EP

United Nations Environment Programme

UNEP(DEC)/MED WG.205/3
15 April 2002

ENGLISH

MEDITERRANEAN ACTION PLAN

Experts meeting on environmentally sound management of sea water desalination plants and brine discharges

Forli', Italy, 16 – 18 May 2002

DRAFT

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

UNEP

Athens, 2002

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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 are 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).

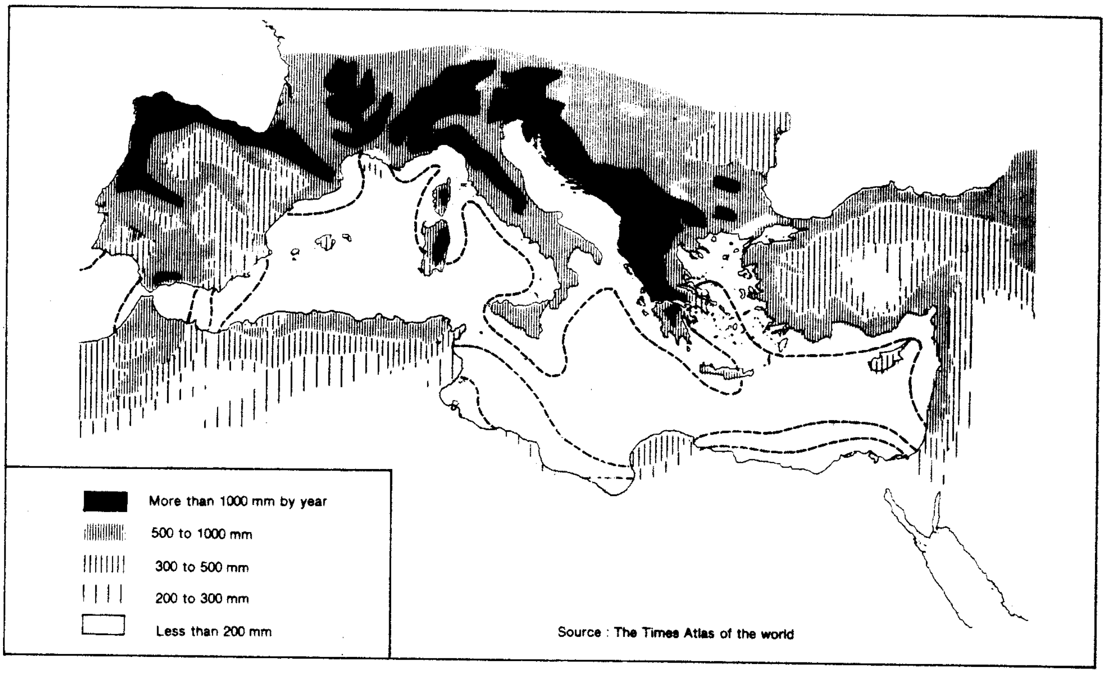
Mediterranean region water resources are limited, fragile and threatened. They are already intensively utilized, especially in the south and east where the lengthy dry seasons with low average annual rainfall is a fact (Fig. 1), (Blue Plan, 1992) (10).

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

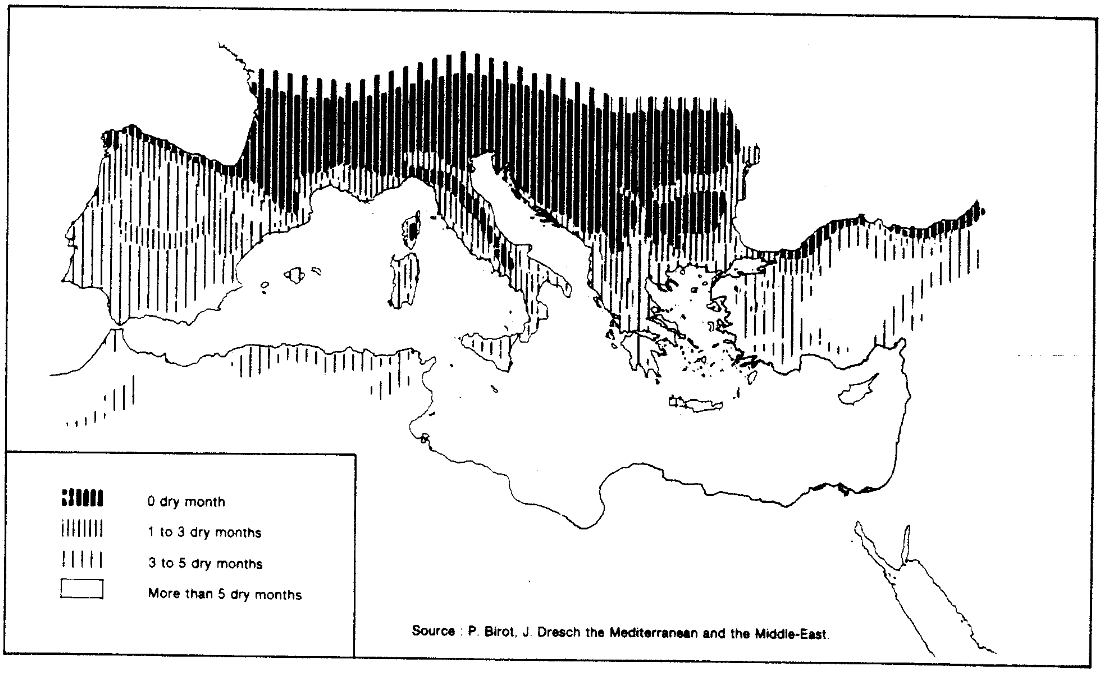
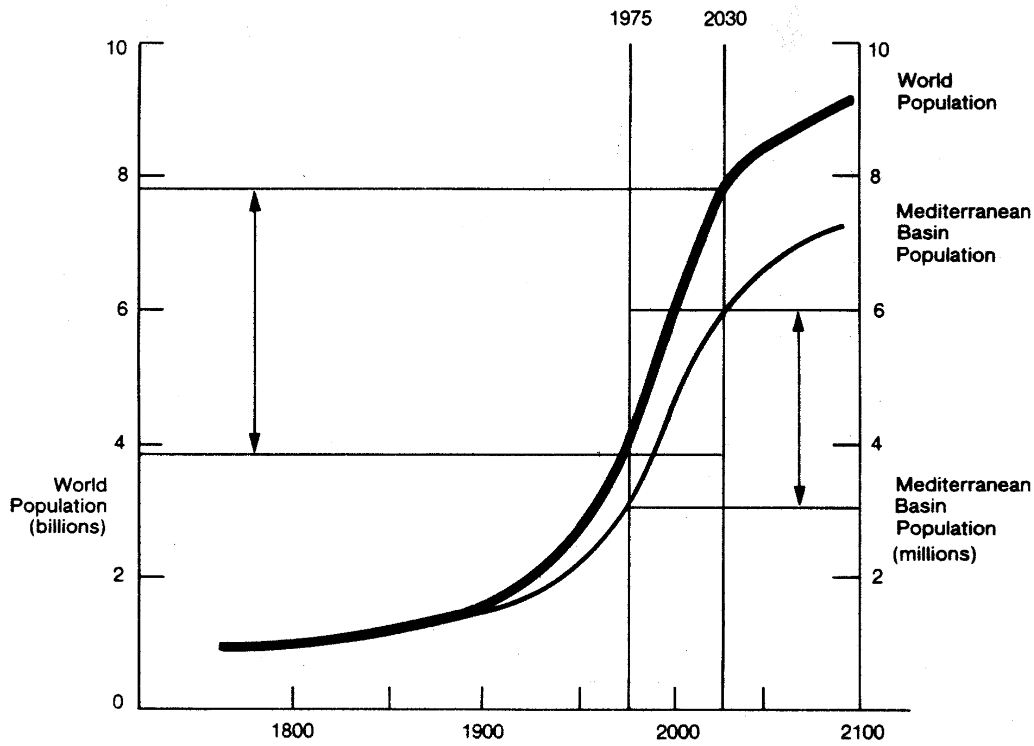


