KUWAIT FUND FOR ARAB ECONOMIC DEVELOPMENT

DESALINATION :

THE NEGLECTED OPTION

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WATER IN THE ARAB WORLD
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LIST OF ABBREVIATIONS

ED.	Electrodialysis.
GCC.	Gulf Cooperation Council (Members - Saudi Arabia, Kuwait, UAE, Bahrain, Qatar and Oman)
HTE.	Horizontal Tube Evaporation.
MED.	Multi-effect Distillation.
MED/VC	Multi-effect Distillation with Vapour Compression.
MSF.	Multi-Stage Flash
MVC.	Mechanical Vapour Compression.
PPM.	Parts Per Million.
RO.	Reverse Osmosis.
SWRO.	Sea Water Reverse Osmosis.
TDS.	Total Dissolved Solids.
TVC.	Thermal Vapour Compression.
VTE.	Vertical Tube Evaporation.

DESALINATION : THE NEGLECTED OPTION

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DESALINATION : THE NEGLECTED OPTION[1]

ABSTRACT

The state-of-the-art of desalination is reviewed and an attempt is made to pin-point the causes of the neglect of desalination in comparison with other modern technologies. The main trend for developing future water resources in the Arab World is shown to be either by the long distance conveyance of water or by desalination and/or recycling, since other options have been substantially exhausted. Desalination, from the point of view of the Arab World, should be given more prominence and take into consideration both local conditions and past experience. Schemes for the long distance conveyance of water are not only strategically vulnerable when more than one country is involved, but they have also proved difficult to agree upon.

The basis upon which the cost of water is determined is reviewed and those aspects that tend to be overlooked in working out the true cost of water from conventional sources are projected. Similarly, the various approaches followed when determining the true cost of desalinated water are reviewed.

It is argued that the cost of desalinated water should not be considered as an isolated process, as is the prevailing attitude, but as part of a complete water-cycle that includes distribution, storage, sewage collection and treatment, as well as reuse of sewage effluent. A computer model has been designed to show the effect on the cost of desalinated water of making improvements in all or some parts of the components of the water-cycle.

The extent of investment in the desalination industry in the next decades is estimated and the urgent need to widen public research in this field emphasised, since research has so far been mainly left to the industry to conduct on its own. The establishment of an international institution is proposed with the objective of streamlining the experience gained in desalination in both industrial and developing countries, particularly in the oil-producing countries, and for promoting desalination through public research based on the particular conditions and expertise that exist at the local level.

1.0. INTRODUCTION

1.1. The consideration of desalination as an option for the provision of potable water is usually neglected owing to its high cost. While this aspect of the process cannot be discounted, there is compelling evidence that desalination will have to be adopted as the only acceptable option for potable

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1 The views expressed in this paper are not necessarily those of Kuwait Fund for Arab Economic Development.

water provision in some developing countries, particularly those in the Arab world. (Ref. 1) Reducing the cost of desalinated water, therefore, is becoming a pressing issue which has to be explored as it is not only dependent on improving desalination technology, but also on improving the management of the conservation and utilization of desalinated water.

1.2. The technology of desalination can no longer be regarded as new since it has been used on a commercial basis for nearly 40 years. It was in the fifties that Kuwait embarked on desalination as the most practical solution to its water supply problems and it has used it successfully ever since. In fact, Kuwait, small country as it is, has gone further and financed research to improve and advance the budding technology when it was seriously disputed as a viable main source of potable water. The original work by Professor Silver of Glasgow University provided a foundation for the development of desalination in Kuwait and, indeed, for much of the progress that has since been made in the use of desalination as a major source for the production of potable water.

1.3. Today, however, the momentum instigated by Kuwait for the advancement of commercial desalination has somehow been lost while other technologies born during the same era or later have flourished and become widespread: computers, electronics and undersea oil exploration, not to mention power generation and space technology, have leapt forward while desalination has been neglected in favour of other sources of water.

2.0. POSSIBLE REASONS FOR NEGLECT OF DESALINATION

2.1. The shortage of water is becoming a vital issue not only as an essential commodity for human survival and a major factor in economic development, but also as a possible cause for conflict between neighbouring countries. It is therefore fitting to consider the reasons underlying the relative lack of major progress in desalination technology since it has the potential to help solve the water supply problems of future generations while at the same time safeguarding the environment.

2.2. A number of possible factors may have resulted in the neglect of the development of desalination. These can be outlined as follows:

(i) **The location:** The countries in need of desalination have been mostly developing countries, while the industrial countries - the seat of technology - have not until recently suffered from water shortages.

(ii) **The market:** The competition between the major manufacturers has been limited and has had a negligible effect on market prices, especially since by far the largest group of "customers" for desalination capacity for the last two or three decades has been the Arab oil-producing states whose demand has been backed by plentiful funds.

(iii) **The research centres:** The public domain has carried out little research; (Ref. 2) even the collation of international data has been carried out on the initiative of private sector researchers. In fact the major development of desalination techniques has been left to the main manufacturers who have a vested interest in existing technology and usually undertake research "in-house" and keep the results secret (Ref. 3)

(iv) **The Universities:** Opportunities for post-graduate studies or courses at universities are extremely limited as there is a lack of suitable staff available to supervise research in desalination. In fact, most universities have not given desalination the importance it warrants at the undergraduate level. Its neglect is highlighted by considering the extensive scope of courses available in computational science, electronics and petroleum engineering.

(v) **Training:** The training required for operating and managing a desalination plant is substantially different from that required for other water treatment plants. The adoption of desalination by well established water authorities was resisted as it would necessitate the introduction of new training procedures and expertise.

3.0. OPTIONS FOR ALLEVIATING PRESENT WATER SHORTAGE

3.1. Current shortages of water, coupled with its unequal distribution, have led to the need to choose between two major solutions to the problems of supply: the conveyance of water over long distances and desalination and/or recycling (Ref. 4). Water can be conveyed by canal, pipeline, tunnel or tanker, either between different regions in the same country or across borders between different countries. Examples of major national water transmission schemes are Libya's artificial river (1900 km) and Tunisia's Majradah canal (about 160 km), the study for Senegal's Cayor canal (230 km), Turkey's Melen project for Istanbul (180 km), and Egypt's conveyance of water from the Nile to the Sinai and the Red Sea. International schemes include the "Peace Pipeline" from Turkey to the Levant and the Gulf[2] (over 3000 km) and the existing pipelines from Malaysia to Singapore (30 km) and from China to Hong Kong (60 km).

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[2] The initial cost estimate of this project is about $ 20 billion and it would take at least 8 to 10 years to put in place (Ref. 5)

3.2. The advantage of conveying water as a solution is that the technologies of canal building and pipeline construction are well-established and can utilize expertise already developed by other industries such as transport and oil production. As for tanker use, the technology required for transporting water is far less complex than that required for oil[3]. In fact, water was conveyed to Kuwait from the Shatt-el-Arab in specially constructed dhows prior to the introduction of desalination.

3.3. The disadvantages of conveying water, however, include the following factors:

a) A very high level of initial investment is required

b) Long lead times are involved in planning.

c) Once schemes are implemented countries are committed to dependence on a particular water source for many years.

d) Water coming from a different country is strategically vulnerable.

e) A degree of inflexibility is involved in that the maximum supply is determined not only by the source, but also by the capital provision available initially for the construction of pipelines and storage capacity etc. Only the richest countries can make provision for their requirements many years hence.

3.4. The situation concerning desalination presents a quite different picture to that pertaining to the conveyance of water. Its advantages can be summarised as follows:

a) Capital expenditure on desalination can be carried out gradually in stages.

b) Plant output is more flexible within capacity limits.

c) The sources of input are less strategically vulnerable as they are normally sited within national borders.

d) Cost reductions in the future seem likely as the increasing use of the techniques means they will almost certainly be improved upon.

3.5. The relative disadvantages of desalination mainly relate to operating costs and can be summarised as follows:

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[3] It is interesting to note, however, that the price the United States would pay to ship water to its troops in Saudi Arabia is at least 10 times the price of oil (Ref. 5)

a) The personnel required for operation and maintenance can be costly as the technology is not widespread and expertise is scarce. It may be necessary to employ expatriates.

b) Spare parts and materials can be expensive, especially as they usually need to be imported.

c) High energy requirements.

4.0. PRINCIPAL DESALINATION PROCESSES

4.1. Two main types of processes are now available commercially: distillation processes and membrane processes. The most important distillation methods are multi-stage flash distillation (MSF) and multi-effect distillation (MED). Both of these involve the evaporation of water from feed water and its condensation back into fresh water, leaving dissolved substances in the waste brine. Both methods are improvements on the original submerged tube process, developed commercially in the 1950's, which involved heating stagnant brine.

4.2. In Multi-stage Flash (MSF), a stream of brine flows through the bottom of up to 25 stages or chambers (Fig. 1). The pressure in each chamber is maintained at a lower level than the saturation vapour pressure of the water and a proportion of it "flashes" into steam and is then condensed.

4.3. In Multi-effect Distillation (MED), evaporation takes place as a thin film of feed water passes over a heat transfer surface. This is usually the outside of horizontal tubes (MED/HTE) but in some small-scale operations is the inside of vertical tubes (MED/VTE) (Figs. 2, 2A). The vapour formed in each effect condenses in the next, providing a heat source for further evaporation. Energy savings are made if the vapour from the last effect is re-compressed thermally or mechanically (MED/TVC or MED/MVC). Fewer stages are involved than in MSF.

