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Desalination in arid regions: Merits and concerns

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ABSTRACT

Water, the essence of life, can no longer be considered a natural, self-renewable, low-cost resource in most arid and semi-arid regions. In order to alleviate water scarcity, new water supply sources are in need to augment available resources. Desalination has received wide acceptance in arid countries because of the alarming rate at which conventional water resources are depleted. The present study aims at examining the impacts of the desalination industry in water-stressed regions. The economics of desalination are compared with conventional and non-conventional water options, taking environmental impacts into consideration. Social and political constraints associated with desalination are outlined with emphasis on its merits and drawbacks in national and/or regional water policies. The paper concludes with emerging water management concepts that can aid arid and semi-arid countries in coping with water shortage.

Key words | arid regions, desalination, economic and environmental impacts, water management

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ACRONYMS

GCC	Gulf Cooperation Council
MENA	Middle East and North Africa
MSF	Multi-stage flash distillation
PM	Particulate matter
RO	Reverse osmosis
SWRO	Seawater reverse osmosis
TDS	Total dissolved solids
UAE	United Arab Emirates
WHO	World Health Organization

INTRODUCTION

Worldwide water consumption has been continuously rising. While the world's population doubled during the 20th century, exploitation of freshwater resources increased by sixfold (ESCWA 1999). Nearly 40% of the world's population suffer from water shortage; this ratio is expected to reach 60% by 2025 due to population growth, improvements in life-style, increased economic activity and contamination of existing water supplies (ESCWA-UNEP 1996).

Alleviation of water scarcity problems and meeting future water demands requires new sources and improved management practices. In this context, desalination along with other non-conventional water supply sources has received wide acceptance particularly in arid and semi-arid countries (Gleick 2000; Saghir *et al.* 2000).

While desalination was for long considered a technology too expensive to adopt in most countries, except those with large reserves of fossil fuels and affluent economies, recent advances in desalination technology are increasing its market share.

This paper examines water options available for exploitation in arid regions, with emphasis on the adoption of desalination technology as an emerging and increasingly affordable non-conventional water resource to bridge the gap between supply and demand. The merits and concerns associated with the introduction of desalination plants into arid countries are assessed on three main levels: economic, environmental and socio-political. For this purpose, the costs of desalinated water are compared with those of other non-conventional and conventional water resources. Environmental impacts related to the introduction of desalination plants are evaluated with particular emphasis on the marine environment. And, the socio-political concerns relating to the desalination industry are explored. The paper concludes with a future outlook on emerging management strategies to complement non-conventional sources such as desalination.

WATER SITUATION IN ARID REGIONS

Arid regions are areas characterized by irregular and scanty precipitation coupled with high evaporation rates, which cause large deficits in the water budget. Such harsh conditions lead arid countries to experience grave imbalances between available water resources and water demand. The Middle East and North Africa (MENA) region and more specifically the Gulf region has the world's lowest per capita availability of water and the highest rate of annual per capita reduction in these resources. The ratio of available renewable water sources to the volume of water being utilized has already exceeded the 200% mark (except for the Sultanate of Oman) and is expected to reach more than 600% by 2025 (Abdurazzak 1999). In order to account for the water deficit expected in the domestic and industrial sectors by the year 2020, it is estimated that new water projects with an added capacity in excess of 14 million m^3 day^{-1} would have to be installed within this region at a cost of about US$15–30 billion (Mandil & Bushnak 1995).

ALTERNATIVE SOURCES

Water sources can be divided into two categories: conventional[1] and non-conventional[2]. Table 1 lists the properties, advantages and disadvantages of the different water resource development options. Clearly, it can be seen that the main advantage of developing unconventional water sources is the ability to surmount the dependence on precipitation patterns that are scarce, unpredictable and unevenly distributed. Yet the main barriers retarding their wide use remain the associated costs, the absence of clear political will and the lack of strategic water policies.

