1	INDU	1999
ITALY	Italy I	3000	VC/2	MUNI	1995
ITALY	La Maddalena	500	RO/1	MIL	1990
ITALY	Lambedousa	1000	VC/2	MUNI	1972
ITALY	Libari	4800	VC/3	MUNI	1987
ITALY	Milazzo	4800	ME/1	INDU	1998
ITALY	Milazzo	1000	VC/2	INDU	1997

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
ITALY	Montalto	7200	MSF/3	POWER	1994
ITALY	Pantelleria	3200	VC/3	MUNI	1987
ITALY	Piombino	600	Other/1	POWER	1992
ITALY	Piombino	1440	MSF/1	POWER	1984
ITALY	Piombino	1440	MSF/1	POWER	1987
ITALY	Porte Torres	16802	MSF/1	INDU	1971
ITALY	Porte Torres	36000	MSF/1	INDU	1973
ITALY	Porte Torres	719	MSF/1	DEMO	1973
ITALY	Porto Emsedocle	4800	VC/3	MUNI	1992
ITALY	Portoferrato	1200	RO	TOUR	1990
ITALY	Priolo Gargallo	7200	ME/2	INDU	1998
ITALY	Ravenna	720	MSF/1	DEMO/1	1980
ITALY	Rome	1160	RO/2	MIL	1990
ITALY	Salina	1200	VC/2	MUNI	1987
ITALY	Sardegna	17280	VC/6	INDU	1998
ITALY	Sardinia	600	MSF/1	INDU	1974
ITALY	Sarroch	8500	MSF/1	INDU	1994
ITALY	Sarroch	8500	MSF/1	INDU	1994
ITALY	Sicily	17000	RO/4	MUNI	1992
ITALY	Sicily	18000	VC/2	MUNI	1993
ITALY	Sicily	18000	VC/2	MUNI	1993
ITALY	Sicily	18000	VC/2	MUNI	1993
ITALY	Sulcis	1200	MSF/1	POWER	1987
ITALY	Sulcis	1200	MSF/2	POWER	1992
ITALY	Taranto	4542	MSF/2	INDU	1964
ITALY	Taranto	2160	MSF/2	INDU	1966
ITALY	Taranto	3000	MSF/3	INDU	1968
ITALY	Taranto	7200	MSF/1	INDU	1979
ITALY	Termini	2830	MSF/2	POWER	1994
ITALY	Termini 1	961	ME/1	POWER	1980
ITALY	Torrevaldaliga	2880	MSF/2	POWER	1980
ITALY	Torrevaldaliga	2880	MSF/2	POWER	1984
ITALY	Torrevaldaliga	1440	MSF/1	POWER	1993
ITALY	Ustica	1200	VC/2	MUNI	1987
ITALY	Villasimius	1500	RO/1	MIL	1990
LEBANON	Beirut	1300	VC/2	POWER	1980
LEBANON	Beirut	2160	VC/3	POWER	1982
LEBANON	Lebanon	650	VC/1	POWER	1995
LEBANON	Lebanon	10560	VC/4	POWER	1996
LEBANON	Nabi Yunis	520	MSF/1	POWER	1971
LIBYA	Abbu Kammash	2880	MSF/1	INDU	1982
LIBYA	Ajdabia	2725	MSF/1	MUNI	1969
LIBYA	Azzawiya	500	MSF/1	INDU	1978
LIBYA	Azzawiya	500	MSF/1	MUNI	1975
LIBYA	Azzawiya	1500	MSF/3	POWER	1974
LIBYA	Azzawiya	2000	VC/2	INDU	1993
LIBYA	Ben Jawad	6000	MSF/2	MUNI	1978
LIBYA	Bengazi	9000	MSF/2	MUNI	1976

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
LIBYA	Bengazi	24000	MSF/4	MUNI	1978
LIBYA	Bengazi	24000	MSF/4	MUNI	1976
LIBYA	Bomba	30000	MSF/3	MUNI	1988
LIBYA	Derna	4700	VC/1	INDU	1996
LIBYA	Derna	9400	MSF/2	MUNI	1975
LIBYA	Homs	52800	MSF/4	MUNI	1980
LIBYA	Libya LAR	1000	RO/2	INDU	1989
LIBYA	Libya LAR	1700	RO/1	INDU	1986
LIBYA	Mersa El Brega	2400	MSF/1	INDU	1980
LIBYA	Mersa El Brega	2400	MSF/1	INDU	1979
LIBYA	Mersa El Brega	4800	MSF/2	INDU	1982
LIBYA	Mersa El Brega	7200	MSF/3	POWER	1975
LIBYA	Misurata	500	VC/1	INDU	1981
LIBYA	Misurata	500	MSF/1	INDU	1985
LIBYA	Misurata	4500	ME/2	INDU	1982
LIBYA	Misurata	10000	RO/5	MUNI	1984
LIBYA	Misurata	31500	MSF/3	INDU	1987
LIBYA	Mlita	20000	MSF/2	MUNI	1995
LIBYA	Port Brega	757	MSF/1	INDU	1969
LIBYA	Port Brega	757	MSF/1	INDU	1965
LIBYA	Port Brega	946	ME/1	INDU	1980
LIBYA	Port Brega	1514	MSF/2	INDU	1967
LIBYA	Port Brega	1892	VC/2	INDU	1984
LIBYA	Ras Lanuf	1000	MSF/2	INDU	1980
LIBYA	Ras Lanuf	1500	MSF/3	INDU	1980
LIBYA	Ras Lanuf	8400	MSF/1	MUNI	1984
LIBYA	Ras Lanuf	8400	MSF/1	MUNI	1995
LIBYA	Ras Lanuf	25200	MSF/3	INDU	1983
LIBYA	Ras Tajura	1500	MSF/3	MIL	1982
LIBYA	Ras Tajura	11000	RO/4	MIL	1984
LIBYA	Sirte	1893	MSF/1	INDU	1988
LIBYA	Sirte	10000	MSF/1	MUNI	1986
LIBYA	Sirte	20000	MSF/1	INDU	1995
LIBYA	Sirte 2	9084	MSF/2	MUNI	1982
LIBYA	Soussa	3785	MSF/1	MUNI	1982
LIBYA	Soussa	10000	VC/2	MUNI	1999
LIBYA	Soussa	13500	MSF/3	MUNI	1977
LIBYA	Tobruk	24000	MSF/4	MUNI	1977
LIBYA	Tobruk	40000	VC/3	MUNI	1999
LIBYA	Tripoli	650	RO/1	MUNI	1996
LIBYA	Tripoli	1000	RO/1	MUNI	1996
LIBYA	Tripoli	2500	RO/1	MUNI	1996
LIBYA	Tripoli	2500	MSF/1	MUNI	1986
LIBYA	Tripoli	10000	VC/2	INDU	1999
LIBYA	Tripoli	23084	MSF/2	INDU	1976
LIBYA	Tripoli-West 2	500	ME/1	MUNI	1992
LIBYA	Tripoli-West 2	32000	RO/5	MUNI	1992
LIBYA	Zliten	4500	MSF/1	MUNI	1978
LIBYA	Zliten	13500	MSF/3	MUNI	1975
LIBYA	Zuara	4540	MSF/1	MUNI	1979

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
LIBYA	Zuara	13500	MSF/3	MUNI	1974
LIBYA	Zuetina	5450	MSF/2	MUNI	1977
LIBYA	Zuetina	30000	MSF/3	MUNI	1983
MALTA	CharLapsi	20000	RO/10	MUNI	1983
MALTA	CharLapsi	4000	RO/1	MUNI	1986
MALTA	Cirkewwa	18600	RO/5	MUNI	1989
MALTA	Delimara	1300	VC/1	POWER	1997
MALTA	Gozo	3000	MSF/1	MUNI	1972
MALTA	Malta	568	RO/1	INDU	1987
MALTA	Malta	1400	VC/2	POWER	1991
MALTA	Malta(BR)	1500	VC/2	POWER	1993
MALTA	Marsa	4500	RO/1	MUNI	1983
MALTA	Pembroke	17600	RO/4	MUNI	1991
MALTA	Pembroke	8800	RO/2	MUNI	1993
MALTA	Pembroke	27600	RO/6	MUNI	1994
MALTA	Tigne	15000	RO/5	MUNI	1987
MALTA	Valetta	4500	MSF/1	MUNI	1967
MALTA	Valetta	16000	MSF/3	MUNI	1969
MOROCCO	El Aiun	7800	RO/5	MUNI	1995
MOROCCO	El Aiun	3501	MSF/1	INDU	1974
MOROCCO	El Aiun	3501	MSF/1	INDU	1972
SPAIN	Adeje	10000	RO/2	MUNI	1996
SPAIN	Almanzora	10000	RO/1	MUNI	1998
SPAIN	Almanzora	20000	RO/2	MUNI	1995
SPAIN	Almeria	500	RO/1	MUNI	1995
SPAIN	Alicante	50000	RO/7	MUNI	2001
SPAIN	Almeria	50000	RO/7	MUNI	2001
SPAIN	Jaen	720	RO/1	MUNI	1987
SPAIN	Gran Ganaria	4000	RO/1	MUNI	2001
SPAIN	Gran Ganaria	5000	RO/2	MUNI	2001
SPAIN	Gran Ganaria	5400	RO/2	IRR	2000
SPAIN	Almeria	1000	ME/1	INDU	1997
SPAIN	Almeria	1200	RO/2	MIL	1992
SPAIN	Almeria	2200	MSF/1	POWER	1982
SPAIN	Aquilas	10000	RO/2	MUNI	1993
SPAIN	Arrecife	3000	VC/2	MUNI	1990
SPAIN	Arrecife	5000	RO/2	MUNI	1993
SPAIN	Arucas-Moya	4000	RO/1	MUNI	1994
SPAIN	Atrium Beach	2400	VC/4	TOUR	2000
SPAIN	Cadiz	1000	ME/1	INDU	1995
SPAIN	Ceuta	800	ME/1	MUNI	1997
SPAIN	Ceuta	4000	MSF/2	MUNI	1966
SPAIN	Ceuta	16000	RO/3	MUNI	1998
SPAIN	CI Guia	1500	VC/1	MUNI	1992
SPAIN	CIFuertaventura	2000	MSF/1	MUNI	1970
SPAIN	CIFuertaventura	1000	VC/2	MUNI	1980
SPAIN	CIFuertaventura	1000	VC/2	MUNI	1982
SPAIN	CIFuertaventura	1000	VC/2	MUNI	1982

Country	Location	Capacity m3/day	Type/Unit	User	Op. Year
SPAIN	ClFuertaventura	600	VC/1	MUNI	1986
SPAIN	ClFuertaventura	1600	VC/1	MUNI	1987
SPAIN	ClFuertaventura	1200	VC/1	TOUR	1988
SPAIN	ClFuertaventura	1200	VC/1	TOUR	1988
SPAIN	ClFuertaventura	600	RO/1	TOUR	1989
SPAIN	ClFuertaventura	1000	RO/1	TOUR	1990
SPAIN	ClFuertaventura	3000	RO/1	MUNI	1990
SPAIN	ClFuertaventura	1000	RO/1	TOUR	1990
SPAIN	ClFuertaventura	640	RO/1	TOUR	1990
SPAIN	ClFuertaventura	2400	RO/1	TOUR	1991
SPAIN	CL Gando	1000	RO/1	MIL	1993
SPAIN	CL Gran Agrico	500	VC/1	MUNI	1992
SPAIN	Corralejo	1500	RO/1	MUNI	1993
SPAIN	Del Rossario	4000	RO/2	MUNI	1992
SPAIN	Formentera	500	RO/1	MUNI	1984
SPAIN	Formentera	500	VC/1	TOUR	1991
SPAIN	Formentera	2000	RO/2	MUNI	1995
SPAIN	Gran Canaria	500	RO/1	MIL	1984
SPAIN	Gran Canaria	800	RO/1	IRR	1988
SPAIN	Gran Canaria	3500	RO/1	MUNI	1989
SPAIN	Gran Canaria	1000	RO/1	INDU	1990
SPAIN	Gran Canaria	10000	RO/2	IRR	1991
SPAIN	Gran Canaria	1000	VC/1	POWER	1992
SPAIN	Gran Canaria	600	RO/1	INDU	1995
SPAIN	Gran Canaria	4000	RO/1	MUNI	1996
SPAIN	Gran Canaria	600	VC/1	INDU	1995
SPAIN	Gran Canaria	1000	VC/1	POWER	1992
SPAIN	Gran Canaria	1000	VC/1	INDU	1990
SPAIN	Gran Canaria	3500	RO/2	MUNI	1989
SPAIN	Gran Canaria	3500	RO/1	MUNI	1999
SPAIN	Gran Canaria	4000	RO/1	MUNI	1996
SPAIN	Gran Canaria	4000	RO/1	IRR	1988
SPAIN	Gran Canaria	5000	RO/1	IRR	1998
SPAIN	Gran Canaria	10000	RO/2	IRR	1991
SPAIN	Gran Tarajal	1500	RO/1	MUNI	1993
SPAIN	Ibiza	8000	RO/2	MUNI	1997
SPAIN	Ibiza	9000	RO/3	MUNI	1991
SPAIN	Lanazrote	500	RO/1	TOUR	1992
SPAIN	Lanzarote	500	RO/1	TOUR	1992
SPAIN	Lanzarote	500	RO/1	MUNI	1987
SPAIN	Lanzarote	500	VC/1	TOUR	1984
SPAIN	Lanzarote	500	VC/1	DEMO	1979
SPAIN	Lanzarote	500	VC/1	MUNI	1983
SPAIN	Lanzarote	500	RO/1	MUNI	1983
SPAIN	Lanzarote	500	MSF/1	MUNI	1974
SPAIN	Lanzarote	500	MSF/1	MUNI	1973
SPAIN	Lanzarote	600	VC/1	TOUR	1985
SPAIN	Lanzarote	600	VC/1	TOUR	1985
SPAIN	Lanzarote	600	VC/1	TOUR	1986
SPAIN	Lanzarote	600	VC/1	TOUR	1986