4.4. The two membrane processes are reverse osmosis (RO) (Fig. 3) and electrodialysis (ED). In RO, a pressure greater than the osmotic pressure of the feed water is applied to the feed water side of a semi-permeable membrane producing a flow of fresh water through the membrane. In ED feed water flows through a stack of membranes to which an electric voltage is applied. Ions migrate to the charged electrodes formed by the membranes so that an ion-depleted product and concentrated reject brine stream are formed in alternate spaces between the membranes.

FIGURE 1 : MULTISTAGE FLASH PROCESS

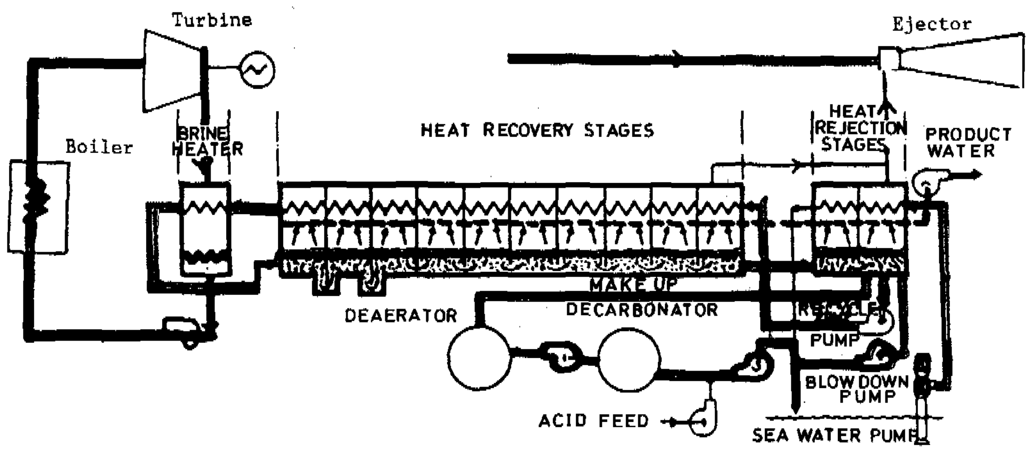


FIGURE 2

CONCEPTUAL DIAGRAM OF HORIZONTAL-TUBE MULTI-EFFECT PROCESS

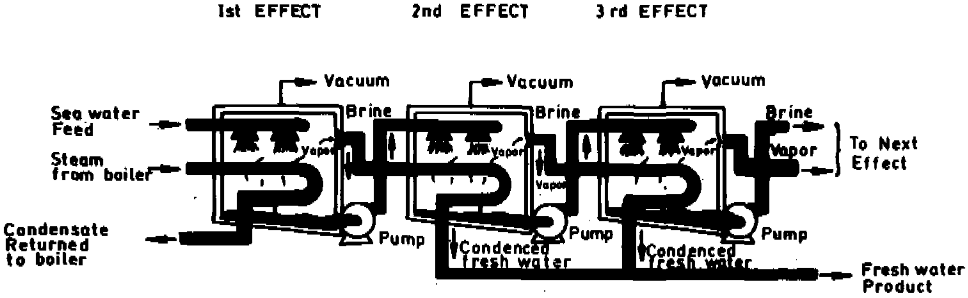


FIGURE 2A

CONCEPTUAL DIAGRAM OF HORIZONTAL MULTI-EFFECT WITH VERTICAL STACKED EFFECTS

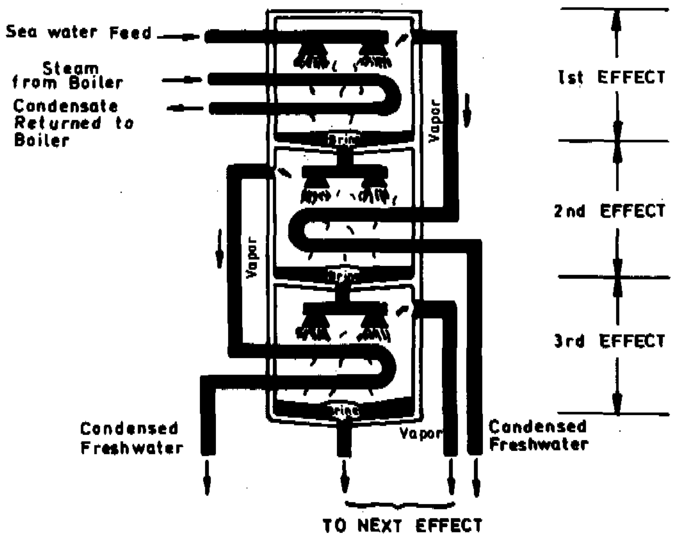
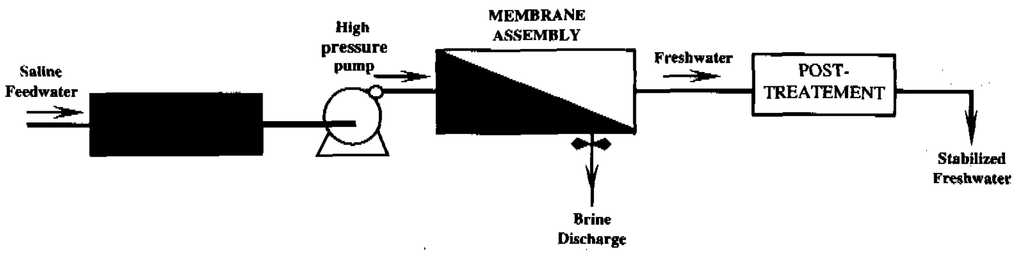
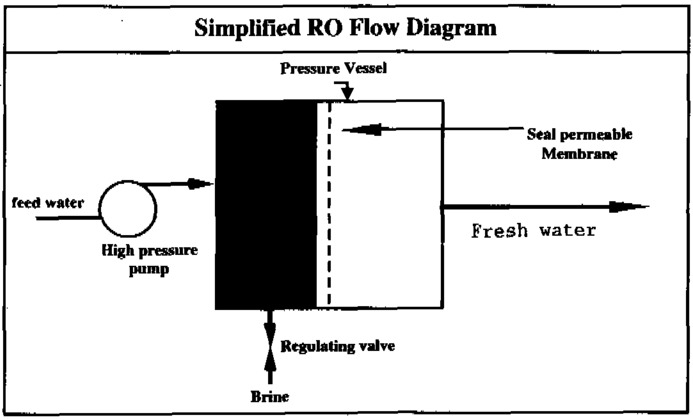


FIGURE 3 : FLOW DIAGRAM OF REVERSE OSMOSIS PROCESS





5.0. COMPARISON OF DESALINATION PROCESSES

5.1. Table 1 has been prepared to show the state-of-the-art of desalination, but the main features of each process can be pointed out as follows:

(i) **Multi-Stage Flash (MSF)** : is the method most widely used on a large scale and there is probably little room left for its improvement except by using high grade alloys to extend its life span. It can make use of low grade heat produced during electricity generation - which would be otherwise wasted - thus considerably reducing the energy demands of the process. For this reason it is usually installed as part of a dual-purpose plant. It has the advantage over RO that it requires less specialised technical expertise and is much more robust. It is particularly competitive for desalinating sea water. The product is usually very pure with less than 30ppm total dissolved solids (TDS) and may need post-treatment to provide drinking water and to protect the distribution network.

(ii) **Multi-effect Distillation (MED)** : which produces a similar product to that of MSF plants has not been used on such a large scale as MSF. However, it promises certain advantages. The process takes place at a lower temperature than MSF thus reducing susceptibility to corrosion and scaling and thereby reducing the demand for additives, maintenance and expensive corrosion-resistant materials. Moreover, fewer stages are necessary so less plant is required. The capacities continue to increase and it is on the point of competing with MSF for all but the largest installations. Vapour compression can reduce energy requirements, independent of electricity generation, to levels approaching those of RO, but MED/VC has not yet been used in large-scale plants.

(iii) **Reverse Osmosis (RO)** : was introduced in the 1970's and is the most widely used process after MSF. It is particularly well suited to the desalination of brackish water - including waste waters - but in the 1980's was also developed for sea water desalination. The latter requires much more energy as pressures of around 65-70 bar are needed compared with 25-30 bar for brackish water. RO can be carried out independently of electricity generation - though it does of course use electricity - since it cannot use waste heat. The amount of desalination plant required is very much smaller than for MSF. The main disadvantage is the sensitivity of the expensive membranes to fouling and the need for very careful operation. It is likely, however, that improvements can be made in process efficiency as well as the sensitivity and cost of membranes. The purity of the product is only fair. It can be 500ppm TDS from the one-stage treatment of sea

