WORLD CONGRESS ON DESALINATION AND WATER SCIENCES

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Taysir Ali Dabbagh
Senior Engineering Adviser
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International Desalination Association (IDA)

Abu Dhabi, U.A.E. November 18 - 24, 1995

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ABSTRACT

The economy of the Gulf Region has developed in the last half century in conditions unprecedented in human history. The "Oil Boom" took the region from scarcity to abundance and enabled it to take advantage of the momentous advances in technology and bring in up-to-date innovations and the benefits of the computer revolution. To catch up on lost time, the region spared nothing in developing its economy on the most sophisticated basis, placing special emphasis on the infrastructure: highways, electricity and water were high on the agenda. But as the exceptionally high standard of living was achieved, the demand for water increased and the limited natural water resources declined.

It is becoming increasingly evident that desalination, when compared with alternative sources of water, is the only reliable source of water for the region in the future. Its advancement and improvement are thus fundamental to the regions welfare. The demand for desalination is also increasing in some developing countries where it imposes itself as the only alternative. As for industrial countries, desalination now has a multitude of uses from the ultra-purification of water to the refining of sewage effluent. In fact, desalination is competing favourably, in some locations and in certain conditions, with the long distance conveyance of water by pipeline or tankers and even competing favourably with the impounding of surface water by small to medium size dams.

Advances in the use of desalination require not only technological innovations, but also efficient management. In the industrial countries the increased efficiency in the management of energy, coupled with design improvements, brought about a remarkable reduction in the consumption of oil - and consequently its cost - within a decade. This experience should provide lessons for bringing about the

*The views expressed in this paper are solely the views of the author and do not represent the views of Kuwait Fund for Arab Economic Development.

more efficient use of desalinated water and thus maintaining its cost at a level capable of sustaining the economic growth expected in the region.

The management of desalinated water should control the water supply system from inception to re-use, since the cost of desalinated water is not only linked to efficient plant operations but also several other factors, such as the storage capacity, the amount of unaccounted for water, and the extent of the reuse of sewage affluent.

The paper reviews, the impact of the oil boom on the region, the expected water crisis and the need to diversify national income. It shows conclusively that desalination is the only viable long-term alternative to the problem of supplying the region with water. The cost of this water must be reduced so as to lessen the burden on the national budgets and to encourage appropriate industrial development.

Advances in desalination technology, should be viewed as a potential lifeline for a large region in the Middle East which could be adversely affected by a prospective shortage of potable water. For this reason, public research should be widely funded by the major users of desalination, particularly those in the Gulf. To this end, mega research fields have been identified and cost estimates have been made, in order to establish the funding and management required. The paper argues that the results of such research should be made public and thus intensify the competition between manufacturers and thereby result in a reduction in the cost of desalinated water.

The present fragmented approach to the management of desalinated water and the restriction of research mainly to in-house research carried out by manufacturers are the two main major constraints on the rapid expansion of the efficient use of desalination, which is vital for maintaining the high standard of living in the region and also contributing to its economic growth.

Key Words : ***Alternatives, Appropriate, Agriculture, Cost, Construction, Desalination, Development, Delivered, Effluent, Funding, GCC, Gulf, Guidelines, Industry, Management, Oil, Quality, Research, Restructuring, Recovery, Requirements, Reduction, Re-use, Sources, Standards, Storage, Survey, Unaccounted-for.***

THE ROLE OF DESALINATION AND WATER MANAGEMENT IN SUSTAINING ECONOMIC GROWTH IN THE GULF

WATER AND CIVILISATION

The history of civilisation is closely linked to the availability of water which has always been the primary source of economic growth, being directly related to food production and thus to the well being of the communities concerned. This phenomenon was not the case in the contemporary Gulf region where wealth sprang almost entirely from oil production and the availability of natural water resources played a minimal role, if any, in promoting its economic growth. Indeed, no nation so deprived of water has managed to achieve such a high standard of living. The money spent on producing potable water has been unequalled in human history, yet the region has remained adamant that food production and the cultivation of greenery are extremely important goals to pursue.

Invariably, the history of nations reveals that the survival of any civilisation is directly related to water management. The shortage of potable water, especially in hot climatic zones, causes social discord and the disruption of economic development. It has been said that one may measure the state of a civilisation by the state of its water-related infrastructure within the total infrastructure of that civilisation (Yevjevich, 1992). In fact, it was the development of water supply, waste removal and drainage that made dense settlement possible. It has been said that in ancient Greece "attention to water supply and drainage, is the *sine qua non* for urbanisation, and hence for that human condition we call civilisation" (Crouch, 1987).

In pre-Islamic Mecca, being in a barren land, Abraham, father of the Arabs, pleaded to God for help: " My Lord, I have made some of my seed to dwell in a valley where is no sown land by The Holy House. Our Lord, let them perform the prayer, and make hearts of men yearn towards them, and provide them with fruits, haply they will be thankful" (Koran, Sura "14", Ibrahim, Verse "36"). With the spread of Islam and the increasing number of pilgrims visiting Mecca every year - over two million this year - it is evident that Abraham's prayer has been answered. For, in spite of Mecca's aridity, potable water has been made available for its most unusual fluctuation in water demand: a peak equal to several times normal demand for only a few days. This has been achieved not only by prayers, but also by hard work and through the determination of the concerned authorities to adopt heroic measures, against all odds, to ensure the availability of potable water for the pilgrims.

This is as true of the present unprecedented expenditure on the provision of desalinated water as of the historical attempts made by various caliphs. During the expansion of the Islamic empire, the first caliph of the Ommayyad dynasty in Damascus, Muawiyah Ibn Abi Sefian, established and improved the aqueducts in Al-Haram, Mecca. When these became dilapidated, the Caliph Haroun Ar-Rashid of the Abbasid dynasty in Baghdad improved them and collected all the flows into one duct called "Ar-Rashadd" (Al-Azraqui, 1859). It did not last long, so Zubeidah, wife of Haroun Ar-Rashid ordered the building of an aqueduct from Al-Haram to the rest of Mecca in the year 194 Hijri, about 733 AD.

This did not prove satisfactory, so she ordered her engineers to bring water from beyond the holy boundaries of Mecca. At the time this was believed to be impossible as the water had to go through mountains, hills and valleys. However, she budgeted a great amount of money and made up her mind to proceed with the project. The aqueduct was built until it reached a place called "Thaniat Khull" which could not be surmounted. Therefore, " she ordered for the mountain to be dug and spent money to an extent that few people would spend, until the water flowed" (Al-Azraqui, 1859 and al-Fakehi et al.). Later she ordered a new aqueduct to be connected to this one and built basins to collect the wadi's surface run-off and also connected these. The aqueduct continued to convey water to Mecca until the early nineteen seventies when the flow reaching Mecca was about 2.0 million m3/year. However, it must have transported much more water in its prime since a lot of water losses were being incurred en route. To avoid these losses and to cope with the city's development it was replaced by pipelines in the mid nineteen seventies.

THE OIL PRICE BOOM

The oil boom in the seventies launched the Gulf region into an era of unprecedented economic development. The increasing price of oil led to an exceptionally high standard of living within a remarkably short period - little more than two decades. Meanwhile in the industrial world, which had recovered from the aftermath of the Second World War, technology was progressing rapidly and the computer revolution was taking place. Both the high income and the technological advances available, steered the Gulf region towards accelerating development in all sectors of the infrastructure: highways, airports, communications and, most importantly, water for domestic, industrial and irrigation purposes.

The extent of the expenditure in the last 25 years on expanding the infrastructure rapidly over the GCC region is shown by the increased consumption of cement - which may be used as an indicator of economic development. In Figure 1, the construction boom in the GCC countries is clearly reflected in a rapid increase in cement consumption. Compared with other industrial countries with relatively similar sized populations, such as Australia and Canada and other developing countries with much larger populations, such as Pakistan, the increased consumption, particularly towards the end of the eighties, is unparalleled. This is also the case in comparison with a rapidly developing country such as Malaysia and an oil-producing country such as Venezuela. The explosion of development in the GCC countries was totally different from other countries where the increase in development was gradual. It is essential that the unusual circumstances underlying regional development in the GCC countries are taken into account when planning for sustainable economic growth and the well being of the population. The sustainability of future economic development in the GCC countries depends on the great progress which has already been achieved in the last two decades being gradually absorbed and developed on sound basis.

Adopting the standard of living of the industrial world was not difficult for the Gulf region. All that was needed was to buy the goods already available in abundance. Even in developing the infrastructure, only minor adjustments had to be made to accommodate the special needs of the local climate. Desalination was the exception to the rule: it was first developed on a large scale for use in the Gulf. Unlike other technologies which appeared at the time, the development of desalination was not rated as top priority in the industrial world; there were far more important priorities in such fields as electronics, space, offshore oil exploration and computing. There has been little incentive to minimise the cost of the process and scientists have been attracted to fields of research where financial rewards seemed more imminent.

Dependency on desalination, backed by substantial funds, has substantially increased during the last 15 years in most GCC countries. Data regarding installed and planned capacity and demand are given in Table 1. Kuwait and

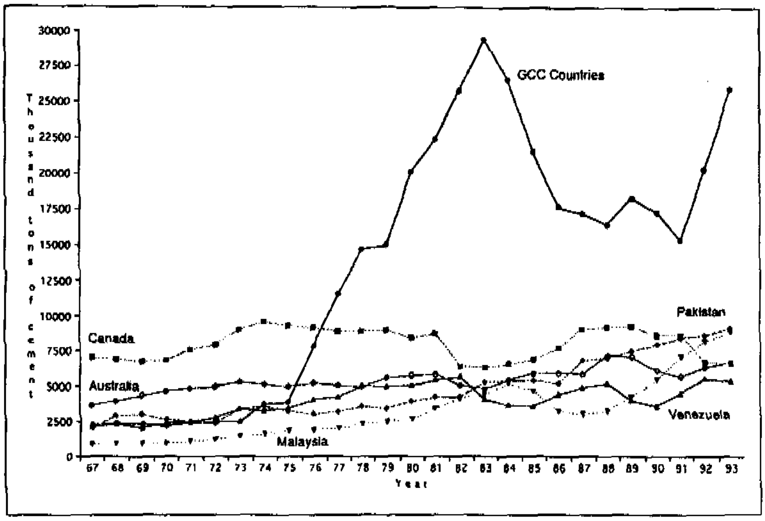

FIGURE 1 : CEMENT CONSUMPTION IN GCC COUNTRIES COMPARED WITH SOME OTHER SELECTED COUNTRIES

SOURCES : CEMUREAU, (1991), INTERNATIONAL CEMENT REVIEW (1994), GOIC (1982) AND GOIC (1994)

Qatar now have sufficient desalination capacity to meet their entire current domestic and industrial water demand, while in Saudi Arabia, the United Arab Emirates, Bahrain and Oman, desalination accounts for between 47% and 75% of domestic and industrial public supply (Al-Alawi et al., 1994).

TABLE (1)

DESALINATION PROJECTS IN GCC COUNTRIES

	1990				2000			
Country	Installed Desalin Capacity	Desalin Product-ion	Domestic/ Industrial Demand	Desalin to Demand Ratio (%)	Planned Desalin Capacity (new)	Total Desalin Capacity	Domestic/ Industrial Demand	Desalin Ratio (%)
S. Arabia	950	795	1,700	47	339	1,289	2,900	44
Kuwait	318	240	303	80	110	428	530	81
Bahrain	75	56	103	54	65	140	155	90
Qatar	112	83	85	98	104	216	140	100
UAE	502	342	540	63	270	772	832	93
Oman	55	32	86	37	13	68	147	46
Total	2,012	1,548	2,817	-	901	2,913	4,704	-

SOURCE : AL-ALAWI *et al* (1994)

It is apparent that the desalination industry will continue to grow and become a major industry competing with shipbuilding and other large industries. Table 2 shows the increasing volume and investment expected in this industry by the year 2016.

TABLE (2)

EXPECTED INCREASE IN CAPACITY AND INVESTMENT IN THE DESALINATION INDUSTRY BY 2016

	Capacity (mcm/day)		Cost (billion US$/year)	
Year:	1991	2016	1991	2016
World capacity	15.6	88.3		
Total O&M cost at $105 m³/day capacity			1.64	9.27
Additional annual capacity	0.25	6.34		
Cost of additional investment at $1687 m3/day capacity			0.42	10.69
Replacing capital (20 year life assumed)	1.25	22.1		
cost of replacing capital at $1687 m³/day capacity			2.03	37.22
Total			4.09	57.18

SOURCE : DABBAGH *et al* (1994)

THE "OIL CRISIS"

Immediately after the sudden increase in oil prices in 1973, the governments of the industrial countries which were members of the Organisation for Economic Co-operation and Development (OECD) made an extensive examination of its effects. They believed the price increase could adversely affect their own industrial growth in particular, and the world economy as a whole by jeopardising the economic and financial development upon which non-industrial countries rely.

To limit this threat policies were proposed and adopted which placed special emphasis on the proper use of oil as a source of energy; it had often been extravagantly used due to its low cost. Governments preoccupation with energy conservation, previously confined to a very few countries with particular supply difficulties, suddenly increased. Every major consuming country introduced a set of mandatory conservation measures accompanied by an information campaign aimed at encouraging voluntary reductions in consumption.

The policies of OECD countries for conserving energy and utilising it more efficiently had the following objectives (OECD, 1975).

(i) Achieving security of supply
(ii) Maintaining a reasonable cost of imported energy
(iii) Maintaining reasonably stable price levels
(iv) Attaining equilibrium in international payments
(v) Maximising economic efficiency
(vi) Protecting the environment
(vii) Controlling business activities
(viii) Controlling access to the industrial countries own resources

Energy conservation possibilities were considered in the various sectors of the economy - electricity conversion, industry and transport, as well as the residential and commercial sector - in order to show the potential savings to be made in sectoral consumption, the cost benefits, and the type of policy actions available.

It was concluded that, by better energy management and the reduction of waste, an increase could be brought about in the proportion of the total primary energy input that was actually used. Figure 2 shows diagrammatically the relationship between energy price, government policy and useful energy. Although it is technically feasible to use a large proportion of the total energy, it is not economic to do so. However, government conservation policies or an increase in energy prices could bring about more efficient energy use, which would increase the proportion of energy used. Increased prices would also increase the size of the fraction that it was economically worthwhile to use. This fraction, along with the fraction of energy that it was technically feasible to use, could be enlarged by Government policies promoting research and development.

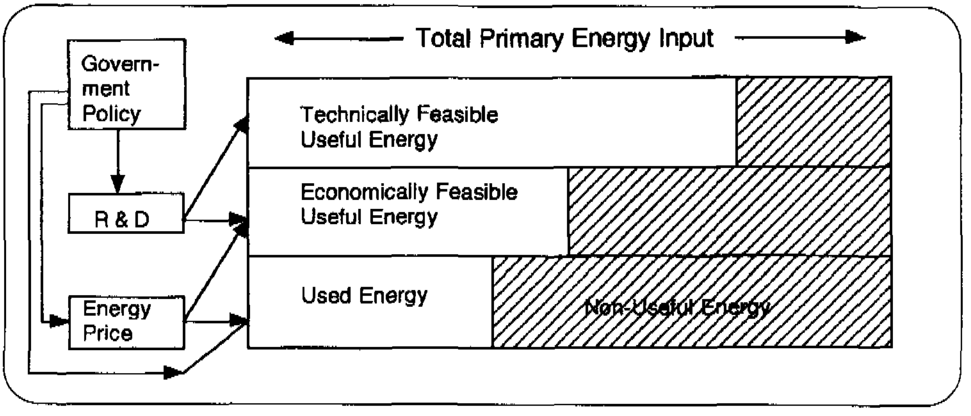

FIGURE 2: THE MAIN FACTORS INFLUENCING THE PROPORTION OF USEFUL ENERGY OBTAINABLE FROM THE TOTAL PRIMARY ENERGY INPUT

SOURCES : OECD (1974)

ANALOGY BETWEEN ENERGY USE AND WATER USE

An analogy can be drawn between this concept of used energy as a proportion of the total primary input and the present water situation in the Gulf region. The present tariff structure is very low and will result in the continuation of the prevailing misuse of water as the consumer does not feel its real value, but increasing the price of water will lead to greater efficiency and thus the use of a greater fraction of the total resources available. As with the use of energy, increasing research and development in the water industry can lead to an increase in the fraction of the total water resources that it is economically and technically feasible to use.

In fact, the adoption by the OECD countries of the policies outlined above, commencing from 1974/5, led to results that surpassed expectations and brought about a reduction in energy consumption within a shorter period than was anticipated. In the late seventies almost all leading specialists and oil experts, including the OECD, expected that OPEC oil exports would continue to rise, but they underestimated the effect of the OECD measures and from 1979 the export of OPEC oil dropped sharply. The predicted oil production for the eighties and nineties, as estimated in 1981 by adopting different scenarios, are shown in Figure 3 together with spotted predictions made in earlier years (Pearce, 1981). As a result, the price of oil settled near to its price prior to the oil crisis, (Flavin, 1994) as seen in Figure 4. It is evident that the predicted and actual productions were very different: oil production was expected to be much higher than turned out to be the case. In 1985, the industrialised countries used 30% less energy and 40% less oil to produce a unit of GNP than they did two decades previously (Nazer, 1995).

