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Environmental impact and impact assessment of seawater desalination

Sabine Lattemann, Thomas Höpner

Institute for Chemistry and Biology of the Marine Environment (ICBM), University of Oldenburg, Carl von Ossietzky Str. 9-11, 26111 Oldenburg, Germany
email: sabine.lattemann@icbm.de

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Abstract

Desalination of seawater accounts for a worldwide water production of 24.5 million m^3/day. A "hot spot" of intense desalination activity has always been the Arabian Gulf, but other regional centers of activity emerge and become more prominent, such as the Mediterranean Sea and the Red Sea, or the coastal waters of California, China and Australia. Despite the many benefits the technology has to offer, concerns rise over potential negative impacts on the environment. Key issues are the concentrate and chemical discharges to the marine environment, the emissions of air pollutants and the energy demand of the processes. To safeguard a sustainable use of desalination technology, the impacts of each major desalination project should be investigated and mitigated by means of a project- and location-specific environmental impact assessment (EIA) study, while the benefits and impacts of different water supply options should be balanced on the scale of regional management plans. In this context, our paper intends to present an overview on present seawater desalination capacities by region, a synopsis of the key environmental concerns of desalination, including ways of mitigating the impacts of desalination on the environment, and of avoiding some of the dangers of the environment to desalination.

Keywords: Seawater desalination; Environmental impact; Impact assessment; EIA; Marine environment; Brine; Wastewater; Energy; Chemicals; Chlorine; Antiscalants

1. Introduction

Many semi-arid and arid regions in the world suffer from structural water shortages, which impose constraints on economic, social and human development. Furthermore, severe ecosystem damage may be caused if water abstraction rates exceed natural renewal rates, leading to a depletion or salinization of stocks and land desertification. To meet the growing demand and to avert damage from ecosystems and aquifers, water management regimes have to increasingly implement non-typical technologies and source waters. Treated wastewater presently accounts for 5%, brackish water for 22% and seawater for 58% of the water produced by desalination technologies [1]. Desalination of seawater is thus the technology predominantly used for alleviating

*Corresponding author.

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the problem of water scarcity in coastal regions. It accounts for a worldwide production capacity of 24.5 million m^3/day.

Although desalination of seawater offers a range of human health, socio-economic, and environmental benefits by providing a seemingly unlimited, constant supply of high quality drinking water without impairing natural freshwater ecosystems, concerns are raised due to potential negative impacts. These are mainly attributed to the concentrate and chemical discharges, which may impair coastal water quality and affect marine life, and air pollutant emissions attributed to the energy demand of the processes. The list of potential impacts can be extended, however, the information available on the marine discharges alone [2] indicates the need for a comprehensive environmental evaluation of all major projects. In order to avoid an unruly and unsustainable development of coastal areas, desalination activity furthermore should be integrated into management plans that regulate the use of water resources and desalination technology on a regional scale [3]. In summary, the potential environmental impacts of desalination projects need to be evaluated, adverse effects mitigated as far as possible, and the remaining concerns balanced against the impacts of alternative water supply and water management options, in order to safeguard a sustainable use of the technology.

2. Regional distribution of capacities

The worldwide installed capacity for desalination of seawater is increasing at rapid pace. The latest figures from the 19th IDA Worldwide Desalting Plant Inventory [1] indicate that the installed capacity for desalination of seawater approached 24.5 million m^3/day[1] by the end of 2005. About two thirds of this water is produced by thermal processes, mainly in the Middle East, whereas membrane desalination is the predominating process outside the region. Six percent of all plants are located in the Asia-Pacific region, 7% in the Americas, 10% in Europe and 77% in the Middle East and North Africa. In the context of this paper, however, it is of greater interest to consider the installed capacities by regional seas, due to potential cumulative impacts of desalination activity on the marine environment.

The largest number of desalination plants can be found in the Arabian Gulf with a total seawater desalination capacity of approximately 11 million m^3/day (Fig. 1) which means a little less than half (45%) of the worldwide daily production. The main producers in the Gulf region are the United Arab Emirates (26% of the worldwide seawater desalination capacity), Saudi Arabia (23%, of which 9% can be attributed to the Gulf region and 13% to the Red Sea) and Kuwait (<7%). In the Mediterranean, the total production from seawater is about 4.2 million m^3/day (17% of the worldwide capacity, Fig. 2). Spain, with 7% of the worldwide capacity, is the largest producer in the region: about 70% of the Spanish plants are located on the Mediterranean coast and the Balearic Islands, and the rest on the Canary Islands. While in the Gulf region thermal processes (MSF: multi-stage flash; MED: multi effect distillation) account for 90% of the production, the main process in Spain is reverse osmosis (RO) with 95% of all plants. In the Red Sea, the third highest concentration of desalination plants can be found, with a combined capacity of 3.4 million m^3/day (14% of the worldwide capacity, Fig. 3). While seawater desalination is already a well-established water source in these regions, the era of large-scale desalination projects is only about to start in other parts of the world. In California, a potential for 20 new projects with a combined production capacity of 2 million m^3/day is expected for 2030. At present,

[1]This figure includes all known plants with a production of more than 100 m^3/day, which use seawater as source water and are in construction, online and presumed online.