FIGURE 2

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

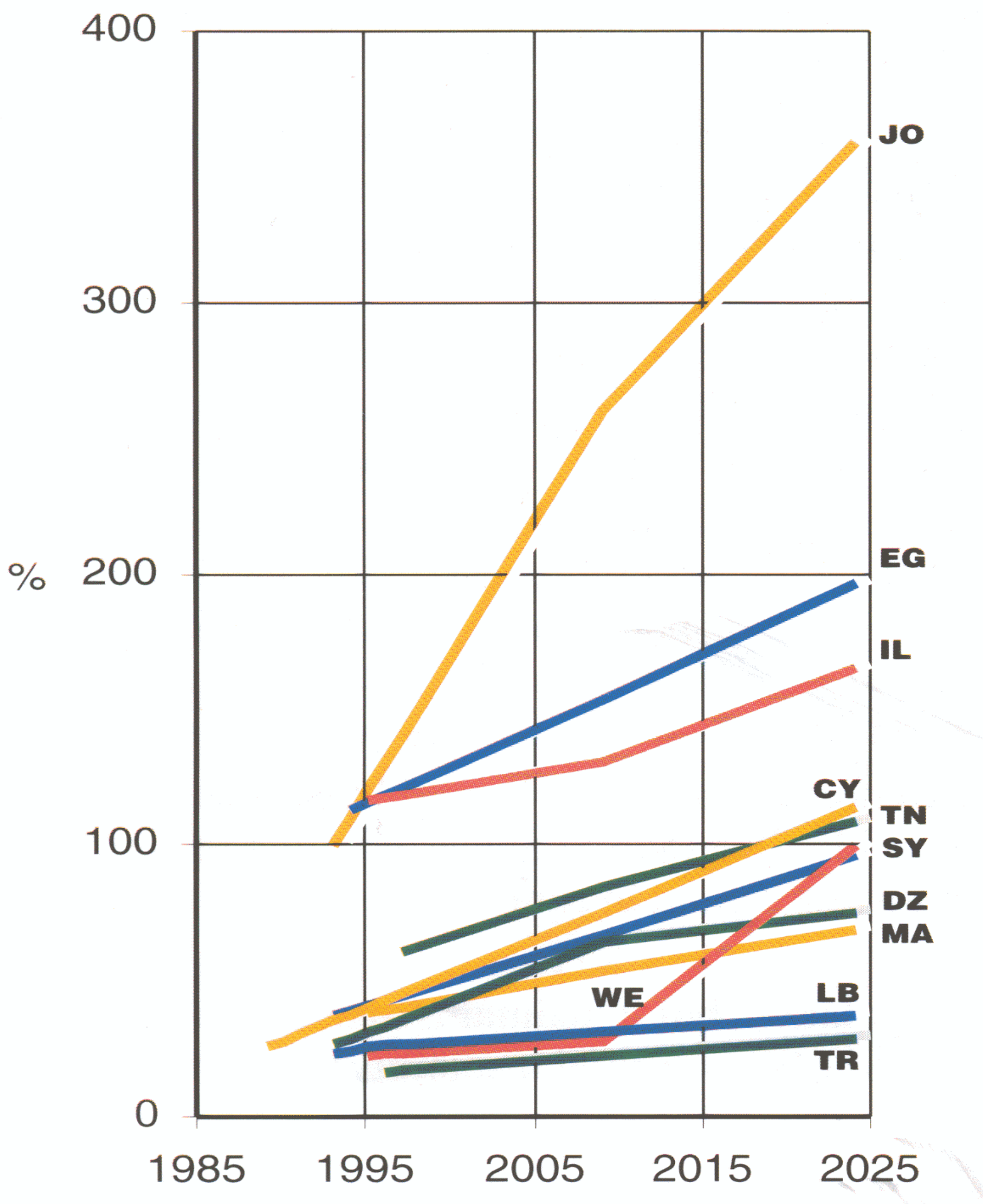
The greatest natural desalination process occurs on Earth and this is the hydrologic cycle. It is a natural machine, a constantly running distillation and pumping system. The sun supplies heat energy and this together with the force of gravity keeps the water moving from the earth to the atmosphere as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

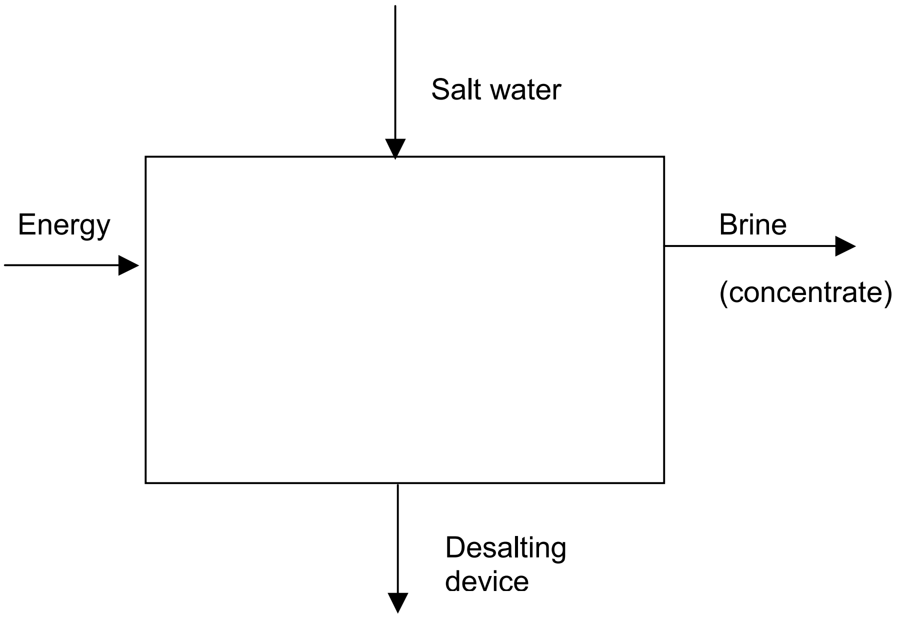
Projected growth of the ratio demand/water resources in Southern Mediterranean countries (moderate trend scenario).

(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 reability 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