TABLE 1 - MAIN CHARACTERISTICS OF IN-USE DESALINATION PROCESSES

	MEMBRANE PROCESSES			DISTILLATION PROCESS				
PROCESS	ELECTRODIALYSIS (ED)	REVERSE OSMOSIS (RO)		MULTI -STAGE FLASH DISTILLATION (MSF)	MULTIPLE EFFECT DISTILLATION (MED)			
		Brackish Water (RO)	Sea Water (SWRO)		Horizontal Tube Evaporation (HTE) With Vapour Compression Thermal Vapour Compression (TVC)	Mechanical Vapou r Compression (MVC)	Without Vapourt Compre-ssion	Vertical Tube Evaporation (VTE)
PRINCIPLE	Feed water flows through a stack of alternate cation and anion exchange membranes to which an electric voltage is applied. Ions migrate to the electrodes and an ion-depleted product and concentrated reject brine stream are formed in alternate spaces.	A pressure greater than osmotic pressure is applied to the feed side of a semi-permeable membrane producing a flow of fresh water through the membrane.		A stream of heated brine flows through the bottom of up to 25 stages at successively reducing pressure . Vapour "flashes" from the the brine and condenses on heat exchanger tubes through which recycled brine flows.	Evaporation takes place as a thin film of brine passes over a heat transfer surface. The vapour formed in each effect condenses in the next, providing a heat source for evaporation. Seawater is evaporated outside horizontal tubes. Part of vapour formed in last effect is recompressed and returned to first effect to save energy.			Seawater is evapurated inside vertical tubes.
REQUIRED PRESSURE		Usually 25-30 bar	Usually 65-70 bar		Thermally	Mechanically		
FEED WATER	Low to medium brackish up to 3,000 ppm TDS	Brackish water 5,000 - 6000 ppm TDS		Sea Water Usually 35,000 ppm TDS ; 45,000 ppm TDS in Arabian Gulf; 100,000 ppm TDS possible				
PRE-TREATMENT	Careful pre-treatment required to avoid membrane fouling. Must be adjusted to water source.			Screening and straining to remove particulates. Anti-scalant according to operating temperature, anti-foaming agents, de-aeration and chlorination against biological fouling.				
	To avoid particulates, and counter scaling, organics, iron, and metallic cations.	To avoid particulates, and counter scaling and biological fouling. Chlorine damages some membranes						
PRODUCT	Less than 250 ppm TDS. Non-ionic species uncharged. Feed variations affect quality more than with RO	*Purity fair*	Can produce less than 500 ppm in one stage. May not need post treatment or can be combined with MED/VC plant product.	*High Purity* Less than 30 ppm Post treatment required to protect distribution network and for drinking water, Brackish water may be added or bycarbonate to increase calcium.				
CONVERSION	80% of feed		30-40% of feed	30-40%				
ENERGY SOURCE	Usually electrical power. Others possible e.g. steam or diesel engine			Mainly low grade waste heat from electricity generation used in dual purpose installation. Some electric power for pumps.				
FACTORS AFFECTING EFFICIENCY	Efficiency maximised by larger membrane area, current low enough to avoid polarisation and scale, and good distribution of feed water.	At low salinities,the operating pressures are lower and the conversion rates higher, so energy recovery not worthwhile compared with SWRO	At higher salinities operating pressures are higher and the conversion rates lower, so energy recovery turbines worthwhile.	Efficiency affected by scale control and heat transfer techniques, the use of corrosion resistant materials, and the mechanical design of larger structures and pumps. Higher temperatures increase efficiency but also increase scaling. Energy input largely independent of dissolved solids level.	Vapour compression reduces energy consumption for a given number of effects			
CAPACITY OF EXISTING COMMERCIAL PLANTS	Relatively small. Used for small commercial undertakings e.g. hotels. Large outputs require a modular approach.	45,000m³/day Using modules	56,800m³/day	34,000 m³/day but 45,000 m³/day planned	10,000 m³/day	1,500m³/day		Small. (A large plant is under consideration for California).
FIRST COMMERCIAL USE	Mid 1960's	1970's	1980	1960	late 1970's			
				These processes are derived from the submerged tube multiple effect distillation used in 1950's in Kuwait.				
OPERATING TEMPERATURES	Ambient temperatures (under 40° C).			Maximum in first stage 110° C or 90° C according to anti-scalant used	Around 65° C in first effect			High temperature
CAPITAL COST	Less plant, materials, civil work and land required than for distillation. Depends on quality of product required.			Much larger heavier plant required than for RO with extensive materials, civil work and more land. High temperature necessitates expensive corrosion resistant alloys e.g. copper-nickel alloys, titanium.				
					Fewer stages so less plant required than for MSF. Lower temperatures therefore less corrosion.			
OPERATION AND MAINTENANCE		Reasonably simple. Can be highly automated. Main cost is membrane replacement. Normally extensive pretreatment essential for successful operation and long life of membranes.		Minimal skill required by operator. High grade materials reduce maintenance time but are expensive. Labour intestive: all water boxes have to be opened for cleaning. Consumes chemiclas to use these cost much less than the energy.				
CHOICE	Operating costs for ED and RO lower than for MSF if salinity lower. Favoured in USA and Europe where energy costs are high and expertise easily available.		Along with MED/MVC best for small-scale seawater desalination in remote areas.	Competitive in Middle East as it is linked to electricity production and cheap labour.	Major contender for all but largest installations.	Along with RO best for small-scale seawater desalination in remote areas.		Mixed results so far.
PROSPECTS		Vast expansion last decade. Prospect of decreasing cost by improving process efficiency and membrane performance.		Limited potential for improvement except for increasing life- span substantially by using high quality materials and alloys.	Scope for development in unit size and reducing energy consumption. *On point of competing with MSF as it is less complex requiring reasonable expertise.*			

water and may not need post treatment. To obtain products with the desired qualities for a public water supply various hybrid plants have been proposed such as RO with MED/VC.

(iv) **Electrodialysis (ED)** : is only used for relatively small units such as those required by hotels. It is suitable only for low to medium brackish waters which must be given careful pre-treatment. Non-ionic substances in the water pass through unchanged, and it is uneconomic for the production of water with less than 250ppm TDS. Product quality is much more easily affected by variations in feed quality than in the case of RO.

6.0. WORLD SUPPLY OF DESALINATED WATER

6.1. The growth in the world supply of desalinated water can be seen from figure 4 which also shows changes in the proportion of the totals contributed by MSF, RO and "other" methods. The proportion of these totals contributed by the Arab World is appreciable, and of this the majority is to be found in the Gulf. Of the 15,582,000 m^3/ day capacity world-wide at the end of 1991, 7,744,552 m^3/day (or 49.7%), were in the six Gulf Cooperation Council (GCC) countries.

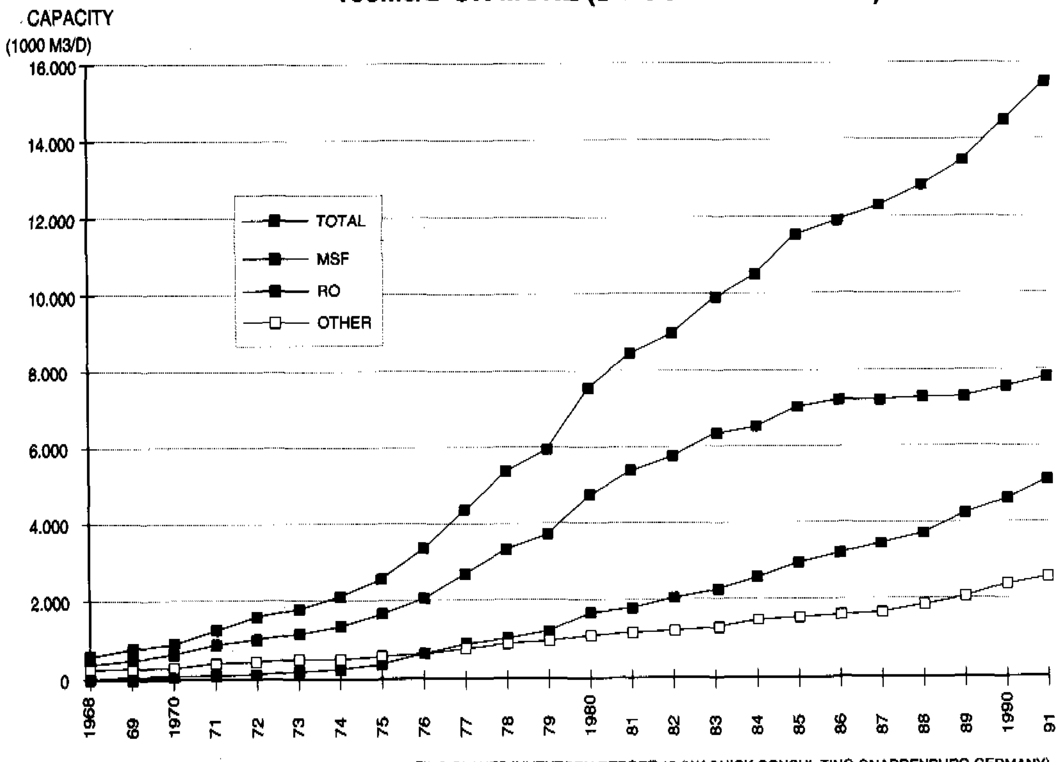
6.2. Graphs in figures 5 and 6 showing the annual capacity contracted in the Arab World and the GCC countries for the period 1965-1991 illustrate the predominance of MSF in the area, where it accounts for 80.25% and, of this, all but an insignificant proportion is provided by dual purpose, (i.e. electricity and water) plants. RO accounts for 16.25% only, and all other methods account for the remaining 2.5%. However, these proportions differ significantly between the six states. The total capacity in Saudi Arabia at the end of 1991 was 3,811,952 m^3/day, and of this MSF represented 2,777,896 m^3/day or 70.25%, RO 963,424 m^3/day (25.25%) and others the remaining 4.5%. Whereas in Kuwait, of a total capacity of 1,393,190 m^3/day, MSF represented 1,350,546 m^3/day (97.1%), RO 29,098 m^3/day (2.1%) and other methods the remaining 0.8%.

6.3. These figures also show significant differences when compared with figures for the world as a whole. Of the world-wide total capacity of 15,582,000 m^3/day, some 7,994,500 m^3/day or 51.3% is provided by MSF; 5,080,200 m^3/day or 32.6% by RO; and the remaining 16.1% by other methods.

