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GUIDELINES

ENVIRONMENTAL SOUND MANAGEMENT OF SEAWATER DESALINATION PLANTS IN THE MEDITERRANEAN REGION

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1. INTRODUCTION

Worldwide, population growth increases the demand for drinking water, while ongoing industrialization, land irrigation and higher living standards cause an additional rise in per capita consumption of freshwater. This development is mostly concentrated in a narrow coastal zone, where by today about half the world population lives, and this number is expected to rise to three quarters by 2020 (Agenda 21, 1992). Similar to the worldwide trend, demographic growth and intense socio-economic activity in the Mediterranean region cause freshwater resources to become an increasingly rare asset. Water withdrawal has already reached a level that exhausts available resources in some Mediterranean countries, while others are expected to approach this level of exploitation in the future. It is estimated that the total demand in the region will increase from 300 billion m^3 per year in 1990 by 32 % until 2010, and by 55 % to over 460 billion m^3 in the year 2025 (Margat and Vallée, 2000).

The prospect of severe water shortage, which restricts future development and may cause environmental damage, stresses the need for new strategies in the field of water resources management. Management policies and plans have to integrate non-conventional methods like wastewater reclamation and seawater desalination, which will become indispensable to meet the growing demand in the Mediterranean and to protect conventional resources from over-exploitation. While waste-water recycling is mostly of benefit for agricultural irrigation, the main sectors of use for desalinated water are drinking water for communities and pure water for high-tech industries (Ribiero, 1996). Desalination is already a well-established industry in some coastal areas of the Mediterranean, but will become increasingly important as a source of freshwater, taking the length of the Mediterranean coastline into account and the importance of this technology for islands, which may predominantly depend on desalination. The sea as a source for fresh water seems to be unlimited and the potential for growth in the desalination sector is enormous.

Exploitation of seawater for desalination requires a good raw water quality, but coastal water bodies are often affected by wastewater discharges from a wide range of land-based activities, including desalination facilities. The waste stream resulting from the desalination process is typically a highly saline brine that may be increased in temperature, contain residual chemicals from the pretreatment process, heavy metals from corrosion or intermittently used cleaning agents. Emission of this multi-component waste into the sea, either directly through coastal outfalls or disposal by ships, might therefore have potential adverse effects on water and sediment quality or impair marine ecosystems. Although impacts are mostly related to the concentrate, desalination plants may also be large industrial facilities that consume space, require energy and emit substantial amounts of combustion gases, or might have indirect effects through socio-economic development.

With regard to the expected high demand for desalination in the Mediterranean region, potential environmental and socio-economic impacts have to be taken into account by Governments in the planning and management of new projects. In this context, MEDPOL prepared an assessment of sea water desalination activities and their environmental impacts (UNEP/MED, 2002a) and recommendations for guidelines for the management of seawater desalination (UNEP/MED, 2002b). Both documents and the outcome of an experts meeting held in Forli, Italy, on 16-18 May 2002, provide the basis for the present “Guidelines for the Environmental Sound Management of Seawater Desalination plants in the Mediterranean Region”, taking further the Land-Based Sources (LBS) and Dumping Protocols into account. Both protocols provide the legal framework for the regulation of waste disposal into the Mediterranean Sea through outfalls or by ships, and are consequently applicable to seawater desalination discharges.

2. OVERVIEW OF THE LEGAL ASPECTS AND POLICIES

2.1 Water resources management and coastal area management

The coastal zone of the Mediterranean region is an area of intense activity, where water is becoming an increasingly rare asset. Future development depends on water availability but will deplete conventional resources further. In this situation, seawater represents an alternative, inexhaustible reservoir that can provide much needed relief by the technical process of desalination. Increased desalination activity, however, could in turn stimulate coastal development if this is no longer under constraint of water limitation.

Desalination activities development should therefore be an integrated part of the national water resources management policy and especially the management of coastal water resources. As water availability and socio-economic growth are closely interrelated, issues of water resources management and seawater desalination must also be integrated into an overall coastal area management for a sustainable development in the region.

In practice, this can for example be realized within MAP’s Coastal Area Management Programme (CAMP), which implements management projects in selected coastal areas of Mediterranean countries. Experience shows that water resources management is already a central component in most projects as a result of locally high demand, pollution or over-exploitation of conventional water resources. Furthermore, the emerging issue of seawater desalination and growth-inducing impacts of new plants have to be considered in CAMP projects. Where CAMP projects have not been implemented, a coastal development plan can provide the legal framework for the management of new desalination plants and resulting socio-economic development.

2.2 Marine environmental protection

Seawater desalination is an industrial process which may have adverse effects on the coastal environment if not well designed and managed. The causes are e.g. a changed land use in the coastal zone, disturbance during the construction phase and emissions into air, ground or water during plant operation.

Especially the discharge to the marine environment could deteriorate water and sediment quality. It is a multi-component waste that may contain residual chemicals from the pretreatment process, heavy metals from corrosion or intermittently used cleaning agents besides increased salinity and temperature values. A changed seawater and sediment quality could in turn impair marine life and have a lasting effect on coastal ecosystems. Seawater desalination effluents should therefore conform with regional and national environmental protocols and policies.

The Land-Based Sources (LBS) and Dumping Protocols provide a legal framework for the regulation of waste disposal into the Mediterranean Sea. As desalination plant wastes are typically discharged directly through coastal outfalls or can be disposed of by ships, they fall under the provisions of both protocols. Since the contracting parties to the Barcelona Convention are obliged to implement the ratified protocols into their national legislation, the national environment authorities should extend the existing policies to cover sea water desalination activities.

Potential environmental impacts can be directly related to desalination activity, e.g. to marine emissions, but environmental effects may also be indirect consequences of water availability. As increased water availability allows for socio-economic growth, seawater desalination has been identified as an emerging issue in water resources management and coastal area management. However, an integrated management of the coastal zone also requires that potential impacts of an activity are considered, including both direct and cumulative indirect environmental effects. New water supplies should therefore stimulate growth only where this is tolerable for the coastal environment and consistent with the long-term goals for coastal development.

3. IMPLEMENTATION OF DESALINATION ACTIVITIES INTO NATIONAL WATER RESOURCES MANAGEMENT AND ENVIRONMENTAL PROTECTION PLANS

Management provisions for seawater desalination plants are so far rather limited in the Mediterranean countries and a proactive approach is required to deal with the expected growth of this industry in the region. Concrete measures include that seawater desalination activity is taken into account in existing coastal development plans, water management policies and environmental regulations by the competent national authorities.

Moreover, the competent national authorities have to react to proposed new facilities on a case by case basis by evaluating potential impacts. These can be of a socio-economic nature, or adverse effects on the marine environment if the desalination plant is not well designed and managed. For example, it has to be assessed if the proposal is consistent with the coastal development plan or if environmental standards like emission limits are being observed.

3.1 Coastal development plan

A coastal development plan can declare development priorities through zoning of land and classification of zones for a certain use. This could for example ensure that new development takes place within or adjacent to existing developed areas. Standards for use can be allocated on different management levels, e.g. on a municipal, regional or national level, given that a plan is consistent with the next higher level. It should be prepared by the national environmental authority or coastal authority with jurisdiction in the proposed area under participation of other relevant national or local bodies.

Based on such development plans, desalination plants should be located in zones where construction of new industrial facilities is permissible and resulting socio-economic growth consistent with the long-term goals identified for this zone. For example, development of new desalination facilities might be preferred within existing urban boundaries, whereas it might not be permissible in a pristine environment where preservation is the main objective.

3.2 National water management policy

To formulate a national water resources management policy that takes the emerging issue of desalination into account, an interagency task force should be established. It should address all issues relating to and affected by desalination. Representatives from different sectors should participate in the task force, including water management, producers, consumers and NGOs. As desalination can have potential adverse impacts on the environment, the national environmental or coastal authorities with jurisdiction in the proposed area are essential elements in the task force.

Aspects to be considered in the formulation of a national water management policy are water extraction, allocation, conservation and reuse. Before new water is supplied by seawater desalination, alternative sources of extraction and the potential for water conservation and reuse should be investigated. National water management policies should only encourage seawater desalination where the use of conventional water resources like ground water is impracticable or causes environmental damage. Conservation measures, for example maintenance of water supply infrastructure and an increasing public awareness for water saving, could further alleviate water scarcity problems. An additional option is reclamation of wastewater, which may be of benefit to water-intensive sectors such as agriculture after minimal treatment.

In the case that seawater desalination is indispensable, the national water management policy should provide guidance in the planning phase of new projects. Aspects to be considered are purpose, size and location of a plant. For example, it should be evaluated if a permanent facility is needed or if temporary supply for draught relief is sufficient. The size of a plant can either be proportioned to the present need or take future demand into account. A plant can provide water for the local population and industry or produce surplus quantities for other areas. In this context, it should be evaluated if a number of small plants or a centralized larger plant is required.

3.3 National environmental protection policy

A desalination plant may have indirect environmental impacts as a result of changed land use and increased development in the coastal zone. New plants should therefore be approved by the authorities responsible for regulating development in the coastal zone. Development should be consistent with environmental protection plans and the long-term goals of the coastal development plan. Direct impacts may be attributed to air emissions and discharges to the marine environment. A discharge permit issued by the national environmental authority should be prerequisite for marine disposal, taking national legislation and corresponding regional protocols into account.

3.3.i Implementation of LBS regulations

According to the Mediterranean Land-Based Sources Protocol, the Parties "shall take all appropriate measures to prevent, abate, combat and control pollution of the Mediterranean Sea Area caused by discharges from rivers, coastal establishments or outfalls, or emanating from any other land-based sources[1]. The amended protocol from 1996 also explicitly provides for disposal into watercourses that communicate with the sea like coastal lagoons, salt marshes and groundwater or disposal under the seabed[2].

Seawater desalination plants commonly discharge directly to the sea through coastal outfalls. Another option is injection of brine into the ground, which is mostly practiced for plants without direct access to the sea. The brine could then enter ground water aquifers that mix with offshore ground waters and eventually enter the Mediterranean Sea. Injection into wells or percolation basins is also possible for coastal plants in order to disperse the brine through dune aquifers or the seabed. In the case that the amended protocol is ratified and enters into force, these alternative discharge options fall under the provisions of the LBS protocol.

Classification of desalination discharges according to annex I & II

The LBS protocol from 1983 distinguishes two categories of pollutants and lists them in separate annexes. Pollution of the protocol area by substances that are toxic, persistent and liable to bioaccumulate as covered by annex I shall be eliminated. For this purpose, the contracting Parties to the Barcelona Convention are obliged to elaborate the necessary programmes and measures, common emission standards and standards for use[3].

Pollutants listed in annex II were selected on the basis of criteria established for annex I, but are generally less noxious. Pollution of the Mediterranean Sea by these substances shall be

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[1] article 1 of the original and amended protocol
[2] article 3 (d) and 4.1 (a) of the amended protocol
[3] article 5 of the original and amended protocol

strictly limited by suitable programmes and measures, and discharges shall be subject to authorization by the competent national authorities[4]. All physical effluent parameters and most chemical compounds that may be present in the desalination discharge fall into this category, i.e. are covered by annex II (Table 3-1 to Table 3-4).

The amended LBS protocol from 1996, which has yet to be ratified, establishes a combined annex that lists most substances previously covered by annex I and II of the original protocol. Pollution and input of these compounds into the Mediterranean Sea shall be eliminated by national and regional action plans and programmes. Furthermore, all point-source discharges shall be strictly subject to authorization or regulation by the competent national authorities. The provisions of the combined annex, which are mostly synonymous with the provisions in annex I and II, are included in Table 3-1 to Table 3-4.

Salinity, temperature and dissolved oxygen are natural seawater parameters that are altered by the desalination process. Their effluent values deviate from ambient levels in the discharge site and could be harmful to marine life (Table 3-1). Annex II includes thermal discharges and substances that have an adverse effect on the oxygen content of seawater. Although low oxygen levels in the brine are often due to physical deaeration rather than oxygen-scavenging substances, the effect is the same and oxygen content should be regulated by annex II. High salinity is not explicitly listed as a pollutant in both annexes, but regulation according to annex II is recommended as it provides for substances of a non-toxic nature that may become harmful. Marine organisms are adapted to the concentration of dissolved salts in seawater, which is a basic living condition and consequently non-toxic. Natural salinity fluctuations can generally be tolerated, but high concentrations of dissolved salts in the effluent may be harmful to marine life.