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
SPAIN	Lanzarote	600	VC/1	TOUR	1988
SPAIN	Lanzarote	1000	MSF/1	DEMO	1975
SPAIN	Lanzarote	1200	VC/1	TOUR	1988
SPAIN	Lanzarote	2000	RO/2	TOUR	1987
SPAIN	Lanzarote	2460	MSF/1	MUNI	1965
SPAIN	Lanzarote	2500	RO/1	MUNI	1987
SPAIN	Lanzarote	3000	VC/2	MUNI	1990
SPAIN	Lanzarote	5000	RO/2	MUNI	1986
SPAIN	Lanzarote	5000	MSF/2	MUNI	1975
SPAIN	Lanzarote	5000	RO/1	MUNI	1990
SPAIN	Lanzarote	5000	RO/1	MUNI	1990
SPAIN	Lanzarote	7500	RO/3	MUNI	1986
SPAIN	Las Palmas	500	VC/1	MUNI	1987
SPAIN	Las Palmas	500	VC/1	INDU	1989
SPAIN	Las Palmas	20000	MSF/4	MUNI	1970
SPAIN	Las Palmas	18000	MSF/4	MUNI	1978
SPAIN	Las Palmas	24000	RO/4	MUNI	1990
SPAIN	Las Palmas	6700	RO/1	MUNI	2001
SPAIN	Las Palmas	35000	ME/2	MUNI	2000
SPAIN	Las Palmas	12000	RO/2	MUNI	1990
SPAIN	Mallorga	520	VC/1	POWER	1982
SPAIN	Mallorga	42000	RO/6	MUNI	1999
SPAIN	Marbella	56400	RO/10	MUNI	1999
SPAIN	Maspalomas	2000	ED/1	MUNI	1988
SPAIN	Maspalomas	21000	ED/8	MUNI	1988
SPAIN	Maspaslomas	7500	RO/3	TOUR	1987
SPAIN	Mazarron	12000	RO/4	MUNI	1997
SPAIN	Murcia	800	ME/1	POWER	1996
SPAIN	Murcia	15000	RO/5	IRR	1999
SPAIN	Murcia	20800	RO/8	IRR	2000
SPAIN	Murcia	65000	RO/9	MUNI	2000
SPAIN	Palma	1500	VC/1	INDU	1995
SPAIN	Palma de mal	43200	RO/5	MUNI	1999
SPAIN	Puerto Rico	1000	VC/1	TOUR	1987
SPAIN	Puerto Rico	2400	VC/2	TOUR	1988
SPAIN	Spain E	600	RO/1	MUNI	1998
SPAIN	Spain E	2000	RO/1	MUNI	1997
SPAIN	Spain E	5000	RO/1	MUNI	1998
SPAIN	Spain E	30000	RO/6	MUNI	1998
SPAIN	Spain E	42000	RO/6	MUNI	1997
SPAIN	Spain E BI	500	RO/1	MUNI	1986
SPAIN	Sureste 1	10000	RO/2	MUNI	1993
SPAIN	Sureste 2	15000	RO/2	MUNI	1998
SPAIN	Tenerife	600	VC/1	POWER	1994
SPAIN	Tenerife	600	VC/1	POWER	1992
SPAIN	Tenerife	3600	VC/1	INDU	1994
SPAIN	Tenerife	24000	RO/3	MUNI	1999
SPAIN	Vandellos	2400	ME/3	POWER	1980

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
TUNISIA		600	VC/1	INDU	1998
TUNISIA		600	RO/1	TOUR	1999
TUNISIA	Gabes	1020	VC/2	INDU	1980

ANNEX II

EXPLANATION OF ABBREVIATIONS –GLOSSARY

a) Process:

ED:	Electrodialysis
HYBRID:	Hybrid process
ME:	multi stage flash
MSF:	multistage flash distillation
OTHER :	all other processes
RO:	reverse Osmosis
VC:	vapour compression

b) User:

DEMO:	freshwater produced for demonstration purposes
INDU:	freshwater used as industrial or process water
IRR:	freshwater used for irrigation
MIL:	freshwater used as drinking water for military facilities
MUNI:	freshwater used as municipal drinking water
POWER:	freshwater used as process water in power station
TOUR:	freshwater used as drinking water for tourist

Plants:

SWDP:	seawater desalination plant
RODP:	reverse osmosis desalination plant

GUIDELINES FOR THE ENVIRONMENTAL SOUND MANAGEMENT OF SEAWATER DESALINATION PLANTS IN THE MEDITERRANEAN

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1. INTRODUCTION

Worldwide, population growth increases the demand for drinking water, while ongoing industrialization, land irrigation and higher living standards cause an additional rise in per capita consumption of freshwater. This development is mostly concentrated in a narrow coastal zone, where by today about half the world population lives, and this number is expected to rise to three quarters by 2020 (Agenda 21, 1992). Similar to the worldwide trend, demographic growth and intense socio-economic activity in the Mediterranean region cause freshwater resources to become an increasingly rare asset. Water withdrawal has already reached a level that exhausts available resources in some Mediterranean countries, while others are expected to approach this level of exploitation in the future. It is estimated that the total demand in the region will increase from 300 billion m^3 per year in 1990 by 32 % until 2010, and by 55 % to over 460 billion m^3 in the year 2025 (Margat and Vallée, 2000).

The prospect of severe water shortage, which restricts future development and may cause environmental damage, stresses the need for new strategies in the field of water resources management. Management policies and plans have to integrate non-conventional methods like wastewater reclamation and seawater desalination, which will become indispensable to meet the growing demand in the Mediterranean and to protect conventional resources from over-exploitation. While wastewater recycling is mostly of benefit for agricultural irrigation, the main sectors of use for desalinated water are drinking water for communities and pure water for high-tech industries (Ribiero, 1996). Desalination is already a well-established industry in some coastal areas of the Mediterranean, but will become increasingly important as a source of freshwater, taking the length of the Mediterranean coastline into account and the importance of this technology for islands, which may predominantly depend on desalination. The sea as a source for fresh water seems to be unlimited and the potential for growth in the desalination sector is enormous.

Exploitation of seawater for desalination requires a good raw water quality, but coastal water bodies are often affected by wastewater discharges from a wide range of land-based activities, including desalination facilities. The waste stream resulting from the desalination process is typically highly 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. Although impacts are mostly related to the concentrate, desalination plants may also be large industrial facilities that consume space, require energy and emit substantial amounts of combustion gases, or might have indirect effects through socio-economic development.

With regard to the expected high demand for desalination in the Mediterranean region, potential environmental and socio-economic impacts have to be taken into account by Governments in the planning and management of new projects. In this context, MEDPOL prepared an assessment of seawater desalination activities and their environmental impacts (UNEP/MED, 2002a) and recommendations for guidelines for the management of seawater desalination (UNEP/MED, 2002b). Both documents and the outcome of an experts meeting held in Forli, Italy, on 16-18 May 2002, provide the basis for the present “Guidelines for the Environmental Sound Management of Seawater Desalination plants in the Mediterranean Region”, taking further the Land-Based Sources (LBS) and Dumping Protocols into account. Both protocols provide the legal framework for the regulation of waste disposal into the Mediterranean Sea through outfalls or by ships, and are consequently applicable to seawater desalination discharges.

2. OVERVIEW OF THE LEGAL ASPECTS AND POLICIES

2.1 Water resources management and coastal area management

The coastal zone of the Mediterranean region is an area of intense activity, where water is becoming an increasingly rare asset. Future development depends on water availability but will deplete conventional resources further. In this situation, seawater represents an alternative, inexhaustible reservoir that can provide much needed relief by the technical process of desalination. Increased desalination activity, however, could in turn stimulate coastal development if this is no longer under constraint of water limitation.

Desalination activities development should therefore be an integrated part of the national water resources management policy and especially the management of coastal water resources. As water availability and socio-economic growth are closely interrelated, issues of water resources management and seawater desalination must also be integrated into an overall coastal area management for a sustainable development in the region.

In practice, this can for example be realized within MAP's Coastal Area Management Programme (CAMP), which implements management projects in selected coastal areas of Mediterranean countries. Experience shows that water resources management is already a central component in most projects as a result of locally high demand, pollution or over-exploitation of conventional water resources. Furthermore, the emerging issue of seawater desalination and growth-inducing impacts of new plants have to be considered in CAMP projects. Where CAMP projects have not been implemented, a coastal development plan can provide the legal framework for the management of new desalination plants and resulting socio-economic development.

2.2 Marine environmental protection

Seawater desalination is an industrial process, which may have adverse effects on the coastal environment if not well designed and managed. The causes are e.g. a changed land use in the coastal zone, disturbance during the construction phase and emissions into air, ground or water during plant operation.

Especially the discharge to the marine environment could deteriorate water and sediment quality. It is a multi-component waste that may contain residual chemicals from the pre-treatment process, heavy metals from corrosion or intermittently used cleaning agents besides increased salinity and temperature values. A changed seawater and sediment quality could in turn impair marine life and have a lasting effect on coastal ecosystems. Seawater desalination effluents should therefore conform to regional and national environmental protocols and policies.

The Land-Based Sources (LBS) and Dumping Protocols provide a legal framework for the regulation of waste disposal into the Mediterranean Sea. As desalination plant wastes are typically discharged directly through coastal outfalls or can be disposed of by ships, they fall under the provisions of both protocols. Since the contracting parties to the Barcelona Convention are obliged to implement the ratified protocols into their national legislation, the national environment authorities should extend the existing policies to cover seawater desalination activities.

Potential environmental impacts can be directly related to desalination activity, e.g. to marine emissions, but environmental effects may also be indirect consequences of water availability. As increased water availability allows for socio-economic growth, seawater desalination has been identified as an emerging issue in water resources management and coastal area management. However, an integrated management of the coastal zone also requires that potential impacts of an activity are considered, including both direct and cumulative indirect environmental effects. New water supplies should therefore stimulate growth only where this is tolerable for the coastal environment and consistent with the long-term goals for coastal development.

3. IMPLEMENTATION OF DESALINATION ACTIVITIES INTO NATIONAL WATER RESOURCES MANAGEMENT AND ENVIRONMENTAL PROTECTION PLANS

Management provisions for seawater desalination plants are so far rather limited in the Mediterranean countries and a proactive approach is required to deal with the expected growth of this industry in the region. Concrete measures include that seawater desalination activity is taken into account in existing coastal development plans, water management policies and environmental regulations by the competent national authorities.

Moreover, the competent national authorities have to react to proposed new facilities on a case-by-case basis by evaluating potential impacts. These can be of a socio-economic nature, or adverse effects on the marine environment if the desalination plant is not well designed and managed. For example, it has to be assessed if the proposal is consistent with the coastal development plan or if environmental standards like emission limits are being observed.

3.1 Coastal development plan

A coastal development plan can declare development priorities through zoning of land and classification of zones for a certain use. This could for example ensure that new development takes place within or adjacent to existing developed areas. Standards for use can be allocated on different management levels, e.g. on a municipal, regional or national level, given that a plan is consistent with the next higher level. It should be prepared by the national environmental authority or coastal authority with jurisdiction in the proposed area under participation of other relevant national or local bodies.

Based on such development plans, desalination plants should be located in zones where construction of new industrial facilities is permissible and resulting socio-economic growth consistent with the long-term goals identified for this zone. For example, development of new desalination facilities might be preferred within existing urban boundaries, whereas it might not be permissible in a pristine environment where preservation is the main objective.