7.0. IMPACT OF LOCAL CONDITIONS ON PROCESS CHOICE

7.01. The impact of local conditions on the choice of process can be illustrated by considering the factors which affect the GCC countries.

FIGURE 4 : CUMULATIVE CAPACITY OF ALL LAND BASED DESALINATION PLANTS OF CAPACITY 100M3/D OR MORE (BY CONTRACT YEAR)



COMPILED FROMIDA WORLDWIDE DESAL TING PLANTS INVENTORY REPORT 12 (WAGNICK CONSUL TING GNARRENBURG GERMANY)

(i) **The nature of the feed water to be treated :** In GCC countries the only water available in abundance is sea water, so the most feasible solution to water shortages is to desalinate sea water and in the case of many inland areas to pipe this desalinated water over long distances. Although improvements in RO membranes have narrowed the gap between MSF and RO for sea water desalination, MSF has maintained an advantage over RO, especially where the salt content is very high as in the Gulf.

World-wide, however, RO has been gaining ground over MSF, with the demand increasing in inland areas where supplies from natural sources have been diminishing. This is especially so in the USA where attention has turned to the purification of brackish ground water or municipal wastes, for which RO is very suitable.

(ii) **Scale economies :** The demand for water in the GCC countries rose rapidly during the "oil boom" years of the seventies due to a sudden increase in wealth and population through the immigration of expatriate labour often accompanied by families. This situation favoured the construction of large-scale plant when MSF was the only method available which allowed scale economies to be exploited to the full. Thus much MSF plant in the Gulf has been in existence for many years, having been established when RO was still in the early stages of development.

(iii) **Co-production of electricity and water :** The rapid increase in population and wealth had other ramifications, notably in the growth in demand for power for industrial, domestic and municipal use. As part of a dual-supply system, where waste heat from the provision of electricity could be utilised for the distillation process, MSF was admirably suited to the circumstances, with cost advantages accruing to both products.

(iv) **Availability of technical expertise :** The demand for technically qualified labour in the area increased far beyond the supply available. Consequently, there was a great reliance on expatriate labour for most industrial activity. The electricity and water industries were no exception, but whereas there was a large pool of expertise concerning electricity supply available in the industrial world which could easily be adapted to Gulf conditions, RO was a new technique for which the expertise had yet to be developed. This gave MSF a further advantage during the early years.

(v) **Simplicity of operation and availability of spare parts :** MSF is easier to operate. and pre-treatment is less sensitive than it is for RO. Whereas MSF spare parts are widely available and some of them can be produced locally, RO membranes are easily fouled, expensive, and have to be imported from a limited number of manufacturers.

(vi) **The proximity of the sea :** The actual preferences reflect the proximity of the sea to population centres, which in turn determines the feed water to be used. Both Libya and Iraq are significant oil producers. The former has the capacity to desalinate 633,517 m^3/day and the latter 333,540 m^3/day, but whereas Iraq with a limited coastline has shown a preference for RO, Libya with an extensive coastline near the major population centres has favoured MSF.

7.2. Turning to the Arab World in general, (Fig. 5) it can be seen that advances in the adoption of desalination have been very sporadic, mainly for reasons which, as shown above, make the GCC countries a special case. Only Algeria of non major oil producers has a desalination capacity in excess of 142,216 m^3/day, but a number of other Arab countries have significant capacity.

7.3. It is obvious that one must guard against extrapolating from the desalination experience of the GCC countries, yet their experience and the adaptations that have been made to suit processes to local conditions provide a pool of knowledge of inestimable value to the rest of the world, especially Arab States with similar climatic conditions.

8.0. TRUE COST OF WATER PROVISION

8.1. Almost all developments in water provision involve an increase in the input of resources, and recently such increases have generally been of a capital nature, so that water is becoming increasingly a produced commodity requiring the input of scarce resources that have alternative uses. The price for the use of these resources is their "opportunity cost", i.e. the value of the opportunities lost by diverting them from use elsewhere. Consequently, the problem of costing of water is becoming more of an economic problem as well as an accounting one. Unfortunately, even the accounting framework has been sadly neglected in many parts of the world, so that when the costs of desalination are compared with the costs of water production by more traditional methods the latter are, in most cases, grossly underestimated. Experience at the Kuwait Fund has shown that a wide variety of practices are used in costing existing supplies. Often, for example, no account is taken of depreciation. Also replacement costs or expatriate fees are sometimes neglected as these are normally covered by technical assistance or grants. Where existing plant is very old, and no sinking fund has been created, the

FIGURE 5 **ANNUAL NEW CAPACITY CONTRACTED**
ARAB WORLD

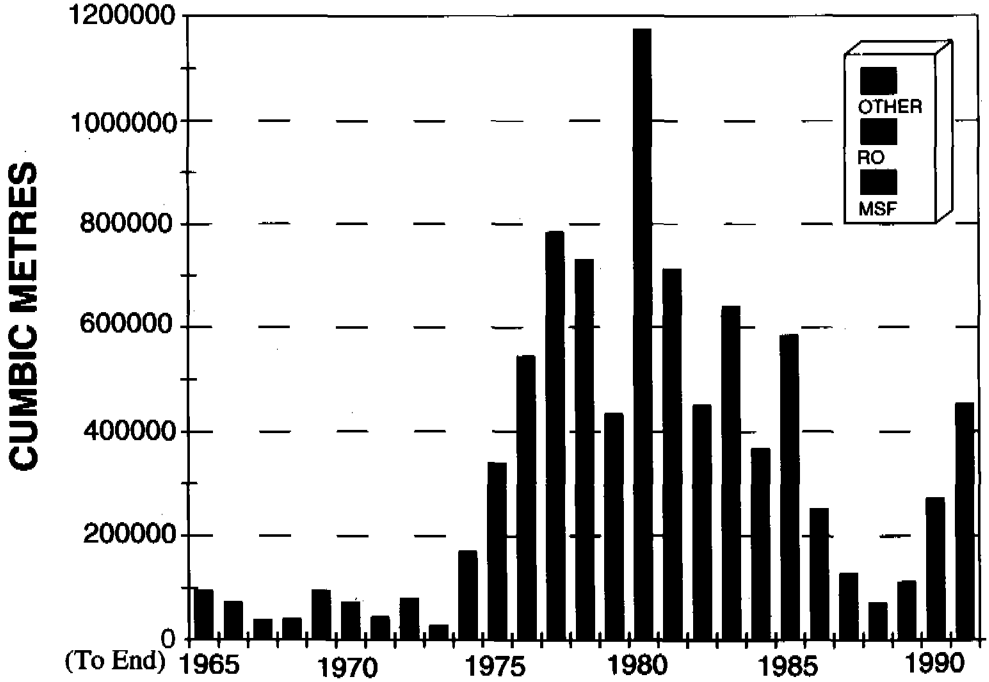
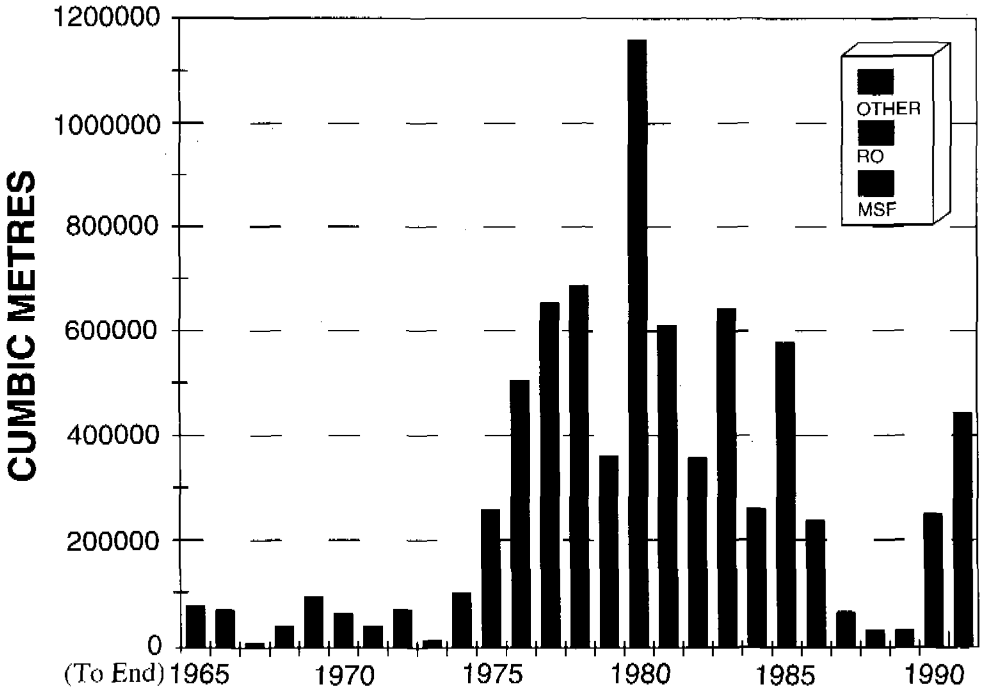


FIGURE 6 **ANNUAL NEW CAPACITY CONTRACTED**

GULF



latter omission is crucial. Such poor accounting methods need improvement before valid comparisons of water supply by alternative methods can be made.

8.2. When economic costs are included the problem becomes even more complicated. As well as the financial costs of extraction and distribution other less tangible costs need to be considered. There are often costs, and sometimes benefits, which accrue to others and which do not appear in the accountant's profit and loss account, but nevertheless must be paid for whether in money, time, or inconvenience.

