UNEP

Resource and Guidance Manual for Environmental Impact Assessments

Desalination






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The world's oceans have always been a source of food and other goods. The industrial-scale production of drinking water from the sea, however, has only become possible since the 1950s. Today the worldwide number of desalination plants increases at rapid pace, as production costs of desalinated water have declined and many regions turn to desalination in order to alleviate the burdens of water scarcity. Desalination undoubtedly offers a wide variety of benefits for human health and socio-economic development. It provides a seemingly unlimited, draught-resistant and constant supply of high quality drinking water while reducing the pressures on freshwater ecosystems and groundwater aquifers.

In spite of these advantages, concerns are raised over potential negative impacts of desalination activity on the environment. These need to be investigated and mitigated in order to safeguard a sustainable use of desalination technologies, which can be attained by conducting project- and location-specific environmental impact assessment (EIA) studies. This publication intends to assist project designers, regulators and decision makers to anticipate and address all relevant public health, socio-economic and environmental concerns that may arise when undertaking a desalination project, for obtaining maximum beneficial use of the desalinated water in terms of quality, safety and environmental protection.

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Preface

For drinking water quality specifications, many countries refer to the World Health Organization (WHO) "Guidelines for Drinking Water Quality" (DGWQ). The guidelines provide a framework for ensuring the safety of drinking water supplies through the control of hazardous water constituents. They cover a broad spectrum of contaminants, from microbial indicators to chemicals, and are aimed at typical drinking water sources and technologies (WHO 2004).

As desalination is applied to non-typical source waters (mainly waste water, brackish and seawater) and often uses non-typical water treatment techniques (including distillation, reverse osmosis, ultra-, micro- and nanofiltration), the concern was raised that the GDWQ might not fully cover the unique factors that can be encountered during the production and distribution of desalinated drinking water.

In 2004, the World Health Organization has therefore initiated a process to prepare a guidance document on "Desalination for Safe Water Supply", which will supplement the WHO Guidelines for Drinking Water Quality (WHO 2007). The guidance document is equally concerned with health and environmental aspects of desalination developments.

Health issues are primarily reflected in respect to potential chemical and microbial components that are specific to desalinated drinking water. Environmental aspects, which are normally not covered in detail by WHO guidelines, were in this case included because the protection of coastal ecosystems and groundwater aquifers from desalination plant discharges were considered key concerns that should also be addressed during the design, construction and operation of a desalination facility.

Five technical work groups were established that addressed the following aspects of desalination during the project:

- Technology: engineering and chemistry
- Health: contaminants and nutritional aspects
- Sanitary aspects and marine microbiology
- Monitoring requirements
- Environmental effects and impact assessments

Independent from these developments, the European Community has decided to foster the sustainable use of desalination processes in the EU by financing the research project MEDINA ("Membrane-Based Desalination: An Integrated Approach") within the Sixth Research Framework (FP6). The project's overall objective is to improve the performance of membrane-based water desalination processes by:

- developing advanced analytical methods for feedwater characterization
- optimizing integrated membrane systems
- identifying optimal pre-treatment and cleaning strategies for membrane systems
- reducing the environmental impacts of brine disposal and energy consumption
- developing strategies for environmental impact assessment (EIA) studies.

The MEDINA project integrates and builds upon the findings of the recent WHO project for developing strategies on how to minimize environmental impacts and conduct environmental impact assessment studies. This report combines results and recommendations of the environmental work group that could only partly be included in the WHO guidance, and recent results from the MEDINA research project.

Executive Summary

By definition, an Environmental Impact Assessment (EIA) is a procedure that identifies, describes, evaluates and develops means of mitigating potential impacts of a proposed activity on the environment. EIAs can be carried out for single development projects (project EIAs) or for strategic plans, policies or management programmes, such as integrated water resources management (IWRM) plans. Strategic EIAs will not make EIAs at the project level dispensable; both are rather complementing instruments.

A detailed EIA is often required for major infrastructure projects, such as large dams or power generation plants. For relatively small projects, a simplified EIA may be warranted due to the limited potential of the project to cause significant environmental impacts. In principle, EIAs for desalination projects will not differ in terms of complexity and level of detail from those for other infrastructure projects and especially other water supply systems. Depending on the proposed project, it is incumbent on national authorities to individually define the need, scope and complexity of each EIA study.

EIAs are usually not limited to environmental aspects, but typically address all potential impacts of new projects, plans or activities on 'man and environment'. This may require an interdisciplinary approach, covering different natural and environmental science disciplines. Taken a step further in relating potential impacts to people and communities, it may also be necessary to consider human health and socio-economic aspects where appropriate. Public participation is another fundamental element of EIAs in order to involve the public in the evaluation and decision-making process of new projects. Where possible, an EIA should try to predict all potential impacts, including those directly and indirectly related to a project, as well as cumulative impacts with other projects or activities, and transboundary effects.

Reader's Guide

With the context so broad, the present document cannot fully encapsulate the whole spectrum and depth of implications of all possible desalination projects. The document tries to be inclusive rather than exclusive by raising a wide range of potentially relevant issues attendant to the use of desalination as a community water supply, including environmental, cultural, socio-economic and human health implications. Based on the information provided in this document, the reader should decide on a case by case basis which issues may be relevant to a particular desalination project.

The document is divided into three parts. In Part A, an introduction to the concept, methodology and practice of EIAs is given. The EIA process proposed for desalination projects involves 10 basic steps. It is not limited to desalination plants, but can be applied to other water infrastructure projects in a similar manner.

In Part B, a modular outline of an EIA report for desalination projects is proposed. It gives an overview on a range of thematic issues that may be relevant to individual desalination projects. It may also serve as a reference source and blueprint for preparing EIA reports. As the EIA report presents and summarizes the information gathered during the EIA process, the structure of part B is reflecting the structure of the methodological approach described in Part A.

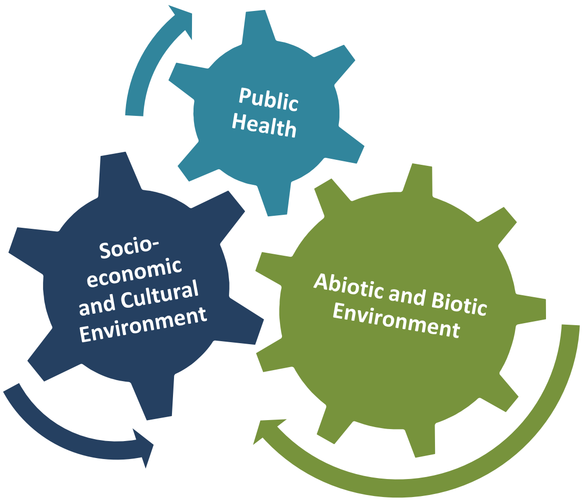
Part C gives an overview on the potential impacts of desalination plants on the environment, based on a comprehensive literature review. Moreover, an attempt is made to evaluate the identified concerns in terms of significance and relevance for EIA studies, using formal criteria.

The appendices provide more detailed information on project screening and scoping, which constitute the first two steps of an EIA.

Key findings and recommendations

I. An EIA should try to predict all impacts related directly or indirectly to the implementation of a desalination project. This comprises all 'environmental' implications including ecosystem, socio-economic, and public health effects and their cumulative and transboundary implications as an integral part of the process. It should attempt to identify the positive effects and offer mitigation measures for negative impacts.