[1] Naturally occurring fresh water sources that can be readily used with limited treatment measures.
[2] Sources that can be tapped and used to satisfy different water needs after a series of elaborate treatment processes.

THE MERITS OF DESALINATION

Clearly, the major merit associated with the adoption of desalination is the ability to tap water containing total dissolved solids (TDS) levels above the 1,000 $mg\,l^{-1}$ threshold for community use. The commissioning of a desalination plant in an arid or water-stressed country can alleviate existing or forecasted water shortages, prevent unsustainable exploitation of renewable and fossilized ground water resources, and minimize saltwater intrusion into coastal aquifers. It will also generate job opportunities for communities near desalination plants.

The quality of desalinated water meets most international standards set for potable water use. The production and distribution of desalinated water will limit the adverse health effects associated with drinking or utilizing poor quality water and will help in controlling a wide spectrum of water-borne diseases ranging from cholera to parasitic diseases.

THE CONCERNS OF DESALINATION

The major concerns associated with desalination plants include the potential impacts on the economic, energy, environmental and socio-political conditions of the area of influence.

Economics

In general, there is a perception that the costs associated with the development of surface water projects and groundwater resources are lower than those needed for the development of sea or brackish water desalination. Recent advances in desalination technology however are

Table 1 | Advantages and disadvantages of various water resources

Water source	Description	Major advantages	Major disadvantages
Conventional			
Surface water	Surface water was the first water source to be exploited historically	Public acceptability	Dependent on precipitation changes
	The building of dams on major waterways was once viewed, and in many countries it still is, as the ultimate solution for augmenting available water supplies	High water volume conveyance	Impacts on marshland, lakes and floodplain ecosystems
	Major dam projects are being re-evaluated by the World Commission on Dams after several major dam projects have been delayed or halted due to opposition from local groups based on their high costs, population displacement, land inundation as well as potential ecological disruptions	Moderate cost	Endangers valuable aquatic/terrestrial ecosystems
			Transfers from basins with surplus water to basins with water deficits are becoming very costly
Groundwater	Estimated to hold more than $8.34 \times 10^{15}\,m^3$ of fresh water, half of which lies within half a mile of the Earth's surface (Castillon 1992)	Public acceptability	Impact on groundwater table
	The Gulf Cooperation Council (GCC) countries have vast fossil groundwater resources and are estimated to hold around $40 \times 10^{12}\,m^3$ (Al-Zubari 1998)	Moderate cost	Impact on land subsidence
	Negligible natural recharge rates coupled with high unsustainable extraction rates are leading to the lowering of water tables, increase in salinity and desertification		Leads to saltwater intrusion
	Groundwater quality is being compromised as a result of wastewater seepage and seawater encroachment into major aquifers		Impacts on marshland, lakes and floodplain ecosystems
Non-conventional			
Desalination	Desalination separates saline water into two streams one with a low concentration of dissolved salts and the concentrate or brine stream that contains the remaining dissolved salts	High quality water	Moderate to high costs

Table 1 | (*continued*)

Water source	Description	Major advantages	Major disadvantages
	The desalination market is growing significantly whereby the desalination capacity of the United States alone is growing at an annual rate of 10–20% while it is anticipated that the Gulf region will almost double its capacity in the next 20 years (Al-Zubari 1998; Ponce & Jankel 1999)	Relatively independent of precipitation changes	Marine impacts
		Diversify water sources	Energy intensive process
		Virtually unlimited supply	Dependent on external aid for technology and spare parts
		Limits unsustainable use of conventional water	Limited to coastal areas or areas with reserves of brackish water
Wastewater reuse	Adopted wastewater treatment procedures include preliminary, primary, secondary, and/or tertiary treatment	Reduce environmental impacts of sewage discharge	Costly if tertiary treated
	The reuse of wastewater is increasingly becoming a viable alternative in arid regions	High water volume production	Public acceptability
	Recycled wastewater can be reused in a multitude of sectors: industrial, agricultural, groundwater recharge, construction, and recreational water reservoirs		Potential water-borne diseases
Other	Includes iceberg towing, transport of water by large tankers, towing water via large capacity rubber bags and the trans-boundary transport of water from neighbouring water rich countries (Khordagui 1997)	Diversify water sources	Very costly
	While all of these options are still either at an experimental stage or too expensive, trans-boundary pipeline transportation has received greatest attention		Politically unacceptable
			Technical feasibility in question
			Lack of previous experience