8.3. Water has a number of uses, and when scarce it has to be allocated among them. If left to market forces, the price system would achieve this, but according to economic criteria only. When the socio-political system is involved, as it is when non-economic goals are sought, society has to make such decisions consciously. For instance providing water for agriculture may mean a choice between not providing it for industry or increasing total supply at a further cost.

8.4. Modern methods of cost-benefit analysis attempt to encompass these problems, but one of the great difficulties is the need to reduce all costs and benefits to a single numeraire, and then to compare competing projects with each other according to a single maximand to which the numeraire is generally analogous, but need not be identical. The maximand is ultimately, although not always explicitly, the social benefit which it is presumed arises from the project when the government is able to allocate the resources which the project makes available. This may be easily calculated for an export producing project whose output can be measured in foreign exchange earnings, but for water with its many different uses, its health implications and its industrial and agricultural applications, the use of these techniques for the economic analysis of its cost must be undertaken with great caution.

8.5. Incorrect pricing leads to the misuse and miss-allocation of scarce resources, as when water is supplied at far below cost a false conception of true costs results. A rigorous method of costing water for developing countries should be established in order to support a sound water policy and also to allow valid comparisons to be made between the costs of different methods for supplying water. Although it may not be desirable to charge full costs under all circumstances when a water policy is being formulated, the cost of allocating water according to non-economic criteria should always be made clear.

9.0. COMPARISON OF COSTS OF WATER SUPPLY METHODS

9.1. Making valid comparisons between the cost of desalination and other forms of water supply is rendered difficult by the frequent lack of rigour in the costing of conventional methods. In 1987 the World Health organization published the results of a world-wide survey on the costs of water (Ref. 6). Table 2, based upon that survey, shows the disparity of the values quoted by those countries which responded (Ref. 1).

TABLE 2

UNIT COST OF WATER PRODUCTION

Country	Cost $/m^3	GNP per Capita $	Cost per Capita %
Cape Verde	4.65	317	1.5
Cayman Islands	2.75	13,000	0.02
Cameroon	2.0	800	0.25
Mexico	1.5	2,080	0.07
Argentina	1.5	1,929	0.8
Netherlands	1.25	9,290	0.01
Zambia	1.05	390	0.3
Saudi Arabia	1.0	8,850	0.01
Sierra Leone	0.9	200	0.45
Tonga	0.8	354	0.23
Botswana	0.75	840	0.09
Togo	0.66	300	0.22
Surinam	0.6	3,030	0.02
Seychelles	0.6	2,250	0.03
Malawi	0.6	170	0.35
Papua New Guinea	0.55	649	0.09
Tunisia	0.5	1,277	0.04
Cook Islands	0.4	7,170	0.006
Cyprus	0.4	3,572	0.01
Djibouti	0.4	480	0.08
Rwanda	0.4	280	0.14
Bahamas	0.37	7,556	0.01
Laos	0.35	100	0.35
Barbados	0.34	4,889	0.01
Ghana	0.35	420	0.08
Burundi	0.35	230	0.15
Mali	0.33	142	0.23

Switzerland	0.33	14,764	0.002
Afghanistan	0.3	163	0.18
Mauritius	0.29	1,020	0.03
Burma	0.25	188	0.13
Singapore	0.24	7,420	0.003
Spain	0.22	4,256	0.005
Vanuatu	0.22	529	0.04
Zaire	0.22	271	0.08
Hungary	0.23	1,909	0.01
Finland	0.21	10,531	0.002
Thailand	0.21	729	0.03
Honduras	0.2	720	0.03
Republic of Korea	0.19	2,032	0.009
Haiti	0.18	320	0.06
Malaysia	0.18	2,033	0.009
Costa Rica	0.17	1,300	0.013
Madagascar	0.17	240	0.07
Angola	0.15	560	0.03
Nicaragua	0.14	770	0.02
Morocco	0.14	512	0.03
Chile	0.12	1,430	0.008
Peru	0.12	1,010	0.012
Iraq	0.118	2,964	0.004
Bangladesh	0.09	136	0.07
Ecuador	0.09	1,160	0.008
Western Samoa	0.09	660	0.013
Panama	0.07	2,100	0.003
Philippine	0.05	585	0.008

9.2. There seems to be no correlation between the costs quoted and any single factor. Singapore, with one of the lowest costs, US$ 0.24/m^3 relies heavily on water imported by pipelines from Malaysia, while Cameroon, with abundant surface water and rainfall, has one of the highest costs, US$ 2.0/m^3. It is interesting to note that an efficient water management, such as Singapore's, which keeps accurate records and includes all the basic costing components in calculations, can keep the cost of water reasonably low in spite of an adverse water resources situation, whereas some developing countries quote a high cost for water production and distribution based on calculations that exclude basic costing components. This indicates that efficient management can not only reduce the cost of water but also provide financial rewards which can be attractive to the private sector.

9.3. The Netherlands quotes a figure of US$ 1.25/m^3 which is almost four times that of Switzerland, at US$ 0.33/m^3, yet both are countries with high national incomes per capita. The difference may be due to the quality of their respective water sources, so that Netherlands with its low-lying land, sea-water intrusion, and very high population density has to bear a water cost almost as high as that for desalinated water in spite of its recognised efficient management. Unfortunately, as can be seen from the table, many countries are facing more difficult situations than the Netherlands with the added disadvantages that they are countries with low national incomes per capita and often inadequate water management. The cost of some conventionally treated national water supplies is indeed approaching that of desalinated water.

9.4. Other factors than management efficiency and local conditions contribute to the disparity between the figures in Table 2 and the following are among those which have been noted from independent experience:

a) Existing infrastructure costs may have been ignored, or when capital has been completely written down[4], no allowance has been made for capital replacement.

b) The price given may be that charged to the consumer and may bear no relationship to costs.

c) Estimates may have been made "off the cuff" because of a lack of data, or may have been based on poor or inefficiently gathered information.

d) Inputs - especially of labour - may have been costed in local currency which may not reflect costs accurately owing to artificial rates of exchange.

e) National estimates are extremely difficult to make and can be almost meaningless where a large number of independent authorities are responsible for supply and the share of GNP per capita varies greatly between regions.

9.5. Allowance has to be made for these possibilities when costing conventional water supply schemes for comparison with other methods. It is also imperative to determine the cost of increasing capacity using the existing

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4 It is worth noting that the cost of construction work for a water supply scheme in Africa can be three to five times the cost of a similar scheme in Europe (Ref. 7).

method, as this is often very expensive and may even be impracticable. Thus, desalination has not only to be compared with conventional methods of supply but also with alternative methods such as long-distance pipelines and tanker transport.

9.6. Whether pipeline or tanker transport is the more economical again depends on many factors such as the terrain over which the pipelines need to be laid and the nature of the sea-leg of the journey. In addition to ships, tanker transport also requires much pipeline and other infrastructure to convey water to the loading points and also from the discharge points to its destination.

9.7. When pipeline and tanker transport were compared for one particular developing country (Unpublished reference) tanker transport only became cheaper at distances greater than 200 to 300 miles, when the price was around US$ 2.0/m^3 at present prices, and then only when most of the distance was over the sea and little land-side infrastructure was required. Beyond that point, however, tanker transport became much more economical and the journey could be doubled without an appreciable increase in costs.

9.8. Desalination was not considered as an option in the above study, but current costings show that it can become cheaper than pipeline transport well before tanker transport does. Indeed, it is fast becoming a serious contender world-wide as a solution to water shortages.

9.9. A case in point is the proposed "Peace Pipeline" which is intended to supply 15 million people with approx. 350 lit/person/day. At a cost of US$ 20 billion, a construction period of 10 years, and a suggested pipeline life of 50 years, the initial capital costs alone would represent between US$ 0.735 per m^3 and US$ 1.758 per m^3 depending on what interest rate/discount factor between 5% and 10% is chosen[5]. Other costs must be added to these initial capital costs. These are the initial charges for water provided by the supplying country; wayleave or toll charges for countries through which the pipeline passes; the costs of operation and maintenance including pumping and other high energy costs; the replacement of pumping and other equipment at intervals; and the cost of treatment before the water enters the final distribution systems. Using equivalent discount rates, it is suggested that desalination would be at least as economic as the pipeline.

10.0. THE TRUE COST OF DESALINATION

10.1. Comparisons between the costs of established and innovative methods of water production can be influenced by inefficient costing, and the validity of the costing methods themselves may be disputed.

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5 See also Annex A Section 1 for further details of the basis of calculating cost.

10.2. An examination of a series of costings of desalination processes (Ref. 8, 9 & 10) has been made. All exhibit the major elements of normal accounting procedures, in that costs are detailed for the initial inputs such as site preparation, building works, machinery and start-up period expenditure, together with labour and capital carrying charges. These are shown generally as capital costs. Detailed running or operational costs are shown on an annual basis. Capital costs are then transformed into annual charges. Briefly, an amount is calculated which if invested annually, would reach, by the end of the life of the installation, a sum which would have been reached had the initial capital costs been invested in the same manner. When this sum is added to the annual operating costs, the whole is treated as total annual costs. (Where water is produced jointly with electricity, a "shadow" amount, equal to the cost of producing electricity independently by the most efficient means available, is first deducted to obtain the cost of producing water). The result divided by the intended annual output, gives the unit cost of the production of water.