In essence, an EIA for a desalination project should address the following 'areas' of impact:



Abiotic and biotic environment

- Abiotic factors include characteristic landscape and natural scenery, as well as soils and sediments, air and water quality.
- The biotic environment encompasses the terrestrial and marine biological resources, including flora, fauna and sensitive species that inhabit the area impacted by the proposed project.

Socio-economic and cultural environment

- Socio-economic and cultural considerations include the project's effects on the day-to-day lives of the individuals and the community, the project's impact on the management of natural resources and the project's impact on local and regional development.
- Gender-specific effects and variations among the potentially affected population or community, such as social or ethnic affiliations, should be considered in the assessment of socio-economic and cultural impacts.

Public health

- Public health addresses the quality of life, improvement in community health, and potential risks associated directly or indirectly with the desalination project.

II. The EIA process proposed for desalination developments and other water supply projects involves ten basic steps:

1. Decide, on the basis of a screening process, whether or not an EIA is required for the proposed project.
2. Conduct scoping to determine the content and extent of the EIA.
3. Identify policy and administrative aspects relevant to the project and the EIA.
4. Describe the technical design and process of the proposed desalination project.
5. Describe and assess the environmental baseline of the project site.
6. Describe and evaluate the potential impacts of the project on the environment.
7. Identify approaches for mitigation of negative impacts.
8. Provide a summary of the major findings and develop conclusions.
9. Establish a programme to monitor impacts during construction and operation.
10. Review the EIA process for decision-making purposes.

III. As EIAs are undertaken before projects are implemented, they can only give a prognosis of the expected impacts based on the information available at that time, even if the EIAs are based upon detailed analyses. It is therefore important to clearly identify any gaps of knowledge in the EIA and to adopt a precautionary approach in the evaluation of potential impacts.

IV. Public involvement is an integral part of the planning, decision-making and implementation process of desalination projects for community water supply.

V. In order to manage increasing desalination activity on a national or regional scale, it is recommended to elaborate management plans which go beyond the scope of individual desalination projects. The most relevant plans to address desalination projects along with other water supply alternatives are integrated water resources management (IWRM) and integrated coastal zone management (ICZM) plans.

If a water resource management plan is developed, it should cover a suite of supply, demand and management options. Water conservation and education programmes, the use of water saving devices and water recycling for agricultural, industrial and environmental applications are important aspects to be considered before new water supply options are developed.

Although this report primarily addresses EIAs on the project level, it is emphasized that strategic plans and assessments could be a more adequate approach to manage water demand and supply on a regional or even national scale.

VI. Despite a 50 year history of large scale desalination projects, the present knowledge of the environmental, socio-economic, cultural and human health implications of desalination activity is still incomplete. More research into the effects should be initiated, monitoring of existing facilities conducted, and monitoring and EIA results made available to a wider public to improve our understanding of the actual impacts of desalination activity on man and environment.

Further remarks

The document recognizes that the need for desalination to augment water supplies varies regionally. Also, environmental settings, cultural backgrounds, socio-economic development and human health conditions are highly variable and show major regional differences, as does the use of desalination technology with regard to facility size, processes, pretreatment systems and discharge options (cf. Introduction).

No universally valid standards for environmental quality, best techniques or acceptable risks of desalination exist nor shall be provided within this document. The consideration of benefits versus impacts of desalination developments can only be achieved at a local, project-specific level.

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Introduction

Water scarcity can be a serious impediment to economic growth, social development and human health. It furthermore may cause severe ecosystem damage if water abstraction rates exceed natural renewal rates. To cope with water scarcity, many communities around the world turn to non-typical source waters and treatment techniques, such as rainwater harvesting, water reuse or desalination of sea- and brackish water.

Desalination has been a well-established technology since the mid-twentieth century. Until a few years ago, large-scale projects were limited to a few arid countries of the Middle East, which had the financial and natural resources and no other water supply options. Today, desalinated water has become a commodity for many other regions that require more water for socio-economic development. Regional centers of desalination activity that become more prominent include for example the Mediterranean Sea, the Red Sea, the Caribbean, or the coastal waters of China and Australia.

Sectors of use and installed capacities

Desalinated water serves a broad range of applications, including community water supply, tourism, industry, military and agriculture. The main sectors of use, however, remain to be drinking water for communities, tourist resorts and pure water for industries, whereas desalinated waste water is still primarily used for irrigation.

The combined production of all desalination plants worldwide, which are known to be in construction or online, was 44.1 million m^3 per day by the end of 2006. Wastewater desalination accounted for 5% of this production, river water for 8 %, brackish water for 19% and seawater for 63% [1]. 28 million m^3 of water per day are produced by seawater desalination plants alone – a volume comparable to the average discharge of the Seine River at Paris. The desalination market has been growing rapidly — at a compound average rate of 12% a year over the past five years. The rate of capacity growth is expected to increase even further, reaching 64 million m^3 per day by 2010 and 98 million by 2015. The prognosis is based on country-by-country analyses involving desalination projects and official data on water supply and demand from agencies around the world [2].

As desalination technology serves a broad spectrum of uses and applications, facilities differ in terms of production capacity, process design and energy supply. They range from small-scale, stand-alone units with a water production of less than 100 m^3 per day to large industrial-sized plants with an installed capacity of more than 1 million m^3 per day.

In the oil-rich countries of the Middle East, large cogeneration facilities predominate, which produce electricity and water at the same time. Historically, the most important process in the Gulf region has been multi-stage flash (MSF) distillation, by which 90% of the water is produced. MSF will continue to be the main process in the foreseeable future, but will lose further market shares to multi-effect distillation (MED) and reverse osmosis (RO). The combined capacity of all *seawater* desalination plants in the Gulf is about 12 million m^3 per day, or slightly less than half (44%) of the worldwide daily production. The largest producers of desalinated water in the region and worldwide are Saudi Arabia (25%) and the United Arab Emirates (23%), followed by Kuwait (6% of worldwide production).

Where cheap fossil energy or waste heat is not available, RO is usually the preferred desalination technology due to its lower energy demand compared to thermal desalination processes. Consequently, most countries outside the Middle East use RO for water production. For example, 70% of the desalinated water in the Mediterranean region is produced by seawater RO plants. The total installed capacity in the Mediterranean is 4 million m^3 per day (14% of the worldwide total). The largest producer of desalinated water in the region is Spain (8% of worldwide production), while the largest RO plant with a daily production of 330,000 m^3 is currently located in Ashkelon, Israel, but projects of similar size are being also planned in Algeria.

In the foreseeable future, Saudi Arabia and the United Arab Emirates will continue to be the largest desalination markets. China is expected to dramatically expand its capacity and establish itself as the third most important desalination market until 2015, overtaking Spain, Algeria and other countries that are at the moment ranking at the top of the list [2].

Cost and energy implications

Desalination projects are typically driven by the limited availability of conventional freshwater resources. However, as conventional water production costs rise in many parts of the world and the costs of desalination decline due to technological advances, desalination also becomes economically more attractive and competitive.

The average investment cost required for engineering, procuring and constructing an MSF plant is given as US$ 1,235 per m^3/day installed capacity. Capital costs for MED and RO plants are lower with US$ 916 and US$ 641 per m^3/day installed capacity, respectively [2]. The average production costs of desalinated water are in the range of US$ 0.5 to 0.6 per m^3. This includes the replacement of parts and membranes, chemicals for pretreatment of the intake water, plant cleaning and post-treatment of the product water, labour costs, and energy demand – as the most important cost factor (Figure 1).