Table 2 | Cost of desalination

Source	Reported cost (US$ m^{-3})
California Coastal Commission 1993	0.8–1.7
Bushnak 1997	0.4–2.5
Dabbagh & Faraj 1997	0.4–2.5
ESCWA 1997	0.25a–2.5
Glueckstern & Priel 1998	0.6–1.0

[a]For the desalination of brackish water

closing this economic gap. Worldwide reported average unit costs for desalinated water range between US$0.25 m^{-3} (slightly brackish water) and US$2.50 m^{-3} (Table 2). This wide range is attributed to variations in operating conditions including amortization and interest rates, price of electricity, plant size, type of process selected, raw water sources, site condition as well as estimated lifetime of the plant (Al Radif 1999). The plant capacity and the desalination technology adopted are considered the main factors affecting the final cost of desalinated water (Figure 1). Plants relying on the reverse osmosis process are generally cheaper.

The cost of desalinated water has shown a decreasing trend with time, whereby the cost of 1 m^3 in 1997 decreased to 5% of its cost in the 1960 s (ESCWA 1997). This trend is clearly depicted in Figure 2, which indicates that the average cost of a cubic metre of desalinated water has decreased from US$1.9 in 1988 to US$0.7 in 2000 (Tsiourtis 2001). This decrease is expected to continue offsetting the cost of desalination as new technological innovations are developed. One estimate expects that by the year 2025 the price of desalinated water could come down to as low as US$0.15–0.25 m^{-3} for brackish water and US$0.25–0.5 m^{-3} for seawater (Al-Alawi *et al.* 2000). Figure 3 compares the costs of desalination with other non-conventional and conventional water sources. The comparison clearly indicates that for many countries desalination has become more economically sensible than investing in new conventional water resources.

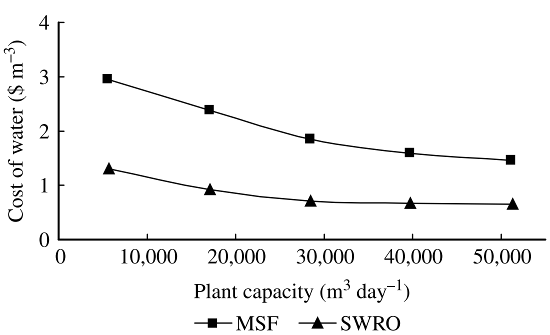

Figure 1 | Variation of cost of desalinated water with size and process (Morin 1999). MSF = multi stage flash; SWRO = sea water reverse osmosis.

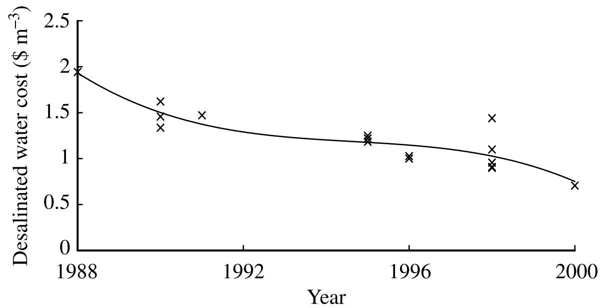

Figure 2 | Desalinated water cost evolution (Jensen *et al.* 1999; Morin 1999; Ponce & Jankel 1999; Tsiourtis 2001).