10.3. In all cases where comparisons of such costs are made, a number of difficulties arise, especially where the time configuration of costs of processes being compared are noticeably different. For example if the length of life of capital in the various processes under consideration were different from that assumed, then the allocation of capital costs to annual charges would be wrongly stated. Or, if process A had high initial capital costs and comparatively low operating costs, and process B the opposite, then the difference between the two costings will be affected by the choice of interest rate used to calculate the return on alternative investments.

10.4. Often a 20-year life-span is assumed for capital in all processes being considered, but some MSF plants have been operating satisfactorily in Kuwait for as long as 26 years. Shuaibah South MSF desalination plant, which has been operating satisfactorily for the last 21 years, is expected to continue to do so for at least another 10 years using routine maintenance procedures. Life span is materially affected by standards of maintenance, the type of materials and alloys used in plant construction and the complexity of the moving parts. Discussions with specialised consultants in desalination indicate that a 20% to 30% increase in initial investment so as to provide better materials for the construction of some MSF plants could result in doubling their life-span. Indeed, MSF could become the modern equivalent of the slow sand filter which lasted for decades, since the bulk of the capital cost of the plant is in the non-moving parts - the shell and pipework - which can last for a very long time indeed if current improvements in corrosion protection are utilised.

10.5. The interest rate (or discount rate) used needs careful selection. An oil-rich country might legitimately use the rate available on the world currency market, while a developing country, with a grave shortage of investment capital, might use the rate of return expected on an investment in foreign exchange-earning industry. Differing conditions demand different rates. It is not possible to compare one process with another on an abstract basis to provide universally applicable answers. They do not exist. Comparisons must be made using criteria applicable in each case where desalination is proposed as a solution to the shortage of water.

10.6. The following Tables 3, 4, and 5 based on figures provided in (Ref.8) illustrate the effect of changes, all within reasonable ranges, in three of the parameters i.e. discount rate, oil prices and life span of capital, used in calculating the costs of water.

TABLE 3

VARIATION IN UNIT WATER COST WITH DISCOUNT RATE

Discount Rate	Unit Water Cost $m^3				
%	Scheme[1]				
	1	2	3	4	5
4	1.38	1.24	0.96	1.15	1.37
6	1.46	1.3	1.02	1.24	1.47
8	1.56	1.37	1.08	1.33	1.58
10	1.66	1.44	1.15	1.43	1.69
12	1.77	1.51	1.22	1.53	1.81
14	1.88	1.59	1.29	1.64	1.93

[1] In the tables 3, 4 and 5:
Scheme 1 uses MSF with a back pressure steam turbine
Scheme 2 used MSF with a gas turbine and waste heat boiler
Scheme 3 as part of a co-generation plant with electricity
Scheme 4 uses RO with a single stage system
Scheme 5 uses RO with a double stage system
Each variant has a 6 M. gallons 27240 m^3 daily capacity, at 85% efficiency.

In Table (3) variations in the discount rate over the range shown results in changes of 36%, 28% and 34% in the unit price of water produced by the MSF processes, and 43% and 41% by those using RO.

In Table (4), the price of oil presumed to be the source energy used in each case has been varied, again over reasonable ranges, depending on the availability to the user. This results in increases of 100%, 109% and 40% over the three MSF processes, but only 24% and 23% over the two using RO.

TABLE 4

VARIATION IN UNIT WATER COST WITH OIL PRICES

Price per Barrel $	1	2	3	4	5
0	1.09	0.92	0.95	1.27	1.51
8	1.35	1.16	1.04	1.35	1.59
18	1.66	1.44	1.15	1.43	1.69
29.5	2.02	1.77	1.27	1.53	1.81
35	2.19	1.92	1.33	1.58	1.86

10.7. The effect on the unit cost of water of extending the life-span of capital - without incurring extra costs - from the base case of 20 years to 25 and 30 years has been calculated in Table 5 for each of the five production schemes illustrated in Table 3 and 4. These calculations have been made for specimen discount rates of 10% (base case), 6% and 4%. The table also shows the savings in total annual costs which would be occasioned by each extension from the 20 year life-span base case. Thus reduction in production costs could be made if an extension in the life of capital to the levels shown could be brought about by increased expenditure, either on an annual basis as part of operating costs, or as an increase in initial capital amortised according to the appropriate discount rate, or by using a combination of both.

10.8. It is evident from the table that, due to the high capital investment and lower running costs of MSF compared with RO, reductions in the costs of water produced by MSF are more proportional than corresponding reductions in those of RO outputs, and that these differences increase as discount rates fall.

10.9. For the above illustration, however, variations have been made in only three of the parameters used, and then only on the basis of "other things being held equal". Comparison of five methods was made for plants of equal capacity, although it is realised that economies of scale, especially in those using the MSF method, would have enhanced the results if optimum sizes of plant had been chosen in each case. Also, the changes in the parameters themselves would encourage shifts in the proportions of the factors utilised. A lowering of interest rates would not only reduce the annual cost of capital, but it would encourage the substitution of capital for labour, thus enhancing the extent of the savings illustrated. Similar shifts would result from other changes of the same nature. It is obvious that severe difficulties arise when using currently accepted procedures to decide between methods of desalination when all possible variations are introduced.

TABLE 5

Variation in Costs per M³ with Life of Capital for Various Discount Rates

Case I : Discount Rate 10%

Discount Rate	Capital Life (Yrs)	1	2	3	4	5
		$ Cost Per M³				
10%	20 Yrs	1.662	1.438	1.147	1.427	1.688
	25 Yrs	1.589	1.349	1.024	1.387	1.643
	30 Yrs	1.548	1.299	.956	1.365	1.618
(Reduction in Total Annual Cost in $)	20 - 25 Yrs	(618,102)	(753,577)	(1,041,461)	(338,686)	(381,022)
	20 - 30 Yrs	(965,256)	(1,176,935)	(1,617,227)	(524,964)	(592,701)

Case II : Discount Rate 6%

6%	20Yrs	1.464	1.303	1.017	1.235	1.468
	25 Yrs	1.375	1.194	0.867	1.186	1.412
	30 Yrs	1.319	1.127	0.773	1.156	1.378
(Reduction in Total Annual Cost in $)	20 - 25 Yrs	(753,577)	(922,920)	(1,270,074)	(414,891)	(474,161)
	20 - 30 Yrs	(1,227,738)	(1,490,220)	(2,065,987)	(668,906)	(762,044)

Case III : Discount Rate 4%

4%	20 Yrs	1.375	1.243	0.959	1.148	1.369
	25 Yrs	1.280	1.127	0.798	1.096	1.310
	30 Yrs	1.217	1.052	0.695	1.063	1.272
(Reduction in Total Annual Cost in $)	20 - 25 Yrs	(804,380)	(982,190)	(1,363,212)	(440,292)	(499,562)
	20 - 30 Yrs	(1,337,811)	(1,617,227)	(2,235,330)	(719,709)	(821,314)

11.0. COSTING THE PROVISION OF DESALINATED WATER

11.1. Desalinated water has generally been costed "from intake to output". That is according to the costs of the process used to transform saline water into water of a potable quality. However, this is not entirely valid when results are used for comparison with other methods. Sea-water is taken in raw for desalination, while, for example, water drawn from a river for conventional treatment has often been used several times upstream and treated before being returned to source.

11.2. Also, when costings are compared, it is generally assumed that all modes of treatment require a similar distribution system, and therefore do not affect subsequent costs. This is not necessarily so, and changes may be required to accommodate the water produced in each case. Product waters have different properties which have different effects on various parts of the distribution system. Desalinated water, for example, is very aggressive when passed through asbestos cement pipes, and leads to their rapid deterioration.

11.3. It is necessary, therefore, to examine the full cycle of utilisation of desalinated water from the intake of sea-water to discharge at the sewage plant, and to examine the main components of the cycle to see whether savings can be made, or extra expenditure is needed to reduce costs elsewhere in the system. Components worthy of examination are:

i) **The distribution network :** Considerable savings are often possible by reducing unaccounted for water, i.e. the difference between water produced and water sold. In virtually all the Arab countries data on this are insufficient, but it is generally thought that the percentage varies between 30% and 50%. Some is used in fountains and public places without being paid for, but much is lost through leakage or the overflow of reservoirs. Recent advancements in leakage detection and control can reduce unaccounted for water to about 5% or 10% (Ref.12 and personal contacts).

ii) **Storage :** The considerable variations in demand between summer and winter restricts the efficient use of the installed capacity of the desalination plant. This is basically due to the insufficient capacity for water storage. For this reason the desalination plant should be operated at its most efficient capacity and when excess water is produced it should be diverted to suitable aquifers and retrieved later (Ref. 11). This should result in appreciable savings in the production of water.

iii) **Sewage Effluent :** The collection and treatment of sewage effluent is of particular importance when desalination is being considered. Irrigation has been the commonest use made of treated sewage (Ref.4), but the economic benefits of such use should be carefully examined. It may be more beneficial to import agricultural products and to use the effluent for blending with brine at the point of intake for desalination, thus reducing desalination costs. Alternatively, the effluent could be used for recharging aquifers under careful supervision, in which case its quality should be improved by infiltration over the passage of time.

These are but examples of the many problems faced in the type of analysis proposed. An analysis in which each case and each location must be treated separately, and in which water provision, its use, and subsequent disposal or re-use must be seen as part of a circular process, so that the costing of water is carried out in such a way that comparisons can be made which permit the system to be selected which results in the cheapest cost of water on delivery to the point of use.

12.0. THE MODELLING APPROACH

12.1. To calculate the lowest cost of delivered water - that is the optimum price obtainable - all the contributory costs must be determined simultaneously and then fed into a computer model of the relationship between the costs. To this end, a model has been constructed which, although simple, is capable of testing some of the hypotheses in this paper as well as being expanded later for application in more specific situations.