The amount of energy needed for water production is process-dependant: MSF plants, having a maximum operating temperature of 120°C, typically require 12 kWh of thermal and 3.5 kWh of electrical energy for the production of 1 m^3 of water. MED plants, which operate at temperatures of 70°C or less, require 6 kWh of thermal and 1.5 kWh of electrical energy per m^3 of water. The RO process consumes between 4 and 7 kWh per m^3 depending on plant size and energy recovery systems used [3].

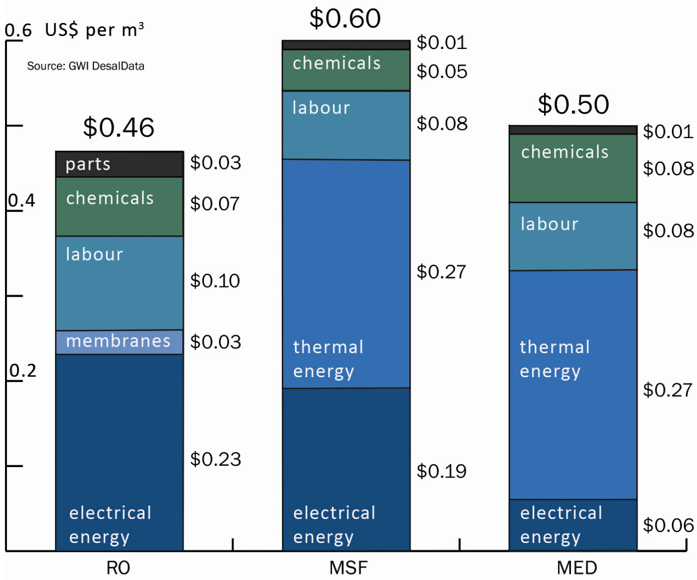

Figure 1: Relative operation costs in US$ of the main desalination processes [2].

For illustration, a medium-sized RO plant with a capacity of about 25,000 m^3 per day and an energy demand of 5 kWh per m^3 would consume about 125,000 kWh per day. The plant could supply more than 41,000 four-person households with water, while the energy that is used for the desalination process could supply more than 9,000 households with electricity (assuming a water consumption of 150 liters per person and day and an average electricity demand of 5000 kWh/year for a 4 person household). Energy demand is thus a major issue in the planning and permitting process of new desalination plants and is closely interlinked with power supply and power management strategies.

Fossil fuels are typically used as primary energy source for producing the electrical or thermal energy. Renewable energy driven desalination technologies using wind or solar thermal energy exist but are mostly limited to small units or demonstration projects. For large plants, compensation seems to be a more suitable approach. For example, a 144,000 m^3 per day RO plant in Perth, Australia, was associated with a 80 MW wind farm to compensate for the electricity demand of the plant, and the 140,000 m^3 per day Thames Water plant near London was proposed to be run on bio-diesel.

Community and equity considerations

Desalination projects – like other water infrastructure projects – often consume considerable community resources which may not be reflected in the investment and operating costs. These may be in the form of financial subsidies, access to coastal land, or the provision of supporting or connecting infrastructure. The desalinated water should therefore be valued as a community asset. In addition to considering the measures outlined in this document to assess and mitigate potential impacts of the production process on the environment, on socio-economic development and on public health, communities should value the desalinated water by non-wasteful use and by looking for opportunities of multiple use. This might be attained by adopting water allocation policies and pricing methods that foster an economic use of the water resources.

It appears reasonable to request that any policy or pricing model used for the allocation of desalinated water will not be contrary to the public interest, if the production process involved a contribution of community resources. Moreover, the allocation of desalinated water should satisfy two criteria. First, the desalinated water should be allocated in a cost-effective way so that the overall benefits for the served population are maximized. However, maximization alone may not be satisfactory if it measures the sum of costs and benefits only, but ignores the pattern of their distribution across the population affected by a desalination project.

Equity considerations should thus be incorporated as a second important criterion in the allocation and pricing model for desalinated water. It has the goal of an equitable and just distribution of the benefits and costs of desalinated water among distinct stakeholder groups or individuals. Equity considerations in water allocation can be a complex undertaking and no general rules exist, but allocations ignoring equity considerations are unlikely to produce satisfactory results in the long run.

Impacts on poverty and development

Poverty is inextricably linked with water and food security, human health, environmental sustainability and socio-economic development in many parts of the world. The links are well understood and widely documented. To break the vicious circle of poverty also means to improve water security for the poor. This implies improving water management practices and providing access to water of safe quality and in adequate quantity, so that basic personal requirements can be met and a livelihood provided.

While desalination is vital for economic development in many water scarce areas of the world, one has to be skeptical whether it can have much effect on poverty reduction in economically less developed countries. The costs of building a large desalination plant are unattainable for many of the poorest countries. Furthermore, operating such a facility requires on-going expenses and technical efforts. Even if the investment and operating costs for a desalination plant can be procured, this does not automatically imply that the poorest in a society will get an equitable share of the benefits. A central problem of water poverty in many countries is after all the inequitable allocation between consumers (in addition to pollution and mismanagement) rather than the absence of water resources. Desalination cannot pose a solution to the problem of water scarcity without addressing these root causes of water poverty, which often strikes the poorest in a society.

As the production of desalinated water requires considerable energy and capital, it is often used as a supplemental resource only. Except for a few countries in the Middle East and some islands, which depend almost exclusively on desalinated water, conventional resources still account for most of the water supplies worldwide. Desalination projects are often proposed although there is still potential for improving the conservation and efficiency of use of conventional resources. This also holds true for less developed countries, where it may be more cost-effective to tap the potential of alternative options before desalination projects are developed. These include for example purification of low-quality local water and measures to reduce water pollution, attaining a more equitable allocation of resources, and encouraging wastewater recycling and reuse. Desalination might after all have a share in securing water for development and poverty reduction when the above options are being considered. One promising approach for less developed countries is the use of small autonomous desalination systems powered by renewable energy for decentralized water supplies, which could make a contribution to poverty reduction in rural areas. However, small systems are not in the focus of this report, which addresses large-scale desalination projects.

Costs and benefits of desalination in comparison with alternative water supplies

Desalination can provide a seemingly unlimited supply of water. The oceans contain 97% of the word's water. Many coastal states and islands have no other option than desalination, but the technology also helps countries with limited resources to meet the growing demand of their populations and economies. Desalination can be a vital need or supplemental commodity. It provides safe, high quality drinking water in any desired quantity, and safeguards a constant supply of water even in the face of draught and climate change. Moreover, it can reduce pressures on conventional resources, and may thus avert severe environmental damage from terrestrial and freshwater ecosystems.

Despite offering many socio-economic, environmental and public health benefits, desalination is not going to be the ultimate solution to the world's water problems. It is more likely going to remain one piece in the water management puzzle [4]. The economic costs are still relatively high compared to water supplies from local ground- or surface water resources. The energy demand is also considerable so that desalination development may increase energy-dependence. Furthermore, concerns are raised over potential negative environmental and socio-economic impacts. These are mainly attributed to the discharges to the sea, which may impair coastal water quality and affect marine life, and air pollutant emissions associated with energy use, which may impair local air quality and foil attempts to reduce greenhouse gas emissions. Desalination may also lead to conflicts with other human or commercial activities in the coastal zone.