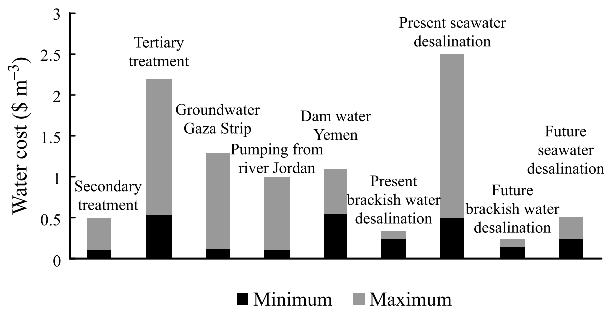

Figure 3 | Desalination costs compared with other conventional and unconventional water options (Isaac 1995; ESCWA 1997; Al-Zubari 1998; Abdurazzak 1999; Ebrahim *et al.* 1999; ESCWA 1999; Morin 1999; Ponce & Jankel 1999; Al-Alawi *et al.* 2000; Semiat 2000).

Energy

Desalination is an energy intensive process whereby the contribution of energy to the operational costs of desalting plants is significant and raises concerns among decision-makers. The contribution of energy to the total cost of desalinated water varies anywhere between 20 and 50% depending on process type and design, energy costs, ambient conditions, presence or absence of energy recovery devices, and the plant's performance ratio (ESCWA-UNEP 1996; ESCWA 1997; IAEA 1997; Tsiourtis 2001). The estimated energy consumption rates of various multi-stage

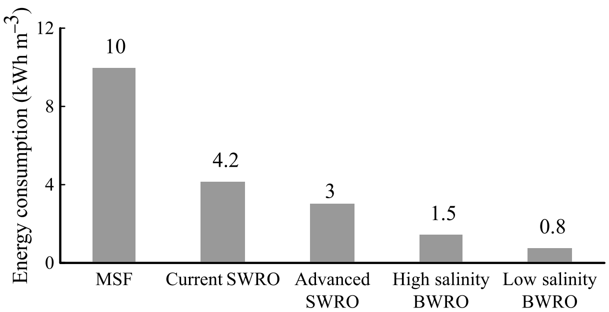

Figure 4 | Typical desalination energy requirements (Tsiourtis 2001).

flash distillation (MSF) and reverse osmosis (RO) based desalination technologies are compared in Figure 4.

Nevertheless, promising reductions in energy consumption can be achieved by connecting energy recovery devices or by proper planning. A well designed, single stage, high recovery, large scale sea water reverse osmosis (SWRO) unit with energy recovery and high equipment efficiency operating on the Mediterranean is expected to utilize around 4 to 5 kWh m^{-3} (Barendsen & Moch 1999; Corral & San Juan 1999). In MSF plants, the energy consumption rate can go as high as 32 kWh m^{-3} making MSF an uncompetitive desalination option when energy costs are high (ESCWA 1997). Reductions in energy consumption rates of MSF units can be achieved by utilizing waste heat from steam power plants where power and desalinated water are co-generated. This arrangement can achieve reductions in the fuel consumption rate compared with the consumption rates needed if the plants are operated independently (Buros 2000; ESCWA 1997).

Environmental

The introduction of a desalination plant is inevitably linked with several potential environmental impacts at both the construction and the operational levels. In general, construction impacts are spatially and temporally restricted to the site and construction periods. Construction activities are usually associated with the release of particulate matter (PM), changes in land use, and increased seawater turbidity (Abu Qdais 1999; Al-Awadhi 1999). Other less pronounced construction-related impacts include disturbance of existing sand dunes, surf zone and seafloor ecology, seabirds and marine mammals, archaeological and palaeontological resources, erosion, interference with public access and recreation rights, noise pollution and visual intrusion (California Coastal Commission 1993).