12.2. The main components of the model are illustrated in Diagram 1. There are four sub-areas which require individual cost inputs: production, distribution, sewage collection and treatment, and disposal. These are assessed as follows:

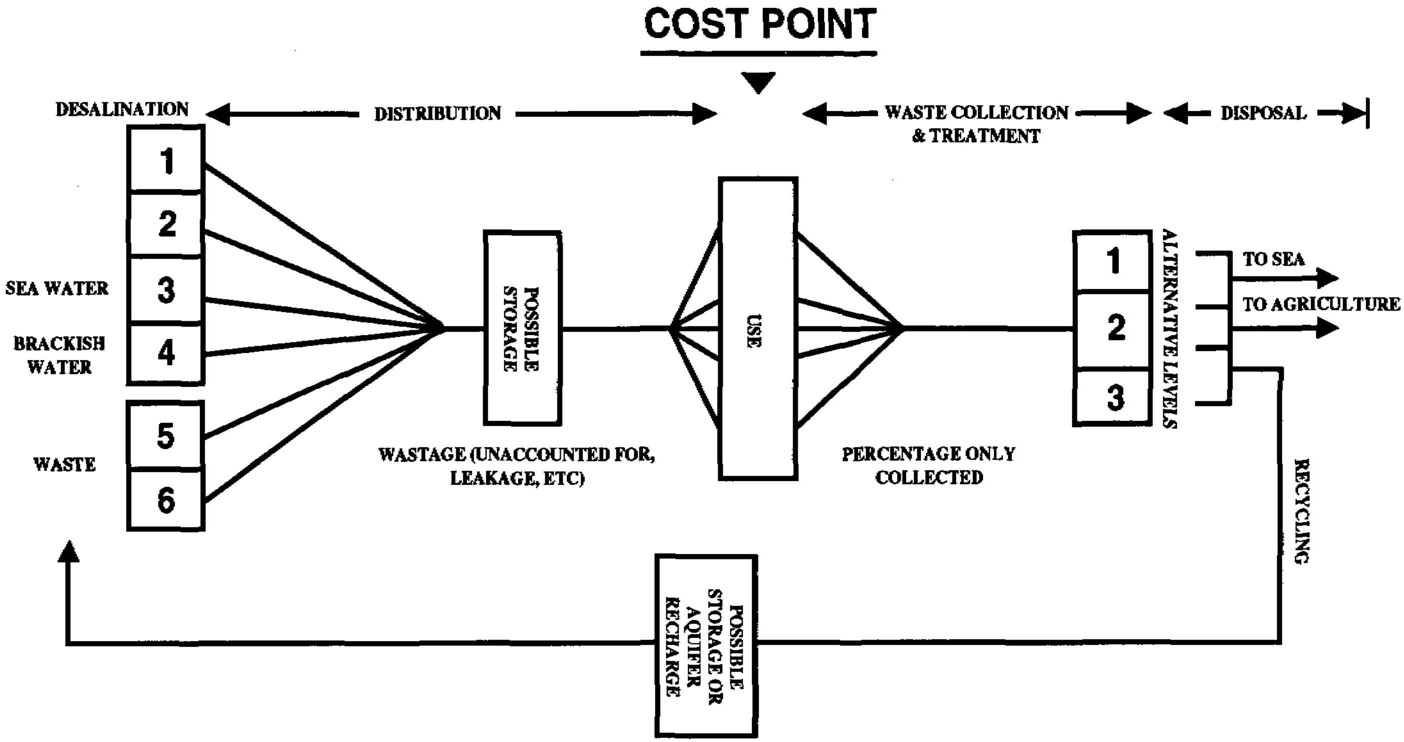
a) Production costs depend on those for the individual desalination systems available. These are inserted into the model and the costs are calculated for each m^3 of output.

b) Distribution costs are determined by adding the costs of the distribution system to the costs of production, allowing for a percentage of unaccounted for water, especially leakage, and then calculating the initial cost per m^3 of delivered water.

c) Sewage treatment costs depend on the percentage of the delivered water which is collected as waste water. The level of treatment required varies according to the subsequent disposal procedure to be adopted.

d) Disposal costs depend on whether sewage effluent is dumped into the sea, used for agriculture, or recycled through the desalination system.

DIAGRAM 1: FLOW PROGRAMME FOR A PRELIMINARY COMPUTER MODEL



12.3. A situation is hypothesized in which the required delivered quantity of water required is 350,000m^3 per day, (or 350,000 x 365.25 = 127,837,500m^3 per annum). In the base case there is an initial leakage factor in the delivery system of 30% and no recycling. Even though the initial cost of produced water is US$ 1.66/m^3, leakage and other costs raise the delivered cost of water to US$ 3.39m^3. Table 6 illustrates: (1) how the cost per m^3 falls as the quantity of sewage recycled is increased, thereby allowing for a reduction in the cost of sewage treatment and a lower intake of sea water for desalination, and (2) how a reduction in leakage lowers delivered costs as a result of lower production levels. These two improvements in combination seem able to reduce the cost of delivered water by over 50% under the conditions postulated.

12.4. However, such results cannot be obtained at nil costs, and the levels of savings must always be balanced against the costs of achieving them. In the case illustrated, if maximum leakage reduction and full recycling of waste (taken as 50% of delivered water) were achieved, the saving of US $ 1.74 per m^3 delivered would represent a saving of over US $ 222 million a year. A sum of this order would, if amortised, support an appreciable quantity of capital expenditure to be devoted to the system's improvement.

12.5. Although the model used is essentially very simple, it is being developed in order that it can be used to test alternative approaches to the problems of water shortages in individual locations. By including costs of each alternative available (e.gs. leakage reduction, extension of supply by MSF or RO, *disposal or recycling of water) and treating these according to the* parameters applicable to that location (e.g. discount rates, size of market, anticipated life of capital) then the optimum points of investment in each location's supply system can be identified. Given the rising cost of water from both desalination and the more traditional sources, it is no longer valid to assume that impending shortages in any situation should automatically be met by additional capacity in the sources of supply.

13.0. IMPACT ON THE ENVIRONMENT

13.1. The use of desalination has a positive impact on the environment. It helps to conserve water resources by enabling water which is otherwise useless for human consumption to be purified and also by providing a means for recycling waste water.

13.2. On the negative side, desalination processes produce reject brine with a very high concentration of salts. In the case of sea-water plants, this brine can usually be dissolved in the sea without much adverse effect, although a temperature differential between intake water and reject brine may affect marine organisms. To protect the environment against harmful effects, various measures can be adopted such as making special arrangements for intake and discharge outlets that take into consideration the main characteristics of the marine environment as well as the turbulence, temperature, and major constituents of the reject brine, which vary according to the process used.

TABLE 6

Cost Reduction by Leakage Control and Waste Recycling
$ Cost per M^3

Volume Recycled / Unaccounted for Water	0	50%	100%
30%	3.39	3.26	3.13
25%	2.96	2.83	2.71
20%	2.60	2.48	2.37
15%	2.30	2.19	2.09
10%	2.05	1.95	1.85
5%	1.84	1.75	1.65

13.3. By contrast, if reject brine from inland plant is deposited haphazardly it can have considerable adverse effects and pollute ground water irreversibly. To avoid this the brine can be deposited in lined ponds, spread out over the desert, or injected into the ground at great depths where it is not expected to harm the environment. Disposing of it safely can cost between 5% and 30% of the total cost of plant installation, depending on its type and location (Ref. 13).

13.4. Although there is still room for improving the environmental protection measures necessary when using desalination, they are attainable. There are even prospects for utilising beneficially the reject brine which is the main pollutant of desalination.

13.5. All in all, the adverse impact on the environment when desalination is adopted as a major source of potable water is minimal in comparison with the harm which has already been done to conventional sources of water. These have been deteriorating so much in quantity and quality that they have often reached a state where they cannot be replenished, let alone protected from further deterioration.

14.0. FUTURE GROWTH OF THE DESALINATION INDUSTRY

14.1. It is expected that the desalination industry will continue to increase. The International Atomic Energy Agency (Ref. 14) anticipates that the growth in demand for desalinated water will double in each decade over the next 20 to 25 years, implying an annual growth rate of 7.18%.

14.2. Various cost estimates for the installation of desalination plant (see inter alia Ref. 8, 9, & 10) have been analysed, and allowing for the current proportion of new plant using the two main desalination methods, the cost of new plant at 1989-1991 prices is estimated to be around $ 1687 per m^3 capacity/day[6]. Using the same sources, it can be estimated that the proportion of 1989-1991 annual operating costs attributable to the industry's manufacturing output, spares, membranes and, say, 10% of general repairs and maintenance would be about $ 105 per m^3/day.

14.3. Based on the world capacity in 1991 of 15.6 M m^3 /day (Ref. 15) and taking into consideration the above figures, Table 7 has be drawn up to compare the capacity and costs of the manufacturing output of plant and machinery for desalination for the years 1991 and 2016 using 1989-91 prices.

14.4. While a complete analysis would require more data and resources than are available, the above analyses show that the total call on the desalination industry for specialised manufacturing output destines it to become one of the world's major industries, growing from about US$ 4 billion turnover in 1991 to nearly US$ 57 billion in 2016 that is an annual rate of increase of 12.2% to cope with an annual increase in demand for water of 7.18%.