The list of potential impacts can be extended, but the given examples already indicate the need for an evaluation of the costs and benefits of desalination projects in comparison with alternative water supply options. No general recommendations can be provided in this regard. Decisions about desalination developments have to revolve around complex evaluations of local circumstances such as demand, financing, environmental and socio-economic impacts [4]. Available alternatives and their costs and benefits also need to be included in this evaluation. For example, the continued use of coastal aquifers may result in a significant increase in groundwater salinity, or the transfers of water from a river or lake may result in significant and irreversible damage to that ecosystem. In such cases, the impacts of constructing and operating a desalination plant may be more acceptable than the consequences resulting from the continuation or expansion of the exiting or alternative water supply practices.

There seems to be little reason to object a desalination project when a clear need has been established and when the facility is carefully regulated and monitored. It is recommended to conduct a feasibility study and an environmental impact assessment study before a new desalination project is implemented. In order to achieve decisions in an open and transparent manner, clear rules and standards for permission and regulation of desalination projects should be developed. To that end, this report offers guidance that shall help regulators, project designers and decision makers to anticipate and address all relevant concerns that may arise when undertaking a desalination project, for obtaining maximum beneficial use of the desalinated water.

Part A

Concept, methodology and practice of environmental impact assessments applicable to desalination projects

A.1 Definition and concept of EIA

An EIA is a systematic process used to identify, evaluate and mitigate the environmental effects of a proposed project prior to major decisions and commitments being made. It usually adopts a broad definition of 'environment' considering socio-economic as well as environmental health effects as an integral part of the process.

The main objectives of EIAs are to provide information on the environmental consequences for decision-making, and to promote environmentally sound and sustainable development through the identification of appropriate alternatives and mitigation measures [5]. The three central elements of an EIA are:

- The establishment of environmental, socio-economic, and public health baseline data for the project site before construction. A prognosis of the 'zero alternative' is given, which is the expected development of the project site without project realization.
- The prediction and evaluation of potential – direct and indirect – environmental, socio-economic, and public health impacts of the proposed project.
- The identification of appropriate alternatives and mitigation measures to avoid, minimize, remediate or compensate for any environmental, socio-economic, and public health impacts resulting directly or indirectly from the project.

In essence, an EIA of desalination projects is a systematic process that examines the environmental, socio-economic and health effects during all life-cycle stages of the project, i.e. during construction, commissioning, operation, maintenance and decommissioning of the plant.

A.2 Systematic EIA process for desalination projects

The EIA process is generally marked by three major phases (Figure 2 and 3):

- screening and scoping of the project;
- environmental impact assessment;
- decision-making and EIA review.

In the following, a 10 step process is proposed for conducting EIAs for desalination projects. It should be noted that in practice, deviations from the outlined process may occur. Single steps may not always be clearly limitable, some steps may overlap or may be interchanged. The EIA procedure should thus be understood as a continuous and flexible process.

Figure 2: Pre- or early EIA phases (scoping and screening) and main EIA phase.

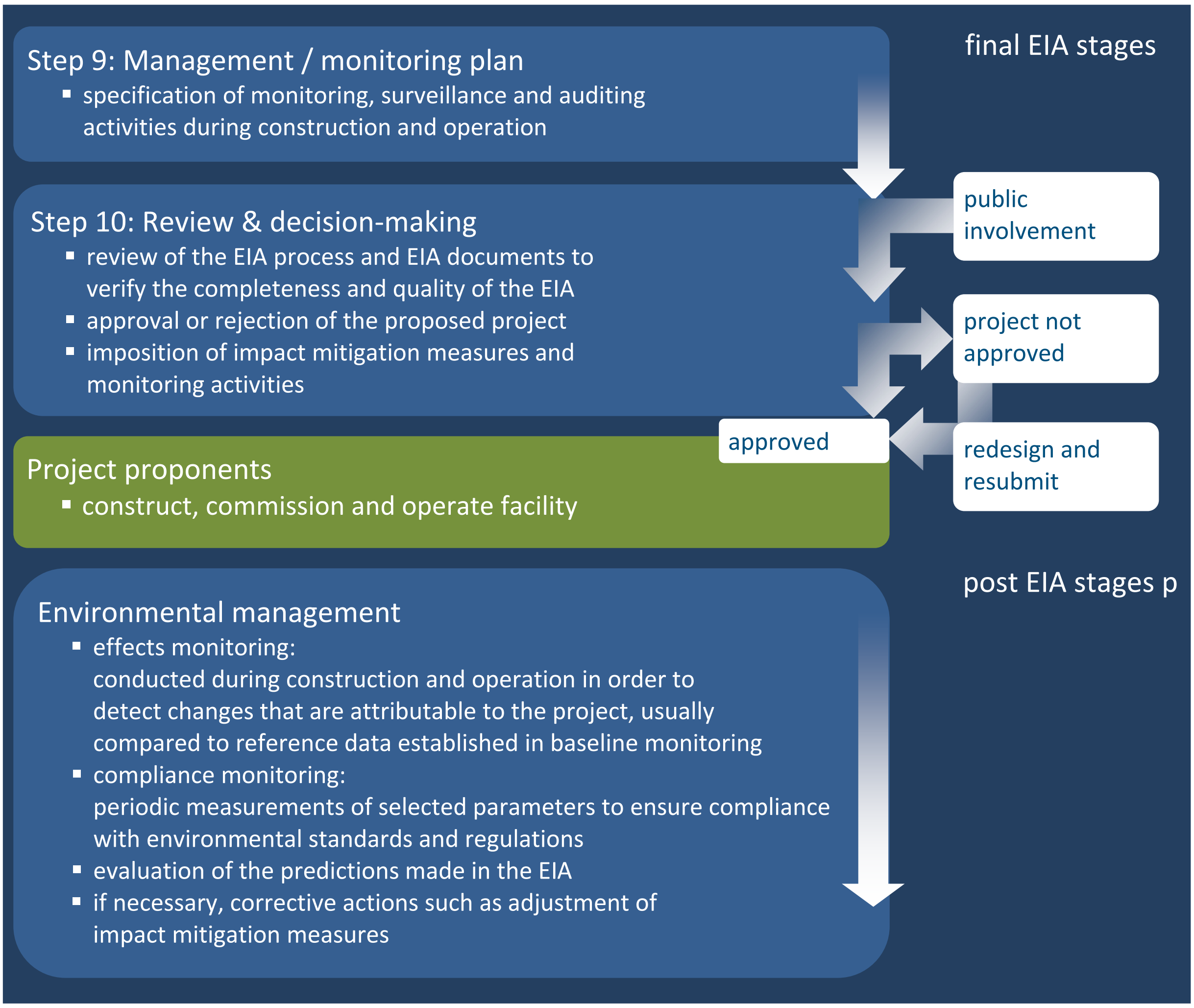

Figure 3: EIA decision phase and follow-up activities.

A.2.1 Step 1 – Screening of the project

Screening is the process by which a decision is taken on whether or not an EIA is required for a particular project. It shall ensure that a full EIA is only performed for projects with potentially significant adverse impacts or where impacts are not sufficiently known.