3.2 National water management policy

To formulate a national water resources management policy that takes the emerging issue of desalination into account, an interagency task force should be established. It should address all issues relating to and affected by desalination. Representatives from different sectors should participate in the task force, including water management, producers, consumers and NGOs. As desalination can have potential adverse impacts on the environment, the national environmental or coastal authorities with jurisdiction in the proposed area are essential elements in the task force.

Aspects to be considered in the formulation of a national water management policy are water extraction, allocation, conservation and reuse. Before new water is supplied by seawater desalination, alternative sources of extraction and the potential for water conservation and reuse should be investigated. National water management policies should only encourage seawater desalination where the use of conventional water resources like ground water is impracticable or causes environmental damage. Conservation measures, for example maintenance of water supply infrastructure and an increasing public awareness for water saving, could further alleviate water scarcity problems. An additional option is reclamation of wastewater, which may be of benefit to water-intensive sectors such as agriculture after minimal treatment.

In the case that seawater desalination is indispensable, the national water management policy should provide guidance in the planning phase of new projects. Aspects to be considered are purpose, size and location of a plant. For example, it should be evaluated if a permanent facility is needed or if temporary supply for draught relief is sufficient. The size of a plant can either be proportioned to the present need or take future demand into account. A plant can provide water for the local population and industry or produce surplus quantities for other areas. In this context, it should be evaluated if a number of small plants or a centralized larger plant is required.

3.3 National environmental protection policy

A desalination plant may have indirect environmental impacts as a result of changed land use and increased development in the coastal zone. New plants should therefore be approved by the authorities responsible for regulating development in the coastal zone. Development should be consistent with environmental protection plans and the long-term goals of the coastal development plan. Direct impacts may be attributed to air emissions and discharges to the marine environment. A discharge permit issued by the national environmental authority should be prerequisite for marine disposal, taking national legislation and corresponding regional protocols into account.

3.3.i Implementation of LBS regulations

According to the Mediterranean Land-Based Sources Protocol, the Parties "shall take all appropriate measures to prevent, abate, combat and control pollution of the Mediterranean Sea Area caused by discharges from rivers, coastal establishments or outfalls, or emanating from any other land-based sources[1]. The amended protocol from 1996 also explicitly provides for disposal into watercourses that communicate with the sea like coastal lagoons, salt marshes and groundwater or disposal under the seabed[2].

Seawater desalination plants commonly discharge directly to the sea through coastal outfalls. Another option is injection of brine into the ground, which is mostly practiced for plants without direct access to the sea. The brine could then enter ground water aquifers that mix with offshore ground waters and eventually enter the Mediterranean Sea. Injection into wells or percolation basins is also possible for coastal plants in order to disperse the brine through dune aquifers or the seabed. In the case that the amended protocol is ratified and enters into force, these alternative discharge options fall under the provisions of the LBS protocol.

Classification of desalination discharges according to annex I & II

The LBS protocol from 1983 distinguishes two categories of pollutants and lists them in separate annexes. Pollution of the protocol area by substances that are toxic, persistent and liable to bioaccumulate as covered by annex I shall be eliminated. For this purpose, the contracting Parties to the Barcelona Convention are obliged to elaborate the necessary programmes and measures, common emission standards and standards for use[3].

Pollutants listed in annex II were selected on the basis of criteria established for annex I, but are generally less noxious. Pollution of the Mediterranean Sea by these substances shall be strictly limited by suitable programmes and measures, and discharges shall be subject to authorization by the competent national authorities[4]. All physical effluent parameters and most chemical compounds that may be present in the desalination discharge fall into this category, i.e. are covered by annex II (Table 3-1 to Table 3-4).

[1] article 1 of the original and amended protocol
[2] article 3 (d) and 4.1 (a) of the amended protocol
[3] article 5 of the original and amended protocol
[4] article 6 of the original and amended protocol.

The amended LBS protocol from 1996, which has yet to be ratified, establishes a combined annex that lists most substances previously covered by annex I and II of the original protocol. Pollution and input of these compounds into the Mediterranean Sea shall be eliminated by national and regional action plans and programmes. Furthermore, all point-source discharges shall be strictly subject to authorization or regulation by the competent national authorities. The provisions of the combined annex, which are mostly synonymous with the provisions in annex I and II, are included in Table 3-1 to Table 3-4.

Salinity, temperature and dissolved oxygen are natural seawater parameters that are altered by the desalination process. Their effluent values deviate from ambient levels in the discharge site and could be harmful to marine life (Table 3-1). Annex II includes thermal discharges and substances that have an adverse effect on the oxygen content of seawater. Although low oxygen levels in the brine are often due to physical deaeration rather than oxygen-scavenging substances, the effect is the same and oxygen content should be regulated by annex II. High salinity is not explicitly listed as a pollutant in both annexes, but regulation according to annex II is recommended as it provides for substances of a non-toxic nature that may become harmful. Marine organisms are adapted to the concentration of dissolved salts in seawater, which is a basic living condition and consequently non-toxic. Natural salinity fluctuations can generally be tolerated, but high concentrations of dissolved salts in the effluent may be harmful to marine life.

Heavy metals are taken up by seawater from corroding surfaces within the plant. Depending on construction materials used, the discharge may contain traces of iron, chromium, molybdenum, nickel, copper and titanium (see also section 4.1.iv). Except for iron, which is not listed as a pollutant, these elements and their compounds are covered by annex II of the LBS protocol. Discharge to the Mediterranean Sea shall therefore be strictly limited and requires an authorization from the competent national authority (Table 3-1). Measures for the control of pollution by copper and its compounds adopted by the contracting parties specify a copper discharge limit of 500 µg/l and a water quality objective of 8 µg/l (UNEP/WHO, 1996).

Chlorine is a commonly used biocide in desalination processes and residual levels are often present in the effluents of distillation plants. As a consequence, organohalogen compounds can be formed within the plant or in the marine environment following discharge (see also section 4.1.iv). Pollution by substances, which may form organohalogen compounds shall be, eliminated according to annex I, except those, which are biologically harmless or converted into biologically harmless substances (Table 3-2). Chlorine rapidly self-decomposes into chloride and oxygen, which are natural seawater components. This fate reduces the risk that organohalogen compounds are formed, but does not prevent the formation entirely. Residence times are long enough to allow for reactions between chlorine and dissolved organic matter in seawater. Sufficient evidence exists that some organohalogens are carcinogenic to animals, e.g. bromoform and other trihalomethanes, which have been clearly detected in desalination effluents and discharge sites. However, composition of chlorination by-products and environmental concentrations are highly variable, as they depend on the availability of organic material in the discharge site. According to annex I, pollution by substances, which have proven carcinogenic, teratogenic and mutagenic properties, shall be eliminated. Annex I does not apply to desalination discharges in the case that effluent concentrations are below the limits defined by the Parties. Annex II provides for biocides and their derivatives not covered in annex I.

Coagulants and coagulant aids accumulate on filters in RO plants and are removed by backwashing, which produces a sludge that can be disposed to the marine environment. The sludge further contains the suspended matter that has been removed from the intake seawater (see also section 4.1.iv)**.** Sludge disposal to the marine environment should be regulated according to annex II of the LBS protocol. It is generally non-toxic but may become harmful by altering the chemical and physical properties of seawater, for example by increasing the amount of suspended material in the water column which may impair light penetration (Table 3-2).

Antifoamings like polyglycol, which are commonly used in distillation plants, have surface-active properties by being soluble in water and organic solvents (see also section 4.1.iv). The LBS protocol provides for non-biodegradable detergents and surface active substances in annex II and requires that their discharge shall be limited (Table 3-2). Polyglycol degradability depends strongly on molecular weight. About 80 % of the fraction with a molecular mass of less than 4,000 g/mole (Falbe and Regitz, 1995) is degradable, but polyethylene glycol can be highly polymerized up to 5,000,000 g/mole. In 1996, the contracting parties elaborated measures for the control of pollution by detergents. Theses included that the use of detergents should be restricted to those, which are reasonably (90 %) biodegradable (UNEP/WHO, 1996).

Antiscalants used in desalination plants and processes (see also section 4.1.iv) belong into different chemical groups so that different regulations may apply (Table 3-3). Polyphosphates, which are still in use in some desalination plants, are essential macronutrients and may cause eutrophication in the discharge site. Annex II of the LBS protocol provides for inorganic compounds of phosphorus in addition to substances, which may have adverse effects on the oxygen content of seawater by causing eutrophication.
Phosphonate antiscalants are organophosphorus compounds, which are listed in annex I of the LBS protocol. This requires that pollution shall be eliminated by necessary measures unless substances are biologically harmless and therefore excepted from annex I. Consequently, measures adopted by the contracting Parties allow the use of products if they have been authorized, it has been proven that there is no direct effect on human and animal health, and that there is no unacceptable impact on the environment (UNEP/WHO, 1996). As phosphonate antiscalants are typically used in non-toxic concentrations, direct effects on human and animal health are unlikely. A major disadvantage, however, is the poor degradability of most organophosphorus compounds. Discharge of phosphonate antiscalants should be authorized taking the toxicity and degradability of a specific product into account.
For polymer antiscalants like polymaleic acid, the most applicable provision refers to substances, which are non-toxic, but may be harmful to the marine environment owing to the quantities in which they are discharged (annex II). While direct impacts due to toxicity can largely be excluded, concern must be expressed about biodegradability and possible interference of polymer antiscalants with dissolved metal ions in seawater (for example essential nutrients like iron). Although dosage is low, this can amount to large waste amounts due to the immense seawater requirements of desalination plants. For example, a dosage of 2 mg/l amounts to a chemical load of 6 kg/d for a production of 1,000 m^3/day, or approximately 10 tons per day for the entire Mediterranean Sea.

Cleaning solutions are usually alkaline or acidic with pH values up to 12 or as low as 2. Additional cleaning chemicals include corrosion inhibitors in thermal processes and biocides, detergents, complexing agents or oxidants in reverse osmosis (see also section 4.1.iv and Table 3-4). Discharge of large volumes of cleaning fluids may have adverse effects on the quality of seawater, which has a pH of around 8, and potential impacts on marine life.
Annex II provides for acid or alkaline compounds, if their composition and discharge quantity may impair the quality of seawater. Annex II further includes biocides and their derivatives if these are not covered by annex I. This applies to non-oxidizing biocides like formaldehyde but probably not to chlorine, which is also used for pretreatment and discussed above.
Non-biodegradable detergents are also listed in annex II of the LBS protocol for the purpose of article 6, which requires that discharges are subject to authorization by the competent national authorities and limited by suitable measures and programmes. Measures for the control of pollution by detergents adopted by the contracting Parties specify that the use of detergents should be restricted to those, which are reasonably (90%) biodegradable (UNEP/WHO, 1996). Substances like dodecylbenzene sulfonate that are used in RO cleaning solutions have become important anionic detergents for their relatively good degradability (e.g. 87 % in 17 days, Zahn-Wellens test; Rott et al., 1982). The remaining cleaning chemicals are not easily classifiable according to annex I and II of the LBS protocol. For example, complexing agents like EDTA may interfere with dissolved metal ions in

seawater and is possibly covered by annex II, which generally provides for substances that are non-toxic, but may be harmful to the marine environment.

Sectors of activity

The amended LBS protocol from 1996 also covers different sectors of activity, which receive priority in the development of programmes and measures to combat pollution. As seawater desalination is not listed in section A of appendix I, the most applicable provision would be the sector "29. Works which cause physical alteration of the natural state of the coastline". The contracting parties may consider to include seawater desalination activity explicitly, e.g. in the form of "Energy production and seawater desalination" for the following reasons. First, distillation plant effluents have similar properties to power plant effluents, e.g. with regard to temperature, heavy metal contamination or residual chlorine levels. Secondly, power and desalination plants are often co-located due to the high-energy requirements of desalination plants or to allow for co-generation, especially by coupling distillation and power plants for simultaneous water and electricity production. Furthermore, co-located plants may use the same infrastructure like seawater intakes and outfall channels. By using the same outfalls, the brine can be diluted with power plant cooling water to mitigate impacts from high salinity. An amended appendix, which covers energy production and seawater desalination at the same time, is more applicable to combined brine and cooling water discharges.

Table 3-1: Physical and chemical brine properties, including heavy metal contamination from corrosion.