The potential negative impacts associated with the operation of desalination plants are of more concern and are mainly due to the release of stack emissions and the discharge of the resulting brine effluent. Other potential operation-related impacts include water abstraction, waste and sewage generation as well as the social perception concerning the quality of desalinated water.

Air quality

As mentioned above, the energy requirement is a characteristic of desalination processes to achieve the separation of fresh water from the saline feed. Predictions of air pollution in urban and industrial agglomerations show that a high percentage of atmospheric emissions are attributed to seawater desalination, especially MSF-power cogeneration plants[3] (Mannaa 1994). This is mainly due to fossil fuel combustion that occurs at power plants supplying electricity or steam to the desalination industry. Fossil fuel combustion is associated with the release of carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM) and carbon monoxide (CO). The production of 1 kWh of electrical or 3–4 kWh of thermal energy results in the emission of up to 1,000 g of CO_2, 14 g of SO_2, 4–5 g of NO_x, 80 g of slag and more than 100 g of flying ash (Grebenyuk *et al.* 1996).

Water abstraction

The marine environment in the vicinity of a desalination plant can be adversely impacted by the abstraction of large volumes of water to feed the process. The expected intake volume per day is a function of the process adopted and its efficiency in converting seawater into potable water. RO processes are more efficient than MSF distillation plants and require smaller volumes of seawater to produce the same amount of potable water (Table 3).

The seawater feed is abstracted either through offshore intake structures, beach wells, or infiltration galleries. Water pumping from offshore intakes is associated with impinge-

[3] The atmospheric emissions associated with MSF plants are expected to be far more than those associated with RO processes due to the energy intensive nature of the process.

Table 3 | Seawater intake for RO and MSF (Buros 2000; Morton *et al.* 1996; Höpner & Windelberg 1997; Semiat 2000)

Process	Typical water conversion (%)	Volume of potable water produced (m^3 day^{-1})	Volume of seawater needed (m^3 day^{-1})a
RO	35	100,000	285,700
	50	100,000	200,000
MSF	9.2	100,000	1,087,000

[a]Volume of seawater needed = volume of potable water produced/typical water conversion

ment causing physical damage, disorientation and/or mortality to marine organisms. Such effects coupled with the entrainment of phytoplankton, zooplankton, sea grass and ichthyoplankton will reduce the productivity of the ecosystem and affect the feeding grounds for several commercially important species such as shrimps, pearl oysters and amphipods since most of the entrained organisms will die as a result of high temperatures, high pressures and/or the poisonous nature of the discharged chlorine (ESCWA-UNEP 1996; ESCWA 1997; Al-Awadhi 1999). Also, direct seawater intake structures can change local eddy currents, which may in turn affect marine resources in the vicinity of the structure (California Coastal Commission 1993; ESCWA 1997; Hinrichs & Kleinbach 2002). While the use of beach wells and infiltration galleries for seawater intake is not linked with the impingement or entrainment of marine organisms, it may result in saltwater intrusion to freshwater aquifers thus adversely impacting groundwater resources.

Brine discharge

The concentrated effluent, referred to as brine or brine blow-down, is laden with various constituents that may exert an environmental stress on the surrounding media particularly near outfalls (Table 4). The degree of degradation is highly dependent on the total volume of the brine, the dilution rate prior to discharge, the properties of the receiving waters, and the geometric installation of the discharge outfall. In open and well-mixed environments, adverse impacts have only been noticed within 300 m of the discharge point (ESCWA 1997). Impacts are more pronounced in environments that are located in shallow and/or semi-closed areas.

Brine can alter the distribution and life cycles of existing aquatic plants and animal communities in the vicinity of intake structures. Species responsible for the phytoplanktonic blooms late in winter and at the beginning of spring could bloom earlier, shifting the density and timing of spring blooms. The taxonomic composition and density of phyto- and zooplankton may also shift giving an added advantage to species that are capable of coping with the new surrounding environment. Monitoring results carried out every six months for four years in the Cypriote Dhekelia SWRO desalination plant (production capacity of 20,000 m^3 day^{-1}) have shown that the situation around the outfall point is steady and that the adverse effects on the benthos life have been confined to an area with a radius of 200 m (Tsiourtis 2001). Table 5 summarizes the characteristics, loads, and potential environmental impacts of pollutants present in the discharged brine.