Screening thus involves making a preliminary determination of the expected impact of a proposed project on the environment and of its relative significance. A certain level of basic information about the proposal and its location is required for this purpose.

The screening procedures can be broadly classified into two approaches: a standardized approach, in which projects are subject to or exempt from EIA defined by legislation and regulations; and a customized approach, in which projects are screened on a case-by-case base, using indicative guidance [5].

Standardized approach

Many states have implemented EIA laws and procedures, which facilitate the screening process by defining for which project categories an EIA is required, such as:

- 'mandatory' or 'positive' lists which include projects always requiring EIA (e.g. major projects, possibly large co-generation plants for electricity and water);
- project lists which define thresholds and criteria above which EIA is required (e.g. a desalination plant larger than 20,000 m^3/d);
- 'exclusion' or 'negative' lists which specify thresholds and criteria below which EIA is never required or below which a simplified EIA procedure applies (e.g. a desalination unit with less than 500 m^3/d capacity).

A class screening may be undertaken for small-scale projects that are routine and replicable, if there is a reasonably sound knowledge of the environmental effects and mitigation measures are well established. For example, class screening could be applicable to small stand-alone reverse osmosis (RO) systems such as for hotels.

The regulations for desalination plants may vary considerably in different states. If a categorization of projects in general or of desalination plants in particular has not been undertaken, or if a proposed desalination project is on the borderline of a threshold, the project needs to be screened on an a case-by-case basis.

Customized approach

Individual screening does not necessarily require additional studies, but can be conducted on the basis of indicative guidance, for example using indicators and checklists. These are intended to be used quickly by people with the qualifications and experience typically found in competent authorities or environmental consultant companies, based on the information which is readily available about the project and its environment.

The World Bank [6] categorization of projects may allow a first, broad screening of desalination plants based on a few common indicators, such as the type, size and location of the project, environmental sensitivity, and likely health and social effects on the local population:

Category A: full EIA required

Projects likely to have significant adverse environmental impacts that are serious (i.e. irreversible, affect vulnerable ethnic minorities, involve involuntary resettlement, or affect cultural heritage sites), diverse, or unprecedented, or that affect an area broader than the sites of facilities subject to physical works (e.g. dams and reservoirs, large-scale industrial plants, ports, thermal- and hydropower developments, etc.).

Category B: limited EIA

Projects likely to have adverse environmental impacts that are less significant than those of category A, meaning that few if any of the impacts are likely to be irreversible, that they are site-specific, and that mitigation measures can be designed more readily than for category A projects (e.g. small scale aquaculture, renewable energy, rural electrification, water supply or sanitation, etc.). The main objective of a limited EIA is to identify suitable mitigation measures.

Category C: no EIA

Projects that are likely to have minimal or no adverse environmental impacts.

A more elaborate approach is the use of comprehensive indicator lists or checklists for screening. For example, two checklists have been prepared by the EU within the EIA directive framework[1] to support the process of deciding whether or not a project is likely to have significant effects on the environment [7].

The first screening checklist provides a list of questions about the project and its environment, which shall help to answer the question if the project is *likely* to have a *significant effect* on the environment. The second checklist provides criteria that shall facilitate the *evaluation of significance*. The checklists have been included in Appendix D.1 for easy reference and slightly modified to fit the specific conditions and requirements of desalination facilities.

There is no specific rule that can be used to decide whether the results of a screening checklist should lead to a positive or negative screening decision (i.e. that EIA is or is not required). As a general principle, the greater the number of positive answers and the greater the significance of the effects identified, the more likely it is that an EIA is required. Uncertainty about the occurrence or significance of effects should also point towards a positive screening decision as the EIA process will help to resolve the uncertainty. If the need for EIA has been affirmed, scoping follows as the next consecutive step.

Preliminary EIA study

In some EIA systems, screening is considered as a flexible process which can be extended into a preliminary form of an EIA study (often termed preliminary or initial environmental assessment). This is typically carried out in cases where the environmental impacts of a proposal are largely unknown, e.g. new technologies or undeveloped areas [5]. If a preliminary assessment is undertaken to assist in the screening decision, the information from the preliminary assessment can also be used for scoping and later in the actual EIA process. The single steps in an EIA may thus not always be clearly limitable and some overlap may occur.

Documentation of screening results

After a formal decision has been made by the competent authority, an official screening document is typically prepared which records the screening decision and provides an explanatory statement for this decision. It may be extended into a short screening report which also gives the results of the preliminary assessment, and can be used to prepare the scoping document for public dissemination in the following stage. The screening decision should be briefly outlined in the EIA report, preferably in the introductory section (cf. section B.3, p. 22).

A.2.2 Step 2 – Scoping of the project

Scoping is the process of determining the content and extent of the EIA studies. The Terms of Reference (ToR), which are elaborated in the process, provide clear instructions to the project proponent on the information that needs to be submitted to the competent authority for EIA, and the studies to be undertaken to compile that information.

Scoping is a crucial step in EIA because it identifies the issues of importance and eliminates those of little concern. In this way, it ensures that EIAs are focused on the significant effects and do not involve unnecessary investigations that waste time and resources. The process is completed with the ToR, however, experience shows that the ToR should be flexible and may need alteration as further information becomes available, and new issues emerge or others are reduced in importance [5].

[1] EIA Directive 85/337/EEC from 1985, amended by Directive 97/11/EC in 1997.

Consideration of alternatives

The consideration of alternatives to a proposal, such as alternative technologies or sites, is a requirement of many EIA systems. It should be understood as a dynamic process, which starts early in project planning and continues throughout the EIA process and decision-making. The process should be open to new, emerging alternatives while previously considered options might be abandoned due to new information becoming available. The aim is to identify the best practicable option under environmental, socio-economic and human health criteria that is also technically and economically feasible.

It should be noted that alternatives to a proposal can be generated or refined most effectively in the early stages of project development. The consideration of alternatives is therefore a fundamental part of the early EIA stages, especially of scoping. At this stage, a number of alternatives is typically identified for evaluation in the EIA. New alternatives may also be identified later on, especially at the stage when impact mitigation measures are elaborated. It is important that the consideration of alternatives during an EIA is not reduced to a superficial and meaningless exercise. This may easily happen if project planning advances faster than the EIA and decisions for a certain project configuration or location have consolidated before the EIA process has been completed.

Selection of the project site

Environmental, socio-economic and public health impacts resulting from the construction and operation of a desalination plant are largely dictated by the location of the facility and its associated infrastructure. Therefore, proper site selection for a desalination plant during the planning process is essential for minimizing these impacts.

Site selection typically takes place in the early stages of a desalination project and leads to the identification of a preferred site and possibly one or two alternatives. An EIA, usually accompanied by a site-specific monitoring programme, will then be carried out for the identified location(s). In many cases, the competent authority will give permission but attach conditions to project approval, such as to implement mitigation measures or to make changes in project configuration, in order to minimize impacts on the project site. In some cases, however, the EIA may also come to the final conclusion that the chosen site(s) are not suitable, even if impact mitigation measures are implemented.

To reduce the likelihood of this outcome, site-selection should be an important consideration in project planning. Site selection can take place during a 'preliminary' EIA study as part of the screening process (cf. Step 1, p. 9) or during scoping when the EIA requirements are determined. To facilitate site selection for desalination plants, public authorities may designate suitable areas in regional development plans or may provide criteria that can be used by project developers for site-selection. Selection of sites must be carried out on a case-by-case basis, since there are a large number of site-specific considerations that vary according to the specific operational aspects of each plant.