Heavy metals are taken up by seawater from corroding surfaces within the plant. Depending on construction materials used, the discharge may contain traces of iron, chromium, molybdenum, nickel, copper and titanium (see also section 4.1.iv). Except for iron, which is not listed as a pollutant, these elements and their compounds are covered by annex II of the LBS protocol. Discharge to the Mediterranean Sea shall therefore be strictly limited and requires an authorization from the competent national authority (Table 3-1). Measures for the control of pollution by copper and its compounds adopted by the contracting parties specify a copper discharge limit of 500 µg/l and a water quality objective of 8 µg/l (UNEP/WHO, 1996).

Chlorine is a commonly used biocide in desalination processes and residual levels are often present in the effluents of distillation plants. As a consequence, organohalogen compounds can be formed within the plant or in the marine environment following discharge (see also section 4.1.iv). Pollution by substances which may form organohalogen compounds shall be eliminated according to annex I, except those which are biologically harmless or converted into biologically harmless substances (Table 3-2). Chlorine rapidly self-decomposes into chloride and oxygen, which are natural seawater components. This fate reduces the risk that organohalogen compounds are formed, but does not prevent the formation entirely. Residence times are long enough to allow for reactions between chlorine and dissolved organic matter in seawater. Sufficient evidence exists that some organohalogens are carcinogenic to animals, e.g. bromoform and other trihalomethanes, which have been clearly detected in desalination effluents and discharge sites. However, composition of chlorination by-products and environmental concentrations are highly variable, as they depend on the availability of organic material in the discharge site. According to annex I, pollution by substances which have proven carcinogenic, teratogenic and mutagenic properties shall be eliminated. Annex I does not apply to desalination discharges in the case that effluent concentrations are below the limits defined by the Parties. Annex II provides for biocides and their derivatives not covered in annex I.

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[4] article 6 of the original and amended protocol.

Coagulants and coagulant aids accumulate on filters in RO plants and are removed by backwashing, which produces a sludge that can be disposed to the marine environment. The sludge further contains the suspended matter that has been removed from the intake seawater (see also section 4.1.iv)**.** Sludge disposal to the marine environment should be regulated according to annex II of the LBS protocol. It is generally non-toxic but may become harmful by altering the chemical and physical properties of seawater, for example by increasing the amount of suspended material in the water column which may impair light penetration (Table 3-2).

Antifoamings like polyglycol, which are commonly used in distillation plants, have surface active properties by being soluble in water and organic solvents (see also section 4.1.iv). The LBS protocol provides for non-biodegradable detergents and surface active substances in annex II and requires that their discharge shall be limited (Table 3-2). Polyglycol degradability depends strongly on molecular weight. About 80 % of the fraction with a molecular mass of less than 4,000 g/mole (Falbe and Regitz, 1995) is degradable, but polyethylene glycol can be highly polymerized up to 5,000,000 g/mole. In 1996, the contracting parties elaborated measures for the control of pollution by detergents. Theses included that the use of detergents should be restricted to those which are reasonably (90 %) biodegradable (UNEP/WHO, 1996).

Antiscalants used in desalination plants and processes (see also section 4.1.iv) belong into different chemical groups so that different regulations may apply (Table 3-3). Polyphosphates, which are still in use in some desalination plants, are essential macronutrients and may cause eutrophication in the discharge site. Annex II of the LBS protocol provides for inorganic compounds of phosphorus in addition to substances which may have adverse effects on the oxygen content of seawater by causing eutrophication.
Phosphonate antiscalants are organophosphorus compounds, which are listed in annex I of the LBS protocol. This requires that pollution shall be eliminated by necessary measures unless substances are biologically harmless and therefore excepted from annex I. Consequently, measures adopted by the contracting Parties allow the use of products if they have been authorized, it has been proven that there is no direct effect on human and animal health, and that there is no unacceptable impact on the environment (UNEP/WHO, 1996). As phosphonate antiscalants are typically used in non-toxic concentrations, direct effects on human and animal health are unlikely. A major disadvantage, however, is the poor degradability of most organophosphorus compounds. Discharge of phosphonate antiscalants should be authorized taking the toxicity and degradability of a specific product into account.
For polymer antiscalants like polymaleic acid, the most applicable provision refers to substances which are non-toxic, but may be harmful to the marine environment owing to the quantities in which they are discharged (annex II). While direct impacts due to toxicity can largely be excluded, concern must be expressed about biodegradability and possible interference of polymer antiscalants with dissolved metal ions in seawater (for example essential nutrients like iron). Although dosage is low, this can amount to large waste amounts due to the immense seawater requirements of desalination plants. For example, a dosage of 2 mg/l amounts to a chemical load of 6 kg/d for a production of 1,000 m^3/day, or approximately 10 tons per day for the entire Mediterranean Sea.

Cleaning solutions are usually alkaline or acidic with pH values up to 12 or as low as 2. Additional cleaning chemicals include corrosion inhibitors in thermal processes and biocides, detergents, complexing agents or oxidants in reverse osmosis (see also section 4.1.iv and Table 3-4). Discharge of large volumes of cleaning fluids may have adverse effects on the quality of seawater, which has a pH of around 8, and potential impacts on marine life.
Annex II provides for acid or alkaline compounds, if their composition and discharge quantity may impair the quality of seawater. Annex II further includes biocides and their derivatives if

these are not covered by annex I. This applies to non-oxidizing biocides like formaldehyde but probably not to chlorine, which is also used for pretreatment and discussed above.
Non-biodegradable detergents are also listed in annex II of the LBS protocol for the purpose of article 6, which requires that discharges are subject to authorization by the competent national authorities and limited by suitable measures and programmes. Measures for the control of pollution by detergents adopted by the contracting Parties specify that the use of detergents should be restricted to those which are reasonably (90%) biodegradable (UNEP/WHO, 1996). Substances like dodecylbenzene sulfonate that are used in RO cleaning solutions have become important anionic detergents for their relatively good degradability (e.g. 87 % in 17 days, Zahn-Wellens test; Rott et al., 1982). The remaining cleaning chemicals are not easily classifiable according to annex I and II of the LBS protocol. For example, complexing agents like EDTA may interfere with dissolved metal ions in seawater and is possibly covered by annex II, which generally provides for substances that are non-toxic, but may be harmful to the marine environment.

Sectors of activity

The amended LBS protocol from 1996 also covers different sectors of activity, which receive priority in the development of programmes and measures to combat pollution. As seawater desalination is not listed in section A of appendix I, the most applicable provision would be the sector "29. Works which cause physical alteration of the natural state of the coastline". The contracting parties may consider to include seawater desalination activity explicitly, e.g. in the form of "Energy production and seawater desalination" for the following reasons. First, distillation plant effluents have similar properties to power plant effluents, e.g. with regard to temperature, heavy metal contamination or residual chlorine levels. Secondly, power and desalination plants are often co-located due to the high energy requirements of desalination plants or to allow for co-generation, especially by coupling distillation and power plants for simultaneous water and electricity production. Furthermore, co-located plants may use the same infrastructure like seawater intakes and outfall channels. By using the same outfalls, the brine can be diluted with power plant cooling water to mitigate impacts from high salinity. An amended appendix, which covers energy production and seawater desalination at the same time, is more applicable to combined brine and cooling water discharges.

Table 3-1: Physical and chemical brine properties, including heavy metal contamination from corrosion.

Source of impact	**Process**		**Regulation according to LBS protocol from 1983** *italics refer to the amended protocol from 1996*
	Reverse osmosis	**Multi-stage flash**	
Salinity	up to 70,000 ppm	up to 50,000 ppm due to mixing with desalination plant cooling water of ambient salinity	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful […] *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Temperature	ambient	5-15 °C above ambient	**article 6; annex II, section A, no. 9** Thermal discharge *article 5; annex I, section C, no. 15* *Thermal discharges*
Plume density	negatively buoyant	positively, neutrally or negatively buoyant	consequence of salinity and temperature values and indirectly covered by respective regulations
Oxygen	decreased as a side-effect by chemicals used for de-chlorination	very low, intentional deaeration and use of oxygen scavengers to reduce corrosion	**article 6; annex II, section A, no. 11** Substances which have, directly or indirectly an adverse effect on the oxygen content […] *article 5; annex I, section C, no. 17* *Non-toxic substances that have an adverse effect on the oxygen content […]*
Heavy metals from stainless steels	iron, nickel, chromium, molybdenum		**article 6; annex II, section A, no. 1** copper, nickel, molybdenum, titanium, chromium *article 5; annex I, section C, no. 5* *Heavy metals and their compounds*
Heavy metals from heat exchanger alloys	not present	copper, nickel; titanium	

Table 3-2: Pretreatment chemicals

Source of impact	**Process**		**Regulation according to LBS protocol from 1983**
	Reverse osmosis	**Multi-stage flash**	*italics refer to the amended protocol from 1996*
Biocides	chlorine is typically used, but usually neutralized with sodium bisulfite, i.e. the discharge is free from residual chlorine; chlorinated by-products may be present at low levels or are non-detectable	chlorine discharge levels are approx. 10-25 % of the dosage due to self-decomposition and reaction with organic compounds, e.g. between 200-500 ppb of an initial dose of typically 2 ppm, but dosage can be as high as 8 ppm during shock treatment many different chlorinated by-products at varying concentrations likely	**article 5; annex I, section A, no. 1 and no. 8** - Organohalogen compounds and substances which may form such compounds in the marine environment. With the exception of those which are biologically harmless […] - Substances having proven carcinogenic, teratogenic or mutagenic properties […] **article 5; annex I, section B,** The present annex does not apply to discharges which contain substances listed in section A that are below the limits defined jointly by the Parties. **article 6; annex II, section A, no. 2** Biocides and their derivatives not covered in Annex I *article 5, annex I, section C, no. 8* *Biocides and their derivatives*
Coagulants	e.g. ferric chloride, aluminum chloride, backwashed from filters and disposed as sludge or discharged to environment	not used	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful […] *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Coagulant aid	e.g. polyacrylamide (disposal as coagulants)	not used	
Antifoaming agents	not used	e.g. polyglycol in doses of 0.1 ppm or less	**article 6; annex II, section A, no. 6** Non-biodegradable detergents and other surface active substances *article 5, annex I, section C, no. 12* *Non-biodegradable detergents and other non-biodegradable surface active substances*

Table 3-3: Pretreatment chemicals (continued)

Source of impact	**Process**		**Regulation according to LBS protocol from 1983**
	Reverse osmosis	**Multi-stage flash**	*italics refer to the amended protocol from 1996*
Antiscalants	typical dose of 2 ppm of e.g. polyphosphates		**article 6; annex II, section A, no.7 and no. 11** - Inorganic compounds of phosphorus […] - Substances which have […] an adverse effect on the oxygen content […], especially those which may cause eutrophication. *article 5; annex I, section C, no. 13* *Compounds of […] phosphorus […] which may cause eutrophication*
	e.g. phosphonates		**article 5; annex I, section A, no. 2** Organophosphorus compounds […]. With the exception of those which are biologically harmless **article 5; annex I, section B,** The present annex does not apply to discharges which contain substances listed in section A that are below the limits defined jointly by the Parties. *article 5; annex I, section C, no. 2* *Organophosphorus compounds […]*
	e.g. polymaleic acid, polyacrylic acid		**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful to the marine environment […] owing to the quantities in which they are discharged. *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Acid	e.g. sulfuric acid, pH 6 to 7		Although acidic discharge is regulated by article 6; annex II, no. 12 (*article 5; annex I, no. 16*), the dose used for pretreatment is not enough to impair the quality of seawater