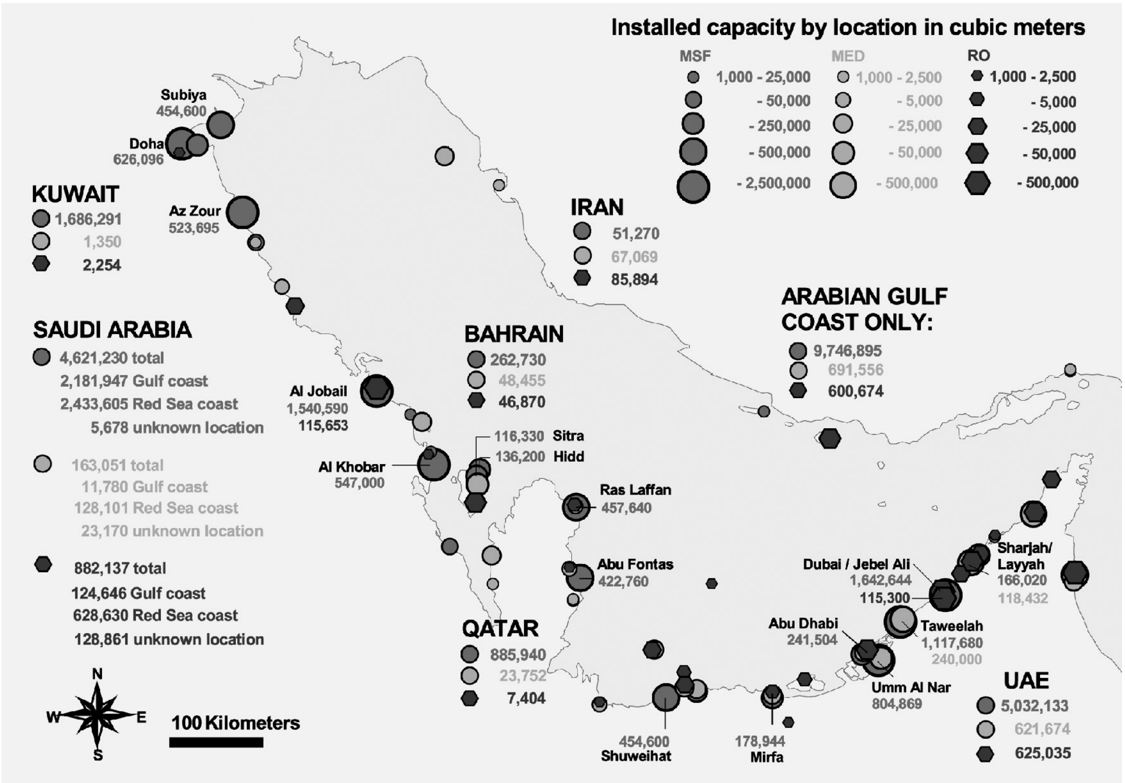

Fig. 1. Seawater desalination capacity in the Arabian Gulf (based on [1], including all plants that are presumed online or in construction). The map shows all sites with capacities >1000 m^3/day and specifically identifies those with capacities >100,000 m^3/day. The total capacity of each riparian state is given, as is the installed capacity in the sea region.

two 200,000 m^3/day plants are planned in Carlsbad and Huntington Beach, which will start operation in 2009 [4]. In Australia, the Perth Seawater Desalination Plant with a capacity of 144,000 m^3/day is the first in a procession of large projects (including the Sydney and Gold Coast projects), and China expects to desalinate up to 1 million m^3/day by 2010 [5].

3. Potential effects on the environment

The list of potential environmental impacts of desalination plants is long and in some aspects, such as land use, similar to other development projects. Effects more specific to desalination plants are the impingement and entrainment of organisms due to the intake of large quantities of seawater, and the emission of air pollutants due to a considerable energy demand of the processes. A key concern of desalination plants are the concentrate and chemical discharges to the marine environment, which may have adverse effects on water and sediment quality, impair marine life and the functioning and intactness of coastal ecosystems. A general overview on the composition and effects of the waste discharges is given in a recent WHO guidance document [31], and discussed in detail in Lattemann and Höpner [2] and MEDRC [6]. In recent publications, special attention is furthermore given to some regional seas with high or increasing desalination activity, such as the Arabian Gulf [7,8], the Red Sea [9], the Mediterranean [3] or the coastal waters off California [10]. Based on these and other sources,