Solid waste and sewage generation

Solid waste generation during the operational phase of an MSF plant is not critical due to the absence of waste producing processes. The operation of RO plants, however, will result in exhausted polyamide membranes that need replacement every three to five years. The appropriate disposal of these membranes is still questionable, although landfilling is currently the practised disposal method (Morton *et al.* 1996; Höepner 1999). Wastewater generation in both MSF and RO plants are not expected to be appreciable in quantity or endangering in quality. Most produced wastewater will be comprised of sewage and cleaning water which is either channelled to the local sewer network or diluted with the brine effluent prior to discharge (California Coastal Commission 1993; Morton *et al.* 1996).

Social perception of desalinated water

Fears have been raised concerning the passage of high levels of heavy metals, toxins from toxic dinoflagellate blooms,

Table 4 | Brine chemical characteristics from three desalination plants in the Gulf region (Khordagui 1997)

Parameter	Unit	MSF Abu-Fintas, Qatar	SWRO Qidfa I Fujairah, UAE	SWRO Qidfa II Fujairah, UAE
Temperature	°C	40–44	32.2	29.1
pH		8.2	6.97	7.99
Conductivity	$\mu S\ cm^{-1}$	NR	77,000	79,600
Calcium	ppm	1,300–1,400	631	631
Magnesium	ppm	7,600–77,000	2,025	2,096
Sodium	ppm	NR	17,294	18,293
Bicarbonate	ppm	3,900	159	149.5
Sulphate	ppm	3,900	4,200	4,800
Chloride	ppm	29,000	30,487	31,905
Total dissolved solids	ppm	52,000	54,795	57,935
Total hardness	ppm	NR	198	207
Free chlorine	ppm	Trace	NR	NR
Silicate	ppm	NR	1.02	17.6
Copper	ppb	<20	NR	NR
Iron	ppb	<20	NR	NR
Nickel	ppb	Trace	NR	NR
Antiscalant	ppm	0.8–1.0	NR	NR
Antifoam	ppm	0.04–0.05	NR	NR

NR, not reported

tube corrosion, and dissolved volatile organic compounds into the desalinated water. Nevertheless, measurements conducted in several RO and MSF plants on the concentration of total halo-methanes and copper in the desalinated water have shown levels below the United States Environmental Protection Agency ($100\ \mu g\ l^{-1}$ for total halo-methanes) and WHO (2 ppm for copper) standards (Ali & Riley 1990; Shams El Din *et al.* 1991; Saeed *et al.* 1999). Data on the concentration of other metals in the product water are lacking although they are expected to be very low (Oldfield & Todd 1996). As such, no direct adverse health impacts have been scientifically correlated with desalinated water.

Socio-politics

One of the most pronounced concerns associated with the introduction of desalination plants into an area is the fear that sabotage or the sudden breakdown of the operating units could lead to devastating outcomes at the socio-