Table 3-4: Cleaning and storage chemicals

Source of impact	**Process**		**Regulation according to LBS protocol from 1983**
	Reverse osmosis	**Multi-stage flash**	*italics refer to the amended protocol from 1996*
Alkaline solution	e.g. sodium hydroxide, pH 11-12	not used	**article 6; annex II, no. 12** Acid or alkaline compounds of such composition and in such quantity that they may impair the quality of sea-water *article 5; annex I, no. 16* *Acid or alkaline compounds which may impair the quality of water*
Acidic solution	e.g. hydrochloric acid, citric acid pH 2-3	e.g. hydrochloric acid, sulfuric acid, citric acid, sulfamic acid pH 2	
Corrosion inhibitors	not used	e.g. benzotriazole	
Biocides	non-oxidizing like formaldehyde, glutaraldehyde, isothiazole derivatives; or hypochlorite (i.e. chlorine)	not used	**article 6; annex II, section A, no. 2** Biocides and their derivatives […] *article 5, annex I, section C, no. 8* *Biocides and their derivatives*
Detergents	e.g. dodecylsulfate, dodecylbenzene sulfonate	not used	**article 6; annex II, section A, no. 6** Non-biodegradable detergents and other surface active substances *article 5, annex I, section C, no. 12* *Non-biodegradable detergents and other non-biodegradable surface active substances*
Complexing agents	e.g. ethylenediamine tetraacetic acid (EDTA)	not used	**article 6; annex II, section A, no. 13** Substances which, though of a non-toxic nature, may become harmful […] *article 5; annex I, section C, no. 19* *Non-toxic substances that may have adverse effects on the physical or chemical properties of seawater.*
Oxidants	e.g. sodium perborate, hypochlorite (i.e. chlorine)	not used	
Membrane storage chemicals	e.g. sodium bisulfite, propylene glycol, glycerine	not used	

3.3.ii Implementation of Dumping Protocol regulations

According to the Mediterranean Dumping Protocol, the Parties "shall take all appropriate measures to prevent and abate pollution of the Mediterranean Sea area caused by dumping from ships and aircraft[5]. Dumping by ship is not a practicable option for coastal desalination plants, where immense effluent volumes are typically discharged directly through coastal outfalls. The LBS protocol and corresponding national legislation consequently apply to most coastal plants. In contrast, inland plants have to rely on alternative disposal options. These usually desalinate brackish water from wells for use in small and medium sized industries and municipalities and generate small amounts of brine. The brine can either be discharged locally into evaporation ponds, sewer systems and deep wells not used for drinking water supply, or can be transported and dumped into the sea by vessels. Dumping of desalination effluents should be regulated according to Article 5 of the Dumping Protocol, which requires that a permit is obtained, in each case, for all wastes listed in annex II.

4. EIA FOR SEA WATER DESALINATION PLANTS

In the amended LBS protocol from 1995, the contracting parties have agreed to undertake environmental impact assessment to prevent, abate, combat and eliminate pollution of the Mediterranean Sea. An environmental impact assessment (EIA) is prerequisite for an activity that probably has significant adverse effects on the marine environment and that is subject to authorization by national authorities[6]. With regard to the potential adverse effects of seawater desalination, an EIA is an essential prerequisite for new desalination projects. It further provides the basis on which different aspects of a new facility can be permitted by the competent national authorities or for imposing restrictions to meet specified requirements, e.g. in the form of marine discharge and coastal development permits.

4.1 Elements of EIA study

An EIA analyzes single components of a project and their expected socio-economic and environmental effects, which results in the formulation of impact mitigation methods. In the following EIA for seawater desalination plants, environmental and socio-economic issues are addressed and recommendations for impact mitigation included.

4.1.i Land use and siting of the plant

Potential impacts. A new desalination facility changes the properties of a coastal site and can permanently alter land use options. Potential impacts can be expected during plant construction and operation, but also from the building itself including intakes, outfalls, pumping stations, and supporting infrastructure like roads, pipelines or power transmission lines.

Construction activity could result in soil disturbance (dunes, beaches, seafloor), erosion, and damage to archeological sites. It requires the use of heavy machinery which produces air emissions and noise, obstructs views or could disturb terrestrial and marine organisms. Similar impacts may result from the desalination plant after completion. Plant operation causes atmospheric and marine emissions or noise from pumping stations, while the building complex and supporting infrastructure alter the visual properties of a landscape permanently.

A changed air, water and sediment quality in addition to auditory and visual effects have potential impacts on human activities and the coastal environment. The recreational value of

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[5] article 1 of the original and revised protocol

[6] article 4 (General obligations), 3.(c) of the revised Barcelona Convention from 1995.

a coastal site for residents and tourists can be reduced or access restricted by the desalination plant. If the plant is located within existing urban boundaries, it could reduce the price for land or the value of adjacent residential properties. Maritime structures like intakes or outfalls could interfere with navigation, access to harbors or other activities like fishing. They also have potential impacts on water currents and sediment transport. The changed land use might further affect habitats of terrestrial and marine animals in the coastal zone, which could be driven away from their breeding, feeding or resting grounds.

Mitigation measures and recommendations. To mitigate impacts from construction activities, they should be scheduled for time periods that guarantee a low interference with recreation and tourism or breeding and migration of coastal animals. Preventive actions further include noise buffering, visual screening and spatially restricted construction corridors. Similar mitigation methods should be considered for the desalination plant, which can be designed to minimize visual and auditory impacts. This includes for example sound proofing of complexes where pumps are housed, limited height of the facility and blending into the surrounding landscape. Impairment of water and air quality should be minimized by implementing best available techniques to limit emissions.

To minimize impacts from changed land use, desalination plants should be located near other facilities with similar needs and consequences. Suitable sites may be where existing infrastructure like roads or seawater intakes can be used, where visual or noise disturbance is an acceptable circumstance or where marine waters have been classified for industrial use. If new infrastructure is unavoidable, siting should be optimized to reduce land use and to avoid impacts on sensitive marine areas and protected species. This means for example that pipelines should be placed underground or number and length minimized without accessing sensitive areas. The different interests and activities in the coastal site should be regulated by the coastal development plan to avoid conflicts. Interests on the seaward side of the coastline, for example the interference of intake and outfalls with other maritime uses, may be included in the coastal development plan or regulated separately.

4.1.ii Energy use alternatives and air quality

Desalination of seawater consumes a significant amount of energy, which is mostly required for the process itself (about 90 %) in the form of thermal energy (distillation processes) or mechanical energy usually obtained by electricity (RO process). Electrical energy is furthermore needed in all plants to operate auxiliary equipment like pumps or dosing systems.

Distillation processes usually have higher energy requirements than membrane processes. For example, a plant operated at a performance ratio[7] of 8 has a thermal energy consumption of approximately 290 kJ/kg distillate (or 80 kWh/m^3), usually added in the form of heated steam, in addition to an electricity demand of 4-6 kWh/m^3 for MSF and 2.5-3 kWh/m^3 for MED plants (C.R.E.S., 1998). However, co-generation of electricity and water in dual purpose plants reduces the primary energy consumption considerably by re-using the exhaust steam from electricity generation as a heat source for the desalination plant. Dual purpose plants are economically attractive and can compete with RO plants in terms of energy cost. For comparison, energy requirements of RO plants can be reduced to 2.5 kWh/m^3 for large units with energy recovery systems, but exceed 15 kWh/m^3 in small plants without energy recovery.

Potential impacts. A major impact is the emission of greenhouse (mainly CO_2) and acid rain gases (NO_x, SO_x) into the atmosphere, if fossil fuels are used as primary energy source.

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[7] The ratio of fresh water production to steam input is a measure for the efficiency of thermal processes. A typical value is 8 kg distillate from 1 kg steam, but values of 10-12 can be achieved.

However, desalination plants also emit gases that do not originate from fossil fuel combustion, but were formerly dissolved in seawater. In thermal plants, the feedwater is usually deaerated and gases evolve from the evaporating brine in flashing chambers. Both processes increase carbon dioxide (CO_2) emissions, which is stored in the oceans in the form of bicarbonate, and cause the release of other atmospheric gases (mainly O_2 and N_2) from seawater.

If power plant capacities have to be increased to meet the additional electricity demand of new desalination plants, impacts related to the use of cooling water may be enhanced. These include entrainment and impingement of marine organisms at the intake and thermal discharges. Further adverse effects may result from the additional transport and handling of fuel required for increased electricity production, which also increases the risk for accidents and spills.

Mitigation measures and recommendations. To mitigate impacts related to energy consumption, national authorities should encourage the use of energy saving technologies and processes. This includes energy recovery systems in RO, which can be used in systems that produce more than 50 m^3/day. Furthermore, implementation of co-generation processes and the use of the same infrastructure for both desalination and power generating plants should be recommended where feasible. However, an efficient operation of the desalination plant requires that the steam turbine for electricity production is operated at the same time. Water and electricity production must therefore be matched to each other and adjusted to the actual demand.

National authorities should also promote the use of renewable energy sources (solar, wind, geothermal energy) where the potential for renewable energy use exists. The substitution of conventional sources of energy (fossil fuel, nuclear power) by renewable ones reduces nuclear wastes and air emissions of CO_2, NO_x and SO_x. If fossil fuels are used as primary energy source, air emissions should comply with national air pollution control standards.

4.1.iii Sea water intake

Desalination plants can receive feedwater from open seawater intakes, below-ground beachwells and infiltration galleries or from the cooling water discharge conduits of power plants. Open seawater generally contains higher and more variable amounts of organic and inorganic material than intakes embedded in the seafloor. These naturally prefiltrate the incoming seawater and thereby reduce bacterial numbers and suspended material. The seafloor sediments might also have unfavourable effects on feedwater properties, for example by increasing the carbonate or hydrogen sulfide content. If the intake water is drawn from cooling water discharges, it might contain residual pretreatment chemicals (e.g. biocides), heavy metals from corrosion and increased temperature values. Depending on the intake option, the feedwater has different properties, requiring that pretreatment in the desalination plant is adjusted to the intake water quality.

Potential impacts. Open seawater intake usually results in the loss of marine organisms when these collide with screens at the intake (impingement) or are drawn into the plant with the seawater (entrainment). An open intake requires an above ground intake structure that can affect surface currents and sediment transport, interfere with shipping or other maritime uses, and provides a surface for the attachment of marine organisms. Pretreatment is generally higher than for beachwells and infiltration galleries to cope with insufficient and more variable surface water quality. Optimal chemical dosage may be difficult to establish and overdosing might ensure safe operation in the case of deteriorating feedwater quality. This in turn increases the risk of chemical discharges to the marine environment.

Besides often minimal chemical pretreatment, underground intake structures eliminate impacts from entrainment and impingement. However, initial disturbance during construction is higher as sediments have to be replaced or become resuspended. Beachwells are typically drilled 30-50 m deep into the seabed, whereas infiltration galleries consist of perforated pipes arranged in a radial pattern in the saturated sand onshore. They could furthermore interfere with aquifers, e.g. by changing groundwater flow or causing saltwater intrusion into freshwater aquifers.

Mitigation measures and recommendations. Screens should be placed in front of the intake structures to prevent the intake of larger marine organisms. While entrainment of smaller plankton, larvae or eggs cannot be avoided by these screens, it can be minimized by locating intakes away from highly productive areas, e.g. in deep water or further offshore. This can also mitigate problems of biological fouling and intake of suspended material so that chemical consumption could be reduced. The intake should be designed to lower the risk of impingement, which can be achieved by specially designed screens or limiting the intake flow velocity to values of week natural ocean flows (e.g. below 5 cm/sec).

Beachwells or infiltration galleries are recommended where a suitable site is available to reduce impacts from impingement, entrainment and to reduce chemical consumption. Drawing of intake water from cooling water discharges has similar advantages and should be considered where co-location of desalination and power plants is possible. Total intake volumes are reduced by reusing the cooling water from the power plant for desalination, thus minimizing entrainment end impingement. As the cooling water is usually disinfected to control biofouling, additional biocide dosing may be unnecessary or minimal. Co-location also minimizes construction and land use as existing intake structures can be used.