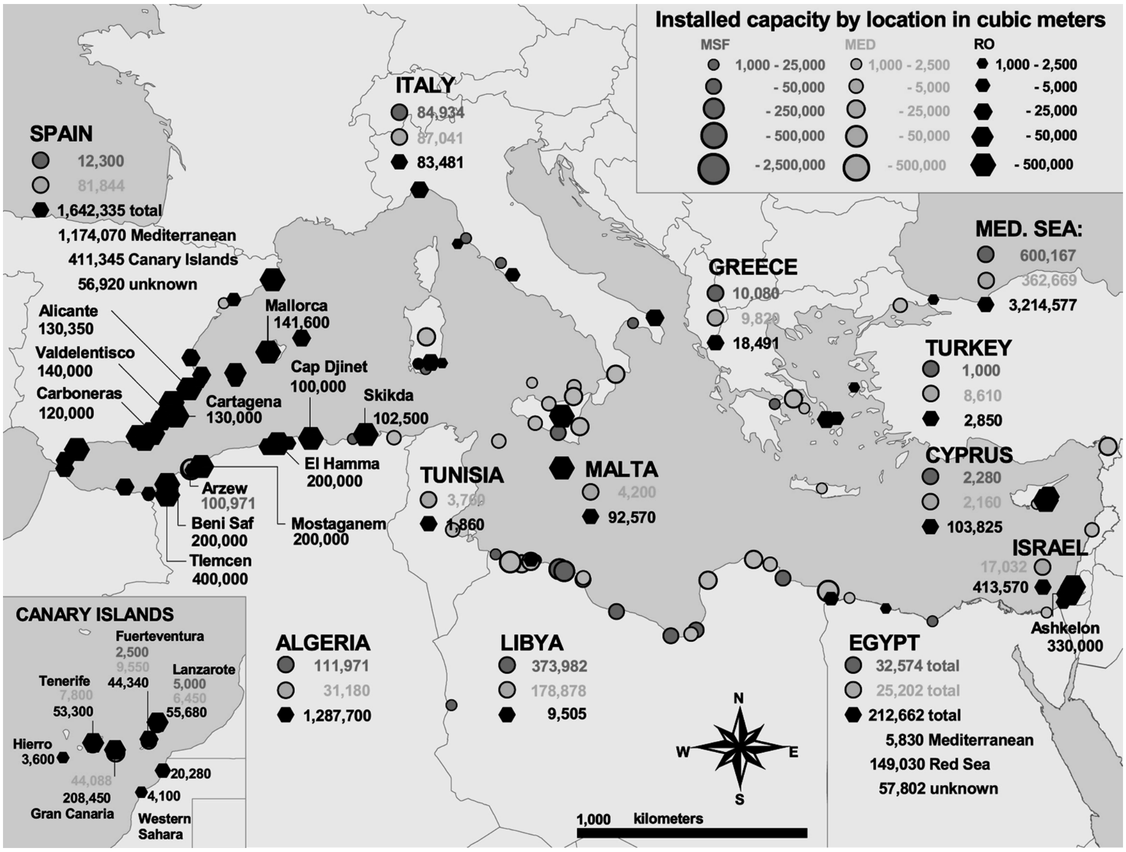

Fig. 2. Seawater desalination capacity in the Mediterranean Sea (based on [1], including all plants that are presumed online or in construction). See also caption of Fig. 1.

a synopsis of the potential impacts of desalination on the environment is given.

3.1. Source water intake

Seawater desalination plants can receive feedwater from different sources, but open seawater intakes are the most common option. The use of open intakes may result in losses of aquatic organisms when these collide with intake screens (impingement) or are drawn into the plant with the source water (entrainment). The construction of the intake structure and pinping causes an initial disturbance of the seabed, which results in the re-suspension of sediments, nutrients or pollutants into the water column. After installation, the structures can affect water exchange and sediment transport, act as artificial reefs for organisms, or may interfere with shipping routes or other maritime uses.

3.2. Reject streams

All desalination processes produce large quantities of a concentrate, which may be increased in temperature, contain residues of pretreatment and cleaning chemicals, their reaction (by-)products, and heavy metals due to corrosion. Chemical pretreatment and cleaning is a necessity in most desalination plants, which typically includes the treatment against biofouling, scaling, foaming and corrosion in thermal plants, and against biofouling, suspended solids and scale deposits in membrane plants. The chemical residues and

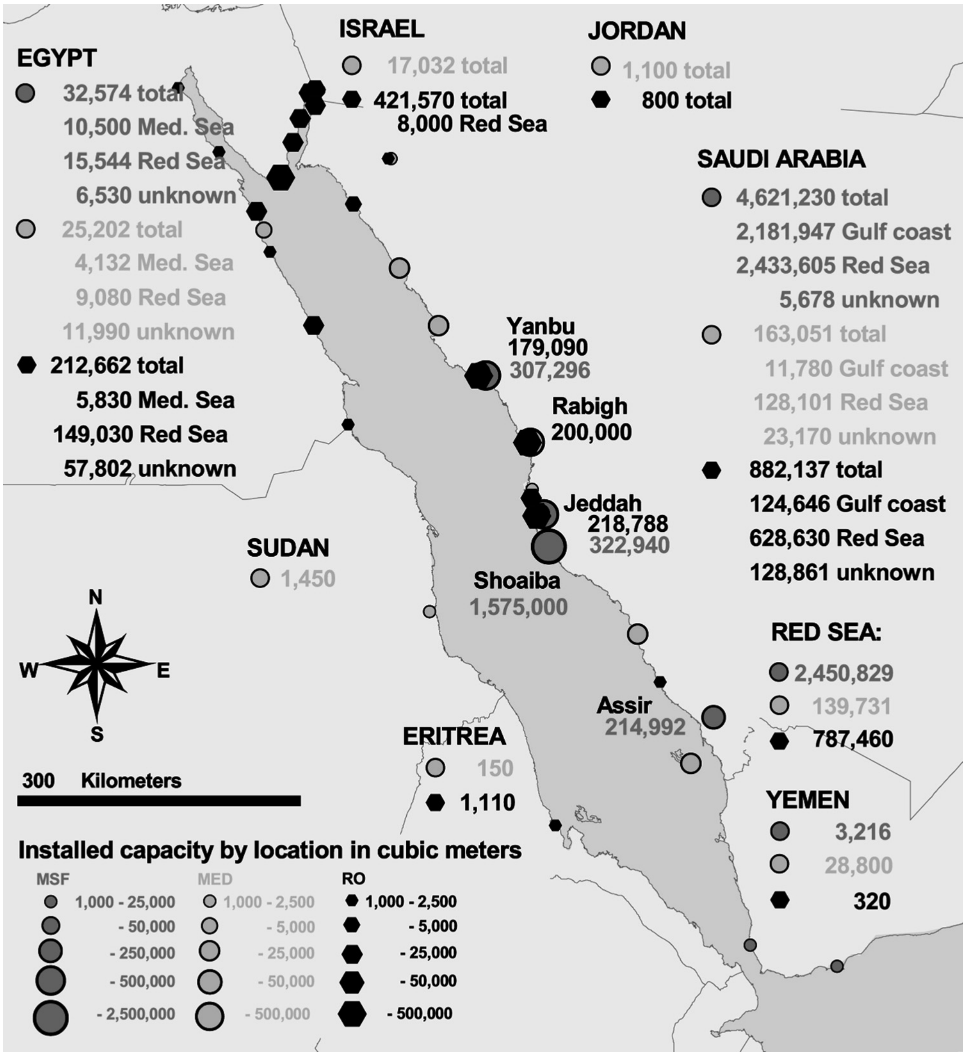

Fig. 3. Seawater desalination capacity in the Red Sea (based on [1], including all plants that are presumed online or in construction). See also caption of Fig. 1.

by-products are typically washed into the sea along with the concentrate.