Source of impact	**Process**		**Regulation according to LBS protocol from 1983** *italics refer to the amended protocol from 1996*
	Reverse osmosis	**Multi-stage flash**	
Salinity	up to 70,000 ppm	up to 50,000 ppm due to mixing with desalination plant cooling water of ambient salinity	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful […] *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Temperature	ambient	5-15 °C above ambient	**article 6; annex II, section A, no. 9** Thermal discharge *article 5; annex I, section C, no. 15* *Thermal discharges*
Plume density	negatively buoyant	positively, neutrally or negatively buoyant	consequence of salinity and temperature values and indirectly covered by respective regulations
Oxygen	decreased as a side-effect by chemicals used for de-chlorination	very low, intentional deaeration and use of oxygen scavengers to reduce corrosion	**article 6; annex II, section A, no. 11** Substances which have, directly or indirectly an adverse effect on the oxygen content […] *article 5; annex I, section C, no. 17* *Non-toxic substances that have an adverse effect on* *the oxygen content […]*
Heavy metals from stainless steels	iron, nickel, chromium, molybdenum		**article 6; annex II, section A, no. 1** copper, nickel, molybdenum, titanium, chromium *article 5; annex I, section C, no. 5* *Heavy metals and their compounds*
Heavy metals from heat exchanger alloys	not present	copper, nickel; titanium	

Table 3-2: Pre-treatment chemicals

Source of impact	Process		Regulation according to LBS protocol from 1983 *italics refer to the amended protocol from 1996*
	Reverse osmosis	**Multi-stage flash**	
Biocides	chlorine is typically used, but usually neutralized with sodium bisulfite, i.e. the discharge is free from residual chlorine; chlorinated by-products may be present at low levels or are non-detectable	chlorine discharge levels are approx. 10-25 % of the dosage due to self-decomposition and reaction with organic compounds, e.g. between 200-500 ppb of an initial dose of typically 2 ppm, but dosage can be as high as 8 ppm during shock treatment many different chlorinated by-products at varying concentrations likely	**article 5; annex I, section A, no. 1 and no. 8** - Organohalogen compounds and substances which may form such compounds in the marine environment. With the exception of those which are biologically harmless […] - Substances having proven carcinogenic, teratogenic or mutagenic properties […] **article 5; annex I, section B,** The present annex does not apply to discharges which contain substances listed in section A that are below the limits defined jointly by the Parties. **article 6; annex II, section A, no. 2** Biocides and their derivatives not covered in Annex I *article 5, annex I, section C, no. 8* *Biocides and their derivatives*
Coagulants	e.g. ferric chloride, aluminum chloride, backwashed from filters and disposed as sludge or discharged to environment	not used	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful […] *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Coagulant aid	e.g. polyacrylamide (disposal as coagulants)	not used	
Antifoaming agents	not used	e.g. polyglycol in doses of 0.1 ppm or less	**article 6; annex II, section A, no. 6** Non-biodegradable detergents and other surface active substances *article 5, annex I, section C, no. 12* *Non-biodegradable detergents and other non-biodegradable surface active substances*

Table 3-3: Pre-treatment chemicals (continued)

Source of impact	**Process** **Reverse osmosis** **Multi-stage flash**	**Regulation according to LBS protocol from 1983** *italics refer to the amended protocol from 1996*
Antiscalants	typical dose of 2 ppm of e.g. polyphosphates	**article 6; annex II, section A, no.7 and no. 11** - Inorganic compounds of phosphorus […] - Substances, which have […] an adverse effect on the oxygen content […], especially those which may cause eutrophication. *article 5; annex I, section C, no. 13* *Compounds of […] phosphorus […] which may cause eutrophication*
	e.g. phosphonates	**article 5; annex I, section A, no. 2** Organophosphorus compounds […]. With the exception of those which are biologically harmless **article 5; annex I, section B,** The present annex does not apply to discharges which contain substances listed in section A that are below the limits defined jointly by the Parties. *article 5; annex I, section C, no. 2* *Organophosphorus compounds […]*
	e.g. polymaleic acid, polyacrylic acid	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful to the marine environment […] owing to the quantities in which they are discharged. *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Acid	e.g. sulfuric acid, pH 6 to 7	Although acidic discharge is regulated by article 6; annex II, no. 12 (*article 5; annex I, no. 16*), the dose used for pre-treatment is not enough to impair the quality of seawater

Table 3-4: Cleaning and storage chemicals

Source of impact	**Process**		**Regulation according to LBS protocol from 1983**
	Reverse osmosis	**Multi-stage flash**	*italics refer to the amended protocol from 1996*
Alkaline solution	e.g. sodium hydroxide, pH 11-12	not used	**article 6; annex II, no. 12** Acid or alkaline compounds of such composition and in such quantity that they may impair the quality of sea-water *article 5; annex I, no. 16* *Acid or alkaline compounds which may impair the quality of water*
Acidic solution	e.g. hydrochloric acid, citric acid pH 2-3	e.g. hydrochloric acid, sulfuric acid, citric acid, sulfamic acid pH 2	
Corrosion inhibitors	not used	e.g. benzotriazole	
Biocides	non-oxidizing like formal-dehyde, glutaraldehyde, isothiazole derivatives; or hypochlorite (i.e. chlorine)	not used	**article 6; annex II, section A, no. 2** Biocides and their derivatives […] *article 5, annex I, section C, no. 8* *Biocides and their derivatives*
Detergents	e.g. dodecylsulfate, dodecylbenzene sulfonate	not used	**article 6; annex II, section A, no. 6** Non-biodegradable detergents and other surface active substances *article 5, annex I, section C, no. 12* *Non-biodegradable detergents and other non-biodegradable surface active substances*
Complexing agents	e.g. ethylenediamine tetraacetic acid (EDTA)	not used	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful […] *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Oxidants	e.g. sodium perborate, hypochlorite (i.e. chlorine)	not used	
Membrane storage chemicals	e.g. sodium bisulfite, propylene glycol, glycerine	not used	

3.3.ii Implementation of Dumping Protocol regulations

According to the Mediterranean Dumping Protocol, the Parties "shall take all appropriate measures to prevent and abate pollution of the Mediterranean Sea area caused by dumping from ships and aircraft[5]. Dumping by ship is not a practicable option for coastal desalination plants, where immense effluent volumes are typically discharged directly through coastal outfalls. The LBS protocol and corresponding national legislation consequently apply to most coastal plants. In contrast, inland plants have to rely on alternative disposal options. These usually desalinate brackish water from wells for use in small and medium sized industries and municipalities and generate small amounts of brine. The brine can either be discharged locally into evaporation ponds, sewer systems and deep wells not used for drinking water supply, or can be transported and dumped into the sea by vessels. Dumping of desalination effluents should be regulated according to Article 5 of the Dumping Protocol, which requires that a permit is obtained, in each case, for all wastes listed in annex II.

4. EIA FOR SEA WATER DESALINATION PLANTS

In the amended LBS protocol from 1995, the contracting parties have agreed to undertake environmental impact assessment to prevent, abate, combat and eliminate pollution of the Mediterranean Sea. An environmental impact assessment (EIA) is prerequisite for an activity that probably has significant adverse effects on the marine environment and that is subject to authorization by national authorities[6]. With regard to the potential adverse effects of seawater desalination, an EIA is an essential prerequisite for new desalination projects. It further provides the basis on which different aspects of a new facility can be permitted by the competent national authorities or for imposing restrictions to meet specified requirements, e.g. in the form of marine discharge and coastal development permits.

4.1 Elements of EIA study

An EIA analyses single components of a project and their expected socio-economic and environmental effects, which results in the formulation of impact mitigation methods. In the following EIA for seawater desalination plants, environmental and socio-economic issues are addressed and recommendations for impact mitigation included.

4.1.i Land use and siting of the plant

Potential impacts. 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. It requires the use of heavy machinery, which produces air emissions and noise, obstructs views or could disturb terrestrial and marine organisms. Similar impacts may result from the desalination plant after completion. Plant operation causes atmospheric and marine emissions or noise from pumping stations, while the building complex and supporting infrastructure alter the visual properties of a landscape permanently.

A changed air, water and sediment quality in addition to auditory and visual effects have potential impacts on human activities and the coastal environment. The recreational value of a coastal site for residents and tourists can be reduced or access restricted by the desalination plant. If the plant is located within existing urban boundaries, it could reduce the price for land or the value of adjacent residential properties. Maritime structures like intakes

[5] article 1 of the original and revised protocol
[6] article 4 (General obligations), 3.(c) of the revised Barcelona Convention from 1995.

or outfalls could interfere with navigation, access to harbours or other activities like fishing. They also have potential impacts on water currents and sediment transport. The changed land use might further affect habitats of terrestrial and marine animals in the coastal zone, which could be driven away from their breeding, feeding or resting grounds.

Mitigation measures and recommendations. To mitigate impacts from construction activities, they 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. Similar mitigation methods should be considered for the desalination plant, which can be designed to minimize visual and auditory impacts. This includes for example soundproofing 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 to limit emissions.

To minimize impacts from changed land use, desalination plants should be located near other facilities with similar needs and consequences. Suitable sites may be where existing infrastructure like roads or seawater intakes can be used, 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. This means for example that pipelines should be placed underground or 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. Interests on the seaward side of the coastline, for example the interference of intake and outfalls with other maritime uses, may be included in the coastal development plan or regulated separately.

4.1.ii Energy use alternatives and air quality

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.

Distillation processes usually have higher energy requirements than membrane processes. For example, a plant operated at a performance ratio[7] of 8 has a thermal energy consumption of approximately 290 kJ/kg distillate (or 80 kWh/m^3), usually added in the form of heated steam, in addition to an electricity demand of 4-6 kWh/m^3 for MSF and 2.5-3 kWh/m^3 for MED plants (C.R.E.S., 1998). However, co-generation of electricity and water in dual-purpose plants reduces the primary energy consumption considerably by re-using the exhaust steam from electricity generation as a heat source for the desalination plant. Dual-purpose plants are economically attractive and can compete with RO plants in terms of energy cost. For comparison, energy requirements of RO plants can be reduced to 2.5 kWh/m^3 for large units with energy recovery systems, but exceed 15 kWh/m^3 in small plants without energy recovery.

Potential impacts. 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 deaerated and gases evolve from the evaporating brine in flashing chambers. Both processes increase carbon dioxide (CO_2) emissions, which are 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.

[7] The ratio of fresh water production to steam input is a measure for the efficiency of thermal processes. A typical value is 8 kg distillate from 1 kg steam, but values of 10-12 can be achieved.

If power plant capacities have to be increased to meet the additional electricity demand of new desalination plants, impacts related to the use of cooling water may be enhanced. These include entrainment and impingement of marine organisms at the intake and thermal discharges. Further adverse effects may result from the additional transport and handling of fuel required for increased electricity production, which also increases the risk for accidents and spills.

Mitigation measures and recommendations. To mitigate impacts related to energy consumption, national authorities should encourage the use of energy saving technologies and processes. This includes 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, an efficient operation of the desalination plant requires that the steam turbine for electricity production be operated at the same time. 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. The substitution of conventional sources of energy (fossil fuel, nuclear power) by renewable ones reduces nuclear wastes and air emissions of CO_2, NO_x and SO_x. If fossil fuels are used as primary energy source, air emissions should comply with national air pollution control standards.

4.1.iii Sea water intake

Desalination plants can receive feed water from open seawater intakes, below-ground beach wells and infiltration galleries or from the cooling water discharge conduits of power plants. Open seawater generally contains higher and more variable amounts of organic and inorganic material than intakes embedded in the seafloor. These naturally prefiltrate the incoming seawater and thereby reduce bacterial numbers and suspended material. The seafloor sediments might also have unfavourable effects on feed water properties, for example by increasing the carbonate or hydrogen sulfide content. If the intake water is drawn from cooling water discharges, it might contain residual pretreatment chemicals (e.g. biocides), heavy metals from corrosion and increased temperature values. Depending on the intake option, the feed water has different properties, requiring that pretreatment in the desalination plant is adjusted to the intake water quality.

Potential impacts. 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. Pretreatment 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 feed water quality. This in turn increases the risk of chemical discharges to the marine environment.

Besides often-minimal chemical pretreatment, underground intake structures eliminate impacts from entrainment and impingement. However, initial disturbance during construction is higher as sediments have to be replaced or become resuspended. Beach wells are typically drilled 30-50 m deep into the seabed, whereas infiltration galleries consist of perforated pipes arranged in a radial pattern in the saturated sand onshore. They could furthermore interfere with aquifers, e.g. by changing groundwater flow or causing saltwater intrusion into freshwater aquifers.

Mitigation measures and recommendations. Screens should be placed in front of the intake structures to prevent the intake of larger marine organisms. While entrainment of smaller plankton, larvae or eggs cannot be avoided by these screens, it can be minimized by locating intakes away from highly productive areas, e.g. in deep water or further offshore. This can also mitigate problems of biological fouling and intake of suspended material so that chemical consumption could be reduced. The intake should be designed to lower the risk of impingement, which can be achieved by specially designed screens or limiting the intake flow velocity to values of week natural ocean flows (e.g. below 5 cm/sec).