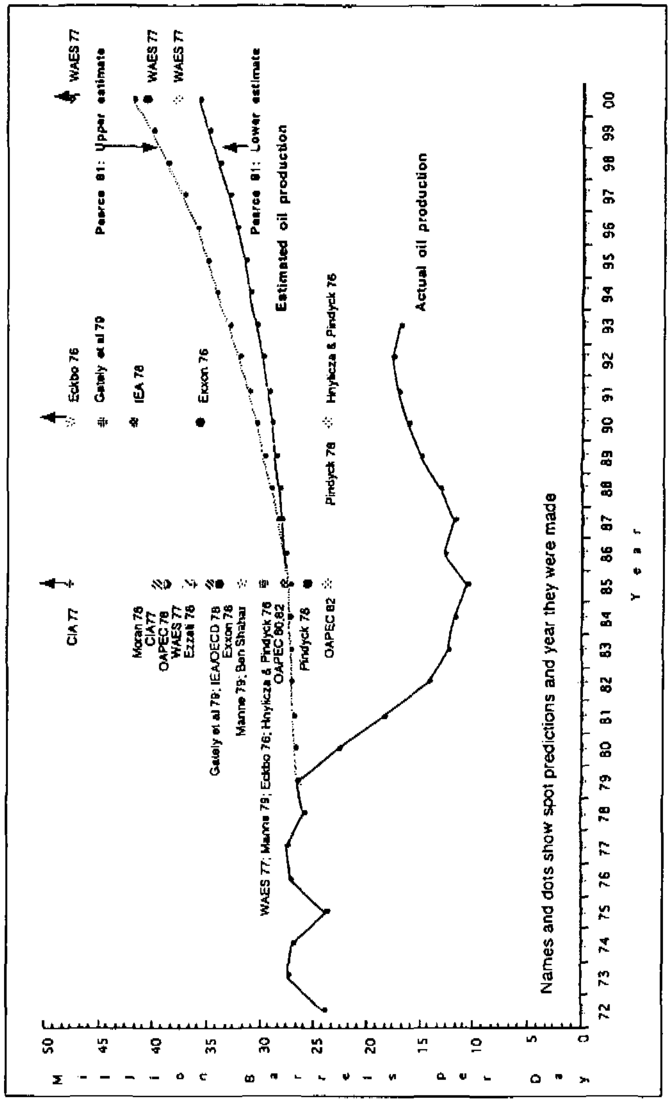

FIGURE 3 : OPEC OIL EXPORTS 1972 - 2000 : ACTUAL AND ESTIMATED

SOURCES : PEARCE (1981), OPEC (1993), AOPEC (1978), AND AOPEC, (1982)

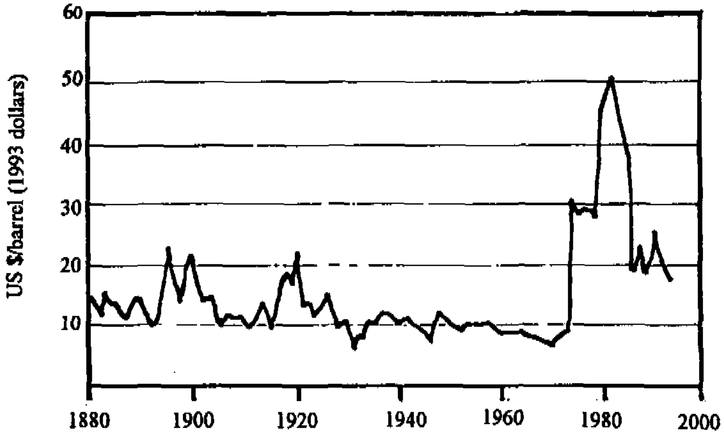

Figure 4 : The Fluctuation of Oil Prices
Sources : Flavin *et al*, (1994)

NEED TO DIVERSIFY NATIONAL INCOME

The large differentials between the predicted and actual output of oil has had an adverse effect on sound planning in the Gulf countries. The expected ever-increasing production and price of oil encouraged planners to embark on ambitious long-term development plans. Each increase in oil prices and income was followed by an increase in planned expenditure - an increase not matched by a decrease when circumstances changed. After 1979, although the export of oil had dropped sharply, the Gulf region used its vastly increased oil revenue to launch an even more ambitious economic development programme, as indicated by the increased cement consumption shown in Figure 1.

OPEC's domination could always prevent prices from rising by increasing production, but some factors affecting the fluctuation in oil prices were outside the control of oil producers, as when the energy saving measures taken by the industrial countries led to a reduction in oil consumption and price. After 1981, OPEC encountered difficulty in preventing prices from falling because of the member countries strong dependence on oil revenue to finance ambitious development programmes and their inability to reduce production (Pakravan, 1984). Agreeing on quotas became increasingly difficult as each producer has interests which may conflict with those of others. The result of all this became clear in financial terms. The income of the Arab oil-producing countries dropped from US$ 216.9 billion in 1980 to US$ 86.3 billion in 1994 (Hammad, 1995).

The unpredictable fluctuation in oil prices has also had an adverse effect on the economy of the region. The budget allocation for desalination has been restricted by falling oil revenues and by increased expenditure on regional defense. Many proposed new desalination projects have been delayed and new approaches, such as privatisation plans, are being given serious consideration by several Gulf countries (Al-Alawi, et al 1994). A further future long-term threat to both sales and prices of oil is presented by the industrial countries' attempts to cut down their reliance on oil by introducing green taxes which aim to reduce the pollution caused by oil and to encourage research into other cleaner sources of energy. There is thus clearly a need to diversify the sources of income for the region, taking into consideration its water resources and the projected water demand. Apart from overseas investment, the two main areas where this might be achieved are agriculture and industry.

Development of the Agricultural Sector

The agricultural sector relies basically on irrigation and its development will require vast amounts of water and put further demands on already highly depleted unrenewable natural water resources. Irrigation in the Gulf region increased substantially in the eighties, particularly in Saudi Arabia, and resulted in extensive mining of deep aquifers (Alawi et al, 1994). In Qatar the renewable water resources are now totally depleted (World Resources, 1993). Such mining will continue to cause lowering of the water table and result in greater pumping costs. The other major source of water in the region, apart from deep aquifers, is sewage effluent. This new source of water is increasing with the increasing demand for potable water. It has costly origins and its utilisation should be considered on account of the potential economic return. Since expanding agriculture substantially would result in the depletion of the deep aquifers or, indeed, the misuse of expensively created sewage effluent, it does not seem to be economically viable on a large scale. This conclusion has been echoed in Saudi Arabia's Fifth Plan regarding water depletion and land distribution where the further large-scale expansion of agriculture was reviewed critically so that better use could be made of the available water resources (Montagu, 1994). This would require an expansion in the employment of efficient irrigation systems, especially those which minimise the losses due to evaporation because of the high temperatures prevailing in the region.

Development of the Industrial Sector

The industrial sector is playing an increasingly important role in helping to sustain economic development. Considerable experience has been gained over the last two decades and the authorities have learnt the importance of basing planning on comprehensive studies that show the economic viability and technical soundness of industrial projects prior to embarking on their implementation (GOIC, 1993).

The diversification of the industrial sector emphasises the growing importance of this sector in comparison with the agricultural sector. The growth of industrial development in the GCC countries is shown in Table 3 in terms of the number of functioning factories, invested capital and the size of the work force. Recently new policies have been adopted towards industry, and Gulf oil producers have been attempting to improve the added value received from each barrel of oil by investing heavily in oil products and petrochemical manufacture. Kuwait has introduced an offset programme whereby foreign firms are being encouraged to set up in Kuwait, bringing with them their own expertise, in return for a share in profits.

TABLE (3)

INDUSTRIAL DEVELOPMENT IN THE GULF REGION

Indicators	Years		Annual % growth
	1975	1990	
Number of functioning factories	1626	4896	7.6
Invested Capital (Million US$)	4125	35072	15.3
Number of work force	48000	285074	12.6

SOURCE : GOIC, (1993)

The industrial sector presents greater scope than the agricultural sector for absorbing the expanding active population which will represent the highest percentage of the population of the Gulf region for some time to come. The high standard of living which resulted from the oil boom in the GCC countries, assisted in increasing the birth rate in this sparsely populated region. The rate of increase in population is very high, varying between 3.1% and 6% for the total population. The rate for the world as a whole is 1.6% and for the less developed world 2.2%. It is worth noting that the growth rate in Oman and Qatar are of the highest in the world.

The rate of increase is also high for the indigenous population, as shown in Table 4. It is expected that the active population aged from 15 to 64 in the GCC countries will represent between 50% and 70% of the population by the turn of the century. and continue to be in the same range, if not more, in accordance with the established trend based on the available statistics for the last fifty years (GOIC, 1993). Although this work force will be gradually replacing the expatriate work force, the indications are that there will be an excess of indigenous workers with high qualifications requiring professional and managerial employment, as excellent opportunities have been provided for increasing the education and expertise of the new generation since the advent of oil wealth. The expansion of the industrial sector is more likely to provide attractive job opportunities than the agricultural sector.

TABLE (4)

POPULATION OF THE GULF REGION

Country	Population (000)1992	Growth Rate 1985-1992	
		Total	Indigenous
Saudi Arabia	15,909	3.5	(n.a.)
Kuwait	2,125	4.5	(3.5.)
Bahrain	532	3.2	(4)
Qatar	524	6.0	(n.a.)
UAE	1,668	3.1	(n.a.)
Oman	1,647	4.9	3.52

SOURCE : THE WORLD BANK ATLAS, (1994), GOIC, (1993) AND POPULATION CONCERN (1994)

There is ample evidence that increasing allocations from oil revenue, will be directed towards appropriate industrial developments in the Gulf region (Hamad, 1995. Nazer, 1995), The prospects of the increasing availability of highly qualified personnel in the region and the availability of power generation facilities will give priority to industries which have the edge over competitors from outside the region. It is natural therefore that priorities are given for investing in catalysts, petroleum refining, and petrochemical industries which fit into the environment of the region. Some of these industries have already scored remarkable successes and are attracting investment. Their prospects will be substantially boosted by an efficient infrastructure, the most valuable element of which is the water supply which relics mainly on desalination to satisfy industrial water demand.

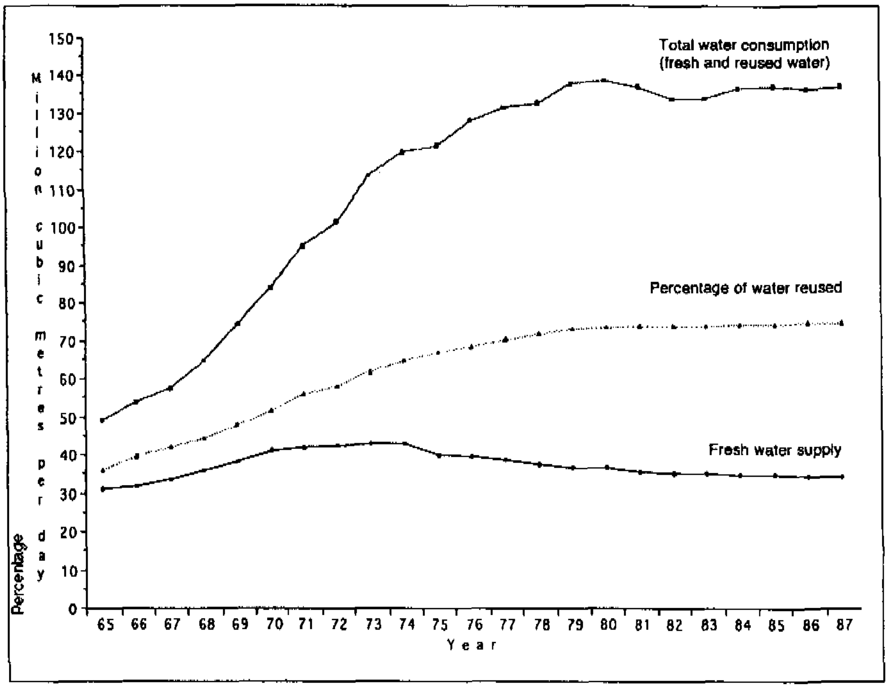

FIGURE 5 : REDUCED FRESH WATER CONSUMPTION AND INCREASED WATER REUSE IN JAPAN

SOURCE : ADAPTED FROM GOTO, (1992)

A further advantage of expanding the industrial sector is that, unlike the agricultural sector, its water supply could be reused so as to reduce its water demand. In Japan, the reuse of industrial water has increased from 36.2% in 1965 to 75% in 1987, as shown in Figure 5 (Goto, 1992), Because of repeated reuse, the additional fresh water intake is on the decline. As a result of this increased efficiency of reuse, Japanese industry used less fresh water in 1987, after its massive industrial expansion, than in 1973. This has been achieved in a country where the per capita share of the natural renewable water resources is about 4430m3 while in the Gulf countries it varies between zero in Kuwait, Qatar and Bahrain; 160m3 and 190m3 in Saudi Arabia and the UAE respectively; and 1360m3 in Oman (The World, Resources, 1993).

THE WATER CRISIS

The impact of rapid economic development on the utilisation of water resources in the Gulf region became very acute. Demand increased substantially, surpassing the availability of water resources in a region deprived of perennial surface water, and led to the reliance on desalination as the main source of water. Table 5 shows the vast increase in water demand in the Gulf region. Present forecasts exceed those for similar regions of approximately the same population.

TABLE (5)

THE INCREASE OF WATER DEMAND IN THE GULF REGION (MCM)

Country	1980		1990		Total Increase 1980 - 90 (%)		Annual Increase (%)	
	Domestic & Industrial	Agriculture	Domestic & industrial	Agriculture	Domestic & Industrial	Agriculture	Domestic & Industrial	Agriculture
Saudi Arabia	502	1,860	1,700	14,600	239	685	12.5	28.5
Kuwait	146	40	303	80	107	100	7.5	7.4
Bahrain	46	92	103	113	124	22	8.5	2.2
Qatar	50	60	85	109	70	81	5.5	5.8
U.A.E.	229	560	540	950	136	69	9	5.5
Oman	15	650	86	110	473	76	19	5.8

SOURCE: AL-ALAWY *et al* (1994)

In the same period, the rate of increase in the demand for water for domestic and industrial purposes was greater than that for water for irrigation in all the countries except Saudi Arabia and Qatar, as shown in Table 5. This is expected to increase further on account of the exceptionally high rate of population increase. Almost all the industrial and domestic water demand in the Gulf countries is met by desalination.

TABLE (6)

PROJECTED WATER DEMAND FOR THE YEARS 2000 AND 2010 (MCM)

Country	Domestic and Industrial		Agriculture		Total Demand	
	Year 2000	Year 2010	Year 2000	Year 2010	Year 2000	Year 2010
S. Arabia	2,900	3,600	20,211	21,700	23,111	25,300
Kuwait	530	650	110	121	640	771
Bahrain	155	180	130	135	285	315
Qatar	140	184	185	204	334	388
UAE	832	911	1,400	1,545	2,232	2,456
Oman	147	270	1,270	1,403	1,417	1,585
Total	4,704	5,795	23,306	25,108	28,019	30,815

SOURCE : AL-ALAWI *et al*, (1994)

The projected water demand for the years 2000 and 2010, as shown in Table 6, estimates that the region will be requiring water resources similar to those available in temperate climates. By the turn of the century, Saudi Arabia is expected to require 23 to 25 billion m3/year of water, which is more than the approximate average flow of the Murray river in Australia (21 billion m3/year) or twice the average discharge of the Hudson river in the USA (12 billion m3/year). In fact the total estimated water demand for the GCC countries for the year 2010, is about 31 billion m3/year (Alawi, et al 1994) which is approximately the same as the average flow of the Nile through Cairo.

However, projections for future water demand in the Gulf region have to take into consideration the fact that past experience can be deceptive for sound planning. Estimating water consumption on the basis that consumers will continue to ask for additional water with time is not justifiable. As the region has already achieved one of the highest standards of living in the world, its per capita consumption should not necessarily rise substantially. The consumers' main demand has, after all, already been achieved by providing them with a 24-hour potable water supply system[1]. The projected increase in demand applies to societies still aspiring to higher standards of living. It is possible that water demand would even decline in some GCC countries if the present subsidy of about 90% of the cost of desalinated water production were to be substantially reduced and the consumers were to become more aware of the real value of water (Alawi, 1994).

Nevertheless, the shortfall in renewable water resources available for satisfying water demand is increasing enormously. Withdrawals in the GCC countries already exceed renewable supplies (World Bank, 1994). Table 7 shows that even if a substantial reduction in demand is achieved by the effective management of demand policies, reliance on renewable water resources remains totally unobtainable. The various classifications adopted for defining scarcity of water indicate that not only the GCC countries will be facing water crises by the turn of the century, but also most of the Arab countries in North Africa and the Middle East (Salih, 1994). Such crises will hamper development and may cause social discontent (Montagu, 1994).