Negative effects on the marine environment can occur especially when high waste water discharges coincide with sensitive ecosystems. The impacts of a desalination plant on the marine environment depend on both, the physico-chemical properties of the reject streams and the hydrographical and biological features of the receiving environment. Enclosed and shallow sites with abundant marine life can generally be assumed to be more sensitive to desalination plant discharges than exposed, high energy, open-sea locations [11], which are more capable to dilute and disperse the discharges.

The desalination process and the pretreatment applied have a significant influence on the physico-chemical properties of the discharges, as shown in Table 1. In both RO and thermal plants, the salinity of the concentrate is higher

Table 1
Typical effluent properties of reverse osmosis (RO) and thermal MSF (multi-stage flash) seawater desalination plants [6,7]

	RO	MSF
Physical properties		
Salinity	Up to 65,000–85,000 mg/L	About 50,000 mg/L
Temperature	Ambient seawater temperature	+5 to 15°C above ambient.
Plume density	Negatively buoyant	Positively, neutrally or negatively buoyant depending on the process, mixing with cooling water from co-located power plants and ambient density stratification.
Dissolved oxygen (DO)	If well intakes used: typically below ambient seawater DO because of the low DO content of the source water. If open intakes used: approximately the same as the ambient seawater DO concentration.	Could be below ambient seawater salinity because of physical deaeration and use of oxygen scavengers
Biofouling control additives and by-products		
Chlorine	If chlorine or other oxidants are used to control biofouling, these are typically neutralized before the water enters the membranes to prevent membrane damage.	Approx. 10–25% of source water feed dosage, if not neutralized
Halogenated organics	Typically low content below harmful levels.	Varying composition and concentrations, typically trihalomethanes
Removal of suspended solids		
Coagulants (e.g. iron-III-chloride)	May be present if source water is conditioned and the filter backwash water is not treated. May cause effluent coloration if not equalized prior to discharge.	Not present (treatment not required)
Coagulant aids (e.g. polyacrylamide)	May be present if source water is conditioned and the filter backwash water is not treated.	Not present (treatment not required)
Scale control additives		
Antiscalants	Typically low content below toxic levels.	Typically low content below toxic levels
Acid (H_2SO_4)	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater)
Foam control additives		
Antifoaming agents (e.g. polyglycol)	Not present (treatment not required)	Typically low content below harmful levels

(*continued*)

Table 1 (*continued*)

Contaminants due to corrosion		
Heavy metals	May contain elevated levels of iron, chromium, nickel, molybdenum if low-quality stainless steel is used.	May contain elevated copper and nickel concentrations if inappropriate materials are used for the heat exchangers
Cleaning chemicals		
Cleaning chemicals	Alkaline (pH 11–12) or acidic (pH 2–3) solutions with additives such as: detergents (e.g. dodecylsulfate), complexing agents (e.g. EDTA), oxidants (e.g. sodium perborate), biocides (e.g. formaldehyde)	Acidic (pH 2) solution containing corrosion inhibitors such as benzotriazole derivates

than source water salinity, but temperature is only elevated in the discharges of thermal plants. Both discharges contain chemical residues of antiscalants, whereas biocides and antifoaming additives are usually only found in the reject streams of distillation plants. Metals from corrosion are usually present in both kind of reject streams in varying, but relatively low concentrations. However, copper contamination may be a concern in the reject streams of distillation plants, when copper-nickel heat exchangers are used that are prone to corrosion. In RO reject streams, coagulants may be present if the backwash water from coagulation and media filtration is combined with the process waste water. In addition, the reject streams, especially of RO plants, may contain spent cleaning solutions if these are mixed with the concentrate and discharged to the sea. The environmental impacts of the single reject stream characteristics are discussed in the following, but it should be kept in mind that the whole effluent is a mix of these pollutants, and that their combination may have additive effects on marine life.

3.2.1. Salinity and temperature

Salinity and temperature are controlling factors for the distribution of marine species, which normally dwell in those areas that provide favourable environmental conditions for the species. Most organisms can adapt to minor deviations from optimal salinity and temperature conditions, and might even tolerate extreme situations temporarily, but not a continuous exposure to unfavourable conditions. The constant discharge of reject streams with high salinity and temperature levels can thus be fatal for marine life, and can cause a lasting change in species composition and abundance in the discharge site. Marine organisms can be attracted or repelled by the new environmental conditions, and those more adapted to the new situation will eventually prevail in the discharge site. Due to their density, the reject streams of RO and thermal plants affect different realms of the sea. The concentrate of RO plants, which has a higher density than seawater, will spread over the sea floor in shallow coastal waters unless it is dissipated by a diffuser system. Benthic communities, such as seagrass beds, may thus be affected as a consequence of high salinity and chemical residues. In contrast, reject streams of distillation plants, especially when combined with power plant cooling waters, are typically positively or neutrally buoyant and will affect open water organisms.

3.2.2. Biocides

In most desalination plants, chlorine is added to the intake water to reduce biofouling, which leads to the formation of hypochlorite and mainly hypobromite in seawater. FRC levels (the sum of free and combined available chlorine residuals) of 200–500 µg/L have been reported for distillation plant reject streams, which is approximately 10–25% of the dosing concentration. In RO plants, the intake water is also chlorinated but dechlorinated again with sodium bisulfite before the water enters the RO units to prevent membrane damage. Following discharge, a further decline in FRC levels by up to 90% is expected [12], which yields estimated concentrations of 20–50 µg/L in the discharge site. This is consistent with observed levels of 30–100 µg/L in the mixing zones of large distillation plants [13,14].