Beach wells or infiltration galleries are recommended where a suitable site is available to reduce impacts from impingement, entrainment and to reduce chemical consumption. Drawing of intake water from cooling water discharges has similar advantages and should be considered where co-location of desalination and power plants is possible. Total intake volumes are reduced by reusing the cooling water from the power plant for desalination, thus minimizing entrainment end impingement. As the cooling water is usually disinfected to control biofouling, additional biocide dosing may be unnecessary or minimal. Co-location also minimizes construction and land use as existing intake structures can be used.

4.1.iv Brine and chemical discharges

The physical and chemical properties of seawater are modified during desalination, depending on the pretreatment methods and desalination process used. Similar pretreatment 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 pretreatment 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.

Salinity

Effluent salinity depends on the salinity of the intake seawater and the concentrating effect of the desalination process. The RO brine is usually more saline (values of 60-70) than the distillation effluent (values around 50), which is mainly due to the use of cooling water in distillation plants. The cooling water from the heat rejection section is discharged along with the brine and effectively reduces overall effluent salinity.

Potential impacts. Salinity is one environmental factor controlling the distribution of marine organisms, which normally occur where environmental conditions are favorable for survival. 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.

Mitigation measures and recommendations. To minimize impacts from elevated salinity levels, desalination effluents should be within 10 % of the ambient value. This can be achieved by blending desalination effluents with power plant cooling water in adequate mixing ratios (see section 4.1.v). Options that improve mixing in the discharge site should further be considered (see section 4.1.vi).

Thermal discharges

Thermal discharges are characteristic of distillation plants, where both brine and cooling water are increased in temperature. Differences of 5-15°C above ambient have been frequently observed.

Potential impacts. The thermal discharge may change 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.

Mitigation measures and recommendations. To minimize potential adverse effects, temperature increase of the distillation discharge should be restricted to 10°C above ambient. Mixing with effluents of lower temperature should be considered where feasible. 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. The discharge situation should further ensure adequate mixing of the effluent plume (see section 4.1.vi) with surrounding seawater to mitigate impacts from elevated temperature. For this purpose, an allowable increase in seawater temperatures due to thermal discharges should be determined. An allowable increase of 2°C over ambient conditions might for example be considered, applying to the edge of a defined mixing zone.

Oxygen content

Potential impacts. Oxygen solubility in seawater is reduced by high temperature and salinity values, but decreased solubility is not the primary cause for low oxygen contents in the effluent. The major decline is due to physical deaeration in distillation plants to prevent corrosion. In RO plants, reducing agents like 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, which could be harmful to marine life.

Mitigation measures and recommendations. 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

The intake seawater of distillation and reverse osmosis plants is commonly treated with chlorine to prevent biofouling. Residual chlorine levels of 200-500 µg/l are typically present in the distillation effluent and are discharged to the marine environment, whereas pre-treatment in RO plants often includes dechlorination to protect sensitive polyamide membranes from oxidation. RO discharge levels of chlorine are consequently very low to non-detectable.

Potential impacts. 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 a major by-product in desalination plant discharge sites, or chlorophenols and chlorobenzenes may arise in the presence of petroleum compounds. The number of by-products can hardly be determined 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.

Mitigation measures and recommendations. Neutralization of residual chlorine levels should receive a high priority to mitigate impacts from distillation plant effluents. Several chemical treatment options exist, for example dosing of sodium bisulfite (used in RO) or sulfur dioxide[8].

Alternative treatment methods should be considered where feasible, for example the use of 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 are prefiltration with fine-pored membranes (microfiltration or ultrafiltration) or the use of beach-wells. Both methods remove biofouling organisms from the intake water, so that continuous biocide dosing could be replaced by intermittent treatment for disinfection and cleaning. Alternative biocides proposed for use in desalination plants include ozone, monochloramine, chlorine dioxide and copper sulfate. However, these substances may also be harmful to marine life and require pre-treatment prior to discharge.

Coagulants

RO plants typically use coagulants like ferric- or aluminum chloride to improve filtration of suspended material from the feed water. Coagulant aids (organic substances like polyacrylamide) and pH control with sulfuric acid are supplementary methods to enhance coagulation.

Potential impacts. The 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.

Mitigation measures and recommendations. 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, which is more feasible for larger plants[9].

Antiscalants

Antiscalants are added to the feed water in both MSF and RO plants to prevent scale formation. The main representatives are organic polymers (mainly polyacrylic acid and polymaleic acid), phosphonates and polyphosphates. Dosing of sulfuric acid is another effective method that increases the solubility of alkaline scales like calcium carbonate. Acid

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[8] Sulfur dioxide eliminated residual chlorine levels, was found to be most cost-effective and technically feasible without system alterations (Khordagui, 1992).

[9] Coagulant dosage is typically correlated to the amount of suspended material in the intake seawater, for example around 1 mg/l is required for a low background concentration of 1 mg/l suspended solids. For a capacity of 1,000 m^3/day, backwash material of 6 kg/day is thus produced at 33 % recovery, which amounts to e.g. 600 kg/d for a 100,000 m^3/day plant.

treatment is problematic in distillation plants that use copper-alloys for heat exchanger surfaces, as enhanced corrosion increases the risk of brine copper contamination.

Potential impacts. Organic polymers are non-hazardous to marine life as toxicity values (LC_{50}) 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 rather 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 rather 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 LC_{50} values of commercial products.

Polyphosphate antiscalants are easily hydrolyzed 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 was observed at the outlets of some desalination plants that used polyphosphates for scale control.

Mitigation measures and recommendations. The use of organic polymers is recommended to mitigate potential impacts from increased nutrient levels in the discharge site. Although these substances are relatively non-toxic, concern must be expressed about their environmental fate and potential impact on dissolved metals in seawater, which requires further investigation. Pre-treatment with sulfuric 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, which is a membrane softening process that partially removes divalent cations like calcium or magnesium from seawater.

Heavy metals

Heavy metal concentration and composition of the discharge depends on construction materials used and their resistance to corrosion. Copper-nickel alloys are common materials for heat exchanger surfaces in distillation plants, while other construction parts like brine chambers are often made from stainless steel. Stainless steel is also a predominant material in RO plants, where non-metal equipment like plastic is additionally used. Corrosion of stainless steel is generally very low, with trace amounts of iron, nickel, chromium and molybdenum present in RO and distillation discharges. In contrast, copper levels from corroding heat exchanger alloys are often a major problem of the distillation discharge, with contents typically ranging between 15-100 µg/l under good process control.

Potential impacts. 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 and passed on to higher trophic levels.

Mitigation measures and recommendations. Heavy metals in the desalination discharge will most likely be within effluent limitations adopted by the contracting parties to the Barcelona Convention. Expected discharge levels of copper are well below an established discharge limit of 500 µg/l, but 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. As the environmental fate of copper is characterized by deposition and bioaccumulation, 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.

Antifoamings

Antifoaming agents like 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 as dosage levels are low and discharge concentrations are further decreased by dilution in the environment.

Cleaning solutions

RO cleaning solutions are either alkaline (pH 11-12) for removal of silt deposits and biofilms, or acidic (pH 2-3) to dissolve metal oxides or scales. They may additionally contain detergents, oxidants, complexing agents and biocides that are used to improve membrane cleaning. For storage of membranes, a chemical preservation solution is used. The cleaning of distillation plants is comparatively simple and usually involves acid washing at pH 2. Special inhibitors may further be added to control corrosion.

Potential impacts. 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 like 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 like EDTA are typically used in cleaning solutions, which was found to be poorly degradable and is consequently rather 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.

Mitigation measures and recommendations. 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. For example, dodecylbenzene sulfonate is to a high extent degradable and formaldehyde can be chemically deactivated by hydrogen peroxide and sodium hydroxide. 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.

4.1.v Combining waste with other discharges

Co-location of desalination and power plants has the advantage that the same infrastructure can be used and that a substantial amount of energy can be saved by co-generation (see section 4.1.i & 4.1.ii). Another important aspect is the possibility for waste stream blending, i.e. cooling water from the power plant and brine from the desalination plant are mixed in the outfall channel prior to discharge to the marine environment. Other waste streams like treated sewage from a wastewater treatment facility can be theoretically used for diluting the brine too, but reuse should be preferred over disposal.

Potential impacts. Waste stream blending has the beneficial effect of diluting saline desalination effluents prior to marine disposal, which could otherwise result in increased salinities in the discharge site with potential negative impacts on marine life. Salinity is an important environmental factor for marine organisms that normally live within their optimal salinity range, while de- or increased values may be at the rim of their tolerable limit (confer section 4.1.iv).

Power plants require large quantities of cooling seawater, which typically allow for good mixing ratios to achieve a significant reduction in brine salinity. While impacts from high salinity are mitigated by waste stream blending, the presence of pollutants in both effluents could give rise to additive or synergistic effects on marine life. The cooling water is usually increased in temperature and may contain residual biocides or heavy metals from corrosion.

Similarly, the mixing of brine and sewage effluents may have favorable but also unwanted side effects. For example, brine salinity and biological oxygen demand (BOD) of the sewage could probably be reduced by waste stream blending, whereas contaminants present in both effluents might form diverse reaction by-products such as chlorinated organics. Mixing of brine and sewage effluents may also cause aggregation of contaminants into differently sized particles with possible impacts on turbidity and sedimentation rates in the discharge site.

Mitigation measures and recommendations. 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.

Although the mixing of brine with treated sewage effluent is practiced in other parts of the world, it is not recommended for the Mediterranean region for the following reasons. First, treated sewage effluent can be reused and marine disposal should not be encouraged. In the case that sewage is discharged to the marine environment, it could impair the intake water quality of the desalination plant. Furthermore, co-located desalination and sewage treatment facilities give rise to health concerns and might be objected for psychological reasons. Finally, environmental risks associated with the formation of reaction by-products are probably higher when desalination effluents are blended with treated sewage instead of power plant cooling water.

It can be concluded that waste stream blending is an effective method for impact mitigation, which reverses the process of concentrating natural seawater constituents into brine during desalination. The pre-treatment chemicals are diluted as a side effect, although dilution is usually not an accepted method for disposal of chemical wastes. The argument applies to substances that are contained in desalination effluents but not in the waste stream used for mixing, such as antiscalants and antifoamings. Both have a low toxicity and are present in concentrations that are not harmful to marine organisms. In contrast, residual biocides, heavy metals from corrosion and thermal pollution are properties of distillation plant effluents but also of power plant cooling water. As these properties are unaffected by dilution and impacts may even be enhanced by waste stream blending, effluent properties should be within acceptable discharge limits. For combined discharges, the party or parties responsible for meeting the discharge requirements should be identified in order to avoid enforcement problems.

4.1.vi Oceanographic conditions and use of dispersion models

The mixing behavior of an effluent depends on the oceanographic conditions in the receiving water body, the discharge practice and certain discharge properties. Site-specific oceanographic features like currents, tidal regime, bathymetry or shoreline topography control to a large extend the mixing and spreading of an effluent, but this is also influenced by outfall design and location, flow rate and discharge velocity. Mixing is further governed by the density difference between effluent and surrounding seawater, with density being a function of salinity and temperature.

Potential impacts. A distinct water mass may be formed under limited mixing conditions, which is characterized by effluent properties such as increased salinity or residual chemical concentrations. The spreading of this discharge plume could affect marine organisms along its trajectory. 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[10]. 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.

Mitigation measures and recommendations. Mixing of the effluent in the receiving water body should be improved by making use of favorable oceanographic conditions and optimising the discharge practice. For example, good mixing results can be achieved on high-energy coasts, where turbulence is high and strong currents cause a rapid water exchange. On the contrary, sheltered sites like bays or estuaries may trap effluents, which results in long residence times of pollutants. To avoid adverse effects on coastal habitats by shore-hugging plumes, 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). Sinking or rising of the effluent through the water column increases turbidity and enhances mixing with surrounding seawater. The outfall can further be technically improved, for example by using multiport diffusers or increasing the discharge velocity.

Different discharge scenarios should be analysed for a proposed desalination plant to determine the best method of disposal. Dispersion models can be used to simulate the near- and far-field mixing behaviour of an effluent in the receiving water body and spreading of the plume. This requires detailed information on the prevailing oceanographic conditions in the discharge site and the planned discharge practice. For example, some parameters of importance are water depth, ambient density including seasonal variations, wind- and

[10] A calculation for Mediterranean surface water (considering a salinity range of 36-38 and a seasonal temperature range of 15-30°C) results in density values of 1022-1028 kg/m^3. Assuming a temperature increase of 5-15°C and salinity values of 41-44 (a 15 % increase is typical for distillation plant effluents), the corresponding density values vary between 1020-1031 kg/m^3.

density-driven currents, tidal regime, diameter and depth of the outfall, effluent velocity and volumes.