TABLE (7)

WATER AVAILABILITY AND DEMANDS FOR
GCC COUNTRIES (BMC)

Year / Type	1980	1990	2000	2010
Renewable Resources	8.6	8.6	8.6	8.6
Total Water Demand	6	22.5	31.5	35.4
Balance	+2.6	-13.9	-22.9	-26.8

SOURCE: SALIH, (1994)

A high proportion of the present forecast of 31 billion m3 of water required by the year 2010 will require the desalination of ground water as well as sea water. Saline water intrusion into aquifers is increasing substantially, and the water quality of most deep aquifers in the Gulf region, is not only inadequate for domestic or industrial use, but in some major aquifers it is not even suitable for agriculture without substantial treatment. The abstraction of water by pumping is becoming increasingly expensive with the rapid decline in water levels. The

1 Recent reports indicate, however, that a 24-hour system is not now available to all the cities in the Gulf region.

average cost of producing and distributing desalinated water[2] is about $2/m3. The abstraction of water from deep aquifers together with the treatment required will also cost a similar amount. If, say, 60% of the amount of water demand for the year 2010 were to cost $2/m3, then the GCC countries would have to budget an amount of nearly $37billion/year to satisfy water demand. Considering that the total income from oil in 1994 was $86.3 billion, it is evident that water shortages will indeed constitute a serious economic and social crisis in the region by the turn of the century.

OPTIONS FOR SATISFYING WATER DEMAND

In order to establish a reliable basis for planning to satisfy water demand, it is necessary to compare alternative sources of water which could be utilised, in particular the nature of the source and the cost of production.

The only alternative to desalination is conveying water long distances. The utilisation of renewable water resources as a major source is becoming less sustainable due to its availability and quality. In future it should be considered as an emergency source for essential services rather than as an alternative to conveying water or desalination.

Alternative Water Sources

Alternative options for obtaining water have always been under consideration in the Gulf region - even prior to the oil boom. Kuwait used to convey water by sea from the Shatt-el-Arab in Iraq. Since the fifties a number of options for the long distance conveyance of water to the Gulf region by pipeline or tanker have been considered, including pipelines from Egypt and Sudan to Arabia, and from the Shatt el Arab in Iraq to Kuwait and Jordan. The main most recent schemes are the following: (Anonymous, 1994).

1. From Malaysia to the GCC countries: Some fifteen tankers would make around thirteen journeys every month to transport about 107,000m3/day of treated water. The estimated cost of the project is US $620 million.

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2 Distillation which is usually preferred for sea water in the Gulf region, costs about $1.0 to 1.5/m3, while reverse osmosis and electrodialysis which are used mainly for brackish water cost about $0.4 - 0.8/m3 (World Bank, 1994). The cost of distribution and pumping of desalinated water is assumed to cost the same as the cost of producing it. (Dabbagh et al 1989). Hence the average figure of about $2/m3 was adopted for production and distribution of desalinated water.

2. From Pakistan to the UAE: The project is still under study and the amount of water is not known, but the cost is estimated at US $15 billion.

3. From the Karoun river in Iran to Qatar: An agreement has been reached between the two countries for four pipelines covering a distance of 1800 km. The discharge would be about 3.3 million m3/day, and it would cost about US $13 billion.

4. From Turkey to the GCC countries: Two pipelines are proposed: one 2650 km to 3600 km long from the west of Turkey to Syria, Jordan, the West Bank and the Gulf with a discharge of 3.5 million m3/day; the other 3900 km long from the east of Turkey to Arabia, with a discharge of 2. 5 million m3/day. This would cost about $20 billion.

5. From Lebanon to the GCC countries: A pipeline 1750 km long with a discharge of about 2 million m3/day is proposed.

While most schemes for the long distance conveyance of water pipeline estimate the initial capital cost, the cost per metre cube is rarely calculated. In the case of the conveyance of water from Turkey to the Gulf, requiring the expenditure of US $20 billion over a period of ten years, the cost of conveyance of one metre cube is in the region of US $0.8 to US $1.0 (Dabbagh et al, 1994 and World Bank, 1994). Financing problems will be formidable, and construction could take a decade at least.

Transporting water by tanker can cost about $2/m3, and then only if most of the distance is over the sea and little land-side infrastructure is required. Such cost estimates do not include any additional costs resulting from having to abandon existing systems. Other costs must be added to the initial capital costs. There are the initial charges for water provided by the supplying country; way leave or toll charges for countries through which the pipeline passes, the costs of operation and maintenance, the replacement of pumping and other equipment at intervals, and the cost of treatment before the water enters the final distribution system. Using equivalent discount rates, it becomes evident that desalination would be at least as economic as the conveyance of water long distances, if not cheaper (Dabbagh et al, 1994). Also, quite apart from the high cost of these projects, the legal and political aspects will constitute major difficulties. At present, the water situations prevailing between Turkey and Syria and Iraq, and also between Ethiopia and Sudan, and Ethiopia and Egypt are becoming increasingly worrying.

Cost of Water from Conventional Sources

Even In countries werc water is abundant, the cost of water is increasing rapidly mainly due to thc high level of pollution particularly in industrial countries. Tablc 8 gives thc cost of producing one mctre cube of water in some countries. Thesc prices are sometimes higher than those quoted for desalinated sea water. It may be argued that sources of water in industrial countries require treatment as elaborate as the desalination process or, alternativcly, that the bases used for calculating the costs of producing water can differ widely.

TABLE (8)

UNIT COST OF WATER PRODUCTION

Conventional Source	
Country	Cost US$/$m^3$
Cameroon	2.0
Mexico	1.5
Argentina	1.5
Netherlands	1.25
Zambia	1.05
Germany	1.4
Jordan	6-7*
U.K.	0.4-0.8
Switzerland	0.9

SOURCES: WORLD WATER/WHO (1987), HERNER (1992) AND SADIK *et al.* (1994)
*Marginal sources of surface water.

In a recent report, the World Bank concluded that the cost of new water supplies is rising rapidly in most areas of the world. The most dramatic cxamples are in large and growing urban areas: in Mexico city new supplies may have to be pumped up to an elevation exceeding 1000 metres; in Lima upstream pollution has increased treatment costs by about 30%; in Shanghai water intakes have been moved 40 km upstream at a cost of US $33 million; and in Amman the most recent project has involved pumping water up 1200 metres over a distance of 40 km. A recent analysis of the cost of supplying raw water for urban areas in World Bank financed projects shows that the unit cost of developing new water resources could double, or in some cases more than triple, in future projects (The World Bank, 1994).

Water as a Produced Commodity

Almost all modern developments in water provision involve an increase in the input of resources and recently such increases have generally been of a capital nature. Thus water is increasingly becoming 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", that is the value of the opportunities lost by diverting the resources from use elsewhere. Consequently the problem of costing water is becoming a complex 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 conventional methods the traditional costs, in most cases, are grossly underestimated. Incorrect pricing leads to the misuse and misallocation of scarce resources. For example, when water is supplied at far below cost, a false conception of true costs results. A rigorous method of costing water should be established in order to support sound water policy and also to allow valid comparisons to be made between the costs of different methods of supplying water (Dabbagh et al, 1994).

Procedure for Costing Water

In a recent publication, WHO attempted to establish a reasonable procedure for costing water, particularly in developing countries. The procedure first takes into consideration the basic assumptions required for projecting water supply and demand: the population to be served; the number of connections required and the numbers in each household; the necessary number of standpipes; and the size of the population that may rely on independent water vendors. It also takes into consideration the demand for industry and gardening. Last, but not least, it makes estimates of the unaccounted-for water, whether technical or due to illegal connections. The procedure covers not only the basic elements required for calculating the cash flow for a particular water supply project, but also takes into consideration the capital, operation, and management costs, as well as interest payments and the repayment of foreign and local loans required for the construction of the project in developing countries (WHO, 1994).

This approach to costing water has not been widely adopted in developing countries. The declared cost of producing and distributing water can vary widely owing to the different methods used for calculation. Therefore comparisons between the cost of water from dissimilar water sources can be misleading. It is therefore essential that the true cost of producing and distributing water should be established, particularly when desalinated water is used.

Costing desalinated water

Desalination has been branded a costly technology, but in arid and semi-arid regions the alternatives for utilising conventional water sources are becoming increasingly expensive. But comparing costs is not straightforward as various components of the cost of the conventional sources available are hard to quantify since they are either finite or subject to radical climatic variations. In either case, the energy required to utilise them is increasing due to the need to pump the water over longer distances and to high altitudes or from deeper aquifers. In the process the water table may be lowered, the aquifer may be depleted altogether, or the intrusion of saline water may be increased.

Calculations of the cost of desalinated water may also vary widely depending on the desalination process used and the assumptions adopted regarding the assumed life span, the discount rate, and the energy cost. Other factors specifically affecting the cost of desalinated water can be difficult to quantify, and are often locality specific, such as the efficiency of the standard of operation and maintenance available in the country concerned, particularly during a plant's initial operation periods. It has been frequently observed that unexpected renovation work has had to be undertaken relatively soon after installation has been completed. This has been mainly due to a lack of understanding of the sensitivity of the plant to the pre-treatment of the raw water; the higher the salinity of the water the more sensitive the process is to the feed water dosing.

Guarantees given by manufacturers or requested by clients are easily subject to disputes as to whether failure is due to the manufacturer or the inefficiency of the operation and maintenance procedures adopted. Resorting to arbitration leads invariably to additional costs which are borne by either the manufacturer or the client or both. In such cases it can be argued that the original estimated cost, upon which a certain process was selected, was fictitious and unrelated to the actual cost which included the cost of renovation.

Calculations of the cost of producing only desalinated water vary between \$1.0/m3 and \$1.9/m3[3] assuming different types of desalination processes and

[3]Figures of about \$0.36/m3 (\$1.37/1000 US gallons) for producing desalinated water in the Gulf region have been published. Such figures are very difficult to accept without substantial verification. Most probably they have not included the cost of energy which is sometimes assumed to be free in oil-producing countries.

taking into consideration different discount rates and energy costs as well as assuming different life spans (Dabbagh et al, 1994). Desalinated water, therefore, remains expensive but according to a recent report by the World Bank, recent cost reductions combined with the rising cost of conventional sources are making it surprisingly competitive in some situations (The World Bank, 1994).

Large-scale desalination is invariably associated with low-cost energy. Provided that a ready supply of energy is assumed - possibly one day the use of solar energy may become competitive - desalinated water provides a very much more predictable and reliable source than that supplied from a renewable resource and avoids many of the management problems (The World Bank, 1994).

Oil in the GCC countries is readily available as a source of energy, but cannot be considered free of charge when calculating the cost of desalinated water in the region. The international price of oil should always be taken into account when costing water in the region, as it could have otherwise been sold on the international market.

On the other hand, the cost of distributing water in the Gulf region is not always available. The fragmented institutional set-up responsible for the distribution of water and the lack of co-ordination between the authorities concerned make it difficult to obtain the appropriate data for the sound calculation of the cost of distribution of water. The consumers in the Gulf region contribute about 5% to 10% only of the water delivered (Al-Migren, 1992).

The water supply situation in Riyadh illustrates the order of expenditure involved in supplying water to Gulf cities. About 830,000 m3/day of desalinated water is pumped to Riyadh, which is some 750m above sea level, from Jubail desalination centre on the coast, by two 1500 mm diameter pipelines over a distance of about 465 km. Another 384 km pipeline of the same diameter and a capacity of 400,000m3/day also delivers water from Jubail to Riyadh (Bushnak, 1993).

While no accurate calculations for producing and distributing desalinated water at such a high altitude are available, it is possible to deduce the cost by comparing it with normally produced and distributed desalinated water without high level pumping. A figure of around US$2.0/m3 is normally quoted for producing and distributing desalinated water in a relatively flat terrain such as in Kuwait. It can therefore be estimated that the cost of the desalinated water reaching the consumer in Riyadh can easily be in the range of US$3/m3 to US$5/m3,if not more.

Desalination the most viable alternative

It is reasonable to conclude that desalination is to continue as the major water source in the Gulf for satisfying domestic and industrial water demand. Apart from the fact that alternative sources are as expensive, none can be considered seriously without major financial losses resulting from the need to change the existing orientation of water production and distribution. If, for example, in Riyadh in Saudi Arabia, water from the present set-up of the irrigation system, fed by mining aquifers, were to be considered as a source for reducing reliance on desalination for satisfying domestic and industrial demand, it would mean abandoning thousands of kilometres of large diameter pipelines which have been constructed to convey desalinated water inland and to high altitude from sea level.

MINIMISING WASTAGE: WATER MANAGEMENT

As potable water has become everywhere more precious, and increasingly stringent rules and regulations have been introduced regarding its acceptable quality, the management of water supply schemes has had to make much more effort to conserve and utilise every drop of water from inception to reuse. When there was a cheap source of cheaply treated water - such as readily available surface water requiring only basic treatment - unaccounted-for water was not seriously tackled, since the cost of renovating distribution networks in old cities would not be recovered by its reduction. Since the seventies, however, much more activity has been concentrated on this aspect of management.

Because desalinated water is basically an artificial source of potable water which is not renewable by natural means, conserving and recycling desalinated water in the Gulf is even more fundamental to sound water management than in less arid regions. Two sources of water which consist of a substantial amount of desalinated water and which could be put to better use are water losses and sewage. If they are conserved the need for increasing the production of desalinated water will be reduced. The Gulf countries are not unaware of this fact and in the last decade active operations for reducing water losses have been vigorously conducted, while very sophisticated treatment plants producing high quality effluent have long been in existence.

Demand Management

Thus, Gulf governments which have up till now always emphasised supply management, which covers the activities required to locate, develop and manage new resources, are finding it increasingly necessary to turn their attention to demand management as new water sources become more and more inaccessible and the cost of projects to augment supply escalate. Demand management includes the promotion of more desirable levels and patterns of water use. It covers both direct measures to control water use, such as regulations and technological means, and indirect methods that affect voluntary behaviour, such as market mechanisms, financial incentives, and public education. The mix of demand management measures may vary, but in all cases it aims to conserve water by increasing the efficiency of its use (The World Bank, 1994).

A key issue in the management of demand is educating the public that water can no longer be taken for granted and used extravagantly. Its production and distribution is a major burden on the budgets of Gulf governments. Some industrial countries have successfully reduced water consumption, in spite of industrial expansion, by taking administrative and technical measures. In the Gulf emphasis should be placed on improving the utilisation of existing facilities. When these countries, with abundant money and a shortage of qualified staff, were rushing to catch up with established modern states, management was more concerned with construction than with operation and maintenance and capacity building.

Now that a high standard of infrastructure has been substantially achieved, it is prudent to plan for its optimum utilisation. The facilities for generating electricity and water could be adequate for some time into the future if their management could be directed towards their more efficient utilisation. In many cases they have been over-designed, as often occurs following a substantial increase in national income. It is said that London benefited from over-designing by the Victorians as they used the increased national income from the expansion of the British Empire. Like Britain, some other European countries also benefited from the expansion of their empires and the export of manufactured products produced following the industrial revolution in the eighteenth century.

Subsidies and Tariff Structure

Subsidies for the water, electricity and gas sector are so high in some GCC countries that costs shown for this sector are negative for some time each year according to the published figures for GDP for the last fifteen years (GOIC, 1993). It is therefore essential to promote better utilisation within the sector and make it more competitive. In most countries of the world, a water tariff system operates to cover at least the cost of operation and maintenance, but in the Gulf countries potable water is either provided free of charge or heavily subsidised so that the tariff is nominal to the consumer. The tariff structure should be readjusted so that it limits the use of water to satisfying basic demand and avoids its irresponsible usage, while having regard to the fact that the availability of water is a prerequisite for establishing a healthy society. The present incentives and subsidies for irrigation in the Gulf region will also have to be reconsidered, not only because of the increasing cost, but also because of the adverse effect on the environment of depleting non-renewable water resources.

Subsurface "lakes" in Gulf Cities

In arid and semi-arid regions the natural ground water table is usually very low or does not exist, but in fact "lakes" of subsurface water are now quite common in large cities in the Gulf region. A study was conducted to identify the sources of water which contribute to this rapidly rising subsurface water in Riyadh and these are shown in Table 9 (An Nimr et al 1992 and Ad-Dahmash et al 1992). Evidently the potable distribution network contributes most to the rising water table, apart from watering gardens, while the sewage network contributes least, apart from rainwater. Presumably the pressure required in the distribution network causes greater leakage than that from the sewers which normally have a gravity flow.

TABLE (9)

SOURCES CONTRIBUTING TO THE SUBSURFACE WATER IN RIYADH

Source	m^3/day	Percentage
Watering gardens*	178,000	32
Leakage from the distribution network	162,000	29
Septic tanks	97,000	17
Faulty in-house connections	88,000	16
Leakage from the sewer network	22,000	4
Rain Water	13,000	2
Total	560,000	100

SOURCE: AN-NIMR *et al* (1992) AND AD-DAHMASH *et al* (1992)

*The total area of gardens in Riyadh is 2736 hectares, 60% of which consists of domestic gardens. The consumption of water for irrigating the total area is 384,000 m3/day. It is estimated that this consumption can be reduced by 35% (Abu Kheat, 1992).