Although environmental FRC levels are quickly decreased by degradation and dilution following discharge, the potential for adverse effects is still high. Chlorine is a very effective biocide and its toxicity has been confirmed by many toxicological studies. Based on toxicological data from a wide spectrum of marine species, the U.S. EPA recommends a long-term water quality criterion for chlorine in seawater of 7.5 µg/L and a short-term criterion of 13 µg/L [15]. The environmental risk assessment of the EU for hypochlorite has determined a PNEC (predicted no effect concentration) for saltwater species of 0.04 µg/L free available chlorine [16]. Discharge levels of 200–500 µg/L and environmental concentrations up to 100 µg/L therefore represent a serious hazard to aquatic life. Furthermore, the EU risk assessment notes that the synergistic effects of thermal stress and exposure to residual chlorine should be taken into account, which were demonstrated in many studies, e.g. for discharge of power plant cooling effluents.

Potential impacts also result from the formation of halogenated organic by-products. Due to many possible reactions of hypochlorite and hypobromite with organic seawater constituents, by-product diversity is high, including trihalomethanes (THMs) such as bromoform or haloacetic acids [17]. Increased THM levels near distillation plants up to 9.5 µg/L [17] and up to 83 µg/L [13] have been reported. As only a few percent of the total added chlorine is recovered as halogenated by-products, and as by-product diversity is high, the environmental concentration of each substance can be expected to be relatively low. It is beyond the scope of a risk assessment to derive toxicity data for all chlorinated and brominated species. Ecotoxicological data in connection with the assessment of seawater chlorination, however, suggest that the ecotoxicities of the brominated THMs are not markedly different from chloroform. In the EU risk assessment, it was therefore concluded that the toxicity of total THMs can be broadly assessed by using the PNEC for chloroform, which is 146 µg/L for freshwater species [16]. The residual chlorine in the discharge thus has a significantly higher ecotoxicity to aquatic life than the by-products. However, sensitive life stages and species may respond to chronic concentrations, especially as THMs were found to have carcinogenic properties to animals.

Due to environmental and health issues raised by residual chlorine and disinfection by-products, several alternative pretreatment methods have been considered. These include e.g. sodium bisulfite [18], monochloramine [19,20], copper sulfate [20], and ozone [18,21]. None of these has gained acceptance over chlorine use, however, chlorine dioxide is presently evolving into an alternative to chlorine dosing in many areas of the Arabian Gulf. Chlorine dioxide is — like chlorine — a strong oxidant, but is assumed to form less THMs if added in small quantities. Therefore, environmental impacts are relatively lower than for chlorine [21], but like other biocides, chlorine dioxide may affect non-target organisms in surface waters if residuals are discharged to surface waters.

3.2.3. Heavy metals

Copper-nickel alloys are commonly used as heat exchanger materials in distillation plants, so that brine contamination with copper due to corrosion can be a concern of thermal plant reject streams. The RO brine may contain traces of iron, nickel, chromium and molybdenum, but contamination with metals is generally below a critical level, as non-metal equipment and stainless steels predominate in RO desalination plants.

Copper concentrations in reject stream are expected to be in the range of 15–100 μg/L. The presence of copper does not necessarily mean that it will adversely affect the environment. Natural concentrations range from an oceanic background of 0.1 μg/L to 100 μg/L in estuaries [22]. In the Arabian Gulf, for example, copper levels were reported in the range of <1 μg/L Qatar [23] to 25 μg/L Kuwait [24]. It is generally difficult to distinguish between natural copper levels and anthropogenic effects, e.g. caused by industrial outfalls or oil pollution [25]. The discharge levels of thermal plants, however, are well within the range that could affect natural copper concentrations. The U.S. EPA recommends a maximum copper concentration of 4.8 μg/L in seawater for brief exposure and 3.1 μg/L for long-term exposure [15]. Values of the same order of magnitude were determined for European saltwater environments: Hall and Anderson [26] derived a PNEC of 5.6 μg/L and the water quality objective for the Mediterranean is 8 μg/L [27]. Copper is like most metals transported and accumulated in sediments, which is a major concern of point discharges, which could lead to increased sediment concentration in these sites. Metals in sediments can be assimilated by benthic organisms, which often form the basis of the marine food chain.

3.2.4. Antiscalants

Antiscalants are added to the feedwater in both thermal and RO plants to prevent scale formation. The term refers to polymeric substances with different chemical structures, in particular policarbonic acids (e.g. polymaleic acid) and phosphonates. Polyphosphates and sulfuric acid are also used to prevent scale formation, though at a limited scale. The toxicity of all antiscalants to aquatic life is very low. Problems of eutrophication have been observed near the outlets of desalination plants in the Gulf where polyphosphates were used, as these are easily hydrolyzed to orthophosphate, which is a major nutrient for primary producers. In contrast, policarbonic acids and phosphonates are stable substances with low biodegradation rates, which results in relatively long residence times in coastal waters. As these substances reduce scale formation by dispersing and complexing calcium and magnesium ions in the desalination plant, they could also influence natural processes of these and other divalent metals in the marine environment.

3.2.5. Coagulants (RO plants)

Coagulants (such as ferric-III-chloride) and coagulant aids (such as high molecular organics like polyacrylamide) are added to the feedwater for coagulation and media filtration of suspended material. The media filters are backwashed intermittently, and the backwash water containing the suspended material and coagulants is typically discharged to the ocean without treatment. The chemicals themselves have a very low toxic potential. However, their discharge may cause an intense coloration of the reject stream if ferric salts are used (“red brines”), which may increase turbidity and reduce light penetration, or could bury sessile benthic organisms in the discharge site.

3.2.6. Antifoaming agents (thermal plants)

To reduce foaming in thermal plants, antifoaming agents like polyethylene and polypropylene glycol can be added to the feedwater. Polyglycols are not toxic, but may be rather persistent in the environment due to a poor biodegradability.