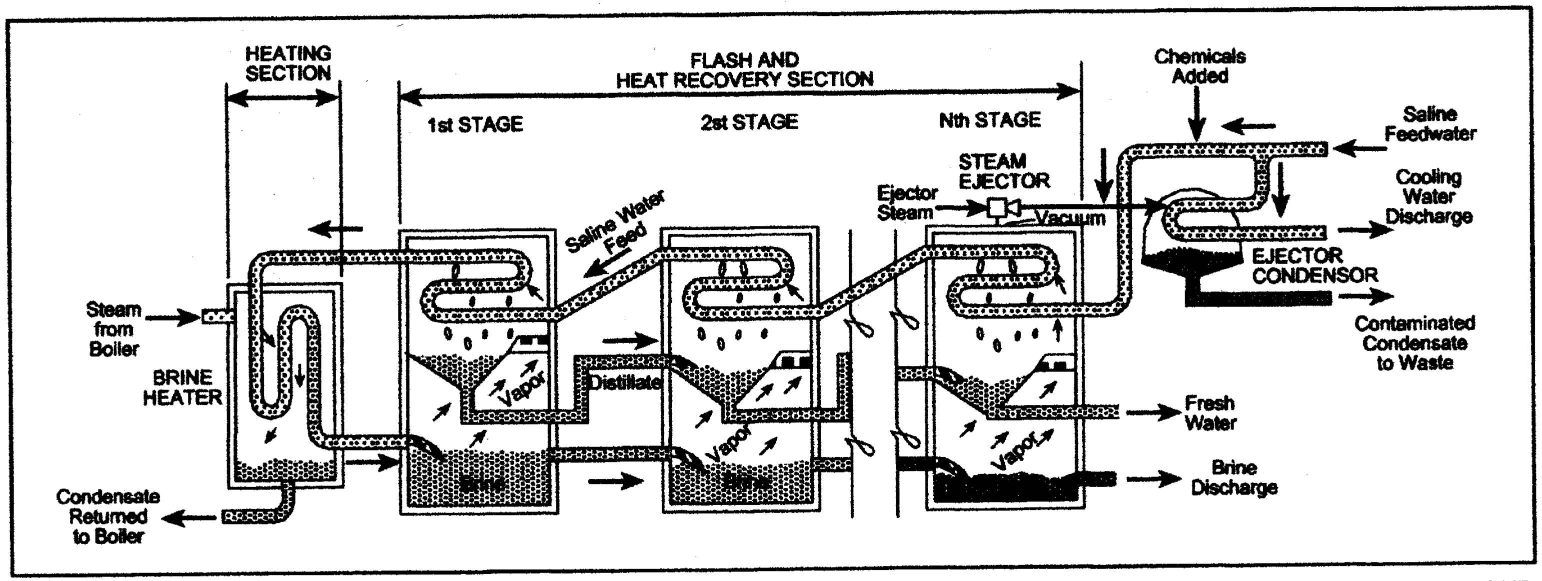


Diagram of a Multi-Stage Flash Plant *USAID*

FIGURE 5

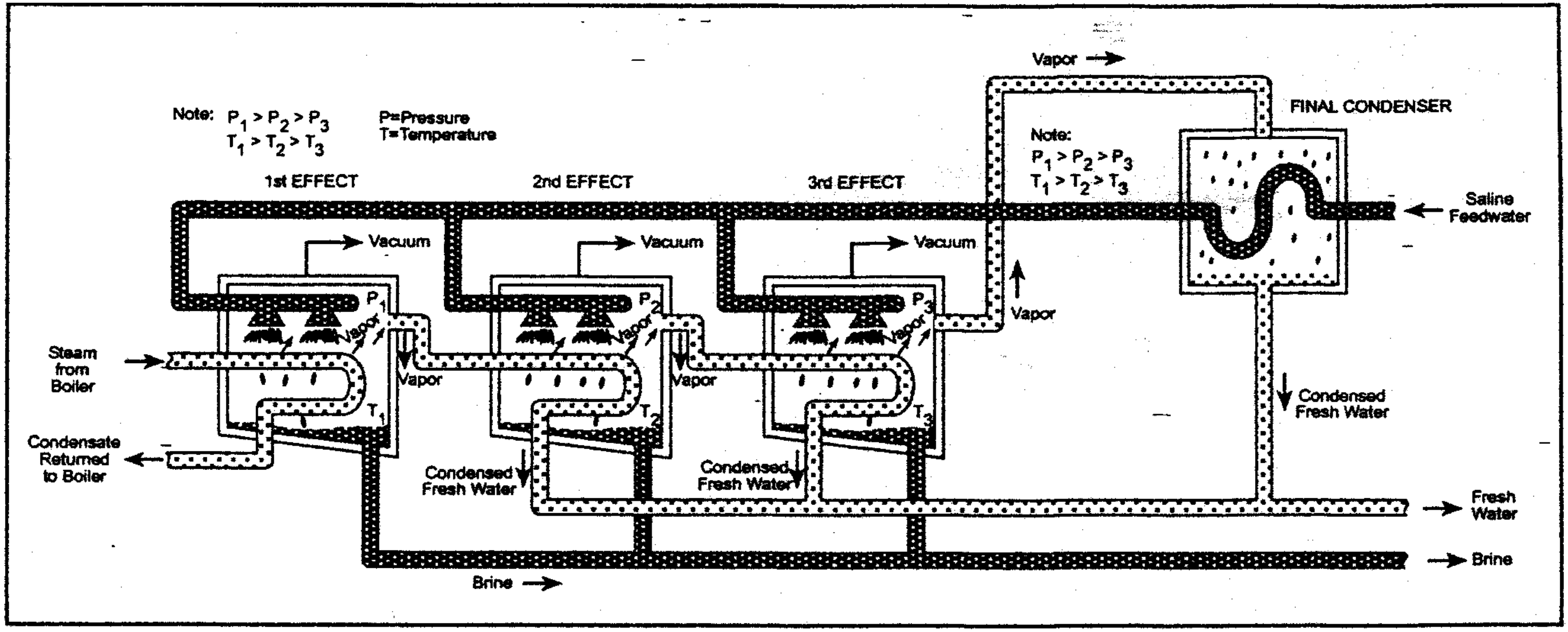


Diagram of a Multi-Effect plant with horizontal tubes. *USAID*

FIGURE 6

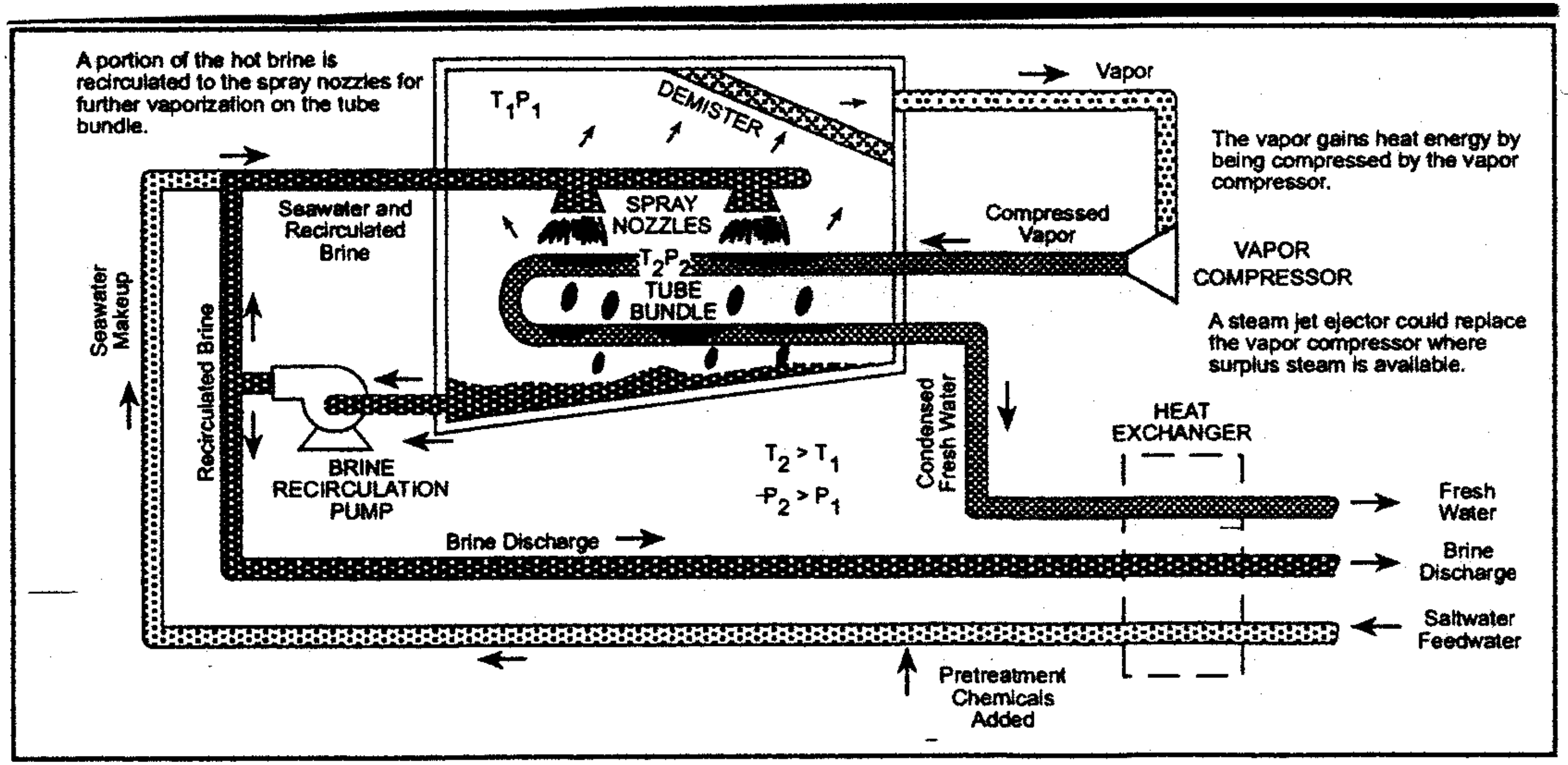


Diagram of a mechanical vapor compression unit *USAID* *ii) Reverse Osmosis (R.O)*

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.

- Pretreatment
- 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.