These "lakes" of subsurface water created in the major cities of the region are a direct result of the misuse of a facility - desalinated water - developed in a land deprived of natural perennial surface water. Even if it is considered that only half the present daily waste of 560,000m3/day of water which reaches the subsurface in Riyadh comes from desalination plants, it can be concluded that no less than $300million/year is literally "money down the drain". As mentioned above, the desalinated water is estimated to cost at least $3/m3 for production, pumping from Jubail on the coast and distribution in Riyadh. Such a high cost justifies substantial expenditure on renovating the existing water system so as to eliminate water and sewage losses to the subsurface zone.

Similar situations prevail in other large cities in the Gulf region. In Kuwait, some consumers have had to install pumps to reduce the rising subsurface water which has been penetrating the basements of houses built before the phenomenon of subsurface water was known in the country. With new houses, waterproofing measures have to be taken to protect basements against water penetration.

MANAGEMENT OF WATER FROM INCEPTION TO REUSE

To make better use of water in the Gulf region, it is essential to quantify the areas where better utilization of water can be achieved. Failure to do so will lead to the ever-increasing exploitation of water resources and an escalation in the cost of producing and distributing potable water. Although the forecasts for the potable water demand in the Gulf region equal or exceed the water demand in heavily industrialised countries with abundant natural resources, data on water losses, reuse of sewage effluent, and the cost of producing and distributing water is much less accessible and verifiable in the Gulf countries. Questionnaires were despatched to most water authorities in the Gulf regions requesting quantified information on unaccounted-for water and reuse of sewage effluent. Responses were received only from Bahrain on the reuse of sewage effluent, while Oman and Qatar provided specific information on unaccounted-for water.

Establishing the basic data relating to a water system is fundamental for locating the major drawbacks of that system since they provide an incentive for taking measures to reduce losses and then to determine their impact. For the effective management of water from inception to reuse, rigorous procedures should be adopted so as to avoid water crises.

Objective

Objectives should be identified taking into consideration the prevailing socio-economic and environmental conditions of the GCC countries, as was done by OECD when faced with the oil crisis. On this basis the following objectives are the most relevant:

(i) Attaining water security so that strategic conditions are strengthened.

(ii) Producing water at a reasonable cost so as to minimise the burden on national budgets.

(iii) Sustaining economic growth by encouraging diversification of national income.

(iv) Ensuring the availability of water to lower income groups.

(v) Protecting the environment.

In order to link these objectives and substantially improve the present set-up for production of water and its utilization and hence make significant reductions in the cost of water, the management of water from inception to reuse is required. This may however, require major changes in the present management of water in the Gulf region.

Changes Required

The changes required are managerial as well as operational and involve the following:

I. Managerial Requirements:

(A) Reshuffle the present fragmented set-up of water management so as to establish single authorities responsible for water management from inception to reuse.

(B) Encourage privatisation on a sound basis.

II. Operational Aspects:

(C) Reduce unaccounted-for water drastically.

(D) Make better use of sewage effluent.

(E) Use aquifer storage recovery whenever possible to utilize the large installed capacities of desalination plants more efficiently.

(F) Allocate substantial funding for carrying out mega research in major fields of both desalination and the reuse of sewage effluent so as to expedite the development of desalination and intensify competition between manufacturers.

While (A) and (B) above should lead to more efficient water management, (C) and (D) would maximise the use of available water, and (E) and (F) could result in reducing the cost of water produced.

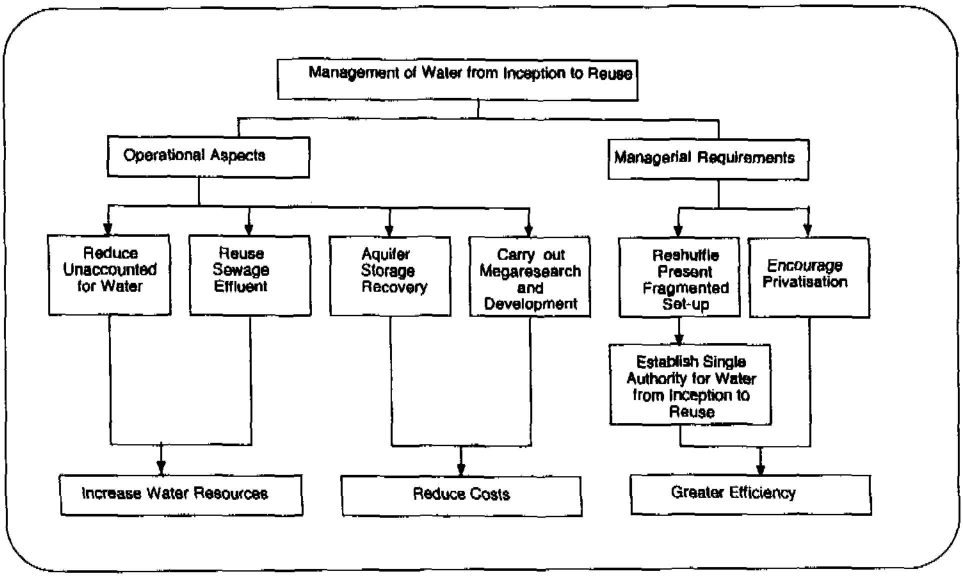

FIGURE 6 : ELEMENTS OF WATER MANAGEMENT FROM INCEPTION TO RE-USE

The above elements shown in Figure 6 have already been widely considered. But it appears, however, that in depth analysis is vital so as to assess the prospects for the better utilisation and development of water resources in the Gulf region. For this reason it is necessary to discuss each of these elements, so as to shed light on aspects for improving the measures adopted at present in the related fields of activities.

PRESENT SET-UP OF WATER MANAGEMENT

The ambitious development programmes pursued in the Gulf region required a vast increase in management. To provide this, a vigorous expansion in education took place, and opportunities became widely available in higher education, not only within the region, but also in industrialised countries. As this did not produce sufficient indigenous manpower, expatriates were also employed to fill the mushrooming requirements resulting from the rapid expansion in the demand for services and the need to deal with sophisticated imported technologies. Changes that took place in industrial countries over centuries, were brought about in the Gulf over a few decades.

Management practices in the region also developed quite differently from those in industrial countries, where establishing a data bank and keeping audited records are considered essential. Financing agencies also try to foster such methods in developing countries and before granting a loan demand a financial analysis from the water authorities which includes audited figures for income and expenditures and the amount of unaccounted-for water. It appears that such analyses are rarely available in the Gulf, according to the evidence of a questionnaire distributed to all the water authorities in the region and the annual reports of the authorities concerned.

The rapid expansion in management brought with it a fragmented set-up for the major sectors of the infrastructure, particularly the water and sanitation sector. Responsibility for this sector was spread over a number of ministries and departments so that, for example, several authorities, each employing a large staff with different ambitious plans and objectives , might be concerned with the development and use of water resources to deal with the rapid increase in water demand (Al-Migren, 1992).

RESTRUCTURING THE MANAGEMENT SET-UP

To make sound planning possible and to avoid the squandering of water resources, the present institutional set-up needs to be restructured. This is more easily said than done, as it requires major movements of staff and strategists. A high degree of co-ordination is required and this is more likely to be achieved by a single authority responsible for water production, distribution and reuse. Many of its important activities should however, be decentralise to autonomous, local, private, or user entities, since stake-holder participation in decision making promotes accountability and transparency, and also nearly always leads to solutions that are more efficient and resilient (World Bank 1994).

The objective of amalgamating authorities could be achieved in stages. Where duplication of work exists, a reduction in the number of staff could be brought about by offering early retirement, or soft loans for setting-up private enterprises which could participate in the running of the water and sanitation sector. The best qualified staff from the various organisations could be integrated to form a core which could provide a dynamic approach within the authority concerned and open up opportunities for promoting the private sector to take a more active part in running some parts of the sector outside the remit of the governmental authorities.

The need for systematic planning reflects the unique characteristics of water as a commodity: its unitary nature and the need for government intervention in its management in case of the failure of market mechanisms.

UNACCOUNTED-FOR WATER

For the effective reduction of unaccounted-for water the figures for water produced and water billed must be recorded. This has been carried out successfully in many developing countries, after prodding from financing institutions, but is not widely used in the Gulf. If unaccounted-for water is not measured, the impact of leakage repair may not be realised, since repairing one pipe may lead to another one bursting if the hydraulics of the distribution system is not properly designed. Thus, reducing leakage from a distribution network may involve reviewing its design as well as locating major leaks.

As the unaccounted-for water is the difference between the amount of water produced and the amount of water billed, sold or recorded, it does not necessarily represent only the lost water. Some of the unaccounted-for water could have been used, but not recorded. The components of unaccounted-for water are therefore of two main kinds: water lost for technical reasons without providing any benefits, and water used but not paid for. There is, however, some difficulty in drawing a line between the two. The former consists of leakage from networks and reservoirs and the latter consists of water used for fire fighting, water removed through illegal connections, as well as operational losses or water used by consumers whose meters are under-registering.

Determining Unaccounted-for Water.

It is easiest to record unaccounted-for water if all consumers are installed with meters. The normal procedure for estimating actual leakage is to measure minimum night flow in a particular zone which is not always simple. It is only possible if there is a 24-hour water supply where meters have been installed for all the customers in the zone, and the points at which water enters and leaves the zone have been clearly identified. The procedure's accuracy as an indicator of possible losses is reduced if there are storage systems on consumers premises which fill at night (Twort et al 1994).

The practice of recording unaccounted-for water has developed dramatically in the last two decades, particularly in industrial countries where water is plentiful. It used to be difficult as consumers in several industrial countries were provided with potable water on a flat-rate basis.

Assessing Effectiveness of Leakage Control

The main component of unaccounted-for water is leakage, chiefly from the main water distribution networks. The prime objective of leakage control is to determine which methods or policies are most cost effective. Different degrees of resource input result in different levels of residual leakage: the more intensive the control, the lower the leakage, but the higher the expense. It may not be economically feasible to eliminate leakage totally, but it is possible to derive an economic leakage control policy. This may be either the benefit-cost solution, where the cost of the water lost through leakage is higher than the cost of leakage control, or the minimum total cost solution, where the summation of the cost of leakage control and the cost of the residual leakage is at a minimum.

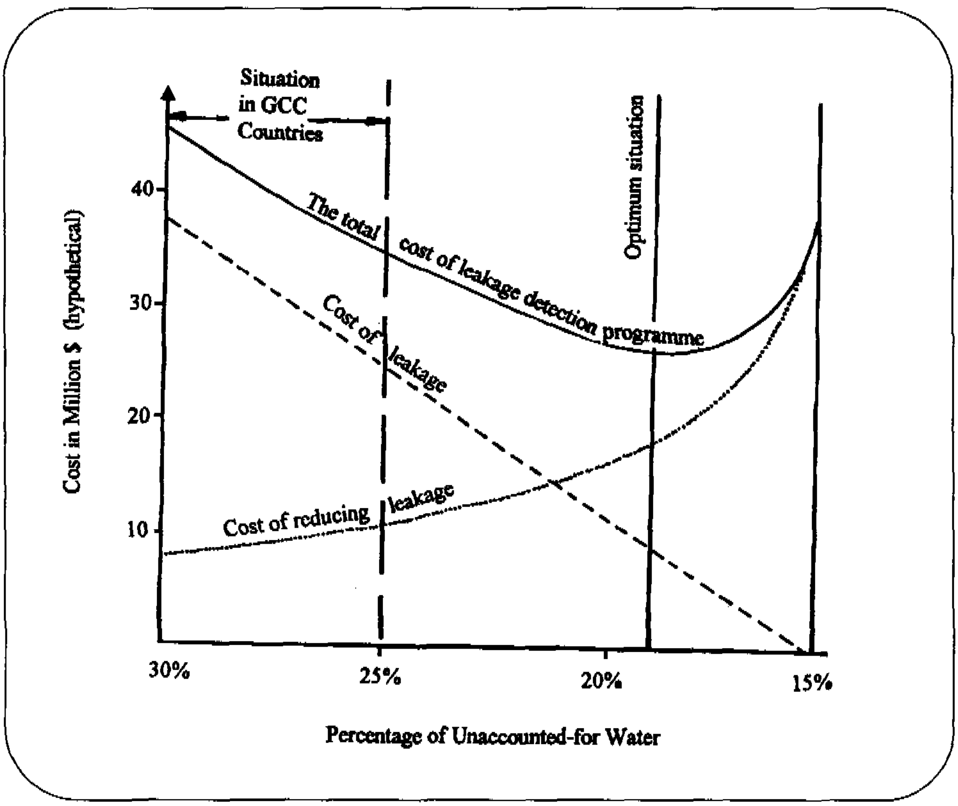

FIGURE 7 : FIXING OPTIMAL POLICY FOR LEAK DETECTION*
SOURCE : CHEONG, (1991)
*This diagram is only indicative. Realistic diagrams can be plotted using estimates based on the experience of the water authority concerned.

One way of determining the optimum level of leakage control which has been exclusively used is shown in Figure 7. The figure shows diagrammatically how this is done by considering the relationship between the level of leakage, the cost of leakage and the cost of leakage reduction (Cheong, 1991). The cost of leakage rises as the level of leakage rises in a linear relationship, providing the source of water does not change and the unit cost of producing water at that source is constant. The cost incurred when reducing leakage is not quite so simple. As the level of leakage is reduced, the effort required to reduce it further becomes higher as the location of small leakages becomes more difficult. The assumption is made that the cost of reducing leakage to zero is infinite and therefore the cost of leakage detection has an inverse relationship to the level of observed leakage. Thus the total cost of the leakage detection programmes for a particular zone is the sum of these two costs. The optimum level of leakage is that where the overall minimum cost is observed (Smith 1992). On this basis the optimal level of leakage in the Gulf region should be less than 10% because of the present high cost of producing and distributing desalinated water.

There are nevertheless still many uncertainties in leakage control. It is not yet possible to state what the actual levels of leakage are in any zone and therefore unaccounted-for water must be calculated very carefully. Improved data acquisition and analyses will help to quantify the level of uncertainty that remains and allow the authorities concerned to promote better solutions (Smith 1992).

Levels of Unaccounted-for Water

In the late seventies a survey was conducted to determine the unaccounted-for water in major industrial cities (Reed 1980). Some of the figures were particularly high, such as those for Glasgow (49.6%), London (42%), Marseilles (36%) and Dublin (31%). Figures of 25% to 30% used to be accepted as moderate and efforts to reduce them would be regarded as incurring unnecessary cost. But these days the attitude to unaccounted-for water has fundamentally changed. The level of losses has had to be substantially reduced, both because of the increasing cost of producing water, sometimes with sophisticated treatments, and the present trend for privatisation in the water industry. The new owners have an incentive for conserving water resources in order to increase their profit. Some water authorities now consider reducing unaccounted-for water to less than 10%. This has been achieved in a number of cities such as Singapore (8%), Federal Republic of Germany (7%), China (7%) (Cheong, 1991), Berlin (3%), Hamburg (6%) and Copenhagen (5.5%) (Reed 1980). Recently the Water Authority of Geneva have implemented a US$ 900,000 project and had their unaccounted-for water reduced from 13% in 1989, to about 7.9% in 1993. The past and future targets for reducing unaccounted-for water are shown in Figures 8a and 8b.

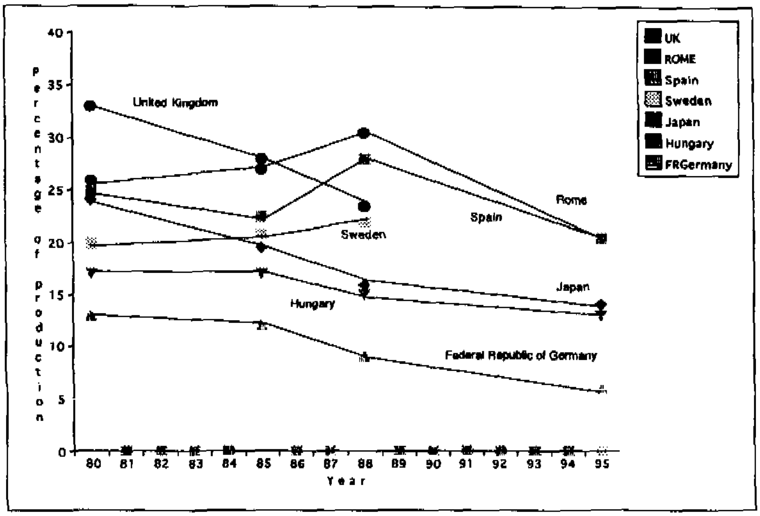

FIGURE 8(A) : UNACCOUNTED-FOR WATER : PAST TRENDS AND TARGETS

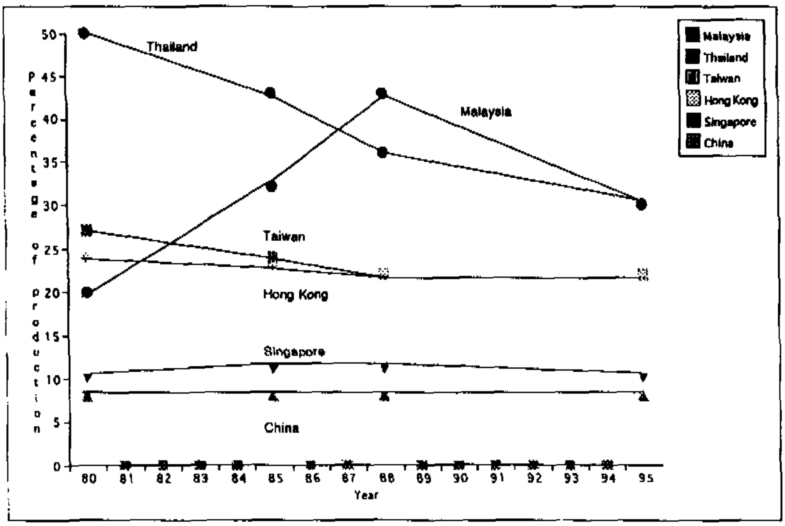

FIGURE 8(B) : UNACCOUNTED-FOR WATER : PAST TRENDS AND TARGETS
SOURCE : CHEONG, (1991)

Unaccounted-for Water in the Gulf

In the Gulf, awareness of the importance of reducing unaccounted-for water has increased substantially in recent years and leakage surveys are being carried out in most of the region, but as yet no records of unaccounted-for water have been published. This means that in these countries the main indicator for assessing the effectiveness of repairs to water networks is not available.