14.5. As already shown (Ref. 15) the six GCC countries have 49.7% of the world's desalination capacity and the Arab world as a whole just over 56%. Although these proportions are bound to change, the Arab world will remain one of the world's foremost users of desalination for the foreseeable future. Technological advances may, and hopefully will, reduce costs and increase efficiency in the industry, but it is up to the Arab world to ensure it is involved in future developments so that it may benefit from the advances financed by its patronage.

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6 See also Annex A Section (2) for further details of the basis of calculating the cost for m^3 of daily capacity.

TABLE 7

COMPARISON OF CAPACITY AND COSTS OF MANUFACTURE OF THE DESALINATION INDUSTRIES OUTPUT FOR THE YEARS 1991 AND 2016

Item	Capacity (Million m^3/day)		Cost (Billion US$/year)	
	1991	2016	1991	2016
World Capacity	15.6	88.25	-	-
Total 0 & M cost at 105 $ m^3 capacity/day	-	-	1.64	9.27
Additional Annual Capacity	0.25	6.34	-	-
Cost of additional Investment at 1687 $ m^3 capacity/day	-	-	0.42	10.69
Replacing Capital (assuming 20 years life span)	1.2	22.07	-	-
Cost of replacing capital at 1687 $ m^3 capacity/day	-	-	2.03	37.22
Total			**4.09**	**57.18**

15.0. INTERNATIONAL INSTITUTIONAL SET-UP

15.1. Research carried out by the existing institutional set-ups in the major oil-producing countries has led to improvements in manufacturing standards, particularly with regard to protection against corrosion, optimum operating procedures, and the use of chemicals. The knowledge of such innovations has, however, been confined mainly to dialogue between manufacturers and researchers who have used it to update technical specifications (Ref. 16). Evidently there is a need for all the available experience to be brought together and streamlined so that improvements can be suggested in both the technology of desalination and the management of desalinated water.

15.2. This could be effected by an international set-up with the following objectives:

1. The collection of data from all the world's desalination plants, particularly those in the GCC countries, placing special emphasis on the quality of feed and product waters, the pre-treatment of brine, energy consumption, performance, the main characteristics of operation and maintenance and the relative advantages and disadvantages of different procedures.

2. The identification and financing of promising fields of research such as improvements in construction materials and process chemicals, the protection of the environment, alternative energy sources - particularly solar energy and nuclear power - and the use and/or extraction of minerals from brine.

3. The provision of specialised advice from a roster of experts drawn up to review designs and alternative technologies.

4. The co-ordination of the above activities by contacts with the governmental, academic, and manufacturing institutions which could try to make the following contributions to the furtherance of desalination technology:

A. Governmental Institutions

a) to subsidise major research and to accelerate the development of promising technology.

b) to assess the economics of using desalination as part of comprehensive water supply schemes that optimise plant operation, reduce unaccounted-for water, increase storage capacity, use aquifer recharge recovery, and maximise the re-use of sewage effluent.

c) to study the optimum conjunctive use of all water, especially in arid zones, i.e. desalinated water, brackish water, and sewage effluent.

d) to establish standards for the protection of the environment when a desalination process is used.

e) to assess the prospects for privatisation in terms of the type of management and procedures required and the water supply organization's relationship with the government concerned.

B. Academic Institutions

a) to identify institutions interested in promoting research related to desalination.

b) to subsidise research.

c) to establish prizes for research in order to encourage international talent to participate more actively in the development of desalination.

d) to propose desalination syllabi to be included in university courses.

C. Manufacturing Industry

a) to establish standards for all materials and replacement parts.

b) to publish manuals specifying the main components of desalination plants.

c) to establish factories for manufacturing desalination plants[7] and/or their components in industrial and also in developing countries where industrial capabilities are available.

15.3. It is envisaged that the proposed international set-up will rely basically on experience available in user countries and on the extensive experience in the design and manufacture of desalination plant in industrial countries. The management of such a set-up requires the backing of all concerned with the industry and they should be represented by a board of directors with full autonomy to direct the institution towards its objectives.

15.4. Substantial financial backing would be needed to establish a set-up of the calibre required to bring about major developments in desalination processes according to the broad outlines described above. The capital and running costs could be raised from sources which will benefit from the industry, either as users or producers. The following sources could be considered:

7 Shipyards, some of which have been abandoned due to the prevailing economic recession, are particularly suited for the construction of MSF and/or ME desalination plants.

(i) **Manufacturers** : These normally allocate budgets for research, but these are affected, sometimes drastically, by fluctuations of the market and some of their work duplicates that of their competitors, so it would be in their benefit to direct some of their research budget towards the support of international research which could benefit all concerned.

(ii) **User countries** : Countries using desalination have been adopting severe tendering conditions to cover all possible risks and introducing hard financial conditions and penalties which have resulted in an increase in the capital cost of construction work (Ref. 17). These conditions are partly due to lack of confidence in the industry. A well established set-up would help to boost the confidence of the would-be owners of desalination plants and thus help to reduce the cost of desalination.

(iii) **Funding Institutions** : These have a direct interest in the development of the desalination industry particularly now that shortages of potable water are increasingly arising in remote areas of developing countries. The institutions' financial support will be very beneficial if low-cost and locally made desalination facilities can be developed.

15.5. The location of an international set-up of this nature should be somewhere with easy access to sources of technology, on one hand, and to practical experience in operation and maintenance, on the other. These tend to be situated on opposite sides of the world, but a compromise should be one that benefits both user and producing countries, with the prestigious aspect of the location being of minor importance. The main considerations should be on ease of communication, availability of expertise and access to information and data.

16.0. CONCLUSION

16.1. The inception and development of desalination have taken place in unusual circumstances. While major technologies usually emanated from industrial countries to satisfy increasing demand, desalination became necessary when industrial countries had no need to promote it. The oil boom in the Middle East created a desalination market which grew rapidly with the result that research was limited to in-house activities within the industry.

16.2. The choice between desalination options is not clear-cut but subject to many variables and it should not be left to the influence of manufacturers. The requirements of industrial countries differ from those of developing countries where there will in the future be a greater demand for desalination.

Developing countries, lacking in expertise and foreign currency, will be anxious to operate simple desalination plants that require spare parts either produced locally or obtained from a wide market not restricted to certain brands of products.

16.3. While the cost of desalination has been branded as high due to its high energy consumption, it is becoming evident that other options for providing water can be as costly, and have, in addition, restrictive disadvantages connected to the need for long-term commitment and planning.

16.4. A reduction in the cost of desalinated water seems possible with efficient management of the water cycle. The reduction of unaccounted for water, the reuse of sewage effluent, and in the case of dual purpose plant, the provision of balancing storage capacity to even out fluctuations in supply and demand, are basic elements of the water cycle that have to be improved when desalination is considered.

16.5. The desalination industry is set to become an important major industry, probably with a positive environmental impact, which will be widely in demand in industrial and developing countries. Concerted efforts should therefore be made to make better use of the experience gained so far, particularly in oil-producing countries, and the expertise available in industrial countries by establishing an international institutional set-up to promote the industry, increase the scope of public research work, and assist would-be owners of desalination plant in its choice, installation and management.

ANNEX A

Basis for Calculating Costs

1. The Peace Pipeline (Page 19)

With a proposed construction period of 10 years, the capital costs incurred in each year also incur a "carrying charge" depending on the rate of interest or discount rate used. With a total expenditure of $ 20 billion spread evenly over the 10 years, the true cost of the investment becomes $ 33.43 billion if a discount rate of 10% is adopted or $ 25.756 *billion if the adopted rate is* 5%.

With a 50 years life-span, the "present worth factor" at 10% is 9.9148 i.e. the total investment cost divided by this factor set aside each year at 10% will reach the same amount at the end of 50 years as would have been reached in the same time if the whole cost of the original investment had been invested at the same rate. The annual capital cost at 10% is therefore $ 3,371,727,000 at a 5% rate of discount this falls to $ 1,410,831,567.

A delivery to 15 million people of .35M^3 per day implies a total annual delivery of 1,917,562.500m3. The annual capital costs alone be borne by each M^3 would be $ 1.758 using a 10% rate of discount and $ 0.735 using a rate of 5%.

2. The Growth of the Desalination Industry (Page 28)

A number of costings for specimen MSF and RO plants were reviewed, and the components for (a) plant and machinery directly relating to desalination in the capital costs, and (b) to replacements, spare parts and specialised requirements for desalination in the operating costs, were isolated. The totals were averaged across the plants reviewed, and reduced to costs per M^3 of daily capacity. In these calculations, all site works and buildings, all local labour and other local inputs, etc. were disregarded, also all elements of costs deemed to be attributable to a electricity production rather than water.

The demand on the industry proper was then calculated in the three parts:

1) The growth element, which represented the addition required in to any year to total daily capacity. This was 7.18%, the figure required to double capacity in any decade.

2) The operational element. Spare parts, replacements, membranes, chemicals, and an arbitrary addition of 10% of operational and

maintenance to allow for miscellaneous requirements. This was calculated against total capacity in each year.

3) The replacement element. Given an average plant life of 20 years, then in any one year the plant established in the year 20 years previous will need replacing.

The total of these three elements was deemed to represent the demand on the industry in each year for which it was calculated. Of course, the calculations are based on a number of assumptions. (1) Constant prices based on 1989-90 figures, i.e. no inflation and no technological change representing increases or decreases in real prices. (2) The proportions of the various methods used will remain constant. Movement between MSF & RO will alter the capital inputs somewhat, but with some compensatory movement in annual operating costs. These two are probably the major assumptions required, but it is unlikely that their relaxation would alter the basic thrust of the conclusions drawn.

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