Generally, it is important to consider the following site features:

Geologic conditions:

Sites should provide stable geologic conditions and little risk that construction and operation of the plant will affect soil and sediment stability.

Biologic resources:

Ecosystems or habitats should be avoided where possible if they are

- unique within a region (e.g. riffs on a mainly sandy shoreline);
- worth protecting on a global scale (e.g. coral reefs, mangroves);
- important in terms of productivity or biodiversity;
- inhabited by protected, endangered or rare species (even if temporarily);
- important feeding grounds or reproductive areas for a larger number of species or certain key species within a region;
- important for human food production.

Oceanographic conditions:
The site should provide sufficient capacity to dilute and disperse the salt concentrate and to dilute, disperse and degrade any residual chemicals. The load and transport capacity of a site will primarily depend on water circulation and exchange rate as a function of currents, tides, surf, water depth and bottom/shoreline morphology. In general, exposed rocky or sandy shorelines with strong currents and surf may be preferred over shallow, sheltered sites with limited water exchange. The oceanographic conditions will determine the exposure time of the ecosystem and marine life to increased salinity and any pollutants discharged along with the waste water (cf. sections C.4.4 and C.4.5).

Raw water quality and proximity:
The intake location should ideally provide a good and reliable water quality, taking seasonal changes into account, with minimum danger of pollution or contamination, in order to avoid performance problems of the plant or impacts on product water quality. The plant site should ideally be close to the source water intake to minimize land use for pipelines and to avoid passage of pipes through agricultural land, settlements, etc. However, this cannot be generalized and in some cases it may be more appropriate to locate the plant further inland, for example when construction on the shore is not possible for certain reasons (e.g. use of beaches, nature reserves, geological instability, etc.).

Proximity to water distribution infrastructure and consumers:
The site should ideally be close to existing distribution networks and consumers to avoid construction and land-use of pipelines and pumping efforts for water distribution. However, impairment of nearby communities (i.e. consumers) by visual effects, noise, air pollution or other environmental health concerns should be avoided.

Vicinity of supporting infrastructure:
The site should allow easy connection with other infrastructure, such as power grid, road and communication network, or may even allow the co-use of existing infrastructure, such as seawater intakes or outfalls.

Conflicts with other uses and activities:
The site should ideally provide no conflict or as little as possible with other existing or planned uses and activities, especially recreational and commercial uses, shipping, or nature conservation efforts.

Public involvement

Public participation is a mandatory requirement in the planning and implementation of development projects, and an inherent component of the EIA process, especially of scoping. As a general rule, the public should be involved as early as possible and continuously throughout the EIA process. The overall goal is the involvement of the public in decision-making. This is based on fundamental premises of democratic societies, such as transparency of decision-making and equity among the affected populations in terms of ethnic background and socio-economic status.

Public involvement seeks to:
- inform the public about the project, the value of the desalinated water and the extent of the community investment, about project alternatives including water conservation and recycling;
- gather a wide range of perceptions of the proposed desalination project and take advantage of the knowledge of indigenous and local communities about their living environment, thereby ensuring that important issues are not overlooked when the Terms of Reference of the EIA are prepared;
- address and dispel if necessary subjective doubts and concerns about the project;
- develop trust and working relationships among the stakeholders, including the affected communities, particularly vulnerable groups, developers, planners, local and national governments, decision-makers, or non-government organizations.

Important steps in the development of a public involvement programme include:

- identification of the stages in project development and decision-making during which public involvement is required;
- identification and categorization of the affected public into stakeholder groups, e.g. in terms of demographic or geographic characteristics (indigenous groups, residents, etc.), employment or work categories (fishermen etc.), social or interest groups;
- anticipation of key public participation issues and questions relating to the project;
- determination of the necessary level of public participation, which should be done at a level compatible with its relevance to the proposed project and available resources
- development of a realistic schedule, phasing and budget for public participation;
- identification of public participation and information mechanisms (e.g. press releases, display booths, distribution of brochures or newsletters, etc.) and information gathering mechanisms (e.g. public hearings, workshops, opinion surveys, telephone hotlines);
- identification of methods for information assimilation, analysis, record keeping and documentation;
- report evaluations and conclusions to policy and decision-makers, stakeholders, and the public.

Examples of public participation issues are:

- site specific sensitivities: e.g. sites with certain religious and cultural significance;
- historical context: e.g. incidences of negative environment or public health impacts of current or early projects;
- political considerations: e.g. concerns with the influence of certain industries, or interest groups, and the equity aspects of benefits and drawbacks of the proposed project;
- public education: e.g. information of the public about benefits and possible drawbacks of the project;
- conflict resolution: e.g. in certain cases public participation may involve the resolution of conflicts and the reaching of a consensus among interest groups concerning the proposed project.

Human health

EIAs, as widely required by national legislations and international agencies, offer integrated analyses of potential impacts of development projects on all components of the environment, including human health. There has been recent emphasis on the necessity to delineate the *health effects of environmental impacts* (as stated in the 2003 European Directives[2] and the ESPOO Convention on EIA[3]) on directly or indirectly affected populations. When conducting scoping for a desalination project, relevant human health effects should therefore be identified, considering the following recommendations.

The human health component should be broadly addressed in EIAs, relying on *readily available* information. This includes community health determinants, such as incidences of disease, public information and concerns, and traditional knowledge of the local inhabitants and indigenous population. Baseline information on health and quality of life needs to be established in order to assess the significance of potential effects of environmental impacts. Potential environmental health impacts should be prioritized, with corresponding indicators and risk factors. Both positive and negative health effects should be delineated, for the public at large as well as for vulnerable groups.

Where there are specific concerns with exposure to certain toxic emissions or infectious agents, the scientific literature should be searched for relevant published studies and epidemiological investigations. This is usually sufficient to address concerns with the potential health impact. Most EIA assessments rely on *existing information*. Except for large projects, it is often too expensive, and too time consuming to

[2] EIA Directive 85/337/EEC from 1985, amended by Directive 97/11/EC in 1997

[3] Convention on Environmental Impact Assessment in a Transboundary Context (Espoo, 1991)

generate new health information within the timeframe allotted to conduct the EIA. The methodology for the Human Health component of EIA is further detailed in section B.7.3. It is generally based on:

- screening and scoping steps to establish an existing setting;
- assessment of potential impacts;
- reporting, mitigation and avoidance measures, and
- plans for monitoring activities.

Gender effects

Gender mainstreaming is a globally accepted strategy for promoting gender equality [8][4]. The UN Economic and Social Council (ECOSOC)[5] defined gender mainstreaming as the "process of assessing the implications for *women and men* of any planned action, including legislation, policies or programmes, in all areas and at all levels", so that "women and men benefit equally and inequality is not perpetuated."

Gender Impact Assessment (GIA) has been increasingly recognized as an adequate tool for implementing gender mainstreaming in recent years, especially in the wake of the Fourth World Conference on Women in Beijing in 1995. It is usually applied to policies and programmes, and means to compare and assess, according to gender relevant criteria, the current situation and trend with the expected development resulting from the introduction of the proposed policy [9].