The kind of problems that prevail in almost all the Gulf countries with regard to obtaining accurate percentages for unaccounted-for water may be illustrated by the situation in Qatar. Leakage detection was carried out, major leaks were located and repaired, and substantial savings were made (Al-Mohannadi, 1994). The amount of potable water produced in 1994 totalled 95,558,656 m3 and the total water billed was 40,697,270 m3. However, since the residential buildings of Qatari consumers and government employees are exempt from billing, the difference between the above figures does not indicate the true unaccounted-for water in Qatar, only that 57% of the water produced is not billed. Apart from water supplied to exempt consumers, this amount is made up of the usual components of unaccounted-for water. Clearly, the true unaccounted-for water cannot be calculated without the installation of water meters for all consumers, whether paying ones or not. Because of this situation, the unaccounted for water in Qatar for that year had to be estimated at between 30% and 35%. It may well have been less - or even more - but there is no data to enable this to be determined.

Recently in Muscat the exact figure of unaccounted-for water has been published for the year 1994 as 25%; the total water produced was 53,417,000 m3 of which 40,062,750 m3 was billed.

Reducing unaccounted-for water should be viewed as a major activity which will increase the amount of water available for use. The prevailing procedure of reducing unaccounted-for water without quantifying the increase in available water minimises the impact of any reduction. It is essential to publish the amount of water produced and the amount of water billed. Savings made by reducing the present large difference between these two volumes of water can be used to offset the increasing budgets necessary for expanding water supply systems. It is apparent, from experience elsewhere, that unaccounted-for water can be substantially reduced by efficient management and the use of advanced technologies. Also new form of contracts have been developed recently which allow for competitive tender, but links payments to results (Harrison, 1993).

A reduction in unaccounted-for water to less than 10% should be aimed at in the Gulf region. It has been achieved over a relatively short period in places like Singapore, Germany and Switzerland. Reducing the present unaccounted-for water in, say, Qatar from an estimated 30% to 35% to about 10% will result in savings in the region of US$50million/year, assuming that the average cost of producing and distributing desalinated water is in the region of US$2/m3.

In Qatar the average daily production of water in 1994 was in the region of 260,000 m3/day. However, other major cities in the Gulf region produce four to five times this amount of water, which means that reducing unaccounted-for water to less than 10% is likely to accrue savings in the region of US$ 200 to 250 million/year following the completion of the required renovation of the water supply system. The assistance and advice of water authorities in countries with *minor unaccounted-for water ought to be sought so as to learn from their* practical experience. It must be emphasised that a leakage control programme conducted in a water distribution system where the institution itself is facing serious problems regarding organisational aspects, which has adopted inadequate metering practices, where the maintenance practices are not appropriate, is not likely to produce any practical or important effect in the levels of unaccounted-for water. The reduction of unaccounted-for water is normally the consequence of improved management and operational practices.

REUSE OF SEWAGE EFFLUENT

Increasing Waste Water Flows

Total waste water flows are rising rapidly world-wide and although in most countries they will remain small relative to the total renewable resources, in the water-short countries of the Gulf region they may represent the predominant long term water supply for intensive irrigated agriculture (World Bank - 1994). So far, however, few Gulf countries have actually made substantial use of the massive sewage produced in the region and established significant economically viable reuse projects which provide a perennial and reliable source of water for irrigation or aquifer recharge purposes.

Reuse World-Wide

The potential for using treated waste water for irrigation has been reviewed in detail by the World Bank. It has been widely exploited in quite a few countries after appropriate treatment - usually in stabilisation ponds. In India, waste water irrigation is promoted by special grants and loans and 55% of available sewage is reused for agriculture. In Mexico city, 100% of sewage effluent is used for irrigation after sedimentation and partial treatment. The city of Johannesburg irrigates 1800 hectares of fodder crops with waste water and supports South Africa's largest cattle herds with the irrigated grazing and feed. None of these countries have reported major outbreaks of disease due to the use of treated sewage effluent. In several countries, however, farmers recognise the potential of waste water and are not waiting for official connections to be made, but breaking into sewage networks and irrigating their crops. Clearly this is a very dangerous practice; in Santiago, for example, typhoid numbers rose rapidly at the beginning of the irrigation season, after 16,000 hectares of vegetables and salad crops had been irrigated with untreated waste water (Shuval, 1990).

Survey of Effluent Reuse

A survey was carried out into effluent reuse by sending questionnaire to about seventy interested international consulting engineers in various parts of the world to clarify the following main aspects regarding the reuse of sewage effluent:

i) The major constraints on the reuse of sewage effluent
ii) The steps required to promote the reuse of sewage effluent
iii) The fields of research required for promoting the reuse of sewage effluent

Also, particulars of the size and number of sewage works completed were requested and how many of these had produced effluent for reuse.

The questionnaire was completed by 33 firms, responsible between them for the design and supervision for some 1,910 sewage treatment works over the last ten years or so, ranging in size from very small to very large. Owing to the data on the forms not always being complete - or strictly comparable - figures are only approximate, but around 17% (317) of these treatment works produced effluent for reuse, made up of 10.5% (200) for irrigation, 3% (58) for watering recreational areas, and 0.3 (6) for artificial recharge, as well as 2.8% (53) for other purposes.

Other uses of effluent given by respondents included supplementing surface water supply and discharging effluent to watercourses, either for reuse downstream or for streamflow augmentation. More specific uses of watering were listed: for greenbelt and urban landscapes, racecourses, golf courses, hotel gardens and private lawns. Environmental enhancement included reed bed technology, lake enhancement, and the irrigation of forests and landscapes. Instances were also given of effluent being reused for industry, fire protection or washwater.

Constraints :

Table 10 shows the outcome of the survey regarding the major constraints on the reuse of sewage effluent. Cost and disease transmission have been rated as the top major constraints. However, both these elements have been dealt with in the Gulf region: the cost has been met and the risk of disease transmission has been virtually eliminated by adopting a high standard of treatment which exceeds the WHO guidelines. Nevertheless, vast amounts of sewage effluent are disposed of because they are of inferior quality for the standards adopted. The present, but low utilisation of the sewage effluent is difficult to justify on a sound economic basis. In India sewage effluent is much more widely used (Ghosh, 1992). It is produced at a much lower cost (Ghosh, 1990) than in the Gulf region and is of inferior quality, but it is proving to be economically viable and socially acceptable (Pye-Smith, 1995).

TABLE (10)

CONSTRAINTS ON REUSE OF SEWAGE EFFLUENT : SURVEY RESPONSE

Constraints	Percentage Importance (Average: most important 100%)	Number of replies
Cost	59	27
Disease transmission	58	29
Psychological objections	50	32
Misunderstanding of treatment standards required	41	25
Managerial indecisiveness	41	26
Industrial pollution	39	29
Religious reasons	35	26

In the Gulf region, the outcome of the questionnaire can be questioned. While cost and disease transmission are the normal culprits for constraining the reuse of sewage, perhaps "psychological" objections, together with "misunderstanding of the treatment required" are causing more constraints. From the response to the questionnaire, it is evident that only a few international consultants have substantial experience in the reuse of sewage effluent. As mentioned earlier, only 17% of the treatment plants designed by the respondents produced effluent for reuse purposes. The vast majority of the consultants appear to have little practical experience, although they may be anxious to get into this growing field of consultancy, which has been promoted by recent publications of WHO (WHO, 1989) and others, (Shuval, 1995) advocating new practical standards for the reuse of sewage effluent for agricultural purposes.

Several constraints were suggested by respondents besides those listed in the questionnaire. The most obvious was the ready availability of raw or potable water, while the most frequently mentioned was the inadequate control of operation and maintenance, which could lead to poor quality effluent and hence health hazards. Technological problems could also be constraints, such as irrigation systems not adapted to effluent reuse. Other concerns included the level of crop restrictions imposed and the possibility of effluent being accidentally used as potable water. Reuse is not perceived as a vote winner, but as lacking in public support and involvement.

Promotion of Reuse of Sewage Effluent :

The results of the questionnaire for establishing the steps required to promote the reuse of sewage effluent, given in Table 11, show that "disease control precautions" have top priority. In second place are "social awareness campaigns" and "setting realistic treatment standards". This signifies that while precautions against disease are paramount, they must be based on setting realistic treatment standards while making the public aware of the importance of reusing sewage effluent as a major source of water. It is significant that "determining areas for cost reduction" of sewage treatment was not considered of major importance and therefore cannot be a major constraint as mentioned earlier. Instead it indicates that there are sufficient technologies which treat sewage appropriately at a reasonable cost for irrigation purposes. This seems to be the case in some developing countries. WHO recommend that industrial countries should learn from the experience gained in this respect in developing countries which are using sewage effluent sucessfully (WHO, 1989). However, few respondents felt that there might be a scope for research to reduce the cost substantially except in the area of operation and maintenance as will be mentioned later.

TABLE (11)

STEPS TO BE TAKEN TO PROMOTE THE REUSE OF SEWAGE EFFLUENT : SURVEY RESPONSE

Promotional steps required	Percentage Importance (Average: most important 100%)	Number of replies
Disease control precautions	61	30
Social awareness campaigns	55	32
Setting realistic treatment standards	55	27
Stronger management	47	28
Determining areas for cost reduction	42	28
Avoiding industrial pollutants	40	27

Most measures suggested for promoting reuse in addition to those listed in the survey, related to steps for increasing public awareness, such as educating children in school - since they can influence both parents and public; changing the attitude to water as a limited resource, demonstrating that the benefits of reuse - not only the financial ones - outweigh the cost; and identifying the need for reuse and marketing it. Other suggestions related to irrigation: the need to update, upgrade and perfect irrigation techniques; to use the appropriate technology; to introduce dual water reticulation schemes or water blending; and to permit irrigation of a larger choice of crops. Reuse could also be made more acceptable by improving operation and maintenance control systems to ensure adequate treatment standards are attained.

Research Topics :

Respondents were invited to suggest research fields and the benefits that might accrue from them. These are outlined below grouped under the promotional topics of the questionnaire (disease, awareness, standards, management, cost reduction, and industrial pollution) as well as process technology, irrigation, and the environment.

Disease Control Precautions : The micro-organisms in treated sewage effluent need to be investigated for their effect on human health. Research should include the contamination of irrigated plants and pathogen survival rates in dry climates. Epidemiological studies need to be carried out and the probability of disease transmission, particularly virus breakthrough estimated. Used as a basis for sewage treatment standards and quality control such information could help maximise confidence in the safety of reuse.

Social Awareness Campaigns : Studies of reuse attitudes, education, and awareness would help enable reuse to be developed as acceptable and the norm for treatment works. Knowledge of the non-financial benefits of reuse needs to be increased, while growth trials could demonstrate the value of effluent reuse to farmers, and pilot studies could identify profitable crops. If practices are to be changed in arid areas with poor wastewater disposal and contamination of raw water sources, the relevant issues and experience must be identified. Environmental and treatment standard studies could be used to educate funding agencies and governments about environmental benefits so that they can encourage reuse.

Standards : A scientific basis is required for developing standards investigations needed include epidemiological studies, microbial risk assessment modelling, and environmental studies of the impact and risks of reuse. Research into quality control, such as identifying new indicator pathogenic organisms which can provide instantaneous and continuous indication of treatment integrity and effluent quality, can assist in applying and maintaining the appropriate standards.

Stronger Management : Studies of public administration and management would help to improve the co-ordination of water supply, water treatment, and reuse authorities and improve the management of area-wide water resources. Incentive studies would demonstrate the inter-relationship between subsidies for other sources of water and the demand for reclaimed water. Investigating ways of improving institutional set-ups for sewage companies and the training of personnel could lead to better managerial practices and higher quality effluent.

Cost Reduction : Cost reduction should result from research and development and improvements in operation and maintenance. The technoeconomic aspects of alternative treatment technologies can be assessed, so least cost options can be selected . Alternative irrigation systems may permit a relaxation in standards or an extension of the cultures to be irrigated. Membrane processes and alternatives to chlorine disinfection should be evaluated to see whether they can lead to cost savings.

Pollution : Alongside biological studies, chemical studies of the impact of effluent reuse are required. The impact of industrial wastes on water quality needs researching so that borders can be determined and the components by-passing treatment identified. The risks to plant growth or to consumers from the various contaminant metals and synthetic organic chemicals in irrigation water need to be identified. The process of catalytic oxidation could be developed, since it can be used to treat recalcitrant COD (chemical oxygen demand) in industrial effluent before it is mixed with domestic effluent.

Process Technology : Although there is a view that the technology already exists to deal with most of the problems of effluent reuse, a number of respondents suggested research fields related to processing technology. Particularly important was the search for alternative, non-chlorine disinfectants which would avoid the formation of contaminants. Also of high priority for evaluation were the new membrane processes, which not only have disinfection properties, but could also increase treatment reliability and provide better water quality. In membrane bioreactors for wastewater treatment three processes are combined in one step and there is no need for chemicals or disinfection, so other contaminants are not introduced. The main obstacle to membrane process utilisation is fouling, one approach to the problem is to electrify the membrane. Other fields of research are the use of sand filters for polishing effluents; the use of maturation or stabilisation ponds to remove pathogens and meet reuse requirements; and nutrient, taste, and odour removal.

Irrigation : Irrigation research in the form of both hydraulic and crop studies was suggested. these included effluent contamination and its influence on plant growth and the physical and chemical properties of the soil. If irrigation techniques are perfected according to the type of final reuse intended, the contaminant hazard resulting from the use of minimum treatment levels can be reduced. Alternative irrigation systems may also permit a relaxation in the standards for suspended solids in effluent. For more effective reuse options, the salt tolerance of plants and methods of avoiding salt build up need investigating.

Environment and Recharge : The effect on the environment of the micro-organisms in treated sewage needs to be studied to provide reassurance that no adverse affects will result from reuse and also to promote the specification of realistic standards. Environmental studies include the assimilation capacities of aquifers for reclaimed sewage; the suitability of effluent for large-scale effluent recharge to augment groundwater systems, and the risks of chemical and bacteriological pollution. Ecologically sound treatment can sometimes be provided by the use of reed beds, which could be studied further.

Effluent Standards for Reuse

Sewage effluent after tertiary treatment can be of better quality than some river water which is used for irrigation. This is not a sound basis for deciding on an appropriate standard for the reuse of sewage effluent, but it does indicate the importance of the psychological barrier against its reuse. The Gulf countries are deterred from using sufficiently treated water because it is considered an unnatural source, while some other countries use highly polluted river water because it is convenient and considered natural.

The availability of financing in the Gulf has also made it possible to appease alarmists by polishing sewage effluent to a standard approaching that of drinking water and then using it to produce fodder or for other uneconomic agriculture. An instance of the high standards in the region is shown in Table 12 which compares the main requirements in Kuwait for effluent for reuse (Ghobrial 1992), with the standards considered acceptable in Brazil for the effluent from a waste stabilisation ponds system. In fact, the WHO *guidelines consider effluent quality* of 200/100ml. Most Probable Number (MPN) of coliform bacteria as acceptable (Refer to note "d" in Table 13). Therefore the required 2.3 MPN coliform in Kuwait is a very high standard indeed. Other Gulf countries require similar standards.

Table (12)

Comparison of acceptable standards of effluent for reuse in Kuwait & Brazil

	Kuwait	Brazil*
Suspended solids (mg/I)	10	45
BOD (Biochemical Oxygen demand) (mg/I)	10	17
MPN (Most Probable Number)	2.3/100ml	30/100ml

Source : Ghobrial, (1992) and Hespanhol (1990)
* Within the guidelines of WHO

In Bahrain, the standard of sewage effluent is also very high. In 1995 the main characteristic of the tertiary effluent was 3mg/litre biological oxygen demand (BOD), 4mg/litre of suspended solids (SS), and about 6mg/100ml MPN coliform. The reuse effluent is subjected to treatment by chlorination, filtration and ozone. Insisting on such a very high standard of treatment has resulted in the effluent from two out of three treatment plants in Kuwait being regarded as of substandard quality (Ghobrial 1992), although doubtless it would have been acceptable in other countries. Other Gulf countries have faced similar situations which have resulted in sewage effluent being rejected because it is not up to the high standards adopted.