4.1.iv Brine and chemical discharges

The physical and chemical properties of seawater are modified during desalination, depending on the pretreatment methods and desalination process used. Similar pretreatment steps in distillation and reverse osmosis plants include scale and biofouling control, whereas differences exist in the removal of suspended material (RO only) or the control of corrosion and foaming in distillation plants. The process has a significant influence on effluent salinity, which is typically higher in the RO brine, whereas elevated temperature is characteristic of distillation effluents. In addition to pretreatment chemicals, the effluent may contain intermittently used cleaning solutions if these are blended with the brine. The single effluent properties have potential impacts on the marine environment and their combined discharge might result in additive or synergistic effects.

Salinity

Effluent salinity depends on the salinity of the intake seawater and the concentrating effect of the desalination process. The RO brine is usually more saline (values of 60-70) than the distillation effluent (values around 50), which is mainly due to the use of cooling water in distillation plants. The cooling water from the heat rejection section is discharged along with the brine and effectively reduces overall effluent salinity.

Potential impacts. Salinity is one environmental factor controlling the distribution of marine organisms, which normally occur where environmental conditions are favorable for survival. Although most organisms can adapt to minor changes or might temporarily cope with strongly deviating salinities, the continuous discharge of highly saline effluents will be harmful to marine life and cause a change in species composition and abundance.

Mitigation measures and recommendations. To minimize impacts from elevated salinity levels, desalination effluents should be within 10 % of the ambient value. This can be achieved by blending desalination effluents with power plant cooling water in adequate mixing ratios (see section 4.1.v). Options that improve mixing in the discharge site should further be considered (see section 4.1.vi).

Thermal discharges

Thermal discharges are characteristic of distillation plants, where both brine and cooling water are increased in temperature. Differences of 5-15°C above ambient have been frequently observed.

Potential impacts. The thermal discharge may change temperature distribution and seasonal variability in the outfall site with potential impacts on biological activity, species abundance and distribution. While warmer seawater temperatures may enhance biological processes in winter, increased summer values could result in stress or cause an abrupt decline in activity when a critical value is exceeded. Marine organisms could be attracted or repelled by the plume, and species more adapted to the higher temperatures could eventually predominate in the discharge site.

Mitigation measures and recommendations. To minimize potential adverse effects, temperature increase of the distillation discharge should be restricted to 10°C above ambient. Mixing with effluents of lower temperature should be considered where feasible. Power plant cooling water is recommended for diluting brine salinity, but does not cause a decline in effluent temperature. However, the power plant cooling water could serve as feedwater to the desalination plant, thereby lowering the total intake and discharge of heated seawater. The discharge situation should further ensure adequate mixing of the effluent plume (see section 4.1.vi) with surrounding seawater to mitigate impacts from elevated temperature. For this purpose, an allowable increase in seawater temperatures due to thermal discharges should be determined. An allowable increase of 2°C over ambient conditions might for example be considered, applying to the edge of a defined mixing zone.

Oxygen content

Potential impacts. Oxygen solubility in seawater is reduced by high temperature and salinity values, but decreased solubility is not the primary cause for low oxygen contents in the effluent. The major decline is due to physical deaeration in distillation plants to prevent corrosion. In RO plants, reducing agents like sodium bisulfite are used for dechlorination, which also depletes oxygen as a side effect. The effluent might cause an oxygen deficiency in the discharge site which could be harmful to marine life.

Mitigation measures and recommendations. To prevent oxygen deficiency, the effluent can be aerated or blended with other waste streams of higher oxygen content prior to discharge. Oceanographic conditions in the discharge site should provide for good mixing of effluent and seawater to adjust oxygen contents to ambient levels within close distance from the outfall.

Biocides

The intake seawater of distillation and reverse osmosis plants is commonly treated with chlorine to prevent biofouling. Residual chlorine levels of 200-500 µg/l are typically present in the distillation effluent and are discharged to the marine environment, whereas pretreatment in RO plants often includes dechlorination to protect sensitive polyamide membranes from oxidation. RO discharge levels of chlorine are consequently very low to non-detectable.

Potential impacts. Chlorine is a highly effective biocide and residual concentrations may be hazardous to marine life. Although environmental concentrations are decreased by rapid selfdegradation and dilution, the potential for adverse effects on the marine environment is high. An initial decrease of 90 % can be expected in warm sunlit seawater, resulting in environmental levels of 20-50 µg/l in the mixing zone of the effluent, which is consistent with observed concentrations in discharge sites of desalination plants. For comparison, the U.S. EPA recommends a quality criterion for seawater of 7.5 µg/l for long-term exposure, which is based on toxicological results from a wide spectrum of species.

Residual chlorine levels in seawater increase the risk that organohalogen by-products are produced, of which a major part will contain bromine in addition to chlorine. Bromide ions are naturally present in seawater and transformed into highly reactive bromine in the presence of chlorine. Organohalogen compounds may be formed from precursors of natural or anthropogenic origin. For example, trihalomethanes (THMs) originate from naturally occurring organics and have been detected as a major by-product in desalination plant discharge sites, or chlorophenols and chlorobenzenes may arise in the presence of petroleum compounds. The number of by-products can hardly be determined due to many possible reactions with organic seawater constituents. While the different organohalogen compounds may not be present in acutely toxic concentrations, sufficient evidence exists that some of them have carcinogenic properties or may cause chronic effects during long-term exposure.

Mitigation measures and recommendations. Neutralization of residual chlorine levels should receive a high priority to mitigate impacts from distillation plant effluents. Several chemical treatment options exist, for example dosing of sodium bisulfite (used in RO) or sulfur dioxide[8].

Alternative treatment methods should be considered where feasible, for example the use of ultraviolet light in small, automated systems. Major advantages of UV-light are that storage and handling of chemicals is not required, physical and chemical seawater parameters are not altered and no toxic by-products are formed. Other non-chemical pretreatment options are prefiltration with fine-pored membranes (microfiltration or ultrafiltration) or the use of beach-wells. Both methods remove biofouling organisms from the intake water, so that continuous biocide dosing could be replaced by intermittent treatment for disinfection and cleaning. Alternative biocides proposed for use in desalination plants include ozone, monochloramine, chlorine dioxide and copper sulfate. However, these substances may also be harmful to marine life and require pretreatment prior to discharge.

Coagulants

RO plants typically use coagulants like ferric- or aluminum chloride to improve filtration of suspended material from the feedwater. Coagulant aids (organic substances like polyacrylamide) and pH control with sulfuric acid are supplementary methods to enhance coagulation.

Potential impacts. The filter backwash is non-toxic, but marine disposal increases the amount of suspended material in the discharge site. A potential adverse effect of higher turbidity and lower light penetration is a decline in primary production, while increased sedimentation rates could cause a burial of sessile organisms.

Mitigation measures and recommendations. The filter backwash should be sufficiently diluted, e.g. by continuous blending with the brine, or be removed from the filters and transported to a landfill. The disposal option will also depend on the amount of material produced. Deposition in a landfill should be considered for large plants, where more material

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[8] Sulfur dioxide eliminated residual chlorine levels, was found to be most cost-effective and technically feasible without system alterations (Khordagui, 1992).

accumulates and potential impacts are more likely. The plant would further have to include a process for removal and means of transportation to the landfill, which is more feasible for larger plants[9].

Antiscalants

Antiscalants are added to the feedwater in both MSF and RO plants to prevent scale formation. The main representatives are organic polymers (mainly polyacrylic acid and polymaleic acid), phosphonates and polyphosphates. Dosing of sulfuric acid is another effective method that increases the solubility of alkaline scales like calcium carbonate. Acid treatment is problematic in distillation plants that use copper-alloys for heat exchanger surfaces, as enhanced corrosion increases the risk of brine copper contamination.

Potential impacts. Organic polymers are non-hazardous to marine life as toxicity values (LC_{50}) exceed required dosage levels by several orders of magnitude. However, biodegradation is relatively slow with half-lives of one month or longer and it must be expected that organic polymers are rather persistent in the marine environment. As these substances control scale formation by dispersing and complexing calcium and magnesium ions in the desalination plant, they could influence natural processes of other divalent metals in the marine environment.

Phosphonates are organophosphorus compounds characterized by a stable carbon to phosphorus (C-P) bond, which is rather resistant to biological, chemical and physical degradation. The environmental fate of phosphonate antiscalants primarily depends on processes such as dilution or adsorption to suspended material. Similar to organic polymers, toxic effects are not to be expected due to relatively high LC_{50} values of commercial products.

Polyphosphate antiscalants are easily hydrolyzed to orthophosphate, especially at high temperatures, which lowers their efficiency in distillation plants. Orthophosphate is an essential nutrient for primary producers, with the potential to cause eutrophication and oxygen depletion in the discharge site. Algal mat formation was observed at the outlets of some desalination plants that used polyphosphates for scale control.

Mitigation measures and recommendations. The use of organic polymers is recommended to mitigate potential impacts from increased nutrient levels in the discharge site. Although these substances are relatively non-toxic, concern must be expressed about their environmental fate and potential impact on dissolved metals in seawater, which requires further investigation. Pretreatment with sulfuric acid might be considered for RO plants, where piping is usually made from plastic or stainless steel, which is more resistant to corrosion than copper alloys. The intake water can further be pretreated by nanofiltration, which is a membrane softening process that partially removes divalent cations like calcium or magnesium from seawater.

Heavy metals

Heavy metal concentration and composition of the discharge depends on construction materials used and their resistance to corrosion. Copper-nickel alloys are common materials for heat exchanger surfaces in distillation plants, while other construction parts like brine chambers are often made from stainless steel. Stainless steel is also a predominant material

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[9] Coagulant dosage is typically correlated to the amount of suspended material in the intake seawater, for example around 1 mg/l is required for a low background concentration of 1 mg/l suspended solids. For a capacity of 1,000 m^3/day, backwash material of 6 kg/day is thus produced at 33 % recovery, which amounts to e.g. 600 kg/d for a 100,000 m^3/day plant.

in RO plants, where non-metal equipment like plastic is additionally used. Corrosion of stainless steel is generally very low, with trace amounts of iron, nickel, chromium and molybdenum present in RO and distillation discharges. In contrast, copper levels from corroding heat exchanger alloys are often a major problem of the distillation discharge, with contents typically ranging between 15-100 µg/l under good process control.

Potential impacts. Trace amounts of stainless steel alloys pose relatively little risk to the marine environment, but copper is highly toxic to most marine organisms. Concentrations as low as 10 µg/l in seawater may have significant effects, but toxicity generally depends on bioavailability and species sensitivity. Background copper levels in the Mediterranean are low and range between 0.04-0.70 µg/l in open water and <0.01-50 µg/l in coastal areas (UNEP, 1996). Dissolved copper levels are decreased by chemical and physical processes in seawater (precipitation, complex formation, adsorption), while the element is enriched in suspended material and finally in sediments. The risk of copper accumulation is potentially high for soft bottom habitats and areas of restricted water exchange, where sedimentation rates are high. Many benthic invertebrates (including shellfish) feed on suspended or deposited material, with the risk that heavy metals are enriched in their bodies and passed on to higher trophic levels.

Mitigation measures and recommendations. Heavy metals in the desalination discharge will most likely be within effluent limitations adopted by the contracting parties to the Barcelona Convention. Expected discharge levels of copper are well below an established discharge limit of 500 µg/l, but exceed the water quality objective of 8 µg/l. The outfall should be placed and configured as to achieve sufficient dilution of copper, so that the quality objective can be met at the edge of the mixing zone. To lower the risk of toxic effects in the mixing zone, it is desirable to decrease copper concentrations in the effluent as far as possible. As the environmental fate of copper is characterized by deposition and bioaccumulation, sediments and organisms should be monitored with regard to quality criteria.

Discharge concentrations can be influenced by controlling corrosion, which is usually achieved by pretreatment of the intake seawater, the choice of corrosion-resistant construction materials, and the use of corrosion inhibitors. Non-metallic equipment should be used where possible, e.g. for intakes and outfall pipes or in RO plants. To mitigate impacts from copper contamination, copper-nickel alloys should be replaced by titanium in distillation plants where feasible.