In the same manner as policies and programmes may have a differential impact on women and men, many development projects will not be gender neutral. Gender-specific effects may not be easily recognized at first glance, but an effort should be made to identify any significant differential impacts that may perpetuate gender inequality.

Water projects and thus desalination projects have a high potential for gender-specific effects. "Women play a central part in the provision, management and safeguarding of water", which is one of four recognized principles of the Dublin Statement on Water and Sustainable Development[6]. The consideration and integration of gender-specific effects in EIAs for desalination plants, from scoping to decision-making, is thus highly recommended to evaluate the advantages and disadvantages of desalination activity on both sexes. Where appropriate, a distinction in the EIA process should be made between impacts on men and women. The different effects may be evaluated for example in the chapter on socio-economic impacts (cf. B.7). It is recommended to outline the scope and approach of how gender effects are addressed in the EIA in the beginning of the report (cf. B.4.4).

Scoping procedure

Scoping procedures may vary considerably in different states. For example, scoping may either be carried out under a legal requirement or as good practice in EIA, or it may either be undertaken by the competent authority or by the project proponent [10].

It is recommended that the competent authority takes responsibility at least for monitoring of the process, for preparing the minutes and official transcripts of the scoping meetings, for keeping the records of the scoping outcome, and for preparing the ToR. The scoping procedure may follow these four general steps:

- Based on the information collected during screening, a scoping document containing a preliminary environmental analysis will be prepared. It will specify details and proposed location(s) of the project, review alternatives, briefly and concisely describe the environmental characteristics of the considered site(s) and raise potentially significant project-related issues. The scoping document serves as a background document for hearings and discussions during scoping.

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[4] UN Office of the Special Advisor on Gender Issues and Advancement of Women (OSAGI 2001)

[5] ECOSOC Agreed Conclusions, 1997/2

[6] International Conference on Water and the Environment, Dublin 1992, organized by the UN World Meteorological Organization (WMO)

- The date and venue for the scoping meeting(s) will be set and a provisional agenda prepared. Invitations for the meeting(s) and the scoping document will be sent to collaborating agencies, stakeholder groups, NGOs, experts and advisers. The scoping meeting will also be announced in public and the scoping document put on display for public inspection. A handout may be circulated, notices posted in communities and media advertisements arranged to enhance public participation. If the number of potentially interested people and organizations is large, questionnaires requesting written comments should be considered.
- During scoping consultations, a complete list of all issued concerns should be compiled. These items may then be evaluated in terms of their relative importance and significance to prepare a shorter list of key issues, which can be classified into different impact categories to be studied in the EIA.
- The Terms of Reference for EIA will be prepared, including information requirements, study guidelines, methodology and protocols for revising the work.

Scoping tools and instruments

When a competent authority or a developer undertakes scoping, three key questions should be answered [10]:

- What effects could this project have on the environment?
- Which of these effects are likely to be significant and therefore need particular attention in the environmental studies?
- Which alternatives and mitigating measures ought to be considered?

Basic instruments such as checklists and matrices are often used to provide a systematic approach to the analysis of potential interactions between project and environment.

For example, checklists for scoping are provided by the EU as supporting information to the European EIA directive framework[7]. The scoping checklists allow users to sift through a set of project characteristics which could give rise to significant effects, and a set of environmental characteristics which could be susceptible to significant adverse effects.

In order to evaluate significance, the same checklist as provided for screening (cf. Appendix D.1) can be used. The scoping checklists have been included in Appendix D.2 for easy reference and have been slightly modified to suit the purpose of this document.

Standardized scoping procedure

An effective way of dealing with an increasing number of desalination projects may be to elaborate a standardized scoping procedure and Terms of Reference. The scoping process will often involve the same representatives of government agencies, NGOs, and consultants.

A guideline, elaborated in a collaborative effort between these groups, may establish a routine and set a standard for the environmental studies to be undertaken and the information to be submitted in EIAs for desalination plants. The guideline could thus serve as a blueprint for scoping, which should still allow for project-specific adjustments.

A.2.3 Step 3 – Identification and description of policy and administrative aspects

EIAs usually take place within the distinctive legislative frameworks established by individual countries and/or international agencies. It is therefore recommendable to gain a deeper insight and understanding of any national policies or international agreements that apply in a country or region and that relate to EIA [5].

For instance, the first two steps of an EIA, screening and scoping, shall determine if a full-

[7] EIA Directive 85/337/EEC from 1985, amended by Directive 97/11/EC in 1997.

fledge EIA will be required for a proposed project, and what the scope and contents of the EIA will be. Existing EIA policies or regulations should therefore be consulted as they will likely contain relevant information for resolving these issues.

Moreover, any other policy relevant to the desalination project needs to be identified. Major thematic areas that should be considered when searching the national or international legal system for relevant laws include:

- conservation of nature;
- biological diversity;
- control and prevention of pollution;
- water resources management;
- land-use and regional planning.

In many jurisdictions, more than one permit will typically be required to realize a desalination project. The main approval process, which authorizes construction and operation of a plant, will not necessarily replace other existing statutory provisions and permits.

For example, work place safety is an important consideration in all industrial facilities. The construction and operation of a desalination plant can present a number of safety hazards to plant workers, so that a specific workplace safety permit will probably be required and/or a plan must be developed to ensure occupational safety and health of the workers.

It is important to clarify early in project planning which additional permits must be obtained and to contact the competent authorities in these regards. The permitting process may be facilitated by nominating a 'lead' agency, which coordinates the process by involving other agencies and by informing the project proponent about permitting requirements.

A chapter should be included in the EIA report, which provides a brief description of all relevant policies, agreements, plans or regulations at regional, national and international level. It should be stated how the project relates to these laws and the competent authority in each area should be named. For further details, please cf. to chapter B.5 on p. 23.

A.2.4 Step 4 – Investigation and description of the proposed desalination project

A technical project description should be prepared and included in the EIA report. It should form the basis of the EIA process by providing background information on the project which is required to investigate and analyze all potential impacts.

The project description should cover the different life-cycle stages of construction, commissioning, operation, maintenance and decommissioning of the desalination plant. It should be succinct and contain all information necessary for impact assessment but omit irrelevant or distracting details. For further guidance on what to include please cf. chapter B.6, p. 27.

A.2.5 Step 5 – Investigation and evaluation of environmental baseline

This step will entail assembling, evaluating and presenting baseline data of the relevant environmental, socio-economic and public health characteristics of the project area before construction, including any other existing levels of degradation or pollution.

A nearby 'reference area' with similar baseline characteristics should be identified and surveyed in addition to the project site. Results from both the potentially affected and non-affected site can then be compared as part of the monitoring process during construction, commissioning and operation of the project. The main purpose of a reference site is to distinguish between changes caused by the desalination project and those caused by natural variability or other anthropogenic activities that are not attributed to the desalination project.

The scope of the baseline studies to be undertaken in an EIA for a desalination project should have been determined during the step of scoping (Step 2) and should be briefly outlined in the EIA report (cf. B.4, p. 22). They will probably have the following information requirements (for further details, please refer to chapters B.7 to B.9).

- ***Socio-economic and -cultural environment:***
Aspects such as demographic changes, land-use, planned development activities, status of existing water resource management programmes (conservation and reuse), community structure, employment, distribution of income, goods and services, recreation, cultural properties, tribal and indigenous people, customs, attitudes, perception, aspiration etc.