Appropriate Reuse of Sewage Effluent

Sewage effluent can be deemed to be the only perennial surface water in the Gulf, and since it has been generated because of the high consumption of potable water, mostly produced by desalination, there are sound economic and technical reasons for using it extensively and appropriately. In fact, its reuse has been considered in almost all the countries of the Gulf region, but unfortunately this extremely important source of water has been subject to doubts and alarmist declarations that have delayed its proper utilisation. As a result, the present use of sewage effluent is either incomplete or uneconomical. Sweeping statements emphasising the dangers inherent in its use have compelled decision makers to adopt such high treatment standards when using it for irrigation purposes that there are often no substantial economic returns, if any.

It is important to define the objective for which sewage effluent is to be reused since the adoption of a standard of treatment needs to be justified economically and environmentally. It has been argued that the prevailing high standard of living in the Gulf region requires full protection of the public. This is the attitude adopted in the USA whereby exposure to treated sewage effluent requires zero risk. This is difficult to define. The public will always be exposed to some risk regardless of whatever measures are undertaken by the authorities concerned. The Gulf region continued with the construction of highways in spite of the present high rate of fatal car accidents. There will always be some risks which has to be left to the judgement of the users who should be made aware of the risks involved through public awareness campaigns.

Objectives for the Reuse of Sewage Effluent

Just as there is evidently a reluctance to pin-point objectives with regard to determining unaccounted-for water, the same is true of reusing sewage effluent. High standards of treatment are adopted which are no longer required according to WHO guidelines. Tertiary treatment systems are commonly used, but they are complicated and expensive and their use in developing countries to produce effluents for crop irrigation is not recommended (Hespanhol, 1990). Instead, the preferred method of waste water treatment in warm climates, whenever land is available at a reasonable cost, is the use of stabilisation ponds, which can be designed to produce effluent that meets WHO guidelines which are summarised in Table 13, (WHO 1989). Adopting high treatment standards results in valuable sewage effluent being wasted whenever its quality falls below the high standards which are normally difficult to maintain.

Table (13)

Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture[a]

Cate-gory	Reuse Conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean No. of eggs per litre[c])	Faecal Coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	<1	<1000[d]	A series of stabilisation ponds designed to achieve the microbio-logical quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	<1	No standard recommen-ded	Retention in stabilisa-tion ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation techno-logy, but not less than primary sedimentation

[a]In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[b]Ascaris and Trichuris species and hookworms
[c]During the irrigation period
[d]A more stringent guideline (<200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e]In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
Source: WHO, (1989)

The variation in standards required for sewage effluent for reuse purposes has a direct impact on the cost of the treatment required. The published figures for the treatment of sewage in the Gulf region vary considerably. It has been reported to cost $0.4/m3 by the World Bank (World Bank 1994) and $O.21/m3 by Bahrain. Such a wide variation indicates inconsistencies in the way in which the cost is calculated. Appropriate use of this source of water can reduce its cost of production, substantially and therefore make it economically viable.

Reducing the Cost of Delivered Water

It has been shown, using a simple computer model for a hypothetical city requiring 350,000 m3/day of desalinated water, that the cost of delivered water can be reduced substantially by increasing the volume of sewage recycled and reducing the unaccounted-for water. Table 14 shows the outcome of the computer model. Such results, however, cannot be obtained at nil cost, and savings must always be balanced against the costs of achieving them. In the case illustrated, it is evident that the savings in reducing the unaccounted for water and increasing the reuse of sewage, will justify allocating appreciable quantity of capital expenditure to be devoted to the system's improvement. (Dabbagh et al, 1993).

TABLE (14)

COST REDUCTION OF DESALINATED WATER BY INCREASING VOLUME OF SEWAGE RECYCLE AND REDUCING UNACCOUNTED-FOR WATER
$ 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

AQUIFER STORAGE RECOVERY

Definition

For fuller utilisation of desalinated water, and hence further cost reduction, greater water storage capacity is required. To this end, Aquifer Storage Recovery (ASR) could be used. This is a system which has been in use in USA since 1984. It has been developed to improve the use of water supply and water treatment facilities. The system involves the use of injection wells for the underground storage of treated drinking water in a suitable aquifer when the capacity of water supply facilities exceeds the demand and its subsequent recovery from the same well to meet seasonal, peak, emergency or long term demand as shown in figure 9. ASR may be used to store surplus water in this way. Also when electricity from a dual purpose plant is in low demand ASR can be used to inject desalinated water into the aquifer. Such seasonal storage may amount to millions of cubic meters through a single well, compared to a few hundred stored in conventional ground or elevated storage tanks to meet demand variation. Aquifer storage is low cost where suitable aquifer is available, since land requirements are minimal .

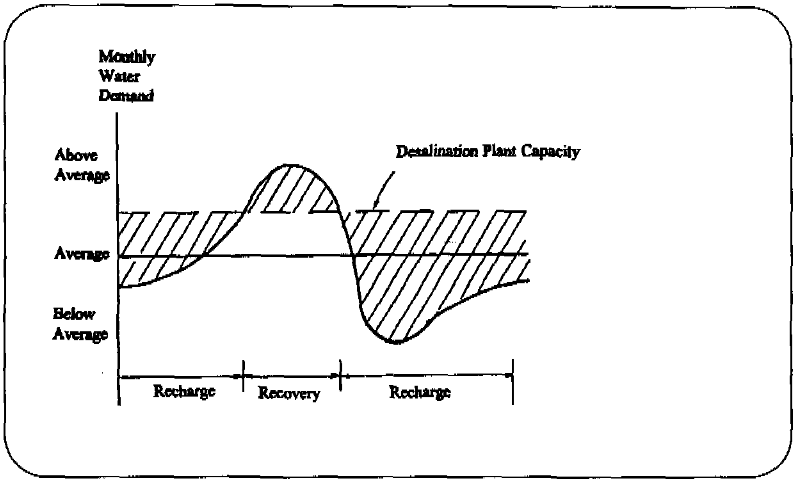

FIGURE 9 : TYPICAL AQUIFER STORAGE RECOVERY OPERATING SCHEDULE
SOURCE : PYNE (1989)

Practical Experience

It has been shown that by making more efficient use of existing water supply systems, ASR can reduce capital costs by 50% to 90% (Pyne. 1994). However, this system has not as yet been used in conjunction with desalinated water. Although, it has been considered in Kuwait, Saudi Arabia and Oman. In each of these countries it has been planned in conjunction with desalination facilities to provide a strategic water reserve for emergency supplies while also meeting other secondary objectives such as seasonal peak demands, recharging brackish water reserves, and salinity intrusion control. In June 1993 there were approximately 60 ASR projects in operation or under development in the USA (Singer et al 1993). Experience in ASR pertinent to the Gulf region occurs in Florida where at least four sites are in operation that have brackish or sea water aquifers with similar characteristics to those found in the Gulf region (Pyne, 1992).

Treatment of the recovered water is generally unnecessary apart from disinfection. There is some evidence that ASR results in the elimination of the undesirable by-products of chlorination (Singer et al, 1993).

DESALINATION RESEARCH AND DEVELOPMENT

Past Experience

The approach to research in desalination has passed through various phases. The earliest research work, which resulted in the development of the multi-stage flash (MSF) system, was instigated by the Gulf region in the fifties (Temperley, 1994). Major contributions to the development of reverse osmosis as well as the refinement of other processes were made by the Office of Saline Water (OSW) in the United States prior to its closure in 1972 (O'Meara, 1992).

Research centres in the Gulf have contributed to refining the design, operation, and maintenance of desalination plants. Being supported by the public sector they have made the results of their research public and have sometimes managed to intensify competition between manufacturers and therefore reduce costs, especially in the case of scaling prevention chemicals, the prices of which have been drastically reduced. They have also contributed to an improvement in various aspects of plant operation, thereby increasing plant life spans (Al-Sofi, 1994).

Elsewhere, public sector research in desalination is now very limited (MEMWG, 1994) and with the prevailing trend towards privatisation, research institutions are far more inclined towards those projects which are most certain to be financially rewarding. Much of the developments in desalination have been made by the desalination industry as it has gained practical experience. This has had several consequences: competing manufacturers have duplicated research; they have kept results to themselves; and they own the patents (Dracup et al, 1991). They maintain, quite rightly, that the results of research cannot be made public free of charge, being the result of hard work and major expenditure on the development of processes and components (Leitner, 1994).

The vital importance of research for the progress of desalination was highlighted in 1990 when an attempt to assess desalination mega research needs was made through survey questions on funding allocation asked in the course of announcing a National Water Supply Improvement Association (NWSIA) and International Desalination Association (IDA) symposium in Washington in 1991. The attendees, including consultants, suppliers and users, awarded 9.1 points out of 10 to the importance of research for the progress of desalination (Buros, 1991).

Later in 1994, the Ministry of Foreign Affairs, Sultanate of Oman, conducted world-wide research and technology survey which concluded also that a strong potential exists for expanding research to meet the aim of identifying and developing new methods by which desalinated water can be used in situations where the cost of existing methods are unacceptable (MEMWG, 1994).

Need for Future Investment in Research

In view of the current water situation in the Gulf and other arid and semi-arid regions, there is an outstanding need for funding public research into desalination processes, and also for the compilation and dissemination of the extensive data which has already been expensively earned through the design, operation, and maintenance of desalination plants.

Investing money in public desalination research will have the advantage over investing it in the long distance conveyance of water in that the latter is an old technology with limited scope for improvement, and commits vast amount of capital for long time horizon, while desalination can benefit substantially from further research. Indeed, for the Gulf region, investment in public research can be regarded as an investment in the future of the region. Since it already has a policy of investing abroad to ensure future post-oil income, investment in the development of desalination could be doubly beneficial: not only would there be a financial return in the form of profit on the investment, but also - since the Gulf is the main market for desalination technology - a benefit from gains in technological efficiency brought about by the public research.

Thus, the major beneficiary from advances in desalination technology would be the Gulf region. To a lesser extent, other parts of the Arab world and some developing countries facing major shortages of sources of potable water would also benefit, should desalination become a cheaper and therefore more attractive option. Industrial countries would also gain, but mainly from improvements in some of the processes involved in refining the quality of potable water - for which standards are now becoming very stringent - and the commercial rewards that come from having the major manufacturers based there.

Apart from cost reductions brought about by technological improvements, investment in public research in desalination, where the results are not patented, could bring about reductions in the cost of desalination through the following effects:

(i) A reduction in the capital cost of desalination plants and their components: This would occur if manufacturers reduced their research budgets when publicly financed research is undertaken.

(ii) An intensification in competition between manufacturers: The results of public research might encourage manufacturers such as ship builders, to produce similar desalination plants and components.

(iii) Elimination of the duplication of research: Public research would help reduce the duplication which often results from the confidentiality sustained by the manufacturers who wish to be the major beneficiaries of research financed from their own private resources.

SURVEY OF MEGA RESEARCH FIELDS

Identifying Research Requirements

To promote public research in desalination technology it is necessary to identify fields of research which are expected to substantially reduce the cost of producing desalinated water. Major possible research fields were selected from publications on the subject by specialists in desalination mainly from Saudi Arabia (Al-Sofi et al, 1994), USA (Dracup, et al 1991) and U.K. (Hanbury, 1994). It is also important to estimate the cost of carrying out the necessary research, so recommendations can be formulated, budgets can be estimated on a sound basis, and decision makers assisted to take a stand on the issues involved and perhaps to promote them.

To try to identify mega research requirements a survey was conducted among organisations and individuals involved in desalination, either as consultants, manufacturers, managers, researchers or academics. Over one hundred questionnaires were sent out inviting the recipients to indicate numerically, their views on possible mega research fields, with regard to their priority for bringing about a possible cost reduction in desalination and suggestions for the time and man/months that might be required to achieve it. They were also asked to add further research fields if not included in the questionnaire's list. Some of the aspects of the fields that seem to need investigation are outlined below.

Fields of research into distillation processes

1. Scaling prevention techniques for film evaporation : Considerable progress has been made in reducing scaling in the MSF tube surfaces, but

this seems to have led to scale deposition being transferred into the flash chambers and causing blockage of the demisters.

2. Corrosion reduction : There is a need to develop alloys and other materials for moving and non-moving parts with corrosion resistance similar to those which have been recently developed, but at more economical prices.

3. Large-scale capacity increase : Increases in the capacity of distillation plants, in pursuit of economies of scale, require the development of the bases of design using mathematical and modelling techniques to establish the optimum plant size - that which can provide desalinated water at the lowest cost.

4. Heat transfer improvement : New alloys with higher heat transferability than those presently available could improve the efficiency of MSF drastically.

5. Computer control of processes : The appropriate and reliable control of a desalination plant is a major element in reducing the cost of operation and maintenance as well as contributing to lengthening the life span of the plant.

6. Flexibility of water/electricity production : The fluctuation in demand for water and electricity requires higher efficiency in operating the turbines linked to desalination plants so that the production of either electricity or water can be varied without having to waste energy or shorten maintenance periods.

7. Computer modelling : Advances in this field might reduce costs if computer modelling could be effectively utilised to simulate desalination plants under adverse operating conditions.

Fields of Research into Membrane Processes

1. Chlorine-resistant seawater membrane : Disinfection of the feed water supplied to the membrane systems of reverse osmosis plants is essential to prevent biofouling of the membrane surfaces which inevitably leads to a loss of performance. Chlorine is by far the most cost-effective water sterilant for potable water, but unfortunately modern RO membranes are generally susceptible to chlorine damage. There is a demand, therefore,

for membranes which are able to tolerate biocidal concentrations of chlorine in continuous operation over several years.

2. Fouling and scaling mechanisms : Fouling of RO membranes is probably the most important factor contributing to the overall cost of operation of RO desalination facilities. The adverse economic impact results from the need for sophisticated pre-treatment systems and/or more frequent membrane replacement. A more fundamental understanding of fouling and scaling mechanisms may ultimately provide information which leads to lower operational costs.

3. Seawater coagulation and filtration techniques (SDI reduction) : The need to pre-treat sea-water to reduce SDI (Silt Density Index) can sometimes be eliminated by taking sea water from boreholes, but in the running of large sea water RO plants with open sea water intakes, the removal of all organic suspended and colloidal matter is a major problem. It is normally carried out using classical water treatment coagulation and filtration techniques. Although these arc well advanced for use in the water supply industry, research into broader spectrum coagulants might be of benefit and the new technology of microfiltration should bc given more consideration and developed further.

4. Membrane performance in typically variable chemical environment : RO membrane efficiency increases with the reduction of thc salinity of the inflow. Mixing sewage effluent with sea water would reduce the salinity, but make the composition more variable. This is the situation when waste waters are reclaimed using RO since most of them contain dissolved organic compounds varying in chemical properties and molecular weight. The problem is further complicated if the water is chlorinated. It is important to determine to what extent the molecules of undesirable chlorination by-products are rejected by RO membranes. In addition, certain organic compounds are know to interact with membranes causing adverse changes in performance.

5. Feed water disinfection, alternative strategies : Drawbacks to chlorine treatment for disinfection of feed water to prevent biological growth on active membrane surfaces, involve potential membrane degradation and the formation of undesirable chlorinated compounds, such as tri-halo-methane (THM) which may be carcinogenic (Dracup et al, 1991). A variety of other biocides such as ozone may prove to be advantageous in RO systems but have not been adequately studied.

Table (15)

Possible Mega Research Field for Reducing cost of Desalination : Questionnaire Results Average of Data from Respondents

Research Fields	Priority *** (%)	No. *	Cost reduction likely (%)	No. *	Time required (Years)	No. *	Research man/ months**	No. *
DISTILLATION PROCESS Scaling prevention	61	19	12	11	4.1	12	77	9
Corrosion reduction	58	16	27	9	5.3	9	225	7
Large-scale capacity increase	49	16	16	8	4.8	10	272	7
Heat transfer improvement	48	17	12	12	3.8	10	70	8
Computer control of processes	33	15	4	6	2.8	9	166	7
Flexibility of wate/electricity production	31	12	8	8	2.4	7	82	5
Computer modelling	27	15	6	7	2.6	7	101	7
MEMBRANE PROCESSES Chlorine resistant	60	27	8	21	4.5	17	890	12
Fouling and scaling mechanisms	56	29	11	22	4.6	18	125	14
Seawater coagulation and filtration techniques (SDI reduction)	51	26	11	19	2.9	16	199	13
Membrane variable chemical environments	50	26	8	17	4.5	12	1158	9
Feedwater disinfection, alternative strategies	45	23	8	18	3	16	152	10
Energy recovery devices	40	26	8	19	3.1	15	949	11
HYBRID PLANTS	36	7	11	7	5.5	7	466	5
OPERATION AND MAINTENANCE STRATEGIES	65	12	15	10	2.5	10	245	9

* Number of responses per field
** Experts only
*** Most important indicated as 100%

6. Energy recovery devices : The cost of energy is the main factor leading to increases in the cost of desalination, so research is required to improve the efficiency of energy utilisation.