Table 5 | Potential environmental impacts of brine discharge pollutants

Discharged pollutants	Pollutant source characteristics and discharged load	Potential environmental impacts
Corrosion products (heavy metals)	Mainly resulting from the corrosion of copper alloy tubing used in MSF plants and increases significantly under high temperature operations typical of such plants. Reported copper concentrations in the effluent can exceed 0.02 ppm which is 200 times higher than natural marine concentrations (Höepner 1999) Other corrosion products in the desalination industry include iron, nickel, chromium, zinc and molybdenum (Shams El Din *et al.* 1994; McGregor *et al.* 1995; Mickeley 1995; ESCWA-UNEP 1996; Khordagui 1997; Abu Qdais 1999; Al-Awadhi 1999; Höepner 1999)	Heavy metals accumulate in sediments and tissues of aquatic organisms and redistribute the trace metals in an area and change the existing phytoplanktonic and fish communities in an area (California Coastal Commission 1993; Höpner & Windelberg 1997; Abdel-Jawad & Al-Tabtabaei 1999; Abu Qdais 1999; Höepner 1999)
Antiscaling additives	Used to remove the scale formations on the plant's tubing The main antiscalants used in the desalination industry are orthophosphate and biodegradable polymeric additives based on maliec anhydride or polyacrylate (California Coastal Commission 1993; Abdel-Jawad & Al-Tabtabaei 1999) Reported dosing rates for polymeric additives do not exceed 0.53 mg l^{-1} (Morton *et al.* 1996)	The use of orthophosphate enhances primary productivity in oligotrophic seas and increases the occurrence of acute red and green algal blooms which in turn depletes the dissolved oxygen levels (Shams El Din *et al.* 1994; Abdel-Jawad & Al-Tabtabaei 1999; Höepner 1999) While polymeric additives are not linked with toxic hazards their potential to cause biogenic and/or abiogenic toxicity has not been well documented (Shams El Din *et al.* 1994; Höepner 1999)
Antifouling additives	Used to hinder the potential of bacteria, algae and other marine organisms to foul the desalination plant Chlorine or hypochlorite are the main antifouling agents While chlorine dosing ranges between 2 and 5 ppm, shock chlorination can reach up to 8 ppm (Khordagui 1992, 1997) Chlorine concentrations at the point of discharge of MSF plants range between 0.2 and 0.5 ppm (Höepner & Lattemann 2002)	Forms halogenated hydrocarbons some of which are known carcinogens and mutagens (Al-Awadhi 1999; Höepner 1999) Forms chloro-amines and bromo-amines which are toxic, stable compounds (Höepner 1999) Results in the formation of hypochlorite ions that disrupt normal enzymatic and biological processes in organisms (Shams El Din *et al.* 1994) Can induce the migration of intolerant species from the affected area (Seegert 1979; Shams El Din *et al.* 1994)
Halogenated organic compounds	Formed as a result of the reaction of residual chlorines and bromines with natural and anthropogenic organic sources Main source of organic compounds in the Arabian Gulf is anthropogenic releases of oil	Stresses marine organisms even at low concentrations Many are known carcinogens and mutagens Impacts the reproductive organs of oysters (Ali & Riley 1989) Significantly increase the mortality rate of larval oysters (Stewart *et al.* 1979) Some halogenated organics can bioaccumulate in tissues (Scott *et al.* 1980)
Antifoaming additives	Used to prevent foam formation in MSF units Typical dosing rates are around 0.1 ppm Nearly 90% degradation is expected before discharge	Disrupts the intracellular membrane system in marine organisms Can react with halogens to form carcinogenic and mutagenic compounds (Höepner 1999)

Table 5 | (*continued*)