Antifoamings

Antifoaming agents like polyethylene- and polypropylene glycol are added to the intake seawater of distillation plants to disperse foam-causing organics and to reduce surface tension in the water-air interface. Polyglycols are not toxic but can be highly polymerized, which reduces their biodegradability. Potential adverse effects are not to be expected as dosage levels are low and discharge concentrations are further decreased by dilution in the environment.

Cleaning solutions

RO cleaning solutions are either alkaline (pH 11-12) for removal of silt deposits and biofilms, or acidic (pH 2-3) to dissolve metal oxides or scales. They may additionally contain detergents, oxidants, complexing agents and biocides that are used to improve membrane cleaning. For storage of membranes, a chemical preservation solution is used. The cleaning of distillation plants is comparatively simple and usually involves acid washing at pH 2. Special inhibitors may further be added to control corrosion.

Potential impacts. Seawater has a good buffering capacity, i.e. the natural pH of about 8 is usually not affected by slightly alkaline or acidic discharges. The discharge of highly acidic or alkaline cleaning solutions, however, may become toxic to aquatic life if dilution in the discharge site is insufficient.

Detergents like dodecylbenzene sulfonate are hazardous to aquatic life as they have the potential to disturb the intracellular membrane system of organisms. Similarly, the oxidizing potential of some chemicals (e.g. sodium perborate) may affect marine organisms by oxidizing their organic tissue. If complexing agents are released into seawater, they could interact with dissolved metal ions and interfere with natural processes of these elements in the environment. Complexing agents like EDTA are typically used in cleaning solutions, which was found to be poorly degradable and is consequently rather persistent in the marine environment. Oxidizing or non-oxidizing biocides (e.g. chlorine or formaldehyde) are used for membrane disinfection, which are particularly hazardous and may be toxic to marine life if released to the environment. Membrane storage solutions containing sodium bisulfite could also have detrimental effects on marine life by causing oxygen deficiency in the discharge site.

Mitigation measures and recommendations. Prior to discharge, cleaning and storage solutions should be recovered to remove any potential toxicity. This requires neutralization of the alkaline or acidic pH values and specific treatment for detergents, oxidants, complexing agents, biocides or other compounds with detrimental effects on marine life and the coastal water body. For example, dodecylbenzene sulfonate is to a high extent degradable and formaldehyde can be chemically deactivated by hydrogen peroxide and sodium hydroxide. A wastewater treatment section should be implemented in the desalination plant, while substances for which existing treatment methods are inadequate should be avoided or replaced by alternative chemicals.

4.1.v Combining waste with other discharges

Co-location of desalination and power plants has the advantage that the same infrastructure can be used and that a substantial amount of energy can be saved by co-generation (see section 4.1.i & 4.1.ii). Another important aspect is the possibility for waste stream blending, i.e. cooling water from the power plant and brine from the desalination plant are mixed in the outfall channel prior to discharge to the marine environment. Other waste streams like treated sewage from a wastewater treatment facility can be theoretically used for diluting the brine too, but reuse should be preferred over disposal.

Potential impacts. Waste stream blending has the beneficial effect of diluting saline desalination effluents prior to marine disposal, which could otherwise result in increased salinities in the discharge site with potential negative impacts on marine life. Salinity is an important environmental factor for marine organisms that normally live within their optimal salinity range, while de- or increased values may be at the rim of their tolerable limit (confer section 4.1.iv).

Power plants require large quantities of cooling seawater, which typically allow for good mixing ratios to achieve a significant reduction in brine salinity. While impacts from high salinity are mitigated by waste stream blending, the presence of pollutants in both effluents could give rise to additive or synergistic effects on marine life. The cooling water is usually increased in temperature and may contain residual biocides or heavy metals from corrosion.

Similarly, the mixing of brine and sewage effluents may have favorable but also unwanted side-effects. For example, brine salinity and biological oxygen demand (BOD) of the sewage could probably be reduced by waste stream blending, whereas contaminants present in both effluents might form diverse reaction by-products such as chlorinated organics. Mixing of brine and sewage effluents may also cause aggregation of contaminants into differently sized particles with possible impacts on turbidity and sedimentation rates in the discharge site.

Mitigation measures and recommendations. Options for waste stream blending should be evaluated in the planning phase of a new project, especially for RO plants with highly saline discharges. Distillation effluents have generally lower salinity values due to the mixing of brine with cooling water from the heat rejection section of the desalination plant. Further dilution with other waste streams is not essentially necessary but may be considered for co-located power and distillation plants to bring effluent salinities as close as possible to ambient values.

Although the mixing of brine with treated sewage effluent is practiced in other parts of the world, it is not recommended for the Mediterranean region for the following reasons. First, treated sewage effluent can be reused and marine disposal should not be encouraged. In the case that sewage is discharged to the marine environment, it could impair the intake water quality of the desalination plant. Furthermore, co-located desalination and sewage treatment facilities give rise to health concerns and might be objected for psychological reasons. Finally, environmental risks associated with the formation of reaction by-products are probably higher when desalination effluents are blended with treated sewage instead of power plant cooling water.

It can be concluded that waste stream blending is an effective method for impact mitigation, which reverses the process of concentrating natural seawater constituents into brine during desalination. The pretreatment chemicals are diluted as a side effect, although dilution is usually not an accepted method for disposal of chemical wastes. The argument applies to substances that are contained in desalination effluents but not in the waste stream used for mixing, such as antiscalants and antifoamings. Both have a low toxicity and are present in concentrations that are not harmful to marine organisms. In contrast, residual biocides, heavy metals from corrosion and thermal pollution are properties of distillation plant effluents but also of power plant cooling water. As these properties are unaffected by dilution and impacts may even be enhanced by waste stream blending, effluent properties should be within acceptable discharge limits. For combined discharges, the party or parties responsible for meeting the discharge requirements should be identified in order to avoid enforcement problems.

4.1.vi Oceanographic conditions and use of dispersion models

The mixing behavior of an effluent depends on the oceanographic conditions in the receiving water body, the discharge practice and certain discharge properties. Site-specific oceanographic features like currents, tidal regime, bathymetry or shoreline topography control to a large extend the mixing and spreading of an effluent, but this is also influenced by outfall design and location, flow rate and discharge velocity. Mixing is further governed by the density difference between effluent and surrounding seawater, with density being a function of salinity and temperature.

Potential impacts. A distinct water mass may be formed under limited mixing conditions, which is characterized by effluent properties such as increased salinity or residual chemical concentrations. The spreading of this discharge plume could affect marine organisms along its trajectory. The RO brine is negatively buoyant as a result of its high salinity, with the potential to sink to the bottom and spread over the ocean floor, where it could have detrimental effects on benthic habitats. While the high density can be primarily attributed to brine salinity in RO plants, the influence of temperature must be considered in addition to salinity for the distillation process. As both parameters have contrary effects on density, the distillation discharge may either be positively, neutrally or negatively buoyant depending on ambient density stratification[10]. Surface spreading or trapping of the plume in intermediate water masses affects the pelagic community, while sinking and spreading along the seafloor is comparable to RO discharges that affect benthic organisms.

Mitigation measures and recommendations. Mixing of the effluent in the receiving water body should be improved by making use of favorable oceanographic conditions and optimizing the discharge practice. For example, good mixing results can be achieved on high energy coasts, where turbulence is high and strong currents cause a rapid water exchange. On the contrary, sheltered sites like bays or estuaries may trap effluents, which results in long residence times of pollutants. To avoid adverse effects on coastal habitats by shore-hugging plumes, the outfall can be located further offshore. Similarly, outfalls near the surface prevent attachment of negatively buoyant plumes to the sea floor (or vice versa for positively buoyant plumes). Sinking or rising of the effluent through the water column increases turbidity and enhances mixing with surrounding seawater. The outfall can further be technically improved, for example by using multiport diffusers or increasing the discharge velocity.

Different discharge scenarios should be analyzed for a proposed desalination plant to determine the best method of disposal. Dispersion models can be used to simulate the near- and far-field mixing behavior of an effluent in the receiving water body and spreading of the plume. This requires detailed information on the prevailing oceanographic conditions in the discharge site and the planned discharge practice. For example, some parameters of importance are water depth, ambient density including seasonal variations, wind- and density-driven currents, tidal regime, diameter and depth of the outfall, effluent velocity and volumes.

As chemical dilution and dispersal is governed by the mixing and spreading behavior of an effluent, chemical parameters may be included in the model to predict environmental concentrations. This information can be used to assess if water quality objectives (if established) will be observed in the receiving water body. Spatially restricted mixing zones can be established to regulate plume spreading and dispersal. Mixing zone definitions should take local oceanographic conditions like hydrodynamics or bathymetry into account and might exclude areas of biological importance. Ambient levels may typically be exceeded to a certain degree within the mixing zone, but water quality objectives usually apply at the edge of the mixing zone.

For example, the U.S. EPA approved CORMIX model can be used to predict the mixing behavior from diverse discharge types, including desalination brines and power plant cooling waters, in diverse ambient conditions. Besides near-field and far-field plume trajectory visualization, the model allows for concentration and dilution predictions (Doneker and Jirka, 2001; Del Bene et al., 1994; Jirka et al., 1996)[11]. Hydrodynamic models used in Israel to simulate the mixing behaviour of desalination brines are the two-dimensional MIKE21 model from the Danish Hydraulic Institute (DHI)[12] and the Princeton Ocean Model from Princeton University[13]. Hydrodynamic models were also developed at the Center for Environment and Water at the Research Institute of the King Fahd University of Petroleum & Minerals, Saudi Arabia. Although they have not been applied to desalination plant discharge, they have been

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[10] A calculation for Mediterranean surface water (considering a salinity range of 36-38 and a seasonal temperature range of 15-30°C) results in density values of 1022-1028 kg/m^3. Assuming a temperature increase of 5-15°C and salinity values of 41-44 (a 15 % increase is typical for distillation plant effluents), the corresponding density values vary between 1020-1031 kg/m^3.

[11] http://www.cormix.info/

[12] http://www.dhisoftware.com/mike21/

[13] http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/

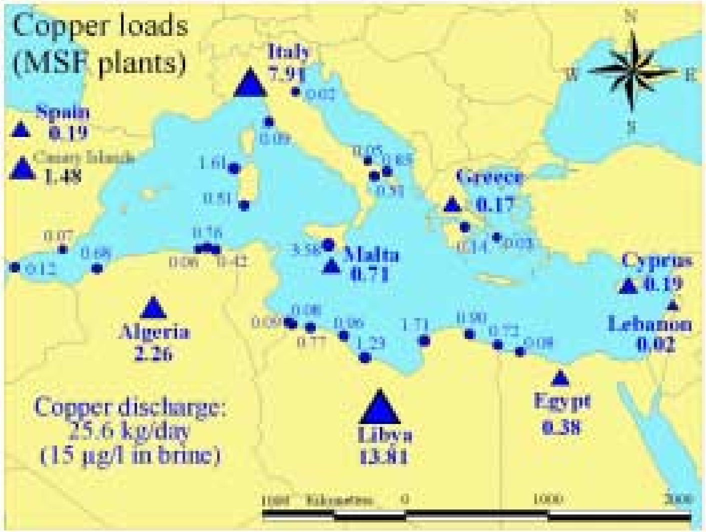
used in simulating the highly saline produced water discharge from offshore oil production operations (Al-Rabeh et al., 2000; Badr et al., 1999).