In addition to the above topics, the recipients were also requested to indicate numerically their views regarding the use of hybrid plants and improvements in operation and maintenance strategies.

Response to the Desalination Questionnaire

Altogether 55 replies were received, 33 of which included a completed questionnaire and a further 13 provided information on desalination research without completing the questionnaire. A small number of the questionnaires were returned from people not on the mailing list, after referral from the original recipient. The forms were completed in accordance with the experience of the respondent, sometimes involving two specialists, one for distillation processes and the other for membrane processes. Some forms were only partially completed as some respondents were unable to answer questions outside their specialisation. The questionnaire included a section inviting suggestions for further research fields not included in the list. Very few used this section, so it appears that most respondents thought the list was fairly comprehensive. There was an overall consensus that all the proposed fields of research were worth pursuing. Two respondents divided each research field into sub-research fields. Others provided general information when they did not feel confident enough to give numerical values required by the questionnaire. Almost all industrial and developing countries which are concerned with desalination were covered by the respondents as users, researchers, academics, managers or manufacturers. The author carried out extended correspondence with some of the respondents who have strong feelings about the importance of research in desalination and the way it should be conducted.

Priority of Mega Research Fields

The first item that the survey wished to establish was the priority given to the above research fields. Respondents were asked to express their opinion regarding a field's relative importance in the form of a percentage, using 100% to indicate the one they thought was most important. When averaged, the replies showed considerable variation in the importance given to particular fields, as shown in Table 15, where they are arranged in order of priority under the different processes. It can be seen that scaling prevention and corrosion reduction have scored top priorities in the distillation processes, while chlorine resistant seawater membrane and developing fouling and scaling mechanism have scored the top priorities in the membrane processes. It is worth noting that the responses per field for the membrane processes were greater than for distillation processes. They varied between 23 and 29 for the former, while they varied between 12 and 19 for the latter, indicating that there is more interest in developing the membrane processes than the distillation processes. However, the highest priority recorded as a percentage was for improving operation and maintenance strategies.

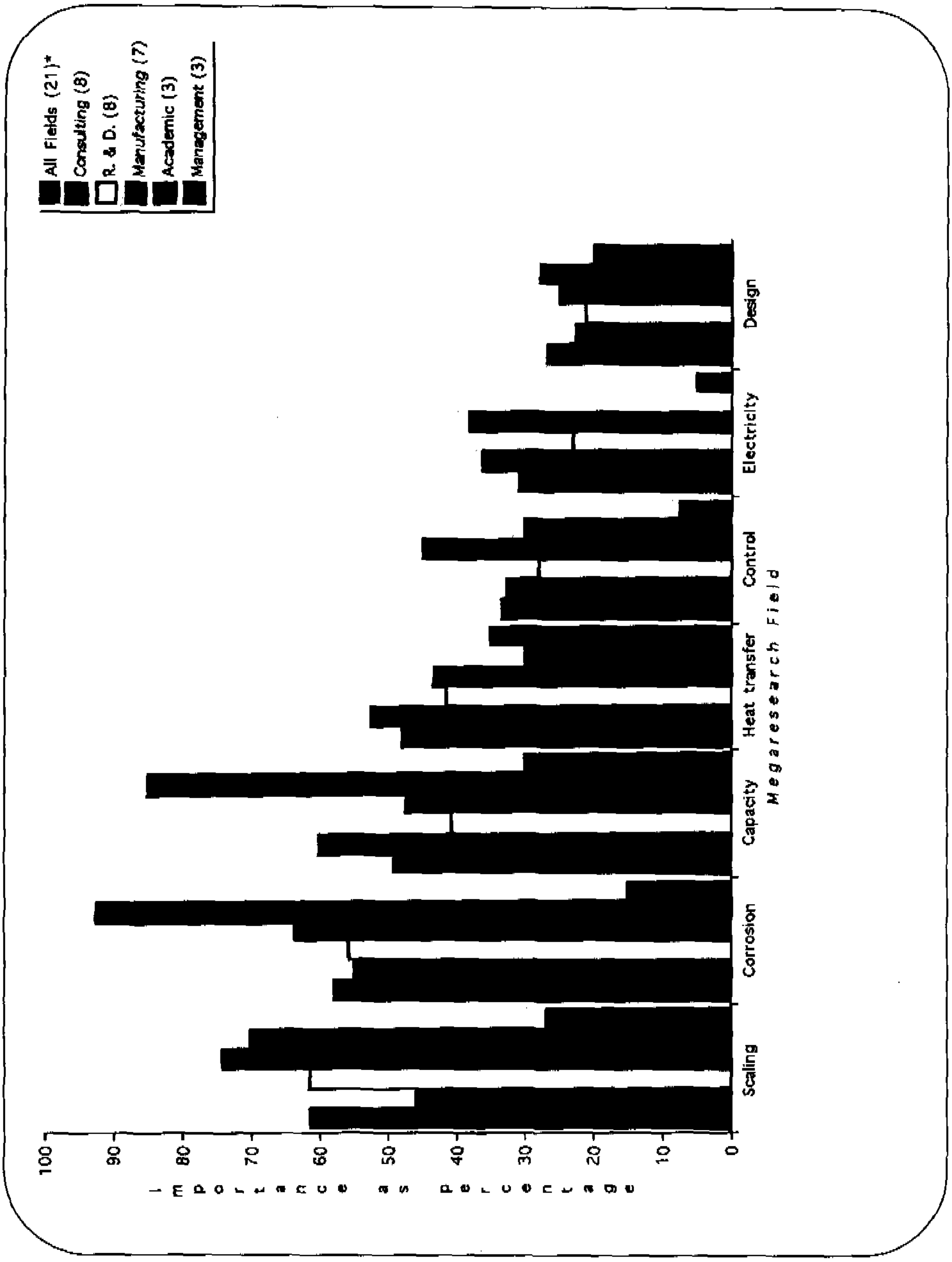

Figure 10 : Distillation processes : Research Priorities According to Fields of Interest of Survey Respondents

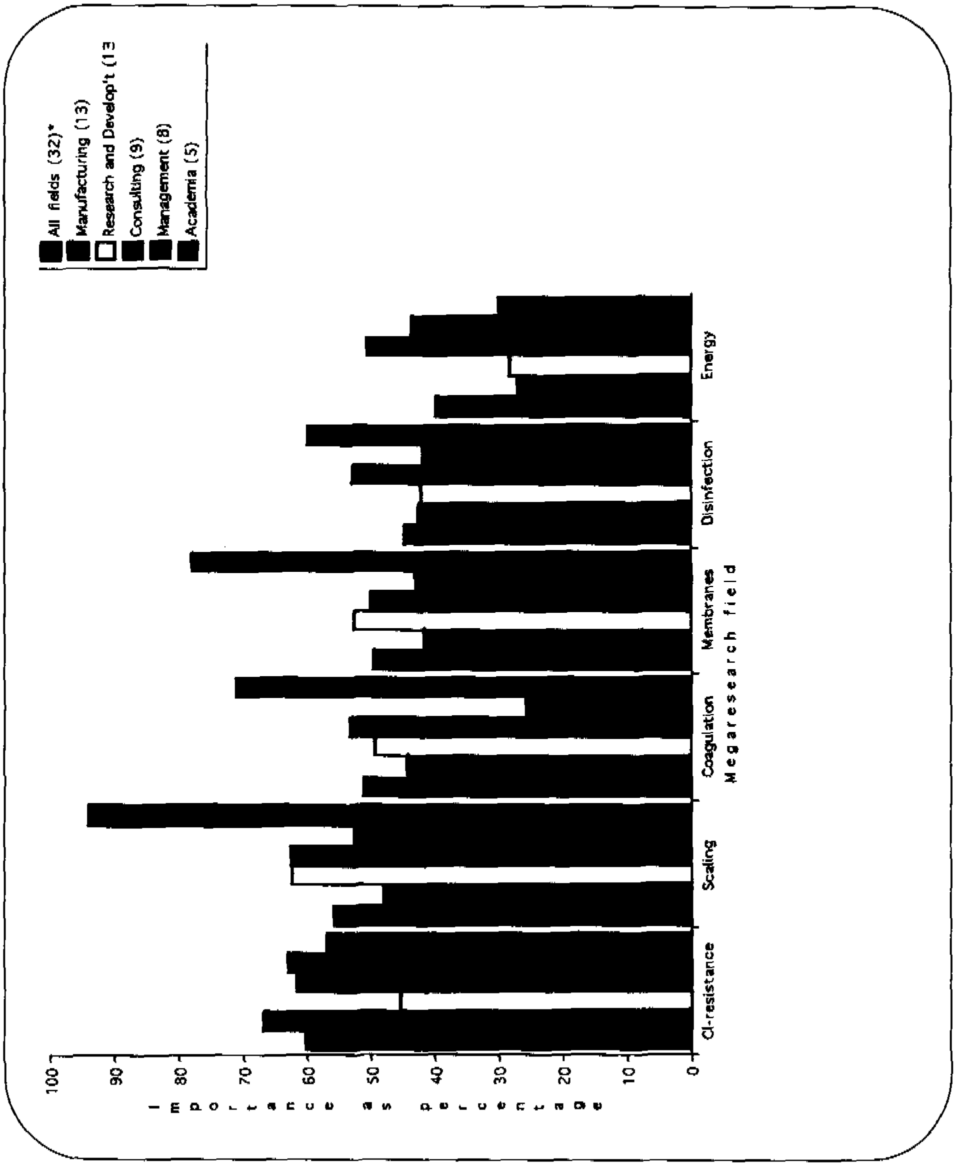

FIGURE 11 : MEMBRANE PROCESSES : RESEARCH PRIORITIES ACCORDING TO FIELDS OF INTEREST OF SURVEY RESPONDENTS

A wide spectrum of attitudes was reflected in the replies. Alongside the need for research some respondents felt there was a crucial need to assess, collate and analyse information from research already carried out and make it more accessible.

In Figures 10 and 11 the priorities are separated in accordance with the field of specialisation of the respondents for the distillation and membrane processes.

Likely Cost Reductions from Research

The second item in the survey invited suggestions regarding the possible percentage cost reductions that might be anticipated as a result of major research efforts in the above fields. The averaged replies, as shown in Table 15, varied between 4% and 27%, according to the field. Some respondents felt that it would be very difficult to provide estimates and did not give figures for this item. Although the questionnaire did not specify whether the cost reduction related to capital cost or unit production, a few respondents volunteered two estimates. The difference between them was marginal, so the figures are considered to represent reductions in both costs. In any case, cost reduction not only results from the direct effect of the technical improvement itself, but also to the impact it may have on market forces relating to desalination products. Intensifying competition may have more impact on membrane processes than distillation processes.

The largest cost reductions of between 4% and 27% were estimated for distillation processes, and 8% to 11% for the membrane processes. It appears that a clearer vision exists regarding the requirements for further research into distillation, the oldest desalination technology, than for membrane processes. However, much more intensified research into membrane technology is required and there is substantial interest, particularly among academics. It is possible that the relative lack of confidence in the outcome of research and the relatively large number of man-months proposed is caused by the confidentiality pertaining to this technology. This may lead to the repetition of research, since specialist knowledge about membrane processes is not as widely known as that for distillation process.

Distillation may not have reached the zenith of its development yet, but it may not have very much further to go. Membrane processes, on the other hand, could make great progress if there is a major published break-through in their development. Competition between the two processes will be decided by market forces and will be affected by plant location, along with the manufacturing possibilities and the prevailing standard of operation and maintenance in the country concerned.

Time and Man/Months Required for Research

Respondents were invited to suggest the amount of time and man/months that might be required to produce cost reductions as the result of mega research in the above fields. The fields considered as most promising for cost reduction were not necessarily those which were regarded as requiring the greatest number of man/months for research.

The relationship between the anticipated cost reduction and the man-months estimated to bring about, varies considerably between the different research fields. Improvements in corrosion reduction, for instance, is estimated to require 225 man-months to bring about estimated 27% reduction in the cost of desalinated water, while research into large scale capacity increase is estimated to require 272 man-months to bring about a 16% cost reduction. This situation is much more evident in the case of membrane processes: the largest reduction in cost was estimated at 11% for both fouling and scaling mechanisms and SDI reduction, but the former was estimated to require 125 and the latter 199 man-months. Membrane performance in a typically variable chemical environment, energy recovery, and chlorine resistance sea water membrane required 1158, 949 and 890 man-months respectively, for an estimated cost reduction of 8%. Research priority should be given to those fields likely to give the maximum return for the least outlay.

FUNDING AND MANAGING RESEARCH IN DESALINATION

Estimating a Budget

In order to estimate a budget for carrying out research in desalination, assumptions need to be made regarding the following items:

1. The nature of the research field and the likelihood of a possible positive outcome.

2. The approximate time and personnel required for achieving useful results which could be developed further by the industry.

3. The institution required to undertake the research and its capability to do so.

4. The material required for constructing prototype models and pilot projects for experimental purposes.

The survey carried out into mega research fields has given an indication of the fields of research that are likely to be productive and also an idea of the amount of time and personnel required. With regard to suitable institutions to carry out the research, both academic and industrial research centres have made considerable advances in promoting the desalination industry. The industrial centres value their achievements and feel they have the right to recover the cost of their research and to benefit from the monopoly they enjoy as long as their competitors are unable to produce similar products of the same calibre. On the other hand, the academic research centres are more accessible to the public and their results can be utilised to intensify competition, although they may be behind in certain fields already tackled by the industry.

In view of the expertise and experience the manufacturers have acquired over the years, they should be supported to enable them to expand their research activities provided they make the results public on terms and conditions acceptable to all concerned. Embarking on major public research in some of the fields required without collaboration with the industry will lead to repetition of research, extensive completion times, and possibly minimal rewards. In fact, carrying out public research without the participation of the industry may accelerate the latter's research as it will be able to make use of published research while continuing to keep its own results confidential. Collaboration of the industry with public research and development organisations is therefore essential.

Just as important is the appropriate involvement of the regional research institutions. Their achievements should be developed, particularly with regard to refining operation and maintenance strategies where data is readily available. Research which requires prototype modelling and access to advanced technologies would be carried out in the industrial countries in collaboration with researchers from the GCC countries.

The collaboration between academic institutions and the industry should lead to an acceleration of research and make it more readily available for commercial production. If a grant is made available for such a set-up, it is possible either for the patents to be assigned to the party giving the grant or for the findings to be published in the scientific literature, depending on the agreement reached before making the grant.

Cost of Mega Research

An indication of the expenditure required for personnel and facilities can be gained from the current fee rate for experts from the industry which is now about US$ 20,000 per month, including the cost of overheads, supporting staff, and holidays, etc. A budget is also required for expanding the facilities and materials needed, particularly if the research is to be carried out in a university or research centre. A rule of thumb, which covers such costs and the cost of material required for prototype models, doubles the total cost of the experts based on the above rate.

Using the figures for man/months obtained from the survey into mega research requirements, cost estimates have been prepared for carrying out the various large scale research into desalination.

It is apparent from Table 16 that the total cost for each of the proposed research fields varies between US$ 2.8, for heat transfer improvements, to about 46.3 million for improving membrane performance in typically variable chemical environments. The annual cost however, was calculated using the estimated time required to complete each research field as shown in Table 15. On this basis the annual budget for each field varies between US$ 0.74 for heat transfer improvement and scaling prevention techniques for film evaporation and 12.2 million for energy recovery devices. All in all, it appears that the total cost of carrying out research in all the fields is about US$ 210 million, that is about US$ 55 million/year for a period of 4 years at least.

Over the period between 1952 and 1982 the US Government funded the OSW and later OWRT (Office of Water Research and Technology), for desalination research, development and demonstration to the extent of about US$ 1.44 billion in 1994 dollars (MEMWG, 1994). This is equivalent to an average of about US$ 48 million per year. In some years the budget went up to about US$ 160 millions and in others did not exceed few million US$.

It is also recognised that the desalination industry, in the sixties and early seventies, have invested about $40 million on developing RO membranes only. It can be seen therefore that the total annual cost estimate of about $55 million is in line with the past level of expenditure of the OSW and the industry.