Discharged pollutants	Pollutant source characteristics and discharged load	Potential environmental impacts
Oxygen scavengers	Used to reduce corrosion especially in MSF plants Sodium sulfite is the most widely used oxygen scavenger (Höepner 1999)	Can slightly reduce the levels of dissolved oxygen in the discharge area (Altayaran & Madany 1992)
Acid	Used mainly as an antiscalant Acid washing can produce effluents with pH values as low as 2	Changes the chemistry of the seawater in the vicinity of the outfall (Shams El Din *et al.* 1994) Can result in the migration of organisms from the affected area thus reducing biodiversity (Mabrook 1994)
Concentrate	Usually reflects the chemical constituents of the feedwater While MSF effluents are 1.1 times more concentrated than the original feedwater, RO effluents can be twice as concentrated as the original feedwater (Morton *et al.* 1996)	Can have lethal impacts on some aquatic organisms (Kryzhanovsky 1989; Iso *et al.* 1994; Höpner & Windelberg 1997; Khordagui 1997) Can retard hatching of fish eggs (Iso *et al.* 1994) Can affect the morphological characteristics of some species (Iso *et al.* 1994) Monitoring of biodiversity within an area 100–200 m from the outfall of the Dhkelia RO plant in Cyprus showed that littoral fauna and flora were impacted by salinity increase (Einav *et al.* 2002)
Reject heat	MSF plants have effluents at 8 to 15°C above ambient RO plants do not contribute to thermal pollution	Reject heat decreases the ability of water to hold oxygen, increases the rate of chemical reactions, changes the available biodiversity, and increases the metabolic rate of cold-blooded animals (Jensen *et al.* 1969; Coutant 1970; Davies & Jensen 1974; GESAMP 1984; Shams El Din *et al.* 1994; Smith 1996; Abu Qdais 1999; Hinrichs & Kleinbach 2002)

MSF = multi stage flash distillation plants; RO = reverse osmosiss

political level. Another concern relates to the fact that introducing desalination plants in arid to semi-arid regions will readily provide freshwater, which is a natural limiting resource for populations and socio-economic growth. Lifting that natural barrier is expected to result in significant demographic changes and increased urbanization which may in turn stress and degrade the environment, especially if environmental issues and infrastructure are not addressed as an integral part of the development process. Desalination plants may also create frictions with local fishermen if fishing stocks in the area decline (Höpner & Windelberg 1997). Finally, desalination plants may interfere with public access to beaches in the vicinity of the plant following the laying and construction of intakes, outfalls, pipelines, wells, and other structures along the coast (California Coastal Commission 1993).

FUTURE OUTLOOK

The alleviation of water scarcity requires that new non-conventional sources such as desalination are needed to augment existing supplies that are being depleted at an alarming rate. Desalination is expected to become an increasingly important technology for arid and water stressed regions irrespective of the associated concerns raised at the economic, environmental and socio-political levels. Nevertheless, the solution to water scarcity in most arid countries can only be accomplished through the development of comprehensive water policies that integrate several conventional and non-conventional water supply options with proper water management and conservation practices, including the installation of new efficient water conveying equipment, the preservation of renewable water resources, the adoption of economic and institutional incentives that aim at reducing consumption and water wastage. Most arid regions have made little effort to adopt such measures and many cities still lack systems capable of measuring or metering water use. The adoption and integration of water management and conservation measures within the water policies of most MENA countries and the Gulf region is still deficient and flawed, whereby water utilities in the region are publicly owned, heavily subsidized, and do not reflect the true price of water (Abdurazzak 1999). Considering water as a commodity (all while ensuring social equity) can be a key economic tool within an integrated water management plan that aims at reducing the consumption of water and encouraging conservation (Al Radif 1999). The progressive liberalization of the water sector and the increased involvement of the private sector are currently being marketed by a multitude of international organizations including the World Bank, World Trade Organization and even the General Assembly of the United Nations (Rillaerts 1999). On the other hand, the concept of trading virtual water is increasingly being recognized as a means through which water-deficit economies balance their water budgets by importing water intensive crops from water-rich countries, while using their limited water supply for activities that generate greater incremental value (Allan 1997; Turton 2001; El-Fadel & Maroun 2002) The adoption of water management and conservation measures could move in parallel with the gradual removal of water subsidies to reflect the true price of water. Adopting such reforms should be well planned to avoid social and political dismay and to assure that these measures will not be regressive in nature particularly in the context of food security. Nevertheless, initiating water policy reforms and acknowledging dependency on foreign water resources (importing virtual water) in arid and semi-arid countries are expected to bring about high political prices. As such, it is likely that politicians will continue to stall and defer the implementation of sound water policies for as long as possible (Allan 1997; World Bank 1997; Yang & Zehnder 2002).

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