3.2.7. Cleaning chemicals

The cleaning procedure depends on the type of fouling. In RO plants, alkaline solutions (pH 11–12) are used to remove silt deposits and biofilms from membranes, while acidic solutions (pH 2–3) are applied to dissolve metal oxides or scales. These solutions often contain additional chemicals to improve the cleaning process, such as detergents (e.g. dodecylsulfate, dodecylbenzene sulfonate) or oxidants (e.g. sodium perborate, sodium hypochlorite). After cleaning or prior to storage, membranes are typically disinfected. For this purpose, either oxidizing biocides (such as chlorine and hydrogen peroxide) or non-oxidizing biocides (such as formaldehyde, glutaraldehyde or isothiazole) can be applied. Distillation plants are typically washed with warm acidic seawater to remove alkaline scales from heat exchanger surfaces, which may contain corrosion inhibitors (e.g. benzotriazole derivates). The cleaning solutions, especially their additives, may be harmful to aquatic life if discharged to surface water without treatment.

3.3. Energy use

Desalination plants require significant amounts of thermal and/or electrical energy depending on the process: for one cubic meter of water produced, 12 kW h of thermal energy and 3.5 kW h of electrical energy is required in MSF plants, which have a maximum operation temperature of 120°C. These figures are lower for MED plants, which operate at lower temperatures (<70°C) and require 6 kW h of thermal and 1.5 kW h of electrical energy per cubic meter. The RO process requires between 4 and 7 kW h/m^3 depending on the size of the plant and energy recovery systems installed [28]. To illustrate these figures, it can be estimated that a middle-sized RO plant with a capacity of about 25,000 m^3/day and an energy demand of 5 kW h/m^3 consumes about 125,000 kW h/day. The plant can supply about 48,000 four-person household with water[2], while the energy that is used for the desalination process could supply about 10,300 four-person household with electricity[3]. Environmental concerns associated with the energy demand and thus indirectly associated with the process of desalination are the emission of air pollutants and cooling waters from electrical power generation, the fuel source and fuel transportation.

4. Mitigating the impact of desalination on the environment

As stated in the introduction, the impacts of a desalination project should be evaluated and adverse effects mitigated as far as possible. The adequate instrument for this purpose is the environmental impact assessment (EIA), which is a systematic procedure for identifying and evaluating all potential impacts of a proposed project, and for developing appropriate mitigation measures and alternatives, such as modifications to the process or alternative project sites. As an EIA is project- and location specific, it is beyond the scope of this paper to present a complete overview of all potential impacts and corresponding mitigation measures. The paper thus focuses on certain key issues.

4.1. Source water intake

In order to mitigate the impacts of open intakes, a combination of differently meshed screens and a low intake velocity should be considered. This can minimize the impingement and entrainment of larger organisms, such as fish or turtles, while the entrainment of smaller plankton organisms,

[2]Assuming a water consumption of 130 liters per person and day (average in Germany).

[3]Assuming an averge electricity demand of 4430 kWh/year for a 4 person household (average in Germany in 2006).

eggs and larvae can be minimized by locating intakes away from productive areas, e.g. into deeper waters, offshore, or underground (e.g. by using beachwells). As the intake water quality is often better in these locations than in near shore and surface waters, only minimal or no chemical pretreatment may be required. However, the initial soil disturbance during construction of below ground intakes or long pipelines may be higher, especially when this involves drilling or excavation activities. (Beach)-well intakes are adaptable to small or medium-sized plants only. Co-location of desalination and power plants should thus be considered for larger plants where possible. The total intake water volume can be reduced when the cooling water from the power plant serves as feedwater to the desalination plant, which minimizes the impacts from entrainment and impingement, the usage of chemicals, and construction and land use impacts.

4.2. Reject streams

There are several approaches to mitigate the environmental effects of the waste discharges. To avoid impacts from high salinity, the desalination plant reject stream can be pre-diluted with other waste streams where applicable, such as power plant cooling water. To avoid impacts from high temperature, the outfall should achieve maximum heat dissipation from the waste stream to the atmosphere before entering the water body (e.g. by using cooling towers) and maximum dilution following discharge. Mixing and dispersal of the discharge plume can be enhanced by installing a diffuser system, and by locating the discharge in a favorable oceanographic site which dissipates the heat and salinity load quickly. To analyze plume spreading in a specific project site, the environmental and operational conditions should be investigated by hydrodynamic modeling, accompanied by salinity and temperature measurements for density calculations before and during operation of the desalination plant.

Negative impacts from chemicals can be minimized by treatment before discharge, by substitution of hazardous substances, and by implementing alternative treatment options. Especially biocides such as chlorine, which may acutely affect non-target organisms in the discharge site, should be replaced or treated prior to discharge. Chlorine can be effectively removed by different chemicals, such as sodium bisulfite as practiced in RO plants, while sulfur dioxide and hydrogen peroxide have been suggested to treat thermal plant reject streams [21,29]. Filter backwash waters should be treated by sedimentation, dewatering and land-deposition, while cleaning solutions should be treated on-site in special treatment facilities or discharged to a sanitary sewer system.

The use of alternative pretreatment methods should be considered where feasible, such as prefiltration with UF or MF membranes, or the use of subsurface intakes such as wells which naturally pre-filtrate the feedwater. This may eliminate or significantly reduce the need for chemical pretreatment. A non-chemical treatment option is irradiation of the intake water with UV light at 200–300 nm wavelength for disinfection, which damages the DNA structure of microorganisms. A major advantage of UV-light is that storage, handling and disposal of toxic chemicals is avoided, but some highly reactive and short-lived active substances are also produced in seawater (i.e. free radicals) which may form by-products. However, to date UV irradiation has not been found to be an effective pretreatment for larger desalination plants.

To conclude, different technical options exist to mitigate environmental impacts, including advanced systems for the intake of the seawater and the diffusion of the waste products, non-chemical pretreatment options such as UF and MF, and wastewater treatment technologies. Equally or even more important than the technical options, however, is the selection of a proper site for a desalination project.