TABLE (16)

ESTIMATED COST OF CARRYING OUT MEGA RESEARCH FOR REDUCING THE COST OF DESALINATION

Research Fields	Total Cost (million US$)	Annual cost (million US$)
DISTILLATION PROCESS Scaling prevention techniques for film evaporation	3.1	0.75
Corrosion reduction, including cost reduction of corrosion resistant materials for moving and non-moving parts	9	1.7
Large-scale capacity increase	11	2.3
Heat transfer improvement	2.8	0.74
Computer control of processes	6.6	2.4
Flexibility of wate/electricity production	3.3	1.4
Computer modelling for plant design	4	1.6
MEMBRANE PROCESSES Chlorine resistant seawater membrane	36	8
Fouling and scaling mechanisms	5	1.1
Seawater coagulation and filtration techniques (SDI reduction)	8	2.7
Membrane performance in typically variable chemical environments	46.3	10.3
Feedwater disinfection, alternative strategies, e.g. ozone	6.1	2
Energy recovery devices	38	12.2
HYBIRD PLANTS	18.6	3.4
OPERATION AND MAINTENANCE STRATEGIES	9.8	3.9
Total	207.6	54.45

Funding Sources

The funding available for public research in major industries is limited and normally comes from the industrial governments concerned. Much greater funding than the amounts normally allocated is required to make a major impact on the desalination process. However, such allocations have been reduced in recent years along with allocations for public research in desalination, for which industrial countries do not seem to consider that there is a particular need, and are apparently satisfied with the progress made by the private sector. Because of the increasing demand for desalination and the apparent monopoly in certain areas of the desalination industry, the private sector appears to be able to recover its research expenses with a margin of profit from the users of desalination, who are mainly in the GCC countries.

While in-house research improves the quality of manufactured desalination products, it also increases costs and strengthens monopolies. Moreover, manufacturers normally concentrate on the least risky research work so as to ensure both cost recovery and profit. Main manufacturers cannot afford the high risk, long-term research programmes needed to produce significant reductions in desalination cost. Also, the strongly conservative nature of the market discourages innovation, since pioneering technology invokes more risks of operating problems - low capacity, poor availability, lower water quality and higher maintenance - than proven technology; no customer wants the first unit of a new design. It is difficult to get main manufacturers to sponsor the development of laboratory scale systems owing to the huge size gap between them and the modules being sold.

It is evident that the major beneficiaries of public research in desalination are the users, who are basically the GCC countries. It is therefore in their direct interest to invest in public research so as to intensify competition and reduce costs. The annual budget required for this purpose is estimated to be about US $55 million which represents about 0.06% of the GCC countries' oil income in 1994. It is, therefore, a reasonable budget for the GCC countries, even though the income from oil has declined in recent years. The need to increase the availability of water, not only to satisfy increasing water demand, but also to diversify income by encouraging their industrial sector in particular, cannot be achieved without establishing a reliable source of water which has to be desalination.

Management of Research

Management of research will most probably be more difficult than finding the funding required for carrying out the research needed. There is considerable evidence that unconstrained research becomes academic and does not lead to commercial product. It is said that research and development is only viable if there is a commercially acceptance end product which will be accepted in the market place (Stewart, 1994).

Selection of basic research projects must depend on the possible contribution that may be made to the understanding of a larger phenomenon, the track record of the principle investigator, and the originality of the proposed work. Since deciding when to discontinue research may be more difficult than starting it. Reviews should consider whether results are just measurements or a discovery. In the case of applied research - which should be easier to judge on useful results - many papers report the intense analysis of minutia of little relevance to improving product or process, or go over old ground because researchers and funding agencies may not be up to date as to what are the real problems and the practical and economic limitations.

The management of research requires therefore international specialists who are familiar with the development of the industry and have objective views on the selection of research fields which are under consideration for financing.

A "Middle East Centre", based in Muscat, Oman is now under active consideration with the expressed mission to carry out, facilitate, co-ordinate, and support desalination related research projects and programmes. To achieve the goals set, however, it is necessary to establish a mechanism with assured continuity for funding research. Some of the GCC countries on the other hand, have already established national funding institutions and also contribute to regional funding institutions in order to assist the economies of developing countries in most parts of the world. Their laws and charters, however, do not allow them to participate in financing research. They normally participate in financing development projects which are economically viable and technically sound. The funding institutions also extend grants in the form of technical assistance for carrying out feasibility studies for justifying projects. Their exposure to dealing with international developing agencies, their ability to ensure the efficient implementation of development projects with minimal staff, together with their concern for the proper development of natural resources - particularly water - and the fact that they represent those countries in the world most affected by water shortages, qualify them to take a lead in funding research in desalination technology. This may mean changes to their laws and charters will be necessary as well as additional funding from the governments represented by their boards of directors.

It appears therefore, that a set-up for management and funding of research in desalination is feasible to be accomplish in the GCC countries. The Middle East Centre could take the rule of formulating plans for implementing research projects with the assistance of visiting specialised committees and submit such projects for financing from the Arab national and regional funding institutions. A nucleus of permanent technical staff can probably be assigned from the staff of the Arab national and regional financing institutions, in collaboration with international financing institutions, such as the World Bank to review research proposals. Funding should be made available for research approved by the funding institutions based on the assessment of the technical committees' of the proposed Middle East Centre. The progress of research should be assessed at appropriate intervals by the Centre and the funding institutions. Assessment should also be made of all ongoing research so as to decide whether further investment is beneficial or should be held back from research projects which are not producing significant results.

References

- Abu Kheat, Mohammed, Salah Ad-Din Al-Jawhari Mohammed Abdul Kader Al-Kharouf, Mohammed An-Nashmi (1992): The Efficient Utilisation of Water for Irrigating Green Areas in Riyadh City, Proceedings of First Gulf Water Conference, Dubai (Arabic).

- Ad-Dahmash, Abdu-Arahman Mohammed, Ahmed An-Nimr, Yousof Osman Al-Farehedi, (1992): Programme for Control of the Problem of the Rising Sub-surface Water Level and Treating its Effect in Riyadh City, Proceedings of the First Gulf Water Conference (Vol II), Dubai, UAE (Arabic).

- Al-Alawi, Jamil, and Mohammed Abdulrazzak (1994): *Water in the Arabian Peninsula: Problems and Perspectives,* Chap. 7 in Peter Rogers and Peter Lydon (eds.), Water in the Arab World: Perspectives and Prognoses, Division of Applied Sciences, Harvard University pp 171-202.

- Al-Azraqui (1859): *Akhbar Mecca Al-Musharafah,* Narrator Al-Khuuzaai, Vol I, Gottingen (Arabic).

- Al-Fakehi, Al-Fassi and Ibn-Zahera (date unknown): *Akhbar Mecca Al-Musharafah,* Narrator Al-Khuzaai, Vol II, based on Ketab Al-Montaqa Fi Akhbar Em Al-Qoura, Min Shefa Al-Gharam Fe Akhbar Al-Balad Al-Haram (Arabic).

- Al-Hammad, A.Y. (1995): *The Role of Oil in Development,* Second International Conference on Catalysts in Petroleum Refining and Petrochemical Industries. Kuwait Institute for Scientific Research, Kuwait (Arabic).

- Al-Migren, Abd Alatif Ibrahim (1992): The strategy of Developing and Conserving Water Resources in GCC Countries, Proceedings of the First Gulf water Conference, Dubai (Arabic).

- Al-Mohannadi, (1994): The Doha Water Loss Control Project, Proceedings of the Second Gulf Water Conference, (Vol II), Water Sciences and Technology Association, Bahrain.

- Anonymus (1994): *Water Transportation Projects to Middle East Countries,* Arab Water World, Vol. XVII Issue No. 6/Vol XVIII, Issue No. 1, pp 51-53., Beirut, Lebanon.

- An-Nimr Ahmed, Yousof Osman Al-Farehedi, Salih Abdul Rahman Al-Fayezi (1992): Study of the Effect of Sub-Surface Water Drainage on Water Balance

Using Computer Modelling, Proceedings of First Gulf Water Conference, Vol I, Dubai, UAE (Arabic).

- AOPEC (1978): The Secretary General 5th Annual Report. OAPEC, Kuwait (Arabic).

- AOPEC (1982): The Secretary General 9th Annual Report. OAPEC, Kuwait (Arabic).

- Al.Sofi, Mohammed Abdul Karim, Essam Ad-Deen Faraj As-Sayed (1994): Available Aspects for Research and Study for Developing Multi Stage Flash Distillation. Proceedings of the Second Gulf Water Conference, Bahrain 5-9 Nov. 1994 Vol. II. Water Sciences and Technology Association, pp 216-225 (Arabic).

- Buros, O.K. (1991): Research Needs for Upgrading Sub-standard Water Supplies. Summary Report of Seminar held as part of 1991 International Desalination Association World Conference on Desalination and Water Re-use, August 25-28, 1991 Washington, D.C.

- Bushnak, Adil A., (1993): *Water Desalination, The Experience of GCC countries,* United Nations Economic and Social Commission for Western Asia, Amman.

- CEMUREAU, (1991): World Statistical Review, European Cement Association, Belgium.

- Cheong, Lai Cheng (1991): International Report, Unaccounted-for Water and the Economics of Leak Detection, Journal Water Supply (Vol 9, Nos. 3 and 4)., London.

- Crouch, Dora P. (1987) : *Water System Evidence of Greek Civilisation,* Water O.Wunderlich and J. Egbert Prins (eds) Water for the future, Water Resources Developments in Perspective, International Association for Hydraulic Research, pp 125-138.

- Dabbagh, Taysir A., and A. Al-Saqabi, (1989): The Increasing Demand for Desalination, Proceedings of the Fourth Congress on Desalination and Water Re-use Vol. I. pp. 3-26. The International Desalination Association, Elsevier Science Publishers.

- Dabbagh, Taysir, Peter Sadler, Abdulaziz Al-Saqabi and Mohammed Sadeqi, (1994): Desalination: an Emergent Option, Chap. 8 in Peter Rogers and Peter Lydon (eds), *Water in the Arab World: Perspectives and Prognoses,* Division of Applied Sciences, Harvard University, pp 203-24.

- Dracup J.A. and J. Glater (1991): Desalination: The need for Academic Research, Submission to the U.S. House of Representatives committee on Science, Space, and Technology, Subcommittee on Science. July 17, 1991, Washington D.C., U.S. Congress.

- Flavin, Christopher and Nicolas Lenssen, (1994): *Power Surge,* W.W. Norton and Company, New York.

- Ghobrial, Fikry H. (1992): Performance Assessment of Three Wastewater Treatment Plants Producing Effluents for Irrigation, Proceedings of IAWPRC Conference, Feb. 1992.

- GOIC, (1982): Consumption of Cement in Arab Gulf State, on line Data Base of GOIC, Industrial Data Bank, Qatar.

- GOIC, (1994): Consumption of Cement in GCC countries, Industrial Data Bank, Qatar.

- GOIC, Gulf Organisation for Industrial Consulting (1993): *The Major Indicators for Industrial Development in the States of Gulf Collaborative Council,* Industrial Development in the Arab States of the Gulf Collaborative Council in the Nineties - Challenges and Opportunities - Kuwait 12th to 13th January 1993, pp. 8-24 (Arabic).

- GOIC, Gulf Organisation for Industrial Consulting (1993): *Gulf Statistical Profile,* Qatar, pp 180.

- Ghosh, D. (1990): A low Cost Sanitation Technology Alternative for Municipal Wastewater Disposal Derived from the Calcutta Sewage-Fed Aquaculture Experience, Wastewater-fed Aquaculture, Proceedings of the International Seminar on Wastewater Reclamation and Reuse for Aquaculture, Calcutta, India, 6-9 December 1988. Environmental Sanitation Information Centre, Asia Institute of Technology, Bangkok.

- Ghosh, D. (1992): Urban Sanitation Ecosystem in the Wetlands to the East of Calcutta, Re-defining the Practice of Wastewater Utilisation in Fish Ponds and Agriculture, Ashoka Foundation, Calcutta.

- Goto, Totaro, (1992), Water Reuse-Industrial Water, The International Desalination and Water Reuse Quarterly Vol 2/3, pp 33-36.

- Hanbury, W.T. (1994), Contributions that Chemistry and Chemists can make to Desalination Technology, An Engineers view. Department of Mechanical Engineering, University of Glasgow, Scotland, U.K.

- Harrison C. (1993): Providing Incentives for Cost-Effective Water Loss Control. Two case studies and recommendation, World Bank International Workshop on water Conservation, Dalian City, China.

- Hespanhol I, (1990): Guidelines and Integrated Measures for Public Health Protection in Agricultural Reuse Systems, J. Water SRT-Aqua, Vol. 39, No. 4 pp 237-249.

- Hirner, W. (1992): Management Issues and Requirements for a Long-term Secure and Economical Water Supply, Water Supply, Vol. 10, Florence, pp. 55-66.

- International Cement Review (1994): Global Cement Report.

- Leitner, Gordon F. (1994): Commentary, IDA News, Vol. 3 Issue 5/6-May/June, 1994, Topsfield, MA 01983, U.S.A.

- (MEMWG) Middle East Multilateral Working Group on Water Resources, Sultanate of Oman, (1994): World-wide Desalination Research and Technology Survey, The Ministry of Foreign Affairs, Sultanate of Oman.

- Montagu, Caroline, (1994): *The Private Sector of Saudi Arabia,* Special Report, Committee for Middle East Trade (COMET), London.

- Nazer, Hisham (1995): Oil Producers Challenges into the Twenty First Century, Second International Conference on Catalysts in Petroleum Refining and Petrochemical Industries, Kuwait Institute for Scientific Research, Kuwait.

- OECD, A report by the Secretary General (1974): *Energy Prospects to 1985* - An assessment of long Term Energy Development and Related Policies OECD, Paris.

- O'Meara, Pat J.W. (1992): A 20 years Hindsight of OSW's Two Decades of Progress. The International Desalination and Water Reuse Quarterly, Vol 2/2 and Vol 2/3, IDA, Topsfield, MA, U.S.A.

- OPEC, (1993): Annual Statistical Bulletin, OPEC, Vienna.

- Pakravan, Karim 1984: *Oil Supply Disruption in the 1980,* Hoover Institution Press, Stanford University, Stanford, California.

- Pearce, David (1981): *World Energy Demand and Crude Oil Prices to the Year 2000,* Annual Conference of the Agricultural Economics Society, Discussion Paper 80-12 Aberdeen University.

- Pye-Smith, Charlie (1995): Salvation from Sewage in Calcutta Marshes, People and the Planet, Vol.4, No. 1, pp 20-21, London.

- Pyne, R.D.G. (1988): Aquifer Storage Recovery: A New Water Supply and Ground Water Recharge Alternative, Proceedings of American Society of Civil Engineers, International Symposium on Artificial Recharge of Groundwater, Anaheim, California.

- Pyne, R.D.G. (1992), Aquifer storage recovery (ASR): Ensuring Water Supply Reliability for the Gulf Region, Proceedings of First Gulf Water Conference (Vol I) Dubai.

- Pyne, R.D.G. (1994): *Groundwater Recharge and Wells,* A Guide to Aquifer Storage Recovery, Lewis Publishers.

- Reed, E.C. (1980) Report on Water Losses, Aqua, International Water Supply Association, London.

- Sadik, Abdul-Karim, Shawki Barghouti, (1994): The Water Problems of the Arab World: Management of Scarce Resources, Chap. 1 in Peter Rogers and Peter Lydon (eds), *Water in the Arab World: Perspectives and Prognoses,* Division of Applied Sciences, Harvard University, pp 1-38.

- Salih, Abdin M. (1994): Water Scarcity in the Arab Region - Options for Survival, The Eighth Islamic Academy of Sciences Conference, Khartoum.

- Shuval, Hillel I. (1990) : Wastewater Irrigation in Developing countries, Health Effects and Technical Solutions, Summary of World Bank Technical paper Number 51, UNDP-World Bank Water and Sanitation Programme, Washington D.C.

- Shuval, Hillel I. (1995) : Optimizing Wastewater Recycling and Resue as a Sustainable Water Resources in Arid Counries, Proceedings of the Sultanate of Oman International Conference on Water Resources Management in Arid countries Vol.2, IWRA.

- Singer, Philip C., R. David G. Pyne, Mallikarjun AVS, Cass T. Miller, and Carolyn Mojonnier, (1993): Examining the Impact of Aquifer Storage and Recovery on DBPs, Journal AWWA.

- Smith, J.A. (1992): An Examination of Recent Developments in Leakage Control Monitoring Techniques, Water Supply (Vol 10, Florence, pp 159-168).

- Stewart, James M. (1994): R and D-Do We Really Need It? IDA News, Vol 3, Issue 5/6, International Desalination Association, Topsfied, MA 01983, U.S.A.

- Temperley, Tom (1994): Commentary, IDA News, Vol 3 issue 3/4 March/April, 1994, Topsfied, MA 01983, U.S.A.

- The World Bank, (1993): Gains that Might be Made from Water Conservation in the Middle East. The World Bank, Washington D.C.

- The World Bank (1994): *Managing Water in the Middle East and North Africa,* The World Bank, Washington D.C.

- The World Resources Institute, UNEP, UNDP (1993): *World Resources,* Oxford University Press U.K. (Arabic Edition).

- Twort, A.C., F.M. Law, F.W. Crowley D.D. Ratnayaka (1994): Water Supply, Fourth Edition, Arnold, London.

- WHO, (1989): *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture,* Technical Report Series 778, WHO, Geneva, 1989.

- World Health Organization (1994): *Financial Management of Water Supply and Sanitation, A Handbook,* World Health Organisation, Geneva.

- World Water/WHO, (1987): *The International Drinking Water Supply and Sanitation Decade Directory,* Edition 3, Thomas Telform Ltd., London

- Yevjevich, Vujica (1992): *Water and Civilisation,* Water International, Vol 17.pp 163-171.

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