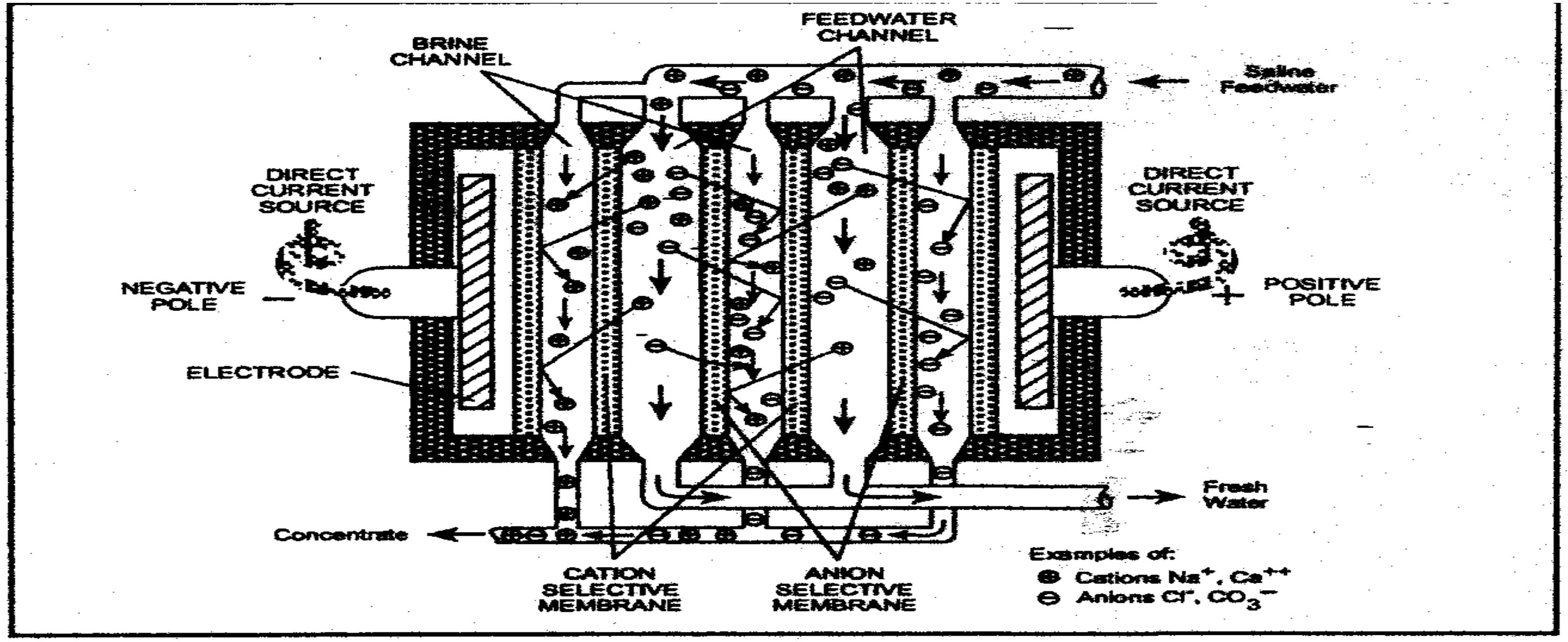
i) Freezing

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

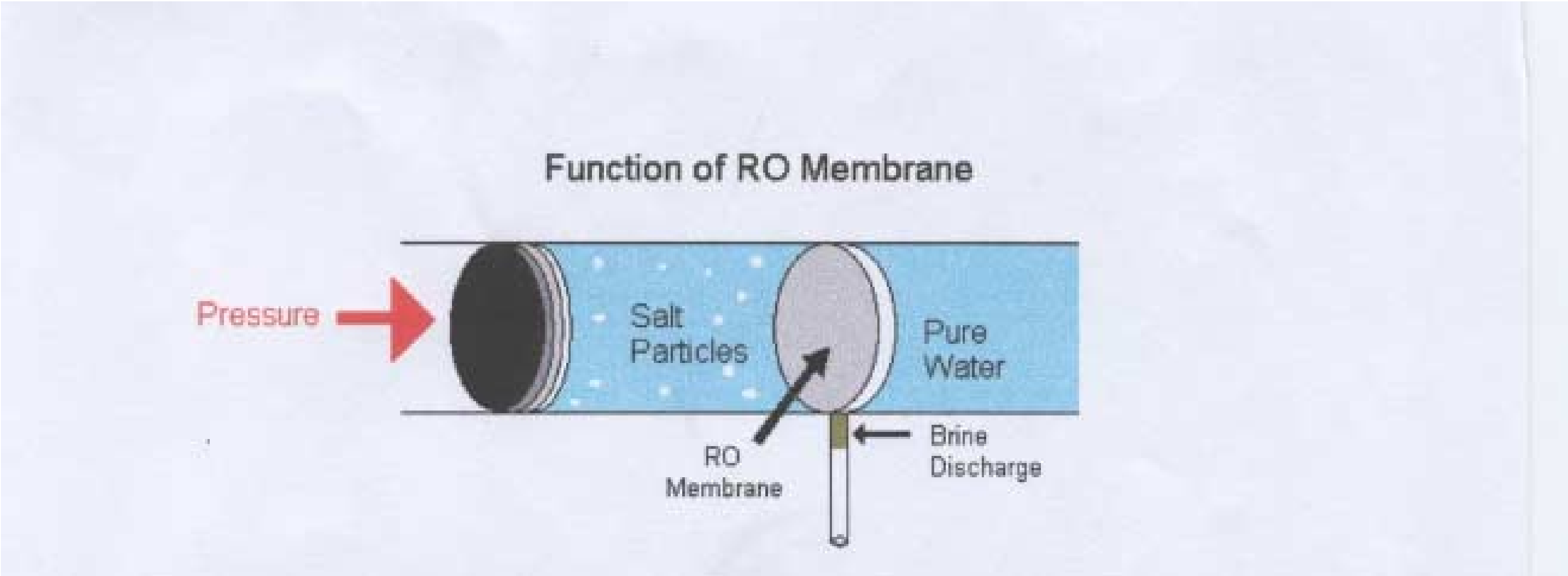
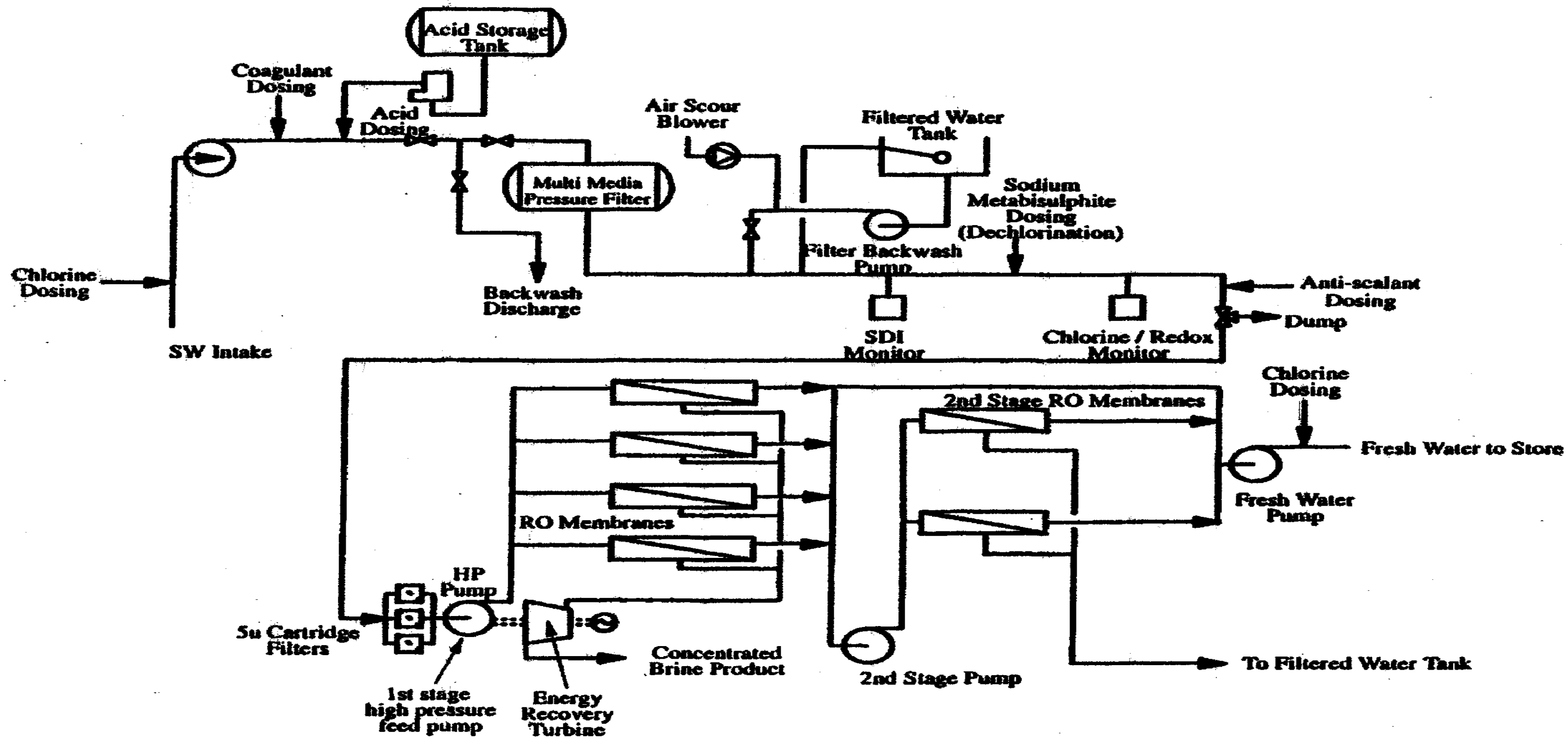

Function of RO Membrane
Pressure
Salt
Particles
Pure
Water
RO
Membrane
Brine
Discharge

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 a 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 rely 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 operated 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 is 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 feedwater. In RO, energy is recovered by converting hydraulic pressure in the brine to electricity or by transferring this energy to the feedwater.

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 wold, 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 is 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 <u>Existing seawater desalination plants in the Mediterranean: their geographical distribution</u>