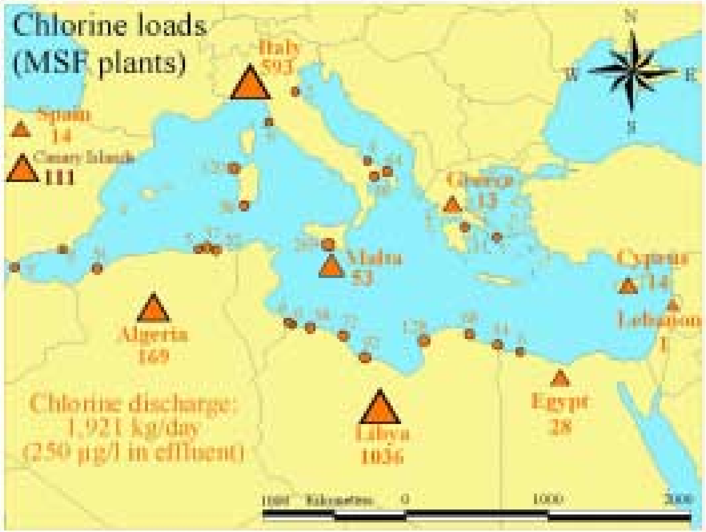
4.1.vii Transboundary effects

Pollutants transported by currents may affect areas far away from where the discharge takes place. Potential impacts beyond the territorial waters or exclusive economic zone of a contracting state should consequently be considered for substances that are persistent and easily dispersed in the marine environment. The degradation of local environments may have transboundary implications too. Intact coastal and marine ecosystems throughout the region are essential for a high biodiversity in the Mediterranean Sea and provide habitats for migratory, endangered or endemic species. An estimate of total chemicals inputs, both locally and into the Mediterranean as a whole, is an important prerequisite for the assessment of transboundary effects.

Persistent and mobile substances in the discharge of desalination plants include for example organohalogen by-products from chlorination, phosphonate and polymer antiscalants or detergents and complexing agents used in cleaning solutions. They may be dispersed by currents, and dilution will cause a further decline of already low discharge concentrations. In contrast, most substances in the desalination discharge have a limited dispersal range so that associated environmental effects will be restricted to the discharge site and its immediate vicinity. Their environmental fate is characterized by processes such self-decomposition (e.g. chlorine) and transport into sediments (e.g. copper, coagulants) in addition to dilution. Local effects may still be significant, especially in desalination 'hot spots' where installed capacities are high.

Residual chemical concentrations in the desalination discharge are relatively low but may amount to immense loads due to the large effluent volumes produced. Estimates of chemical loads are not only of concern for accumulating substances, but also for highly toxic or persistent compounds in the discharge. Figure 4-1 shows estimated inputs of three representative substances, namely copper, chlorine and antiscalants, into the Mediterranean Sea. Based on desalination capacities and discharge concentrations, the daily chemical load may amount to 25 kg copper, 1.9 tons chlorine and 10.2 tons antiscalants. Taking the size and length of coastline of the Mediterranean Sea into account, chemical inputs from desalination plants are still limited and fairly well distributed, although some hot spots of increased capacity exist.





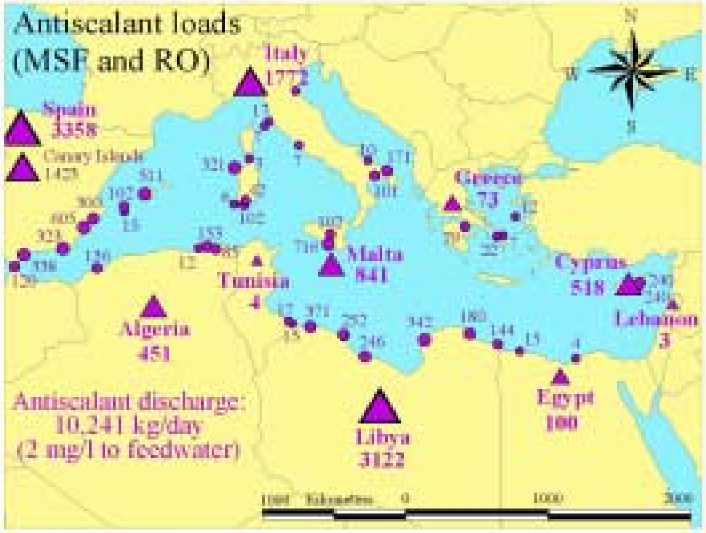


Figure 4-1: Estimated copper, chlorine and antiscalant discharges into the Mediterranean Sea in kg per day. Dots and triangles show discharge loads of single locations and cumulative national loads, respectively.

Copper and chlorine are present in discharges from multi-stage flash (MSF) distillation plants. The estimate is based on a brine copper level of 15 µg/l, while residual chlorine levels of 0.25 mg/l were assumed for both brine and cooling water effluents.

Antiscalants are used in both multi-stage flash (MSF) distillation and RO plants. The figure shows the estimated discharge of both processes based on a dosage of 2 mg/l to the feedwater.

4.1.viii Potential growth of water demand

A main reason for water shortage is the unequal distribution of water resources among Mediterranean countries. The North coast receives most of the natural input and is backed by more temperate regions with abundant water resources. The Eastern and Southern parts, in contrast, are characterized by low rainfall and little water input from neighboring areas[14]. The already high pressure on water resources in the South-East is further increased by rapid demographic growth, economic and agricultural development[15].

Sectorial water demand. Only a minor amount of water is consumed by communities, which currently account for about 8 %, 14 % and 15 % of the total demand in the Southern, Eastern and Northern parts, respectively (Table 4-1). Similarly low shares ranging between 7 % and 13 % can be attributed to industrial activity, so that agricultural irrigation is and will remain the predominant sector of use in most Mediterranean countries. In the South-East, the demand for irrigation water exceeds 80 % of the total and is much greater than in the North, where approximately 42 % of the water is used for agricultural purposes. Water shortage is most pronounced in summer months when peak amounts are needed to irrigate crops, but rainfall is low or non-existent. Furthermore, the problem is seasonally aggravated by tourism and interannually by droughts, when water input can be as low as a third of average input (Margat and Vallée, 2000).

Expected growth of water demand. In most Mediterranean countries, water withdrawal has already or will reach a level that exhausts available water resources. The total demand in the Mediterranean region approached 300 billion m^3/year in 1990, but is anticipated to increase by 32 % until 2010, and by 55 % to over 460 billion m^3/year in 2025 (Table 4-1). The underlying trends reflect the different demographic and economic development in the sub-regions: While the demand will almost double in South-Eastern parts, a comparatively slow increase of 20 % is predicted for the North. As a result of limited resources and rapidly growing demand, pressure on natural water resources will be most pronounced in the South-East, where eleven countries will withdraw more than 50 % of their average renewable resources by 2010 and eight countries will require more than 100 % in 2025 (Margat and Vallée, 2000).

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[14] Natural input in the North is about 72 % of the total, while the East and South receive about 23 % and 5%, respectively. An exception is the Nile river basin with abundant water resources which originate in the highlands of central Africa.

[15] The total population in the Eastern and Southern countries tripled within one generation and exceeded 223 million in 1995. For the whole Mediterranean, a population growth of 20-37 % is anticipated according to United Nations estimations, from 420 million inhabitants in 1995 to 508-579 million in 2025.

Table 4-1: Sectorial water demand in 1990 and moderate trend forecasts for Mediterranean countries by sub-regions for 2010 and 2025. Figures are given in km^3 per year and as percentage of the total demand from 1990 (100 %). The North includes Albania, Bosnia-Herzegovina, Croatia, Spain, France, Greece, Italy, Malta, Monaco, Portugal, Slovenia, F.R. of Yugoslavia; East: Cyprus, Israel, Jordan, Lebanon, Syria, Territories under Palestinian Authority (Gaza, West Bank), Turkey; South: Algeria, Egypt, Libya, Morocco, Tunisia (source: Margat and Vallée, 2000).

		Reference year 1990										2010	2025
		Communities		Agriculture		Industry		Energy		Total		Total	Total
		km^3/a	%	km^3/a	%	km^3/a	%	km^3/a	%	km^3/a	%	%	%
1990	North	23	**15**	65.5	**42**	20	**13**	47	**30**	155	**100**	**116**	**120**
	East	7.5	**14**	43	**79**	4	**7**	0	**0**	54	**100**	**152**	**202**
	South	7.5	**8**	72.5	**82**	8.5	**10**	0	**0**	89	**100**	**148**	**189**
	Total	38	**13**	181	**61**	33	**11**	47	**16**	299	**100**	**132**	**155**
2010	Total	62	**16**	237	**60**	46	**12**	50	**13**	395	**100**		
2025	Total	75	**16**	276	**60**	51	**11**	61	**13**	463	**100**		

Non-conventional resources. The figures reveal that future demand can only be met if water is withdrawn from non-renewable resources (fossil groundwater), or supplied by non-conventional methods like wastewater reclamation and desalination. Seawater desalination is already a well-established and reliable industry in some coastal areas of the Mediterranean (Figure 4-2), but the region as a whole has a comparatively low share in worldwide capacities: Its current production exceeds 1.7 million m^3/d compared to a total of 15 million m^3 extracted from the sea each day (data based on Wangnick, 1999). Capacities in single locations are also relatively low and plant size is typically below 100,000 m^3/d, with most plants producing 10,000 m^3/d or less. Although multi-stage flash distillation is the dominant process for seawater applications worldwide followed by reverse osmosis, both processes are used about equally in the Mediterranean region. On a national level, however, capacities deviate strongly from this overall regional trend. For example, Spain's desalinated water is produced almost exclusively in RO plants, while the majority of plants in Libya are based on thermal desalination processes. From the distribution of plants, it can be concluded that the energy and cost intensive technology is so far restricted to areas, where natural water resources are very limited, fossil energy is readily available, or where the high price for desalinated water can be afforded.

According to the moderate trend scenario of the Mediterranean Blue Plan (Margat and Vallée, 2000), non-conventional resources may supply 5 to 10 % of the water demand in 2025, which amounts to 63-126 million m^3 per day. A major proportion of this quantity will be provided through waste-water recycling and be of benefit for agricultural irrigation. In contrast, the main sectors of use for desalinated water are drinking water for communities and pure water for high-tech industries (Ribiero, 1996). The potential for growth is enormous, although future desalination capacities in the Mediterranean can

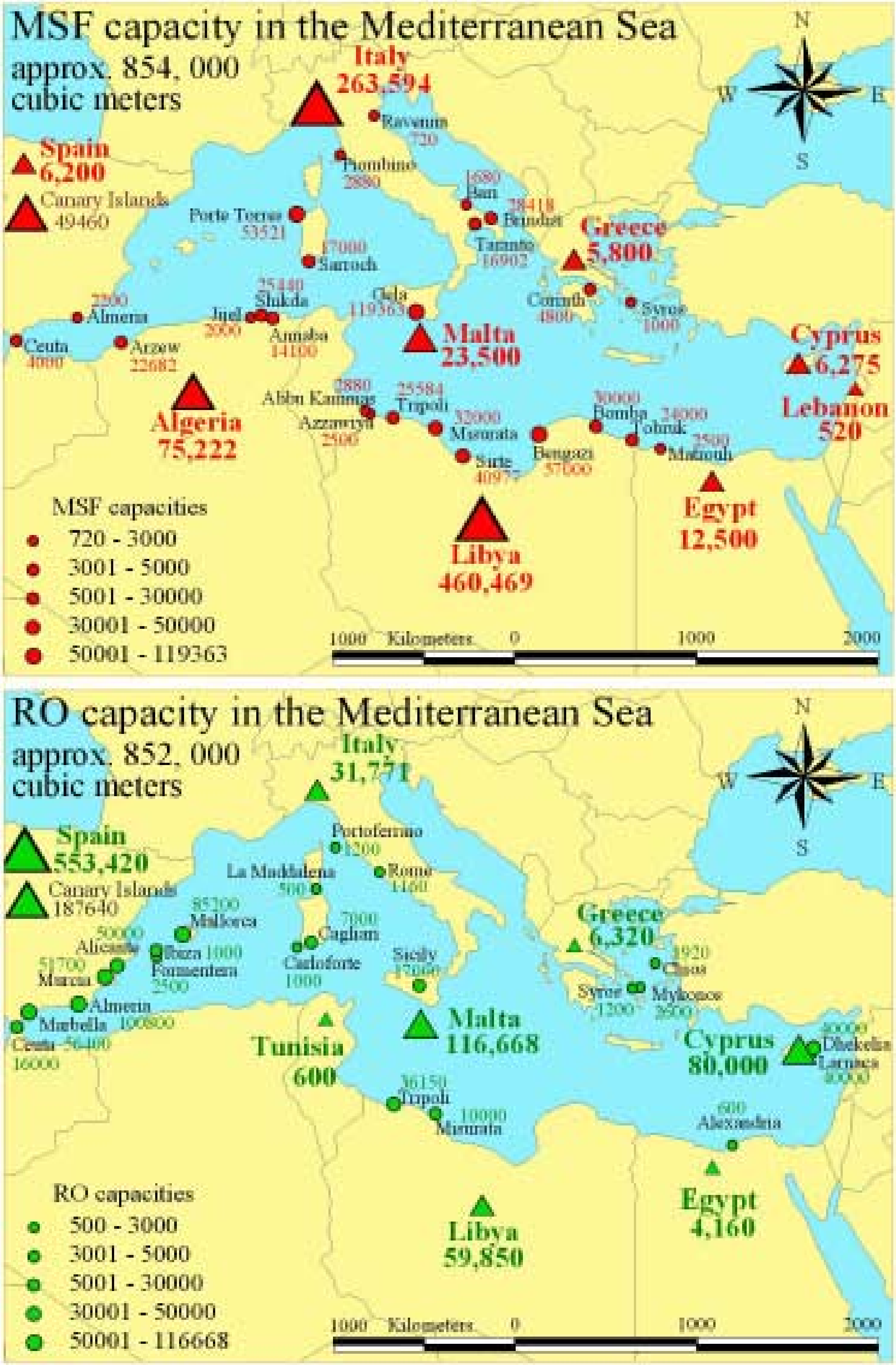

Figure 4-2: MSF and RO capacities in the Mediterranean Sea, with each process contributing about 0.85 million m^3/day. Triangles refer to national capacities, dots illustrate capacities of selected plant locations (data based on Wangnick, 1999).