As chemical dilution and dispersal is governed by the mixing and spreading behaviour of an effluent, chemical parameters may be included in the model to predict environmental concentrations. This information can be used to assess if water quality objectives (if established) will be observed in the receiving water body. Spatially restricted mixing zones can be established to regulate plume spreading and dispersal. Mixing zone definitions should take local oceanographic conditions like hydrodynamics or bathymetry into account and might exclude areas of biological importance. Ambient levels may typically be exceeded to a certain degree within the mixing zone, but water quality objectives usually apply at the edge of the mixing zone.

For example, the U.S. EPA approved CORMIX model can be used to predict the mixing behaviour from diverse discharge types, including desalination brines and power plant cooling waters, in diverse ambient conditions. Besides near field and far-field plume trajectory visualization, the model allows for concentration and dilution predictions (Doneker and Jirka, 2001; Del Bene et al., 1994; Jirka et al., 1996)[11]. Hydrodynamic models used in Israel to simulate the mixing behaviour of desalination brines are the two-dimensional MIKE21 model from the Danish Hydraulic Institute (DHI)[12] and the Princeton Ocean Model from Princeton University[13]. Hydrodynamic models were also developed at the Center for Environment and Water at the Research Institute of the King Fahd University of Petroleum & Minerals, Saudi Arabia. Although they have not been applied to desalination plant discharge, they have been used in simulating the highly saline produced water discharge from offshore oil production operations (Al-Rabeh et al., 2000; Badr et al., 1999).

4.1.vii Transboundary effects

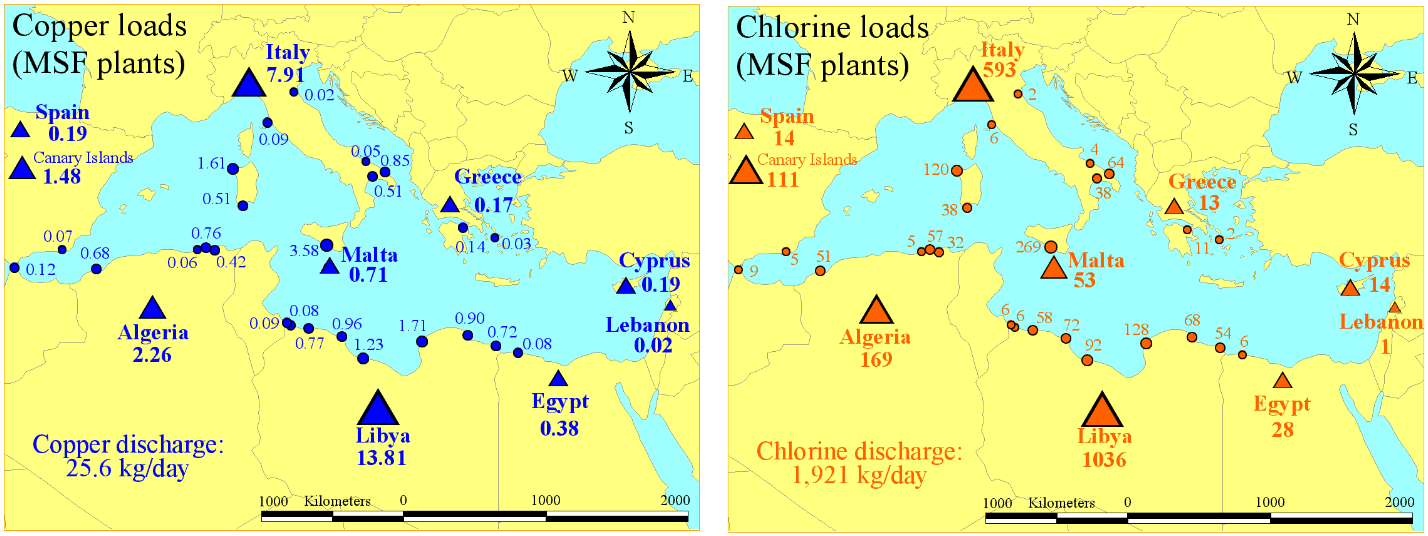
Pollutants transported by currents may affect areas far away from where the discharge takes place. Potential impacts beyond the territorial waters or exclusive economic zone of a contracting state should consequently be considered for substances that are persistent and easily dispersed in the marine environment. The degradation of local environments may have transboundary implications too. Intact coastal and marine ecosystems throughout the region are essential for a high biodiversity in the Mediterranean Sea and provide habitats for migratory, endangered or endemic species. An estimate of total chemicals inputs, both locally and into the Mediterranean as a whole, is an important prerequisite for the assessment of transboundary effects.

Persistent and mobile substances in the discharge of desalination plants include for example organohalogen by-products from chlorination, phosphonate and polymer antiscalants or detergents and complexing agents used in cleaning solutions. They may be dispersed by currents, and dilution will cause a further decline of already low discharge concentrations. In contrast, 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 self-decomposition (e.g. chlorine) and transport into sediments (e.g. copper, coagulants) in addition to dilution. Local effects may still be significant, especially in desalination 'hot spots' where installed capacities are high.

Residual chemical concentrations in the desalination discharge are relatively low but may amount to immense loads due to the large effluent volumes produced. Estimates of chemical loads are not only of concern for accumulating substances, but also for highly toxic or persistent compounds in the discharge. Figure 4-1 shows estimated inputs of three representative substances, namely copper, chlorine and antiscalants, into the Mediterranean

[11] http://www.cormix.info/
[12] http://www.dhisoftware.com/mike21/
[13] http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/

Sea. Based on desalination capacities and discharge concentrations, the daily chemical load may amount to 25 kg copper, 1.9 tons chlorine and 10.2 tons antiscalants. Taking the size and length of coastline of the Mediterranean Sea into account, chemical inputs from desalination plants are still limited and fairly well distributed, although some hot spots of increased capacity exist.



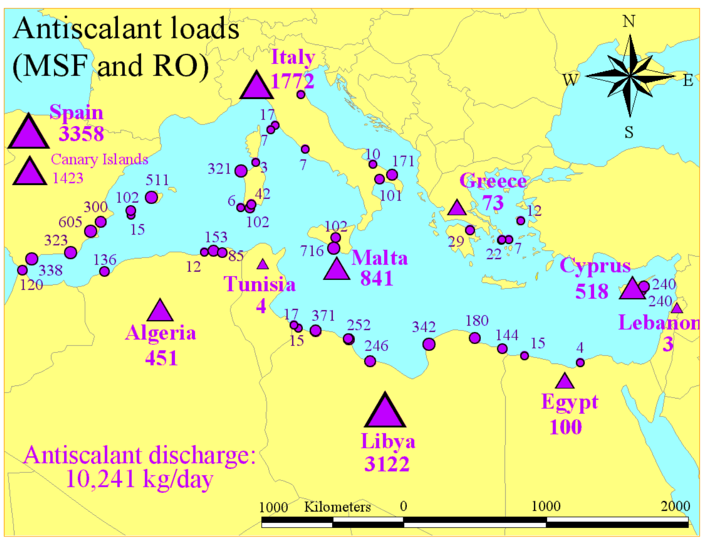


Figure 4-1: Estimated copper, chlorine and antiscalant discharges into the Mediterranean Sea in kg per day. Dots and triangles show discharge loads of single locations and cumulative national loads, respectively.

Copper and chlorine are present in discharges from multi-stage flash (MSF) distillation plants. The estimate is based on a brine copper level of 15 µg/l, while residual chlorine levels of 0.25 mg/l were assumed for both brine and cooling water effluents.

Antiscalants are used in both multi-stage flash (MSF) distillation and RO plants. The figure shows the estimated discharge of both processes based on a dosage of 2 mg/l to the feed water.

4.1.viii Potential growth of water demand

A main reason for water shortage is the unequal distribution of water resources among Mediterranean countries. The North coast receives most of the natural input and is backed by more temperate regions with abundant water resources. The Eastern and Southern parts, in contrast, are characterized by low rainfall and little water input from neighbouring areas[14]. The already high pressure on water resources in the Southeast is further increased by rapid demographic growth, economic and agricultural development[15].

Sectorial water demand. Only a minor amount of water is consumed by communities, which currently account for about 8 %, 14 % and 15 % of the total demand in the Southern, Eastern and Northern parts, respectively (Table 4-1). Similarly low shares ranging between 7 % and 13 % can be attributed to industrial activity, so that agricultural irrigation is and will remain the predominant sector of use in most Mediterranean countries. In the Southeast, the demand for irrigation water exceeds 80 % of the total and is much greater than in the North, where approximately 42 % of the water is used for agricultural purposes. Water shortage is most pronounced in summer months when peak amounts are needed to irrigate crops, but rainfall is low or non-existent. Furthermore, the problem is seasonally aggravated by tourism and interannually by droughts, when water input can be as low as a third of average input (Margat and Vallée, 2000).

Expected growth of water demand. In most Mediterranean countries, water withdrawal has already or will reach a level that exhausts available water resources. The total demand in the Mediterranean region approached 300 billion m^3/year in 1990, but is anticipated to increase by 32 % until 2010, and by 55 % to over 460 billion m^3/year in 2025 (Table 4-1). The underlying trends reflect the different demographic and economic development in the sub-regions: While the demand will almost double in Southeastern parts, a comparatively slow increase of 20 % is predicted for the North. As a result of limited resources and rapidly growing demand, pressure on natural water resources will be most pronounced in the Southeast, where eleven countries will withdraw more than 50 % of their average renewable resources by 2010 and eight countries will require more than 100 % in 2025 (Margat and Vallée, 2000).

[14] Natural input in the North is about 72 % of the total, while the East and South receive about 23 % and 5%, respectively. An exception is the Nile river basin with abundant water resources, which originate in the highlands of central Africa.

[15] The total population in the Eastern and Southern countries tripled within one generation and exceeded 223 million in 1995. For the whole Mediterranean, a population growth of 20-37 % is anticipated according to United Nations estimations, from 420 million inhabitants in 1995 to 508-579 million in 2025.

Table 4.1: Sectorial water demand in 1990 and moderate trend forecasts for Mediterranean countries by sub-regions for 2010 and 2025. Figures are given in km^3 per year and as percentage of the total demand from 1990 (100 %). The North includes Albania, Bosnia-Herzegovina, Croatia, Spain, France, Greece, Italy, Malta, Monaco, Portugal, Slovenia, F.R. of Yugoslavia; East: Cyprus, Israel, Jordan, Lebanon, Syria, Territories under Palestinian Authority (Gaza, West Bank), Turkey; South: Algeria, Egypt, Libya, Morocco, Tunisia (Source: Margat and Vallée, 2000).

		Reference year 1990										2010	2025
		Communities		Agriculture		Industry		Energy		Total		Total	Total
		km^3/a	%	km^3/a	%	km^3/a	%	km^3/a	%	km^3/a	%	%	%
1990	North	23	**15**	65.5	**42**	20	**13**	47	**30**	155	**100**	**116**	**120**
	East	7.5	**14**	43	**79**	4	**7**	0	**0**	54	**100**	**152**	**202**
	South	7.5	**8**	72.5	**82**	8.5	**10**	0	**0**	89	**100**	**148**	**189**
	Total	38	**13**	181	**61**	33	**11**	47	**16**	299	**100**	**132**	**155**
2010	Total	62	**16**	237	**60**	46	**12**	50	**13**	395	**100**		
2025	Total	75	**16**	276	**60**	51	**11**	61	**13**	463	**100**		

Non-conventional resources. The figures reveal that future demand can only be met if water is withdrawn from non-renewable resources (fossil groundwater), or supplied by non-conventional methods like wastewater reclamation and desalination. Seawater desalination is already a well-established and reliable industry in some coastal areas of the Mediterranean (Figure 4-2), but the region as a whole has a comparatively low share in worldwide capacities: Its current production exceeds 1.7 million m^3/d compared to a total of 15 million m^3 extracted from the sea each day (data based on Wangnick, 1999). Capacities in single locations are also relatively low and plant size is typically below 100,000 m^3/d, with most plants producing 10,000 m^3/d or less. Although multi-stage flash distillation is the dominant process for seawater applications worldwide followed by reverse osmosis, both processes are used about equally in the Mediterranean region. On a national level, however, capacities deviate strongly from this overall regional trend. For example, Spain's desalinated water is produced almost exclusively in RO plants, while the majority of plants in Libya are based on thermal desalination processes. From the distribution of plants, it can be concluded that the energy and cost intensive technology is so far restricted to areas, where natural water resources are very limited, fossil energy is readily available, or where the high price for desalinated water can be afforded.