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

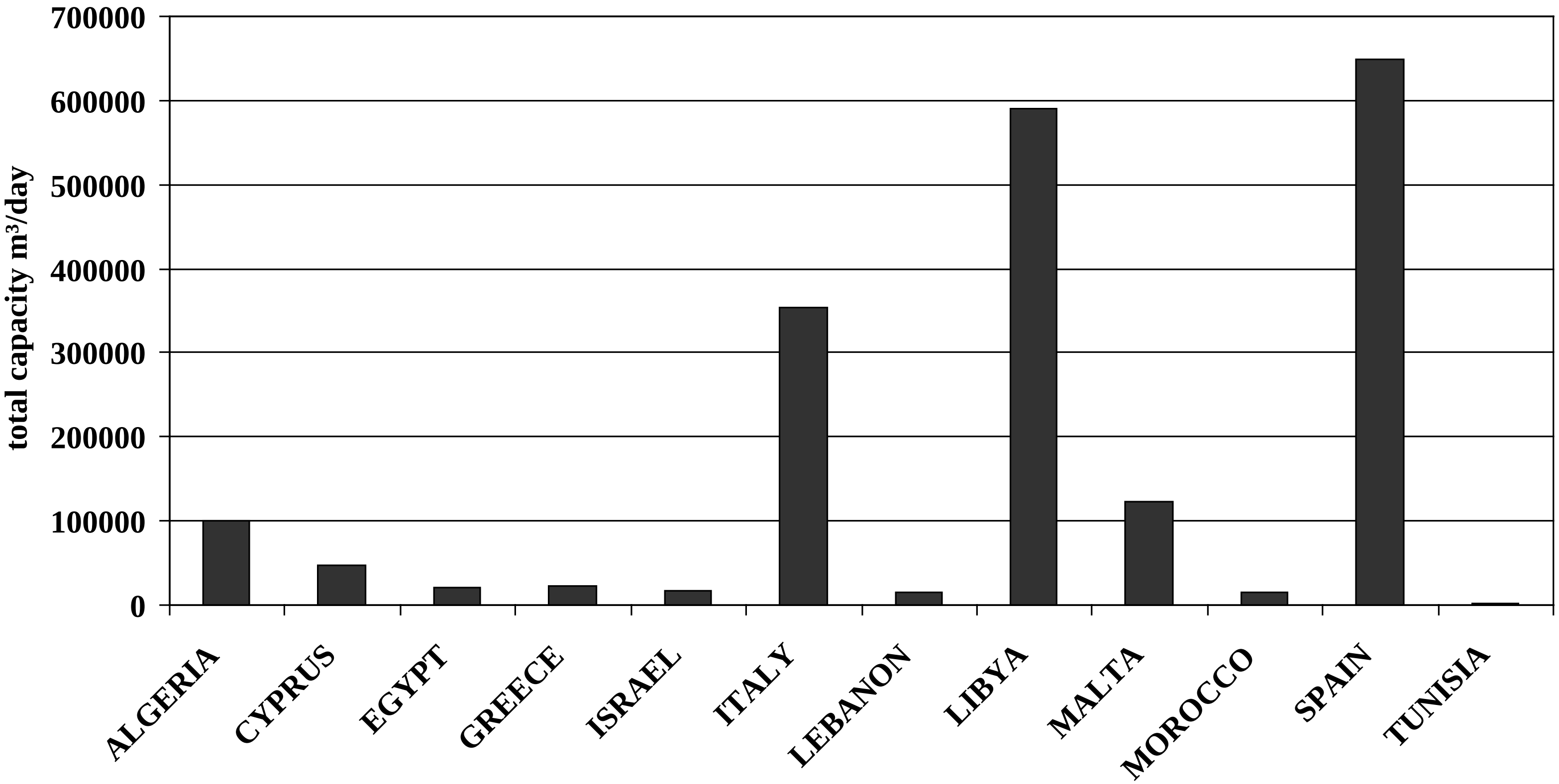
Country	TOTAL	*% of the total*
ALGERIA	100739	*5.15*
CYPRUS	46561	*2.38*
EGYPT	20860	*1.07*
GREECE	21840	*1.12*
ISRAEL	17032	*0.87*
ITALY	353990	*18.10*
LEBANON	15190	*0.78*
LIBYA	589604	*30.15*
MALTA	123868	*6.33*
MOROCCO	14802	*0.76*
SPAIN	648980	*33.18*
TUNISIA	2220	*0.11*
TOTAL	1955686	*100.00*

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 (m³/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.

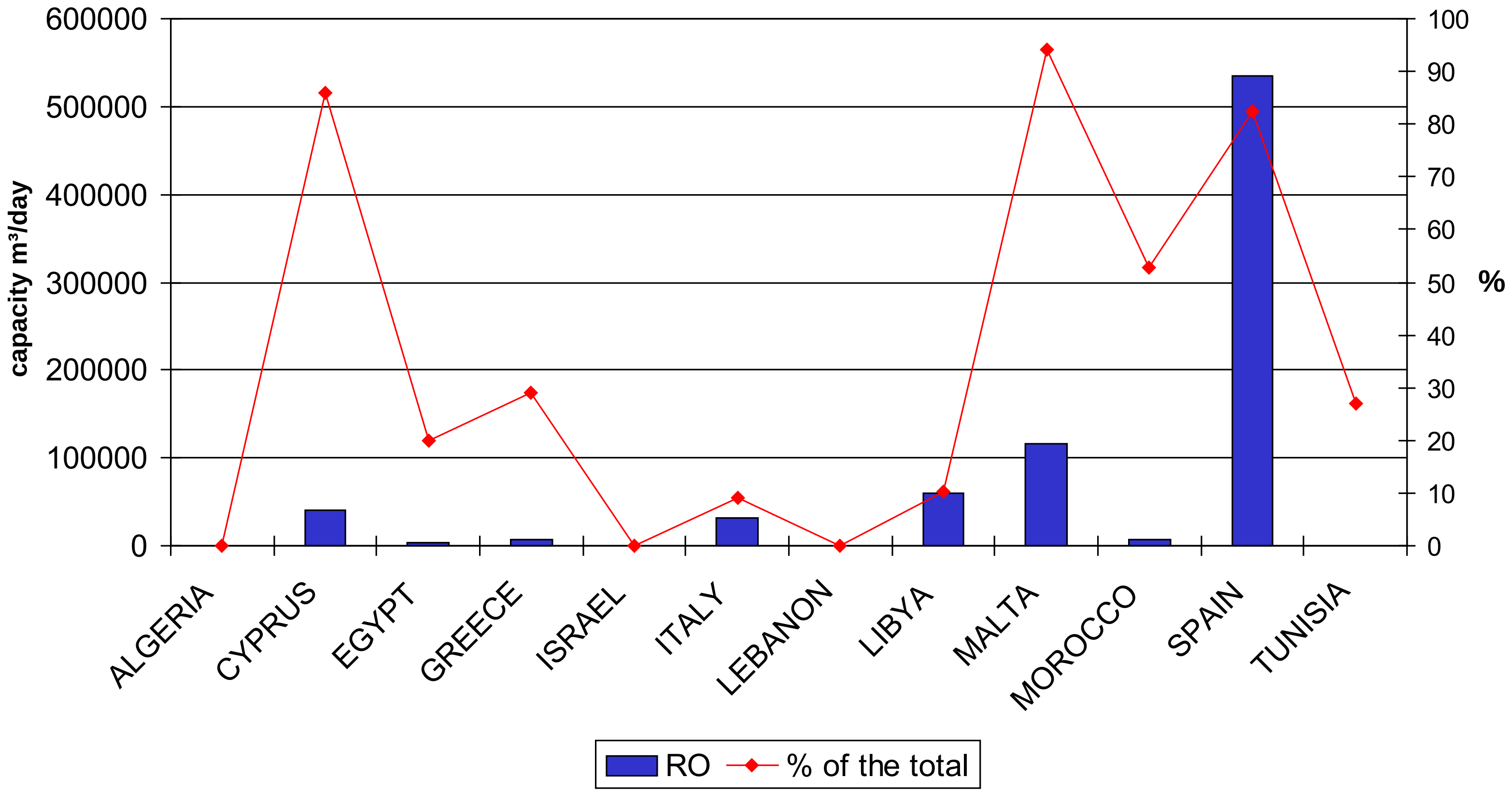


Fig. 12. Production capacity (m³/day) of MSF seawater desalination plants with the percentage of the total capacity in each country by the end of 1999.