hardly be predicted. If only 1 % of the water demand is provided by desalination, capacities will exceed 12 million m^3 per day, i.e. will increase sevenfold until 2025. The use of desalination technology may be restricted to developed countries with very low resources in the case that costs remain high, but a widespread low-cost development is anticipated if costs drop below US$ 0.25 per m^3. Currently, the trend is towards large facilities where production costs can be significantly reduced. For example, the planned Ashkelon RO plant in Israel has a guaranteed capacity of more than 270,000 m^3/day with a record low price of US$ 0.53 per m^3 (Kronenberg, 2002).

4.1.ix Socio-economic impacts including impact on the citizens

Seawater desalination has the potential to eliminate water scarcity and quality problems, which may otherwise have direct and indirect impacts on human health and well-being. Health problems can be directly related to inadequate access to safe drinking water for human consumption, or a lack of water for sanitation and hygiene. For these basic requirements, an absolute minimum of 50 liters per person per day (or 18 m^3 per year, Gleick, 1999) is necessary. The question is consequently how much additional water is needed to maintain a certain standard of living, allow for agricultural irrigation and industrial development.

Severe constraint on socio-economic development has to be expected when renewable water resources are below 1,000 m^3 per capita per year. In the South-Eastern Mediterranean, annual resources are even lower with quantities of often less than 500 m^3 per inhabitant. These countries, including Malta, Cyprus, Syria, Israel, Palestinian Territories of Gaza and the West Bank, Jordan, Algeria, Tunisia, Egypt and Libya, already experience structural shortages and a future decline in water resources per capita is anticipated (Margat and Vallée, 2000). Seawater desalination could therefore help to overcome water scarcity, which impedes development in water-dependent sectors and prevents a rise in living standards.

Water scarcity may cause environmental problems with direct or indirect implications for the citizens. A high water demand increases the pressure on natural water resources, which could result in unsustainable exploitation and adverse effects on the ecosystems from which the water is drawn. For example, overuse of water resources may enhance desertification, which also impairs the quality of life of citizens by deteriorating climatic conditions (higher daytime temperatures through lacking vegetation and surface water) or increasing the amount of dust in the air.

Furthermore, the allocation of limited resources to different consumers, e.g. the agricultural and industrial sector, municipalities or the tourism business, may lead to conflicts between these groups. This also holds for countries in the region, if jointly used water resources become scarce.

It can be summarized that seawater desalination may be beneficial for Mediterranean citizens by:

- ensuring access to sufficient and safe drinking water for domestic use
- creating wealth through tourism, industrial and agricultural development, or even new employment opportunities in the desalination industry
- decreasing the pressure on natural resources, protecting freshwater ecosystems, preventing desertification or ground-water salinization
- guaranteeing stability and peace in the region

Possible negative socio-economic impacts of desalination include:

- a changed consumption pattern or even misuse of water due to the impression that water is readily available
- a further concentration of development and activity in the coastal zone, migration of people from inland/rural regions to coastal/suburban areas
- dependency on a technology that may in turn depend on the import of know-how or energy, that is vulnerable to deteriorating seawater quality (e.g. oil spills), and is probably centralized in a few locations requiring the transport of water over large distances

The magnitude of socio-economic impacts depends on the future development of desalination activity in the Mediterranean region. Trend scenarios range from a restricted use in developed countries to a widespread applicability in the whole region if costs can be further reduced. The cost factor can be influenced by water management decisions, such as to subsidize desalination to keep the price for water low. Although this ensures that desalinated water is affordable to lower income groups, it provides a falsely priced product, especially to those sectors that could bear the actual cost of desalination (e.g. industries or the tourism business). The tariff system could be designed to ensure sufficient water for all without encouraging misuse, and to avoid subsidies where these are unnecessary.

4.1.x Pre- and post-operational monitoring programmes

In article 8 of the LBS Protocol, the contracting parties have agreed to carry out monitoring programmes to systematically assess the levels of pollution along their coasts. This is in particular required for the sectors of activity and categories of substances listed in Annex I and II to the protocol. Although seawater desalination is not explicitly listed as a sector of activity, many brine components fall under the provisions of annex I and II. With regard to potential pollutants in the desalination discharge, the expected growth of this industry in the Mediterranean region and resulting transboundary implications, monitoring programmes for seawater desalination plants should be established. They may be carried out separately or as an integrated part of national monitoring programmes.

Monitoring of effluents and environmental quality are furthermore required to ensure compliance with effluent limitations and water quality objectives. The competent national authorities responsible for permitting the discharge may therefore specify monitoring requirements or could be actively involved in the surveying process. Monitoring may involve pre- and post-operational activities to gather information on specific projects and to evaluate if predictions made in the EIA are accurate, but may also include baseline studies to improve general knowledge about potential impacts.

Baseline information on potential impacts. Desalination effluents could be used for laboratory tests to evaluate acute and chronic toxicity of the effluent, preferably using marine species that are characteristic of a specific site or region. Whole effluent tests have the advantage that the combined impacts of all effluent parameters are investigated (additive or synergistic effects) rather than impacts of single components. Laboratory tests may further improve knowledge about the environmental fate of chemical compounds in the discharge, for example by investigating biodegradation and bioaccumulation rates, possible side-reactions with other seawater or effluent components, transport processes into suspended matter and sediments.

Pre-operational monitoring. Pre-operational monitoring should include a chemical analysis of samples taken from water, sediment and organic tissue of marine organisms in the discharge site. Sampling may be carried out along transects or at defined stations in a grid that allow for a spatial analysis, e.g. using (geo)-statistical methods. The same stations may be used for investigating distribution and abundance of benthic species, which are typically sessile or have a limited radius of action. Suitable methods include sampling, video cameras or divers. Marine organisms in the pelagic (e.g. fish, plankton) have a higher mobility or are dispersed by currents, so that spatial trends may be less obvious. A general inventory of these species in the discharge site is nevertheless recommended. Both chemical analysis and species composition data will act as a reference for future monitoring.

Oceanographic conditions in the discharge site should further be investigated to assess transport direction and impact range of the discharge plume. Important parameters to be included are salinity and temperature values, hydrographical information like currents and tides, and topographical features like water depth and shoreline morphology. The data can be implemented in computer models to simulate plume spreading and environmental dispersal of pretreatment chemicals. Actual measurements of dispersion rates using tracers (e.g. non-toxic dye) may be additionally carried out.

Post-operational monitoring. Samples of water, sediment or organic tissue for post-operational chemical analyses should be taken from the same stations defined during pre-operational monitoring. Also, an inventory of marine organisms in the area of the outfall is required for comparison with pre-operational data. Possible changes in water and sediment quality or species composition and abundance can thus be determined and allow for conclusions regarding the potential impacts of the discharge. In this context, it can be investigated if environmental levels of salinity, temperature, dissolved oxygen or chemical concentrations in the discharge site comply with water and sediment quality objectives. Biomonitoring is further recommended for heavy metals that tend to accumulate in organic tissue of edible marine species.

Possible changes in oceanographic conditions should be investigated following plant start-up, as the discharge plume may affect water circulation in the discharge site. Salinity or other effluent parameters can be measured as indicators for plume spreading and dispersal. Results can be checked with predictions for the plume trajectory (if available) based on modeling simulations or tracer studies.

4.2 How to undertake EIA study

An impact assessment study has the purpose to identify the location, process technology and construction method with the least adverse socio-economic and environmental impacts. It may further weigh the benefits of a new project against the risks involved. To influence the realization of a project, an EIA should be integrated into the planning and development process as early as possible. For example, an initial EIA may be part of the feasibility study of a new project to consider aspects of environmental concern. To address a broad range of potential impacts, a scoping phase or the establishment of a task force may precede or parallel the EIA. Feedback from the public, government agencies, resource users or other interest groups and participation of these groups in the planning phase may achieve a broad consensus and prevent conflicts later on.

The scope of the EIA study should be defined and terms of references outlined by the authority that approves the EIA study. A check list of aspects to be considered in an EIA is provided in the next section, while a more general procedure is proposed in the following. It involves five basic steps and takes the UNEP methodological approach into account for an environmental impact assessment of projects affecting the coastal and marine environment (UNEP, 1990), applied to seawater desalination:

A. Collection of background information and review of existing legislation. This step recognizes that knowledge from analogous cases can be used to reduce duration and costs of environmental impact studies.

B. Investigation of the project and selected site, including the natural environment, socio-economic setting and possible alternatives to the proposed process design and location.

C. Identification and assessment of potential impacts on environmental quality as a consequence of project implementation by:

   i. analyzing the causes of environmental impacts. For seawater desalination plants, impacts may occur during construction or regular plant operation. Plant operation typically causes emissions of wastewater to the marine environment, combustion gases into the atmosphere, and possibly accidental spills into the ground or coastal water body. Activities and emitted compounds of particular concern should be identified.

   ii. defining the links between causes and effects. For example, how does the discharge influence physical and chemical properties of seawater, are discharge components toxic or otherwise harmful to marine life, what is their environmental fate, do several components have additive effects, etc.

   iii. analyzing the impacted ecosystem. Coastal ecosystems may be more or less suited for receiving desalination discharges depending on the sensitivity of the marine organisms present and oceanographic conditions prevailing.

D. Recommendation of alternatives or mitigation measures for every component that may have adverse effects, with the purpose to reduce the overall impact of the proposed activity. For seawater desalination plants, e.g. by identifying the discharge composition with the least impact on marine species and the best discharge site for dilution and chemical dispersal.

E. Establishment of a monitoring programme for the construction and operational phase of the project to verify if predictions made in the EIA study have been correct, and to gather further information on effects. Monitoring requirements should be specified by the authority that approves the EIA study and issues permits for construction and operation.