According to the moderate trend scenario of the Mediterranean Blue Plan (Margat and Vallée, 2000), non-conventional resources may supply 5 to 10 % of the water demand in 2025, which amounts to 63 - 126 million m^3 per day. A major proportion of this quantity will be provided through wastewater recycling and be of benefit for agricultural irrigation. In contrast, the main sectors of use for desalinated water are drinking water for communities and pure water for high-tech industries (Ribiero, 1996). The potential for growth is enormous, although future desalination capacities in the Mediterranean can hardly be predicted. If only 1 % of the water demand is provided by desalination, capacities will exceed 12 million m^3 per day, i.e. will increase sevenfold until 2025. The use of desalination technology may be restricted to developed countries with very low resources in the case that costs remain high, but a widespread low-cost development is anticipated if costs drop below US$ 0.25 per m^3. Currently, the trend is towards large facilities where

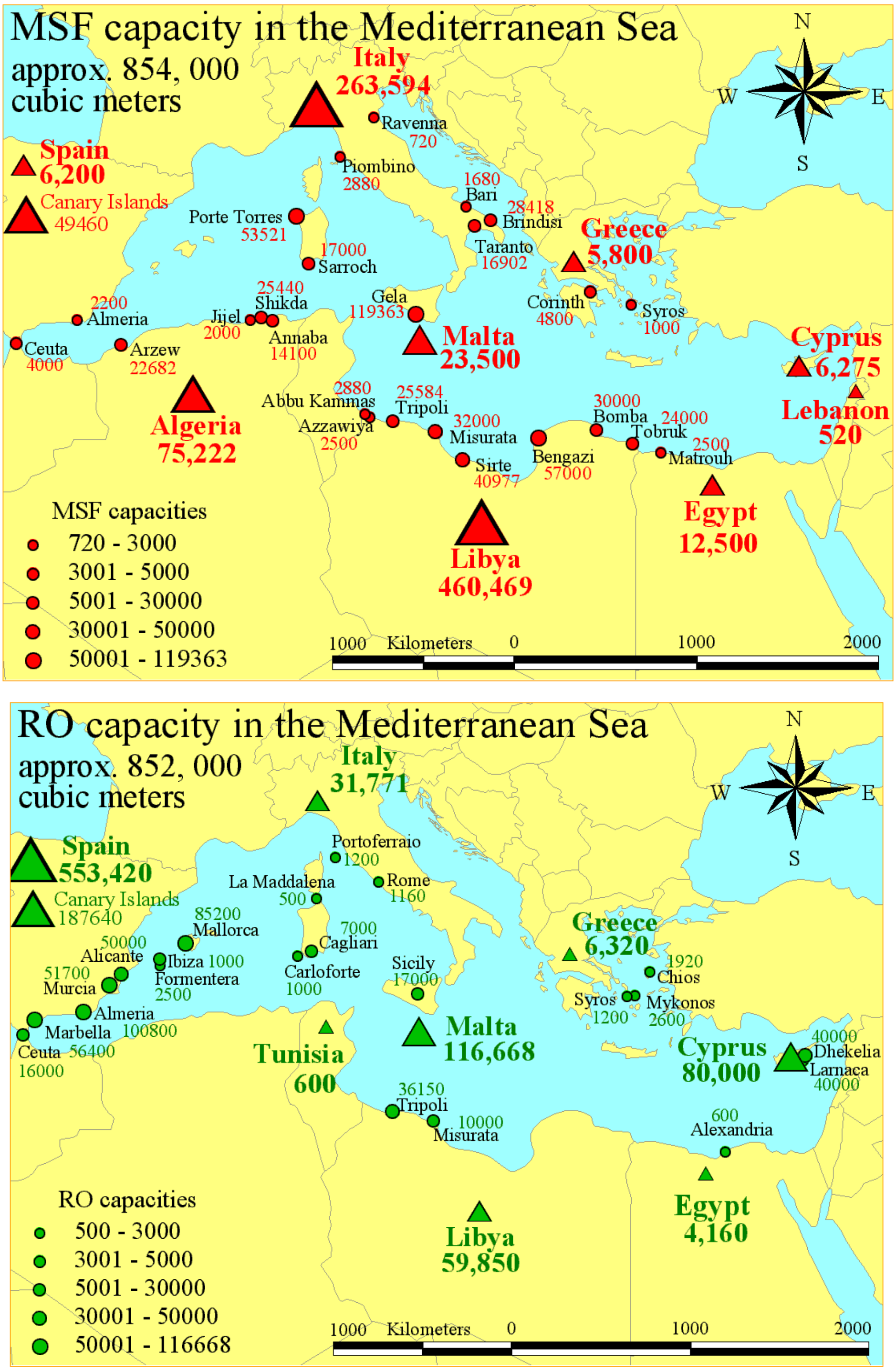


Figure 4-2: MSF and RO capacities in the Mediterranean Sea, with each process contributing about 0.85 million m^3/day. Triangles refer to national capacities, dots illustrate capacities of selected plant locations (data based on Wangnick, 1999).

production costs can be significantly reduced. For example, the planned Ashkelon RO plant in Israel has a guaranteed capacity of more than 270,000 m^3/day with a record low price of US$ 0.53 per m^3 (Kronenberg, 2002).

4.1.ix Socio-economic impacts including impact on the citizens

Seawater desalination has the potential to eliminate water scarcity and quality problems, which may otherwise have direct and indirect impacts on human health and well-being. Health problems can be directly related to inadequate access to safe drinking water for human consumption, or a lack of water for sanitation and hygiene. For these basic requirements, an absolute minimum of 50 liters per person per day (or 18 m^3 per year, Gleick, 1999) is necessary. The question is consequently how much additional water is needed to maintain a certain standard of living, allow for agricultural irrigation and industrial development.

Severe constraint on socio-economic development has to be expected when renewable water resources are below 1,000 m^3 per capita per year. In the South-Eastern Mediterranean, annual resources are even lower with quantities of often less than 500 m^3 per inhabitant. These countries, including Malta, Cyprus, Syria, Israel, Palestinian Territories of Gaza and the West Bank, Jordan, Algeria, Tunisia, Egypt and Libya, already experience structural shortages and a future decline in water resources per capita is anticipated (Margat and Vallée, 2000). Seawater desalination could therefore help to overcome water scarcity, which impedes development in water-dependent sectors and prevents a rise in living standards.

Water scarcity may cause environmental problems with direct or indirect implications for the citizens. A high water demand increases the pressure on natural water resources, which could result in unsustainable exploitation and adverse effects on the ecosystems from which the water is drawn. For example, overuse of water resources may enhance desertification, which also impairs the quality of life of citizens by deteriorating climatic conditions (higher daytime temperatures through lacking vegetation and surface water) or increasing the amount of dust in the air.

Furthermore, the allocation of limited resources to different consumers, e.g. the agricultural and industrial sector, municipalities or the tourism business, may lead to conflicts between these groups. This also holds for countries in the region, if jointly used water resources become scarce.

It can be summarized that seawater desalination may be beneficial for Mediterranean citizens by:

- 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 salinization
- guaranteeing stability and peace in the region

Possible negative socio-economic impacts of desalination include:

- a changed consumption pattern 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. The cost factor can be influenced by water management decisions, such as to subsidize desalination to keep the price for water low. Although this ensures that desalinated water is affordable to lower income groups, it provides a falsely priced product, especially to those sectors that could bear the actual cost of desalination (e.g. industries or the tourism business). The tariff system could be designed to ensure sufficient water for all without encouraging misuse, and to avoid subsidies where these are unnecessary.

4.1.x Pre- and post-operational monitoring programmes

In article 8 of the LBS Protocol, the contracting parties have agreed to carry out monitoring programmes to systematically assess the levels of pollution along their coasts. This is in particular required for the sectors of activity and categories of substances listed in Annex I and II to the protocol. Although seawater desalination is not explicitly listed as a sector of activity, many brine components fall under the provisions of annex I and II. With regard to potential pollutants in the desalination discharge, the expected growth of this industry in the Mediterranean region and resulting transboundary implications, monitoring programmes for seawater desalination plants should be established. They may be carried out separately or as an integrated part of national monitoring programmes.

Monitoring of effluents and environmental quality are furthermore required to ensure compliance with effluent limitations and water quality objectives. The competent national authorities responsible for permitting the discharge may therefore specify monitoring requirements or could be actively involved in the surveying process. Monitoring may involve pre- and post-operational activities to gather information on specific projects and to evaluate if predictions made in the EIA are accurate, but may also include baseline studies to improve general knowledge about potential impacts.

Baseline information on potential impacts. Desalination effluents could be used for laboratory tests to evaluate acute and chronic toxicity of the effluent, preferably using marine species that are characteristic of a specific site or region. Whole effluent tests have the advantage that the combined impacts of all effluent parameters are investigated (additive or synergistic effects) rather than impacts of single components. Laboratory tests may further improve knowledge about the environmental fate of chemical compounds in the discharge, for example by investigating biodegradation and bioaccumulation rates, possible side-reactions with other seawater or effluent components, transport processes into suspended matter and sediments.

Pre-operational monitoring. Pre-operational monitoring should include a chemical analysis of samples taken from water, sediment and organic tissue of marine organisms in the discharge site. Sampling may be carried out along transects or at defined stations in a grid that allow for a spatial analysis, e.g. using (geo)-statistical methods. The same stations may be used for investigating distribution and abundance of benthic species, which are typically sessile or have a limited radius of action. Suitable methods include sampling, video cameras or divers. Marine organisms in the pelagic (e.g. fish, plankton) have a higher mobility or are dispersed by currents, so that spatial trends may be less obvious. A general inventory of these species in the discharge site is nevertheless recommended. Both chemical analysis and species composition data will act as a reference for future monitoring.

Oceanographic conditions in the discharge site should further be investigated to assess transport direction and impact range of the discharge plume. Important parameters to be included are salinity and temperature values, hydrographical information like currents and tides, and topographical features like water depth and shoreline morphology. The data can be implemented in computer models to simulate plume spreading and environmental dispersal of pre-treatment chemicals. Actual measurements of dispersion rates using tracers (e.g. non-toxic dye) may be additionally carried out.

Post-operational monitoring. Samples of water, sediment or organic tissue for post-operational chemical analyses should be taken from the same stations defined during pre-operational monitoring. Also, an inventory of marine organisms in the area of the outfall is required for comparison with pre-operational data. Possible changes in water and sediment quality or species composition and abundance can thus be determined and allow for conclusions regarding the potential impacts of the discharge. In this context, it can be investigated if environmental levels of salinity, temperature, dissolved oxygen or chemical concentrations in the discharge site comply with water and sediment quality objectives. Biomonitoring is further recommended for heavy metals that tend to accumulate in organic tissue of edible marine species.

Possible changes in oceanographic conditions should be investigated following plant start-up, as the discharge plume may affect water circulation in the discharge site. Salinity or other effluent parameters can be measured as indicators for plume spreading and dispersal. Results can be checked with predictions for the plume trajectory (if available) based on modeling simulations or tracer studies.

4.2 How to undertake EIA study

An impact assessment study has the purpose to identify the location, process technology and construction method with the least adverse socio-economic and environmental impacts. It may further weigh the benefits of a new project against the risks involved. To influence the realization of a project, an EIA should be integrated into the planning and development process as early as possible. For example, an initial EIA may be part of the feasibility study of a new project to consider aspects of environmental concern. To address a broad range of potential impacts, a scoping phase or the establishment of a task force may precede or parallel the EIA. Feedback from the public, government agencies, resource users or other interest groups and participation of these groups in the planning phase may achieve a broad consensus and prevent conflicts later on.

The scope of the EIA study should be defined and terms of references outlined by the authority that approves the EIA study. A checklist of aspects to be considered in an EIA is provided in the next section, while a more general procedure is proposed in the following. It involves five basic steps and takes the UNEP methodological approach into account for an environmental impact assessment of projects affecting the coastal and marine environment (UNEP, 1990), applied to seawater desalination:

A. Collection of background information and review of existing legislation. This step recognizes that knowledge from analogous cases can be used to reduce duration and costs of environmental impact studies.

B. Investigation of the project and selected site, including the natural environment, socio-economic setting and possible alternatives to the proposed process design and location.

C. Identification and assessment of potential impacts on environmental quality as a consequence of project implementation by:

   i. analysing the causes of environmental impacts. For seawater desalination plants, impacts may occur during construction or regular plant operation. Plant operation typically causes emissions of wastewater to the marine environment, combustion gases into the atmosphere, and possibly accidental spills into the ground or coastal water body. Activities and emitted compounds of particular concern should be identified.

ii. defining the links between causes and effects. For example, how does the discharge influence physical and chemical properties of seawater, are discharge components toxic or otherwise harmful to marine life, what is their environmental fate, do several components have additive effects, etc.

iii. analysing the impacted ecosystem. Coastal ecosystems may be more or less suited for receiving desalination discharges depending on the sensitivity of the marine organisms present and oceanographic conditions prevailing.

D. Recommendation of alternatives or mitigation measures for every component that may have adverse effects, with the purpose to reduce the overall impact of the proposed activity. For seawater desalination plants, e.g. by identifying the discharge composition with the least impact on marine species and the best discharge site for dilution and chemical dispersal.