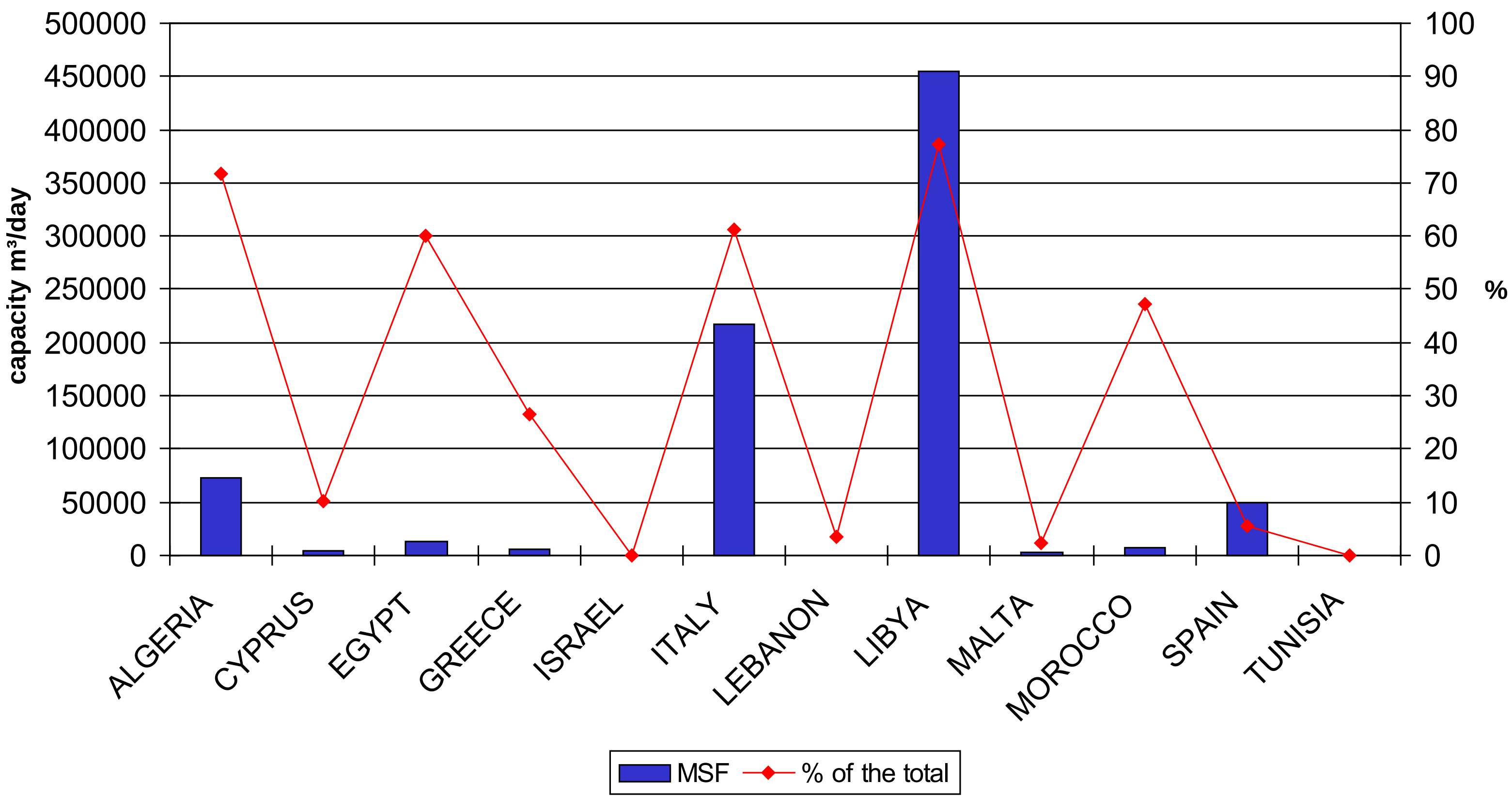


Fig. 13. Production capacity (m³/day) of VC seawater desalination plants with the percentage of the total capacity in each country, by the end of 1999.

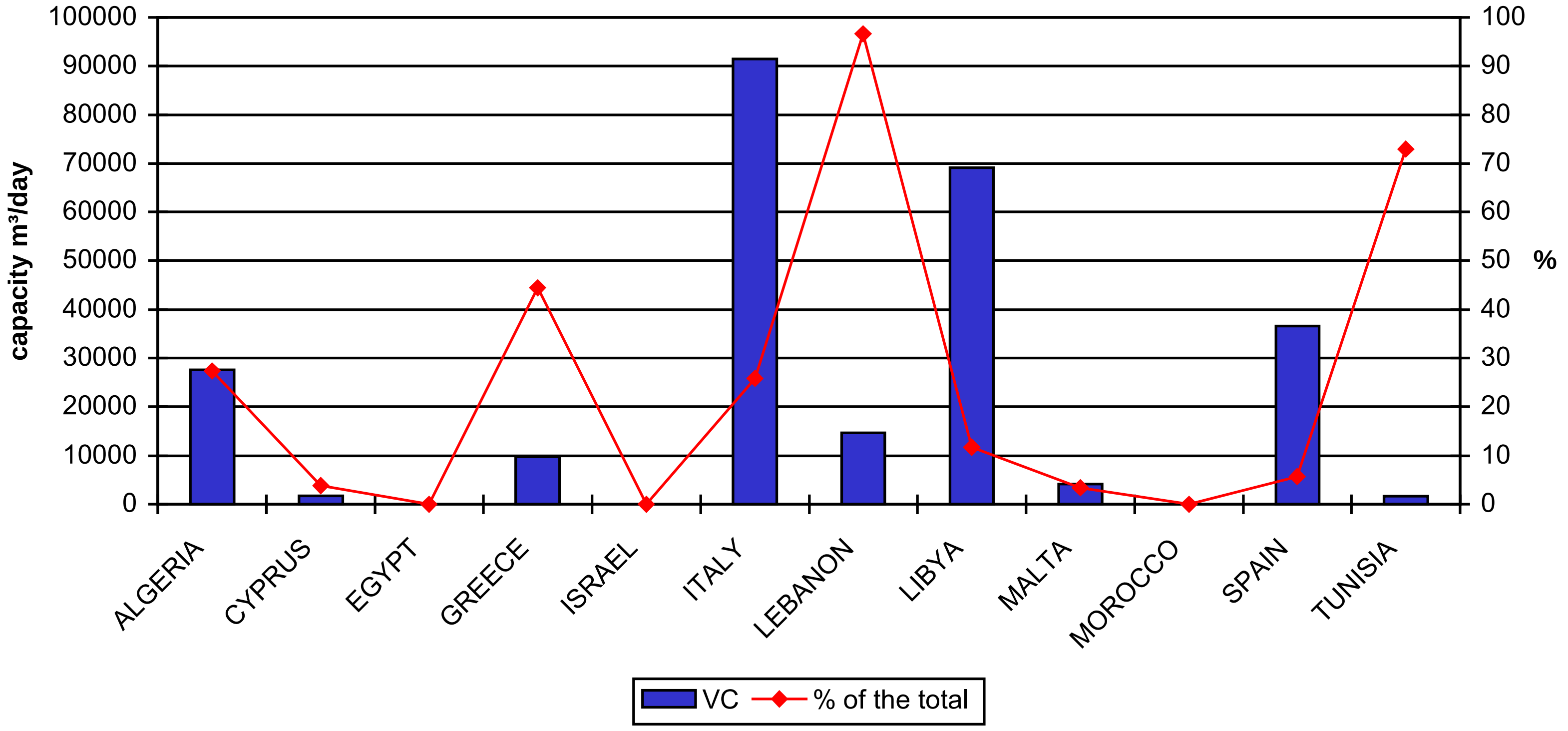


Table 4

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 is 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.

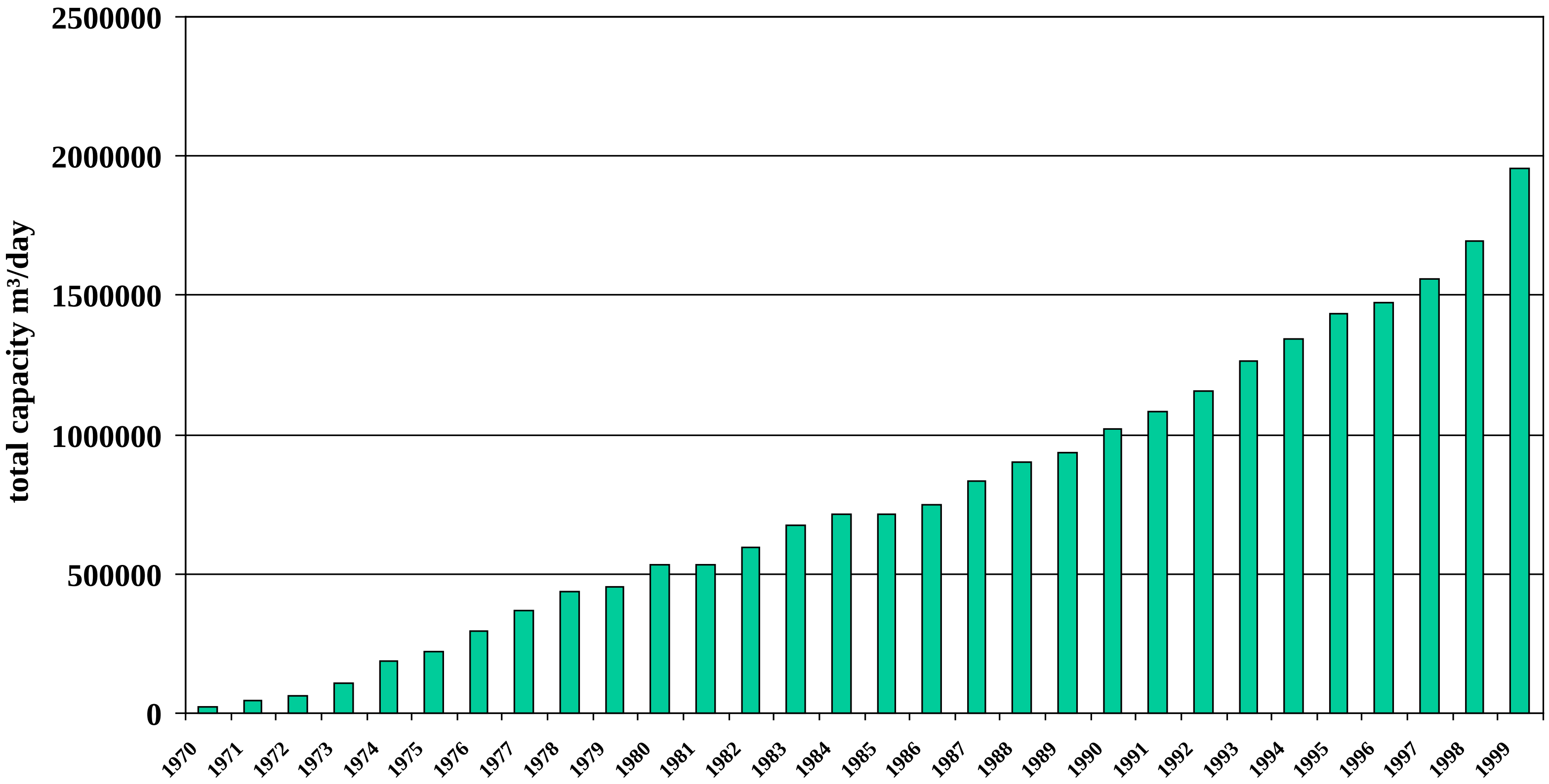
Table 5 shows the production capacities of different types of plants put in operation each year, while in Table 6 and Figure 15 the total calculated capacities of different types of plants operated by the Mediterranean countries since 1970.