4.3. Energy use

Energy use is a main cost factor in water desalination and has already been reduced by some technological innovations, such as the use of energy recovery equipment or variable frequency pumps in RO plants. A very low specific energy consumption of 2–2.3 kW h/m^3 has been reported for a seawater desalination plant that uses an energy recovery system consisting of a piston type accumulator and a low pressure pump [30]. Furthermore, the potential for renewable energy use (solar, wind, geothermal, biomass) should be investigated to minimize impacts on air quality and climate. This may be in the form of renewable energy driven desalination technologies or as compensation measures such as the installation and use of renewable energy in other localities or for other activities.

4.4. Site selection for impact mitigation

When selecting a site for a desalination project, a large number of site-specific features must typically be considered depending on the specific operational aspects of the plant in question. In order to minimize the impacts of the project on the environment, it is generally recommendable to take at least the following biological and oceanographic site features into account [31]. Ecosystems or habitats should be avoided, if they are unique within a region or worth protecting on a global scale, inhabited by protected, endangered or rare species, important in terms of their productivity or biodiversity, or if they play an important role as feeding or reproductive areas in the region. The site should furthermore provide sufficient capacity to dilute and disperse the salt concentrate and to dilute, disperse and degrade any residual chemicals. The load and transport capacity of a site will primarily depend on water circulation and exchange rate as a function of currents, tides, surf, water depth and shoreline morphology. In general, exposed rocky or sandy shorelines with strong currents and surf may be preferred over shallow, sheltered sites with little water exchange. The oceanographic conditions will determine the residence time of residual pollutants and the time of exposure of marine life to these pollutants.

Moreover, the site should be close to the sea, to water distribution networks and to consumers to avoid construction and land-use of pipelines and pumping efforts for water distribution. It should allow easy connection with other infrastructure, such as power grid, road and communication network, or may even allow the co-use of existing infrastructure, such as seawater intakes or outfalls, while conflicts with other uses and activities, especially recreational and commercial uses, shipping, or nature conservation, should be avoided.

5. Avoiding some of the dangers of the environment to desalination

Site selection can keep the impacts of the desalination plant on the environment at a minimum, but can also minimize the impacts of the environment on the desalination plant. In order to minimize the impacts on the desalination process, the site should provide a good and reliable water quality, taking seasonal variations and periodic events into account. Raw waters should generally be avoided that are subject to anthropogenic pollution as caused by municipal, industrial, shipping or other wastewater discharges. A naturally poor water quality should equally be avoided, especially locations with high concentrations of particulate and dissolved organic matter, a high biological activity and thus fouling potential, or the potential for contamination of the intake water quality due to periodically recurring toxic algal booms. Intakes that are located further offshore and in deep water layers and thus away from land-based sources of pollution and areas of high biological productivity often provide a more stable and reliable water quality than near shore surface waters. This is also true for below-ground intakes, such as beachwells, where the surrounding sediment layers naturally prefiltrate the incoming seawater. Moreover, when selecting a site, the risk for oil pollution should be considered [32] and high risk areas (e.g. near major shipping routes) avoided if possible, as oil films can cause serious damage inside a desalination plant and oil contaminants may affect the product water quality.

6. Outlook

At present, a standard EIA procedure for evaluating and minimizing the effects of desalination projects is not available. The existing general concept of EIAs (which can be applied to all development projects) should thus be underpinned by reference material and a methodological approach that is specific to desalination projects, in order to facilitate the implementation of EIAs for desalination projects on a broader scale. This should include basic information on all relevant impacts of desalination activity, a modular framework for conducting monitoring activities in order to investigate the environmental impacts of each project, the establishment of criteria for evaluating and assessing the monitoring data, and a decision-making tool for balancing the benefits and impacts of desalination and of other water supply options against each other.

A first step in this direction has been taken by the World Health Organization (WHO), which has initiated a project and established five technical work groups for the preparation of a Guidance Document on Desalination for Safe Water Supply [31]. The document will supplement the WHO Drinking Water Quality Guidelines when published in 2007. The technical work groups addressed a broad range of issues, including technological, health, nutritional, microbiological, sanitary, and environmental aspects relevant to desalination projects. Environmental concerns, which would normally not be part of a WHO guideline, were deliberately included as the protection of coastal ecosystems and groundwater aquifers from contamination by concentrates and chemicals are considered key issues that need to be addressed during the design, construction and operation of a desalination facility. The guidance document intends to assist project designers and decision makers to anticipate and address both the health and environmental concerns that may arise when undertaking a project, for maximum beneficial use. The main objective of the environmental working group was therefore to review the potential impacts and to investigate the scope and formal requirements of an EIA study for desalination projects. This process will be continued in the MEDINA project, which has been recently awarded within the 6th research framework of the EU (Membrane-Based Desalination: An Integrated Approach). The project will integrate the preliminary work of the WHO project, and will further develop it specific to membrane desalination processes. The deliverables will compose a guidance manual and reference source for carrying out EIA studies, which includes background information on potential impacts, a methodological concept for project EIAs, a framework for monitoring activities including criteria for assessing the data, and a decision-making tool.

References

[1] IDA, IDA Worldwide Desalting Plant Inventory, No. 19 in MS Excel format, Media Analytics Ltd., Oxford, UK, 2006.

[2] S. Lattemann and T. Hoepner, Seawater Desalination — Impacts of Brine and Chemical Discharges on the Marine Environment, Desalination Publications, L'Aquila, Italy, 2003, p. 142.

[3] UNEP/MAP/MEDPOL, Sea Water Desalination in the Mediterranean: Assessment and Guidelines, MAP Technical Reports Series No. 139, United Nations Environment Programme (UNEP), Mediterranean Action Plan (MAP), Programme for the Assessment and Control of Pollution in the Mediterranean region (MEDPOL), Athens, Greece, 2003.