E. Establishment of a monitoring programme for the construction and operational phase of the project to verify if predictions made in the EIA study have been correct, and to gather further information on effects. Monitoring requirements should be specified by the authority that approves the EIA study and issues permits for construction and operation.

4.3 Check list for EIA study

The following check list provides an overview on single aspects to be evaluated in an environmental impact assessment for seawater desalination plants and outlines how the EIA report may be organized to present the results:

A. Background information (Introduction)
   i. purpose and need for the project
   ii. permit requirements and legal background
   iii. scope of the EIA

B. Project description including
   i. general location
   ii. onshore components of the facility including pipelines, pump stations, chemical treatment area, electrical sub-stations, etc.
   iii. offshore components including seawater intake, brine outfall and submerged pipelines
   iv. construction activities for onshore and offshore components, equipment required, work schedule, etc.
   v. operation and maintenance procedure including chemical treatment, designed intake and discharge flow rates

C. Socio-economic background and environmental setting, potential impacts of the project and recommendations for mitigation

i. Land use
- description of landscape characteristics for onshore and offshore areas such as current use, archaeological and cultural value, topography, geology and soils
- potential impacts of changed land use, geology and soil conditions, including aesthetic impacts, destruction of habitats, erosion, landslides, water drainage, etc.
- mitigation measures, e.g. how can land use be minimized and impacts on sensitive areas avoided by siting of the plant, how can plant operation and construction be modified?

ii. Energy use
- description of energy requirements of the plant
- potential impacts of energy use, especially for non-renewable energy sources in terms of waste, emissions, hazards
- mitigation measures, e.g. how can fossil energy use be reduced by implementing energy-saving techniques (e.g. energy recovery in reverse osmosis, co-generation) or avoided by using renewable energies?

iii. Use of the marine environment

a) natural setting
- description of marine water body, including oceanographic conditions and water quality
- description of biological resources, including sensitive coastal ecosystems, endemic or endangered species

b) seawater intake
- description of seawater intake practice
- potential impacts, e.g. entrainment and impingement
- mitigation methods for seawater intake, e.g. how can the intake be designed (screens, beach wells) or relocated to minimize impacts?

c) brine and chemical discharges
- description of effluent composition and chemical concentrations as resulting from the process and pretreatment scheme
- potential impacts of effluent components on the marine environment, identification of parameters of special concern
- mitigation methods, e.g. how can the process and pretreatment scheme be modified, the effluent treated or diluted, or the plant and its outfall located to reduce environmental impacts?

iv. Socio-economic impacts
- description of other coastal activities in the proposed area, distribution and use of the desalinated water
- potential impacts on other resource uses (e.g. public access, tourism, fisheries and aquaculture, navigation, etc.) and potential impacts of water availability (demographic and economic growth in the coastal zone)
- mitigation methods, how can conflicts be solved by enabling different sectors to simultaneously use the resource or by relocating certain activities into different areas? How can seawater desalination be integrated into a sustainable development concept?

D. Assessment of overall impacts of the proposed activity
   i. identification of activities or components which may have a significant impact on the environment or socio-economic development
   ii. evaluation of cumulative effects of single activities or components
   iii. summary of recommendations for impact mitigation, including alternatives for project site and process design
   iv. identification of unavoidable adverse effects, risk assessment and cost-benefit analysis of the project

E. Consistency with regional, national, or local plans and policies, e.g.
   i. coastal development plan
   ii. national water management plan
   iii. regulations for coastal discharge, LBS protocol

F. Establishment of a monitoring programme
   i. to assess if predictions of environmental effects are accurate
   ii. to control if mitigation methods implemented to reduce significant adverse impacts are effective
   iii. to gather further information on environmental effects

5. CLASSIFICATION OF DESALINATION TECHNOLOGIES IN RELATION TO THEIR IMPACTS

Socio-economic impacts may result from an increased water availability and are therefore related to the product rather than the desalination technology used. In contrast, environmental effects are attributable to the emissions of a desalination plant, which are process-dependent and include the waste stream discharged to the marine environment as well as combustion gases released into the atmosphere. For marine emissions, it should be distinguished between the normal operation mode of the plant, which produces the brine discharge that also contains residual pretreatment chemicals, and intermittent cleaning cycles.

Normal plant operation

In the previous sections, single components of desalination effluents were assessed with regard to their likely environmental impacts. From these results, it can be concluded that pre-treatment chemicals used in the RO process pose a relatively low risk to the marine environment. This is mainly due to the lack of biocides in the discharge and low concentrations of heavy metals, while other pre-treatment chemicals can generally be classified as non-hazardous:

i. Residual chlorine levels are typically removed from the feed water directly ahead of the RO unit to prevent damage of polyamide membranes by oxidation. In the case that non-oxidizing disinfectants (e.g. copper sulfate) or more oxidant-resistant membranes (e.g. cellulose acetate) are used, residual biocides could be present in the brine blow-down. However, polyamide membranes are almost exclusively used in modern plants and chlorination-dechlorination is the most common method to control biofouling.

ii. Stainless steel and non-metallic equipment are predominantly used in RO plants. Corrosion of stainless steel is usually very low in seawater, though it may occur in the form of local pitting in crevices if conditions are unfavourable. The RO brine consequently contains relatively low concentrations of corrosion products, with iron as the main component and minor amounts of nickel, chromium and molybdenum.

iii. Further pre-treatment chemicals include coagulants and scale control agents, which are generally non-toxic to marine life. Harmful effects may occur but can be prevented or mitigated by certain precautionary measures. For example, filter backwash material can be sufficiently diluted in the brine blow-down or deposited as solid waste in a landfill to avoid increased turbidity and sedimentation rates in the discharge site. Regarding scale control agents, new polymers might be preferred over polyphosphate antiscalants to reduce eutrophication.

The main disadvantage of the RO process is its high effluent salinity, which is usually between 60 and 70, but can be as high as 90 if total recovery is raised by a second RO stage. While the RO concentrate may contain twice the seawater concentration, the distillation effluent is rarely more than 15 % above ambient with potentially lower impacts on the marine environment. The difference in effluent salinity can be attributed to the discharge of cooling water, which is a waste product from the heat rejection section of distillation plants and effectively dilutes the brine blow-down.

Similar to the decrease in salinity, pre-treatment chemicals are diluted by mixing of brine and cooling water discharges. The argument applies to antiscalants and antifoamings, which are added to the feed water of distillation plants but not to the cooling water intake. However, both substances are of minor concern with regard to their low toxicity. Dilution will therefore only affect brine constituents that are not central to the impact assessment of desalination waste, while the discussion is not appropriate for substances of importance for the following reasons:

i. Chlorination typically occurs at the intake of the plant so that both cooling water and desalination feed water are chlorinated. The cooling water discharge from distillation plants consequently increases the total amount of chlorine that enters the coastal water body without affecting discharge concentrations. Although chlorine content is reduced by rapid self-decomposition, residual levels in the effluent and environment are probably of toxicological importance for marine life. Furthermore, reactions with organic seawater constituents give rise to halogenated compounds.

ii. Copper from corroding heat exchange alloys is a major pollutant in distillation brines and is probably also present in cooling water discharges. Although blending of both waste streams might reduce copper discharge levels, it will not affect total discharge loads. Loads are of particular concern for substances that have the potential to accumulate in sediments or marine organisms, such as copper.

iii. As temperature is increased in both brine and cooling water, mixing will not lower the overall effluent temperature. In fact, a major amount of the thermal discharge must be attributed to the cooling water. Elevated temperatures may influence marine life in the mixing zone similar to increased salinity values.

Intermittent plant cleaning

While pre-treatment chemicals from the RO process are relatively non-hazardous, the opposite applies to acidic and alkaline membrane cleaning solutions, which contain chemicals of particular concern for marine organisms. Among these are:

i. highly effective disinfectants (e.g. formaldehyde and isothiazole)

ii. detergents which disturb the intracellular membrane system of organisms (e.g. dodecylbenzene sulfonate)

iii. poorly degradable chelating agents that influence the environmental fate of heavy metals in the coastal water body (e.g. EDTA)

Discharge to the sea should consequently be avoided as it will likely impair marine life until the chemicals are sufficiently diluted and degraded in the coastal water body. For waste treatment or alternative discharge options, it is advantageous that required cleaning volumes are typically low and that wastes are only produced in certain time intervals.

The cleaning procedure of distillation plants is comparatively simple and involves circulation of a warm, acidic solution of pH 2. The only supplement is usually a chemical inhibitor that adheres to the metallic surfaces within the plant to prevent corrosion. Low amounts of acid (or alkaline solution as in the case of RO) are generally of low concern for the marine environment if sufficient dilution is guaranteed. As seawater has a good buffering capacity, it will neutralize surplus acidity or alkalinity almost immediately. However, large amounts of acidic waste may be harmful to marine life and neutralization prior to discharge is recommended.

Conclusion

Regarding impacts on the marine environment, it can be concluded that reverse osmosifavourable favorable than distillation due to a lack of biocides and heavy metals in the brine discharge. However, new construction materials like titanium are increasingly used in thermal processes which eliminate copper contamination of the brine. Furthermore, residual chlorine levels could be neutralized similar to the current practice in RO plants. In contrast, cleaning solutions that are periodically used to restore the performance of RO membranes are potentially more hazardous than the waste produced during cleaning of thermal distillers.

Lower energy consumption is another advantage of RO plants that makes the process more environmentally friendly than distillation. However, dual-purpose plants can compete with RO in terms of energy requirements, as the exhaust steam from electricity generation is used as a heat source for the desalination plant instead of being wasted to the atmosphere.

6. MODEL PERMIT FOR CONSTRUCTION AND OPERATION OF SEA WATER DESALINATION PLANTS

Seawater desalination involves different activities, which may require separate permits, such as the development of coastal areas for new plants, the intake of seawater, or the discharge of concentrate to the coastal water body. Permits are typically tailored to single plants, especially if a plant has little in common with other facilities, for example due to its size, process design or location in a unique and sensitive marine environment. However, a model permit may be provided for a group of facilities with similar properties by providing general information on the most common plant features. The following list includes items, which may be included in such a model permit, but can be modified and expanded to address plant-specific details.

Coastal development permit for desalination plants

A. Name and address of applicant and owner of the property

B. Brief description of the planned development

C. Brief description of the current land use

D. Detailed description of the facility containing the following information, which may be supported by site plans and topographical maps:

i. location, size, height, use and distance between facility structures

ii. access and connections to infrastructure outside the facility, such as roads, power grid, pipelines, etc.

iii. size of the site including the size of the area covered by the facility or changed by landscaping

iv. drainage and modifications to watercourses

v. earthwork and modifications to landscape and topography, e.g. affecting seabed, beaches, dune systems, wetlands, vegetation, etc.

E. The competent authority should further identify if

i. the planned desalination facility and resulting socio-economic growth are compatible with the specifications of the coastal development plan

ii. the plant may lead to conflicts between competing sectors of use

iii. the site was chosen and construction activities will be carried out considering aspects to minimize land use and environmental impacts

Marine intake and discharge permit for desalination plants

I. Synopsis of application

A. Name and address of applicant

B. Facility name, mailing address, general location

C. Brief description of desalination process and pre-treatment steps including type of process, design capacity, withdrawal, discharge and recovery rate, main pre-treatment steps and chemical use

D. Intake and outfall location including approximate coordinates (latitude, longitude), distance from shore, discharge depth, total water depth, identification and brief description of water body used for withdrawal and/or disposal

E. Attachments of

i. flow diagrams showing the route taken by the water from intake to discharge including all process and pre-treatment steps

ii. a topographical map extending beyond facility boundaries, showing facility outline, intakes, outfalls, wells embedded in the seafloor, chemical storage and treatment tanks, pumping stations, etc.

II. Sources and average flows contributing to the total effluent

A. Regular mode of operation, e.g.:

i. brine discharge (m^3/day)

ii. cooling water discharge of thermal plants (m^3/day)

B. Intermittent discharges, e.g.:

   i. RO filter backwash water (m^3/day)

   ii. cleaning solutions (m^3/event)

III. Limitations and monitoring requirements for effluent parameters, for example:

Effluent characteristic	Maximum value	Quality objective	Monitoring requirements	
			Frequency	Sample type
Discharge flow (m^3/day)			continuous	recorder
Conductivity (mS/cm)	max. 10% above ambient		continuous	recorder
Temperature	max. 10°C above ambient		continuous	recorder
Salinity (ppt) or Chlorides (ppm)	max. 10% above ambient		1 / week	grab
Dissolved oxygen	absolute min. of 4 mg/l; 5 mg/l as 24hr average		1 / week	grab
pH	6.5 – 8.5		1 / week	grab
Turbidity	max. 10% above ambient		1 / week	grab
Residual chlorine	below detection limit		1 / week	grab
Total recoverable copper	500 µg/l	8 µg/	1 / week	grab

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