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.

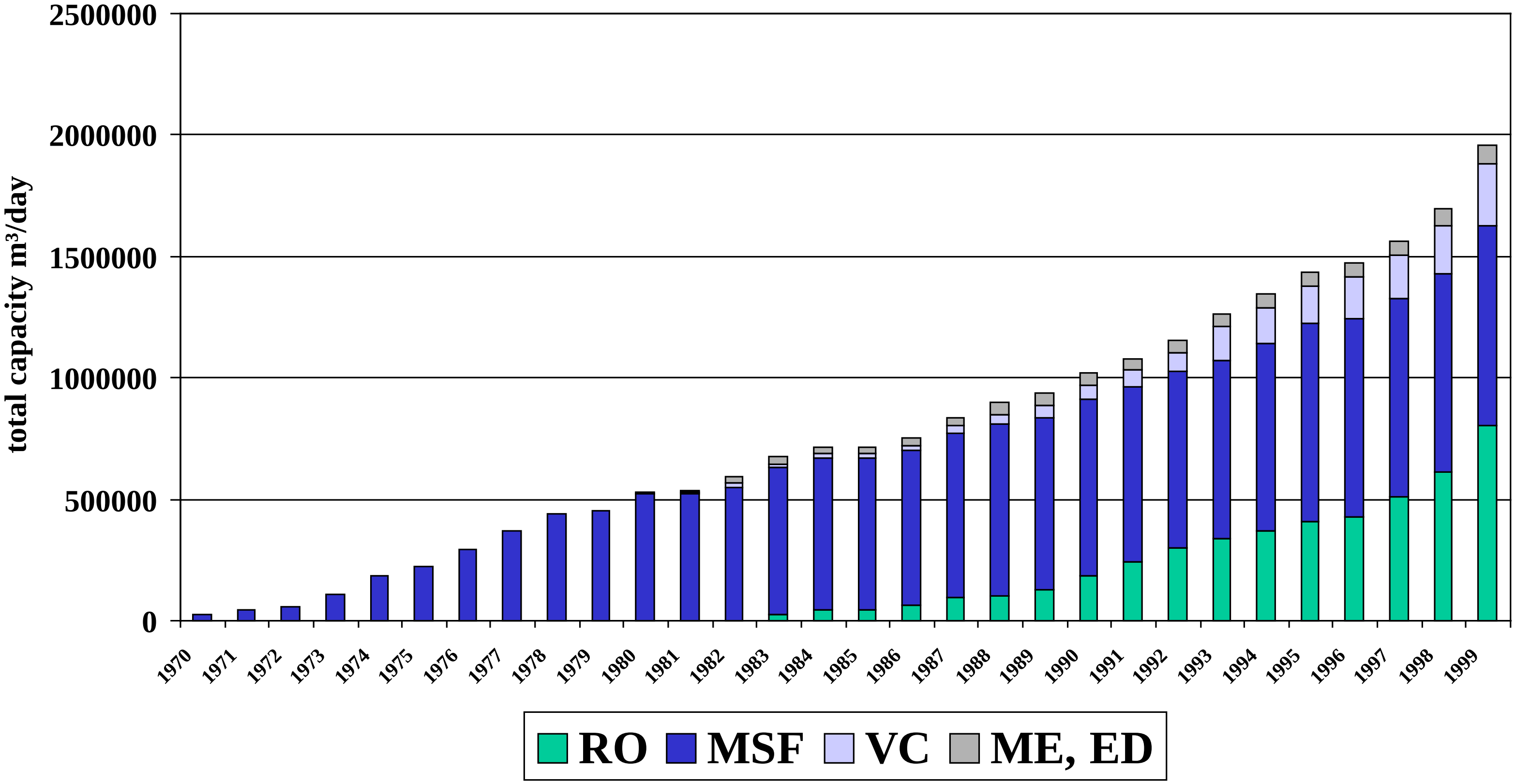
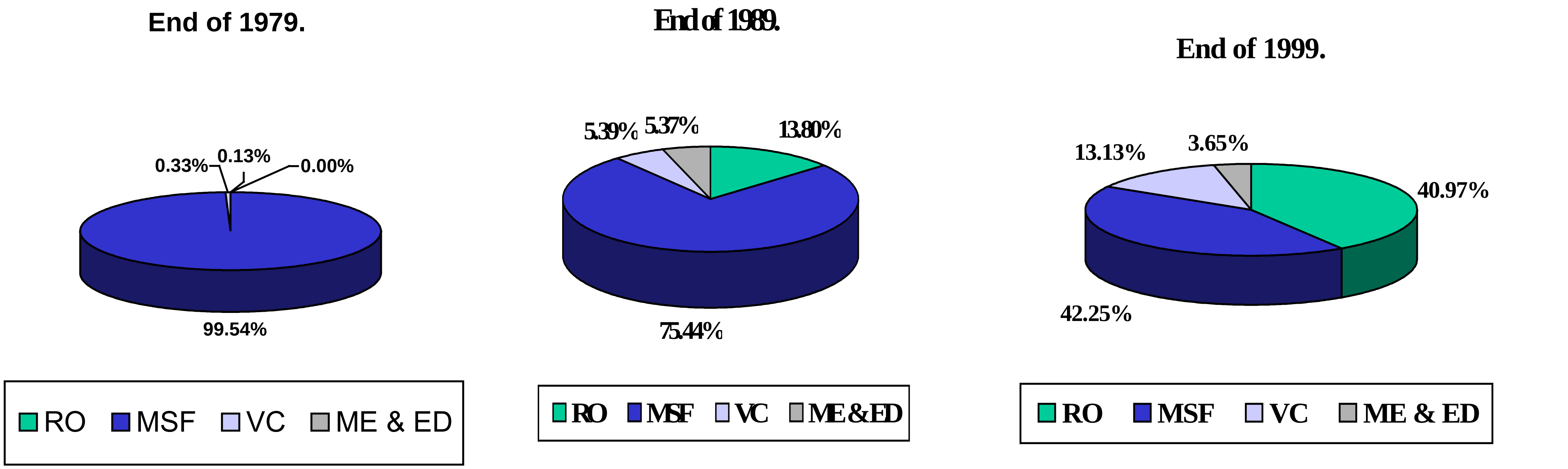


Fig. 16. The change in the type of desalination processes operated by the Mediterranean countries for the last thirty years (1970 - 1999).



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 were 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*

YEAR	MUNI	INDU & POWER	DEMO, IRR & MIL	m³/day
1985	371249	329161	16620	717030
	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.