[4] N. Voutchkov, Drought-proofing California's Water Future, Desal. Water Reuse, 16 (3) (2006) 10–17.
[5] R. Wiseman, Editor's corner, Desal. Water Reuse, 16 (3) (2006) 10–17.
[6] MEDRC, Assessment of the Composition of Desalination Plant Disposal Brines (Project NO. 98-AS-026), Middle East Desalination Research Center (MEDRC), Oman, 2002.
[7] S. Lattemann and Th. Höpner, Impact of desalination plants on marine coastal water quality, In: Barth, Abuzinada, Krupp and Böer (Eds.), Marine Pollution in the Gulf Environment, Kluwer Academic Publishers, Netherlands (in review).
[8] H. Khordagui, Environmental impacts of power-desalination on the gulf marine ecosystem, In: Khan et al. (Eds.), The Gulf Ecosystem: Health and Sustainability, Backhuys Publishers, Leiden, 2002.
[9] Th. Höpner and S. Lattemann, Chemical impacts from seawater desalination plants — a case study of the northern Red Sea, Desalination, 152 (2002) 133–140.
[10] AMBAG, Desalination Feasibility Study in the Monterey Bay Region, prepared for the Association of Monterey Bay Area Governments (AMBAG), 2006. http://ambag.org/
[11] Th. Hoepner and J. Windelberg, Elements of environmental impact studies on coastal desalination plants, Desalination, 108 (1996) 11–18.
[12] A. Shams El Din, R. Arain and A. Hammoud, On the chlorination of seawater, Desalination, 129 (2000) 53–62.
[13] M. Ali and J. Riley, The distribution of halomethanes in the coastal waters of Kuwait, Mar. Poll, Bull., 17 (1986) 409–414.
[14] M. Abdel-Jawad and M. Al-Tabtabaei, Impact of Current Power Generation and Water Desalination Activities on Kuwaiti Marine Environment, In: Proceedings of IDA World Congress on Desalination and Water Reuse, San Diego, September 1999, Vol. 3, pp. 231–240.
[15] U.S. EPA, National Recommended Water Quality Criteria, 2006. http://www.epa.gov/waterscience/criteria/nrwqc-2006.pdf
[16] ECB, Risk Assessment Report for Sodium Hypochlorite, DRAFT of November 2005, European Chemicals Bureau (ECB), 2006. http://ecb.jrc.it/existing-chemicals/
[17] T. Saeed, H. Khordagui and H. Al-Hashash, Contribution of power/desalination plants to the levels of halogenated volatile liquid hydrocarbons in the coastal areas of Kuwait, Desalination, 121 (1999) 49–63.
[18] J. Redondo and I. Lomax, Experiences with the pretreatment of raw water with high fouling potential for reverse osmosis plant using FILMTEC membranes, Desalination, 110 (1997) 167–182.
[19] DuPont, PERMASEP Products Engineering Manual, Bulletin 1020, 2010 and 4010, DuPont Company, Wilmington, DE 19898, USA, 1994.
[20] FilmTec, FILMTEC Membranes Tech Manual Excerpts, FilmTec Corporation, The Dow Chemical Company, Liquid Separations, Customer Information Center, P.O. Box 1206, Midland, MI 48642–1206, USA, 2000.
[21] H. Khordagui, Conceptual approach to selection of a control measure for residual chlorine discharge in Kuwait Bay, Environ. Manage., 16 (3) (1992) 309–316.
[22] M. Kennish, Practical handbook of estuarine and marine pollution, 2nd edn., CRC Press, Boca Raton, 1997 p. 524.
[23] M. Abdel-Moati and T. Kureishy, Dissolved copper, cadmium and lead in the coastal waters of Qatar, Arabian Gulf, Ind. J. Mar. Sci., 26 (1997) 143–149.
[24] S. Bou-Hamad, M. Abdel-Jawad, S. Ebrahim, M. Al-Mansour and A. Al-Hijji, Performance evaluation of three different pretreatment systems for seawater reverse osmosis technique, Desalination, 110 (1997) 85–92.
[25] UNEP, Overview on land-based sources and activities affecting the marine environment in the ROPME sea area, UNEP Regional Seas Reports and Studies No. 168. UNEP/ GPA Coordination Office, P.O. Box 16227 2500 BE The Hague, The Netherlands and Regional Organization for the Protection of the Marine Environment (ROPME), Box 26388, Safat 13124, Kuwait, 1999, p. 127.
[26] W.L. Hall and R.D. Anderson, A deterministic ecological risk assessment for copper in European saltwater environments, Mar. Poll. Bull., 38 (3) (1999) 27–218.
[27] UNEP/WHO, Guidelines for Authorizations for the Discharge of Liquid Wastes into the Mediterranean Sea, MAP Technical Reports Series No. 107, UNEP, Athens, Greece, 1996.

[28] K. Wangnick, IDA Worldwide Desalting Plants Inventory Report No. 18. Wangnick Consulting GmbH, 27442 Gnarrenburg, Germany, 2004.
[29] A. Shams El Din and R. Mohammed, Kinetics of reaction between hydrogen peroxide and hypochlorite, Desalination, 115 (1998) 145–153.
[30] K. Paulsen and F. Hensel, Design of an autarkic water and energy supply driven by renewable energy using commercially available components, Desalination, 203 (2007) 455–462.
[31] WHO, Desalination for Safe Water Supply, Guidance for the Health and Environmental Aspects Applicable to Desalination, World Health Organization (WHO), Eastern Mediterranean Regional Office (EMRO), Cairo, Egypt (in review).
[32] W. Elshorbagy and A.B. Elhakeem, Risk assessment maps of oil spill for major desalination plants in United Arab Emirates, Desalination (in review).