4.3 Check list for EIA study

The following check list provides an overview on single aspects to be evaluated in an environmental impact assessment for seawater desalination plants and outlines how the EIA report may be organized to present the results:

A. Background information (Introduction)
   i. purpose and need for the project
   ii. permit requirements and legal background
   iii. scope of the EIA

B. Project description including
    i. general location
    ii. onshore components of the facility including pipelines, pump stations, chemical treatment area, electrical sub-stations, etc.
    iii. offshore components including seawater intake, brine outfall and submerged pipelines
    iv. construction activities for onshore and offshore components, equipment required, work schedule, etc.
    v. operation and maintenance procedure including chemical treatment, designed intake and discharge flow rates

C. Socio-economic background and environmental setting, potential impacts of the project and recommendations for mitigation

    i. Land use
        - description of landscape characteristics for onshore and offshore areas such as current use, archeological and cultural value, topography, geology and soils
        - potential impacts of changed land use, geology and soil conditions, including aesthetic impacts, destruction of habitats, erosion, landslides, water drainage, etc.
        - mitigation measures, e.g. how can land use be minimized and impacts on sensitive areas avoided by siting of the plant, how can plant operation and construction be modified?

    ii. Energy use
        - description of energy requirements of the plant
        - potential impacts of energy use, especially for non-renewable energy sources in terms of waste, emissions, hazards
        - mitigation measures, e.g. how can fossil energy use be reduced by implementing energy-saving techniques (e.g. energy recovery in reverse osmosis, co-generation) or avoided by using renewable energies?

    iii. Use of the marine environment
        a) natural setting
        - description of marine water body, including oceanographic conditions and water quality
        - description of biological resources, including sensitive coastal ecosystems, endemic or endangered species
        b) seawater intake
        - description of seawater intake practice
        - potential impacts, e.g. entrainment and impingement
        - mitigation methods for seawater intake, e.g. how can the intake be designed (screens, beachwells) or relocated to minimize impacts?
        c) brine and chemical discharges
        - description of effluent composition and chemical concentrations as resulting from the process and pretreatment scheme
        - potential impacts of effluent components on the marine environment, identification of parameters of special concern
        - mitigation methods, e.g. how can the process and pretreatment scheme be modified, the effluent treated or diluted, or the plant and its outfall located to reduce environmental impacts?

- iv. Socio-economic impacts
    - description of other coastal activities in the proposed area, distribution and use of the desalinated water
    - potential impacts on other resource uses (e.g. public access, tourism, fisheries and aquaculture, navigation, etc.) and potential impacts of water availability (demographic and economic growth in the coastal zone)
    - mitigation methods, how can conflicts be solved by enabling different sectors to simultaneously use the resource or by relocating certain activities into different areas? How can seawater desalination be integrated into a sustainable development concept?

D. Assessment of overall impacts of the proposed activity
- i. identification of activities or components which may have a significant impact on the environment or socio-economic development
- ii. evaluation of cumulative effects of single activities or components
- iii. summary of recommendations for impact mitigation, including alternatives for project site and process design
- iv. identification of unavoidable adverse effects, risk assessment and cost-benefit analysis of the project

E. Consistency with regional, national, or local plans and policies, e.g.
- i. coastal development plan
- ii. national water management plan
- iii. regulations for coastal discharge, LBS protocol

F. Establishment of a monitoring programme
- i. to assess if predictions of environmental effects are accurate
- ii. to control if mitigation methods implemented to reduce significant adverse impacts are effective
- iii. to gather further information on environmental effects

5. CLASSIFICATION OF DESALINATION TECHNOLOGIES IN RELATION TO THEIR IMPACTS

Socio-economic impacts may result from an increased water availability and are therefore related to the product rather than the desalination technology used. In contrast, environmental effects are attributable to the emissions of a desalination plant, which are process-dependent and include the waste stream discharged to the marine environment as well as combustion gases released into the atmosphere. For marine emissions, it should be distinguished between the normal operation mode of the plant, which produces the brine discharge that also contains residual pretreatment chemicals, and intermittent cleaning cycles.

Normal plant operation

In the previous sections, single components of desalination effluents were assessed with regard to their likely environmental impacts. From these results, it can be concluded that pretreatment chemicals used in the RO process pose a relatively low risk to the marine environment. This is mainly due to the lack of biocides in the discharge and low concentrations of heavy metals, while other pretreatment chemicals can generally be classified as non-hazardous:

i. Residual chlorine levels are typically removed from the feedwater directly ahead of the RO unit to prevent damage of polyamide membranes by oxidation. In the case that non-oxidizing disinfectants (e.g. copper sulfate) or more oxidant-resistant membranes (e.g. cellulose acetate) are used, residual biocides could be present in the brine blow-down. However, polyamide membranes are almost exclusively used in modern plants and chlorination-dechlorination is the most common method to control biofouling.

ii. Stainless steel and non-metallic equipment are predominantly used in RO plants. Corrosion of stainless steel is usually very low in seawater, though it may occur in the form of local pitting in crevices if conditions are unfavourable. The RO brine consequently contains relatively low concentrations of corrosion products, with iron as the main component and minor amounts of nickel, chromium and molybdenum.

iii. Further pretreatment chemicals include coagulants and scale control agents, which are generally non-toxic to marine life. Harmful effects may occur but can be prevented or mitigated by certain precautionary measures. For example, filter backwash material can be sufficiently diluted in the brine blow-down or deposited as solid waste in a landfill to avoid increased turbidity and sedimentation rates in the discharge site. Regarding scale control agents, new polymers might be preferred over polyphosphate antiscalants to reduce eutrophication.

The main disadvantage of the RO process is its high effluent salinity, which is usually between 60 and 70, but can be as high as 90 if total recovery is raised by a second RO stage. While the RO concentrate may contain twice the seawater concentration, the distillation effluent is rarely more than 15 % above ambient with potentially lower impacts on the marine environment. The difference in effluent salinity can be attributed to the discharge of cooling water, which is a a waste product from the heat rejection section of distillation plants and effectively dilutes the brine blow-down.

Similar to the decrease in salinity, pretreatment chemicals are diluted by mixing of brine and cooling water discharges. The argument applies to antiscalants and antifoamings, which are added to the feedwater of distillation plants but not to the cooling water intake. However, both substances are of minor concern with regard to their low toxicity. Dilution will therefore only affect brine constituents that are not central to the impact assessment of desalination waste, while the discussion is not appropriate for substances of importance for the following reasons:

i. Chlorination typically occurs at the intake of the plant so that both cooling water and desalination feedwater are chlorinated. The cooling water discharge from distillation plants consequently increases the total amount of chlorine that enters the coastal water body without affecting discharge concentrations. Although chlorine content is reduced by rapid self-decomposition, residual levels in the effluent and environment are probably of toxicological importance for marine life. Furthermore, reactions with organic seawater constituents give rise to halogenated compounds.

ii. Copper from corroding heat exchange alloys is a major pollutant in distillation brines and is probably also present in cooling water discharges. Although blending of both waste streams might reduce copper discharge levels, it will not affect total discharge loads. Loads are of particular concern for substances that have the potential to accumulate in sediments or marine organisms, such as copper.

iii. As temperature is increased in both brine and cooling water, mixing will not lower the overall effluent temperature. In fact, a major amount of the thermal discharge must be attributed to the cooling water. Elevated temperatures may influence marine life in the mixing zone similar to increased salinity values.

Intermittent plant cleaning

While pretreatment chemicals from the RO process are relatively non-hazardous, the opposite applies to acidic and alkaline membrane cleaning solutions, which contain chemicals of particular concern for marine organisms. Among these are:

i. highly effective disinfectants (e.g. formaldehyde and isothiazole)

ii. detergents which disturb the intracellular membrane system of organisms (e.g. dodecylbenzene sulfonate)

iii. poorly degradable chelating agents that influence the environmental fate of heavy metals in the coastal water body (e.g. EDTA)

Discharge to the sea should consequently be avoided as it will likely impair marine life until the chemicals are sufficiently diluted and degraded in the coastal water body. For waste treatment or alternative discharge options, it is advantageous that required cleaning volumes are typically low and that wastes are only produced in certain time intervals.

The cleaning procedure of distillation plants is comparatively simple and involves circulation of a warm, acidic solution of pH 2. The only supplement is usually a chemical inhibitor that adheres to the metallic surfaces within the plant to prevent corrosion. Low amounts of acid (or alkaline solution as in the case of RO) are generally of low concern for the marine environment if sufficient dilution is guaranteed. As seawater has a good buffering capacity, it will neutralize surplus acidity or alkalinity almost immediately. However, large amounts of acidic waste may be harmful to marine life and neutralization prior to discharge is recommended.

Conclusion

Regarding impacts on the marine environment, it can be concluded that reverse osmosis is more favorable than distillation due to a lack of biocides and heavy metals in the brine discharge. However, new construction materials like titanium are increasingly used in thermal processes which eliminate copper contamination of the brine. Furthermore, residual chlorine levels could be neutralized similar to the current practice in RO plants. In contrast, cleaning solutions that are periodically used to restore the performance of RO membranes are potentially more hazardous than the waste produced during cleaning of thermal distillers.

Lower energy consumption is another advantage of RO plants that makes the process more environmentally friendly than distillation. However, dual purpose plants can compete with RO in terms of energy requirements, as the exhaust steam from electricity generation is used as a heat source for the desalination plant instead of being wasted to the atmosphere.

6. MODEL PERMIT FOR CONSTRUCTION AND OPERATION OF SEA WATER DESALINATION PLANTS

Seawater desalination involves different activities which may require separate permits, such as the development of coastal areas for new plants, the intake of seawater, or the discharge of concentrate to the coastal water body. Permits are typically tailored to single plants, especially if a plant has little in common with other facilities, for example due to its size, process design or location in a unique and sensitive marine environment. However, a model permit may be provided for a group of facilities with similar properties by providing general information on the most common plant features. The following list includes items which may be included in such a model permit, but can be modified and expanded to address plant-specific details.

Coastal development permit for desalination plants

A. Name and address of applicant and owner of the property

B. Brief description of the planned development

C. Brief description of the current land use

D. Detailed description of the facility containing the following information, which may be supported by site plans and topographical maps:

   i. location, size, height, use and distance between facility structures

   ii. access and connections to infrastructure outside the facility, such as roads, power grid, pipelines, etc.

   iii. size of the site including the size of the area covered by the facility or changed by landscaping

   iv. drainage and modifications to watercourses

   v. earthwork and modifications to landscape and topography, e.g. affecting seabed, beaches, dune systems, wetlands, vegetation, etc.

E. The competent authority should further identify if

   i. the planned desalination facility and resulting socio-economic growth are compatible with the specifications of the coastal development plan

   ii. the plant may lead to conflicts between competing sectors of use

   iii. the site was chosen and construction activities will be carried out considering aspects to minimize land use and environmental impacts

Marine intake and discharge permit for desalination plants

I. Synopsis of application

A. Name and address of applicant

B. Facility name, mailing address, general location

C. Brief description of desalination process and pretreatment steps including type of process, design capacity, withdrawal, discharge and recovery rate, main pretreatment steps and chemical use

D. Intake and outfall location including approximate coordinates (latitude, longitude), distance from shore, discharge depth, total water depth, identification and brief description of water body used for withdrawal and/or disposal

E. Attachments of

  i. flow diagrams showing the route taken by the water from intake to discharge including all process and pretreatment steps

  ii. a topographical map extending beyond facility boundaries, showing facility outline, intakes, outfalls, wells embedded in the seafloor, chemical storage and treatment tanks, pumping stations, etc.

II. Sources and average flows contributing to the total effluent

A. Regular mode of operation, e.g.:

  i. brine discharge (m^3/day)

  ii. cooling water discharge of thermal plants (m^3/day)

B. Intermittent discharges, e.g.:

  i. RO filter backwash water (m^3/day)

  ii. cleaning solutions (m^3/event)

III. Limitations and monitoring requirements for effluent parameters, for example:

Effluent characteristic	**Maximum value**	**Quality objective**	**Monitoring requirements**	
			Frequency	**Sample type**
Discharge flow (m^3 /day)			continuous	recorder
Conductivity (mS/cm)	max. 10% above ambient		continuous	recorder
Temperature	max. 10°C above ambient		continuous	recorder
Salinity (ppt) or Chlorides (ppm)	max. 10% above ambient		1 / week	grab
Dissolved oxygen	absolute min. of 4 mg/l; 5 mg/l as 24hr average		1 / week	grab
pH	6.5 – 8.5		1 / week	grab
Turbidity	max. 10% above ambient		1 / week	grab
Residual chlorine	below detection limit		1 / week	grab
Total recoverable copper	500 µg/l	8 µg/	1 / week	grab

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