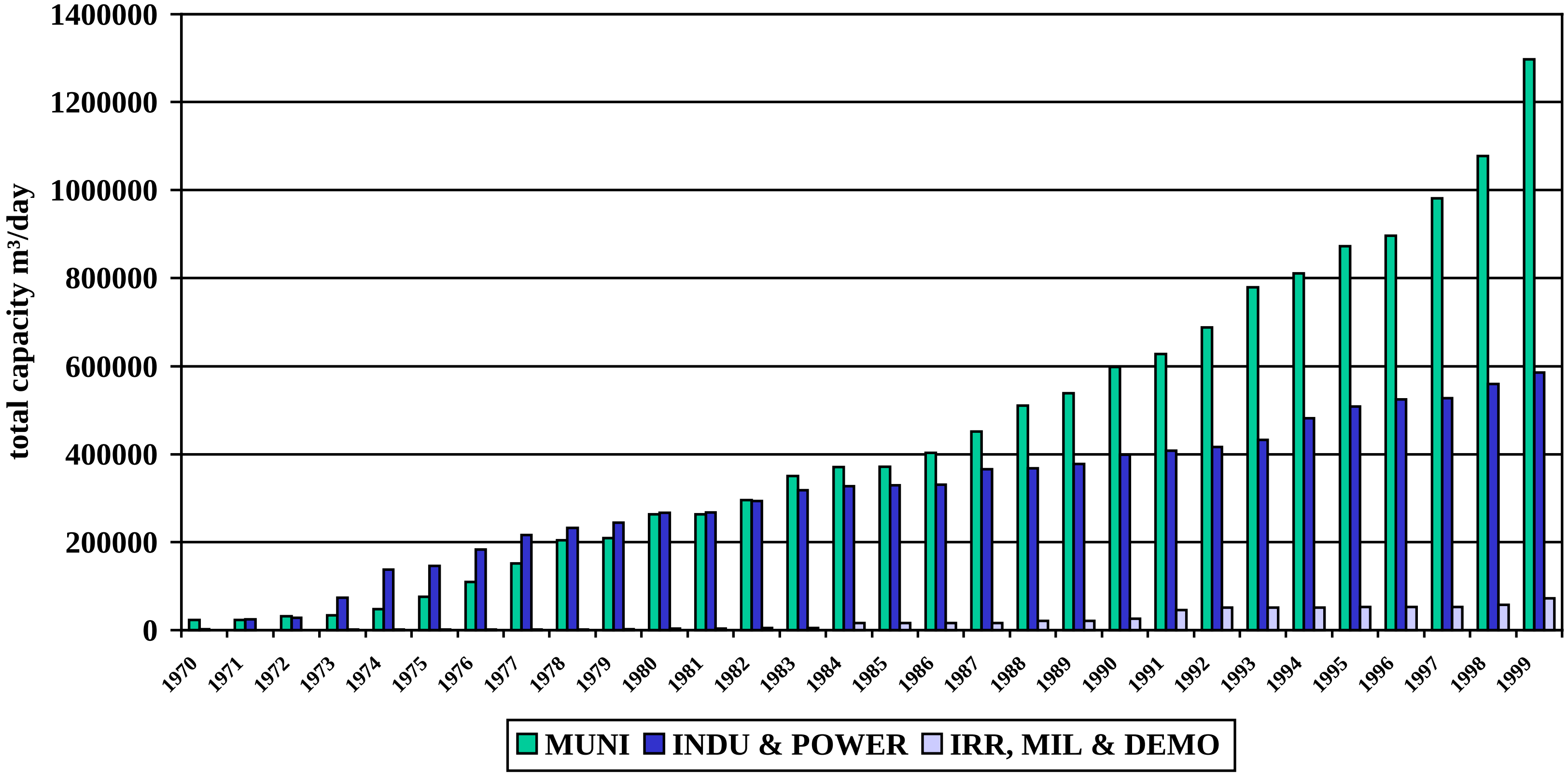


Fig. 18. The change in use of desalted water for the last thirty years by the Mediterranean countries

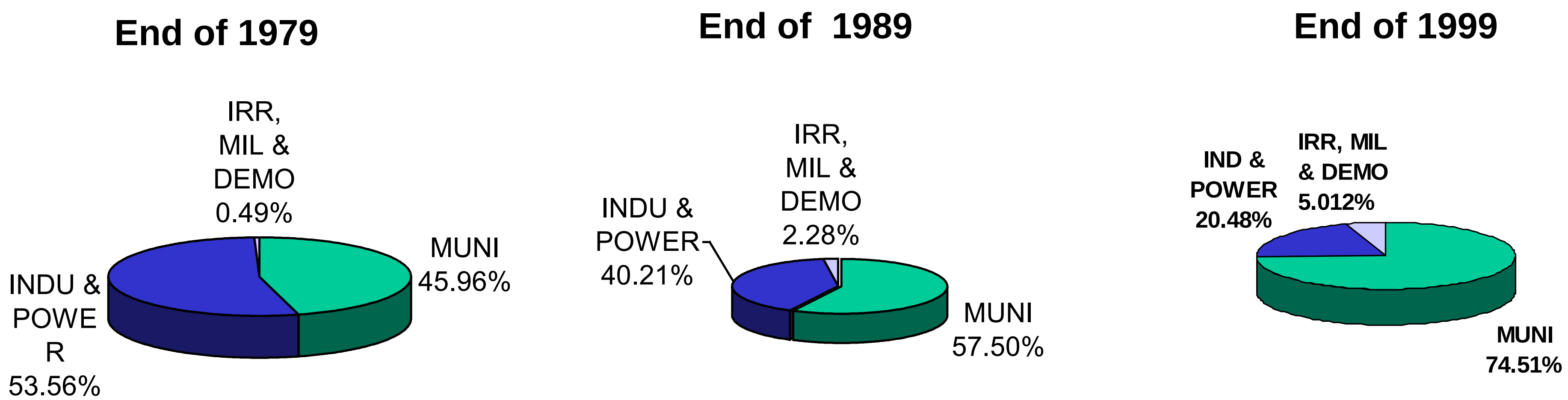
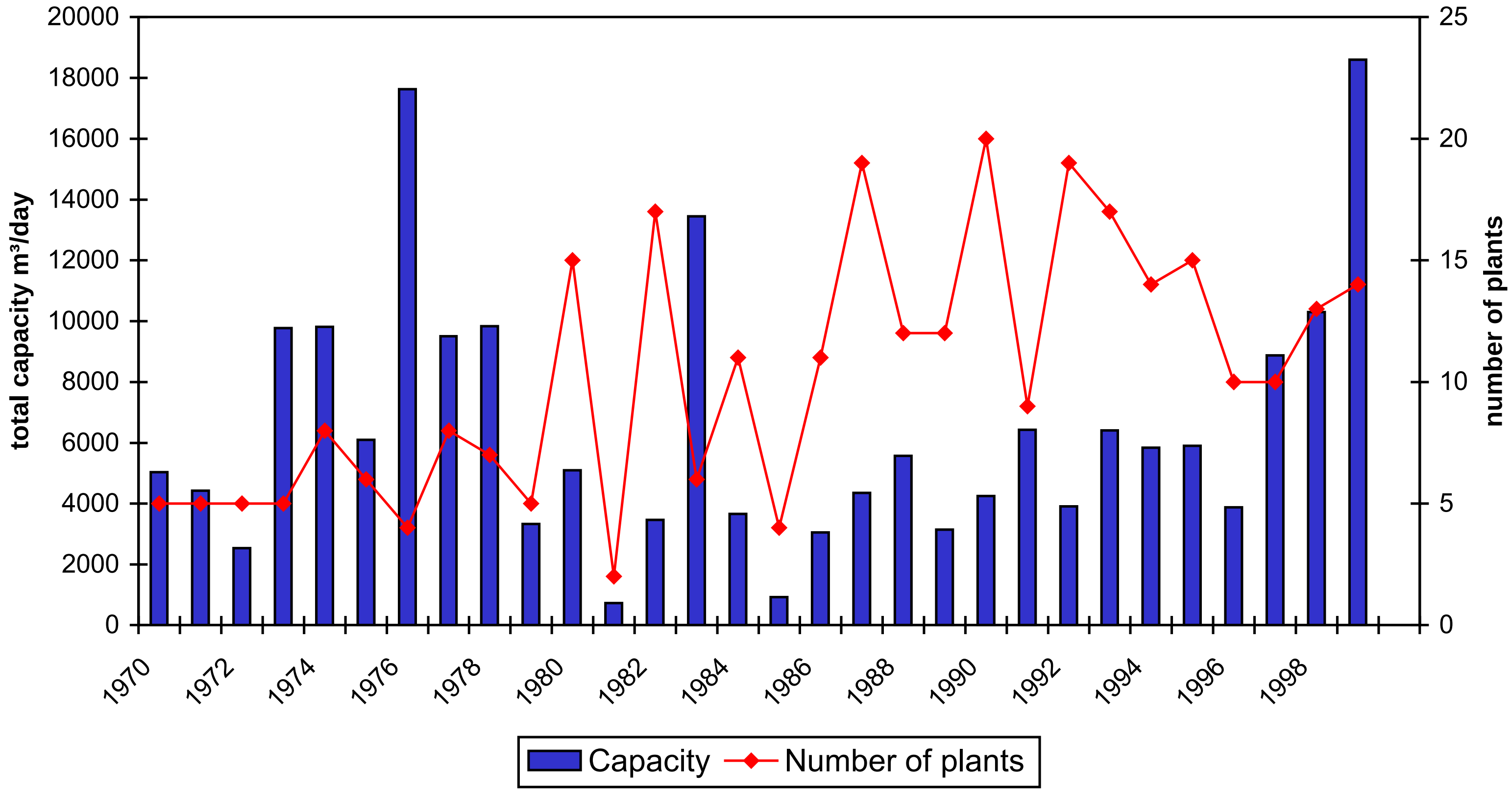


Fig. 19. Capacities and number of plants put in operation each year since 1970.



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 degassifier (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 is 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 sea water
(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 the 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 turbitity 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(Callifornia 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 eliminate 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 to be 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 sea water 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 sea water 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 color	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 sea water 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 entrainement 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 feedwater	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)
- Disifection of 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 feedwater		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 are of very limited application and are 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 pretreatment, 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 byproducts may discharged with the concentrate. Their addition should be controlled to avoid so to have 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 were 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 outake 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

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
EGYPT	Alexandria	600	RO/1	MIL	1995
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 (fishfarm)	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

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
ITALY	Libari	4800	VC/3	MUNI	1987
ITALY	Milazzo	4800	ME/1	INDU	1998
ITALY	Milazzo	1000	VC/2	INDU	1997
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

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
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
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

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
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
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

Country	Location	Capacity m³/day	Type/Unit	User	Op. Year
SPAIN	Ceuta	4000	MSF/2	MUNI	1966
SPAIN	Ceuta	16000	RO/3	MUNI	1998
SPAIN	CI Guia	1500	VC/1	MUNI	1992
SPAIN	ClFuertaventura	2000	MSF/1	MUNI	1970
SPAIN	ClFuertaventura	1000	VC/2	MUNI	1980
SPAIN	ClFuertaventura	1000	VC/2	MUNI	1982
SPAIN	ClFuertaventura	1000	VC/2	MUNI	1982
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

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
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
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

Country	Location	Capacity m^3/day	Type/Unit	User	Op. Year
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
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:	vapor 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