- ***Public health environment:***
Health indices of the populations at risk of being affected by the project, e.g. rates of morbidity, mortality, injuries, accidents, and life expectancy, as well as relevant socio-economic indicators of the quality of life. It should be noted here that WHO Constitution defines health as the "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity".

- ***Abiotic environment:***
Aspects such as geology, topography, climate, meteorology, ambient air quality, surface and ground water quality and hydrology, coastal and marine environmental quality, existing sources of emissions to air, soils and water, capacity of environmental systems to take up, degrade, dilute and disperse emissions or noise levels, etc.

- ***Biotic environment:***
Aspects such as flora and fauna, including rare and endangered species, sensitive habitats, species of commercial value, species with potential to become nuisances, alien species, etc.

A.2.6 Step 6 – Investigation and evaluation of potential impacts of the project

In this step of the EIA, a prognosis, description and evaluation of the potential environmental, socio-economic and health impacts of the proposed project is elaborated. Furthermore, the magnitude, spatial and temporal range of all identified impacts and their relative significance should be evaluated at this stage. Where possible, an attempt should be made to further distinguish between direct and indirect impacts, immediate and long-term impacts, reversible and irreversible impacts, avoidable and unavoidable impacts, positive and negative impacts. It is recommended that identified positive and negative effects are also balanced in terms of their societal and environmental costs and benefits.

If possible, potential cumulative, transboundary and growth-inducing effects should be identified and investigated. This can be done in the individual chapters of the EIA report dealing with socio-economic, human health and environmental implications of the project (cf. B.7 – B.9), while relevant aspects should also be pointed out in the concluding section (B.10).

It is recommended to deliberate carefully about the accuracy of all predictions made in the EIA. These can only be as accurate and valid as the data and information available. It is therefore necessary to identify any information gaps and deficiencies in the EIA, and to assess any uncertainties associated with the prognosis of impacts. A precautionary approach should be pursued where uncertainty about impacts exists.

Methods for predicting impacts

All predictions in an EIA are based on conceptual models of the environmental systems. Several approaches and instruments can be used for predicting impacts. Each covers the range of impacts only partially and should therefore be used in conjunction with others.

- ***Field and laboratory experimental methods:***
This might include simple tests to predict impacts of a certain agent or activity on an indicator (e.g. salinity tolerance or toxicity studies using a sensitive species from the region).

- ***Physical or image models:***
This involves the design and construction of small scale models to study effects with a high degree of certainty in miniature (e.g. a miniature model of a discharge diffuser system tested in a laboratory simulation).

Analogue models:
Predictions are based on analogies, i.e. by comparing the potential impacts of the proposed desalination project to a similar existing project.

Mathematical models:
Models vary in complexity from simple input-output relationships to highly sophisticated dynamic models with a wide range of interrelations, variables and coefficient constants that have to be identified and determined.

Mass balance models:
These models are based on the difference in the sum of the inputs as compared to the sums of outputs (e.g. life cycle analyses).

Matrices:
A two dimensional matrix is often used which cross-references the project activities on one axis with the environmental, socio-economic and human health setting in the project site on the other axis. This method allows for a systematic identification and evaluation of cause-effect-relationships.

Criteria for evaluating significance

General criteria can be used to assess the significance of environmental and socio-economic impacts of a desalination project. These criteria are not mutually exclusive but are very much interrelated. The following general criteria should be taken into account when examining potentially significant adverse effects:

- nature of impacts (direct/indirect, positive/ negative, cumulative, transboundary);
- time-span (short/medium/long-term, permanent/temporary, frequent/seldom);
- extent (geographical area, size of affected population/habitat/species);
- magnitude (severe, reversible/ irreversible);
- probability (high/medium/low probability)
- possibility to mitigate, avoid or offset significant adverse impacts.

Further details for evaluating the significance of impacts are given in Appendix D.1.3.

A.2.7 Step 7 – Mitigation of negative effects

The consideration of major alternatives such as alternative location, technology etc. should start early in the planning of a new project (cf. Step 2) as the flexibility and disposition to make major modifications is typically still high at this time. As project planning progresses and consolidates, major alternatives will only be seriously considered if the EIA has revealed significant impacts (as part of Step 6) that cannot be mitigated otherwise. The investigation of impact mitigation measures should thus be understood as a process, which starts with the consideration of major alternatives in early project planning and continues after potential impacts have been analyzed. At this stage, specific recommendations need to be elaborated that mitigate the predicted effects of the project.

The step of impact mitigation should identify the most feasible and cost-effective measures to avoid, minimize or remedy significant negative impacts to levels acceptable to the regulatory agencies and the affected community. The definition of 'acceptable' will vary according to different national, regional or local environmental standards, which depend on a society's or community's social, ideological and cultural values, on economic potentials and on politics.

For impacts which cannot be mitigated by technically and economically feasible methods, compensation methods should be identified. These may include monetary compensation or remediation activities. The elements of mitigation are organized into a hierarchy of actions [5]:

Prevention:
Avoid impacts by preventive measures, consider feasible alternatives and identify the best practicable environmental option.

Minimization:
Identify customized measures to minimize each of the main impacts predicted and ensure they are appropriate, environmentally sound, technologically feasible and cost-effective.

⏩ *Remediation:*
Remedy or compensate for adverse residual impacts, which are unavoidable and cannot be reduced further, as a last resort.

Mitigation can include *structural measures* (e.g. design or location changes, technical modifications, waste treatment) and *non-structural measures* (e.g. economic incentives, policy instruments, provision of community services, capacity building). Remediation and compensation may involve *rehabilitation* of the affected site (e.g. habitat enhancement, restocking of fish), *restoration* of the affected site to its previous state after project demolition, and *replacement* of resource values at another location.

A.2.8 Step 8 – Summary and conclusions

This chapter gives a concise account of the main findings and recommendations of steps 5 to 7 (corresponding to chapters B.7 to B.10 in Part B). It should focus on the key information that is needed for decision-making.

An overview of the main impacts (possibly in the form of a table) should be provided for this purpose, distinguishing between significant impacts which can be prevented or minimized, and those which cannot. Both direct and indirect impacts, positive and negative impacts, as well as potential cumulative effects, should be considered. Mitigation or alternative options should be offered for significant impacts where possible. In essence, the original project proposal should be systematically compared with alternative project configurations in terms of adverse and beneficial impacts and effectiveness of mitigation measures. As far as possible, trade-offs and uncertainties should be mentioned.

Finally, the '*best practicable environmental option'* should be identified, which is the preferred project configuration under environmental, social, cultural and public health criteria. It should be ensured that this option is both economically and technologically feasible. The decision should be transparent and supported by arguments.

A.2.9 Step 9 – Establishment of an environmental management plan

An environmental management plan should be elaborated to ensure the ongoing assessment and review of the effects of the proposed desalination project during construction, commissioning, operation, maintenance, and decommissioning. It thus builds continuity into the EIA process and helps to optimize environmental benefits at each stage of project development.

Increasing attention should furthermore be given to public involvement in the EIA implementation, for example by establishing stakeholder monitoring committees. In general, the key objectives of EIA implementation and follow up are to [5]:

- identify the actual environmental, socio-economic and public health impacts of the project and check if the observed impacts are within the levels predicted in the EIA;
- determine that mitigation measures or other conditions attached to project approval (e.g. by legislation) are properly implemented and work effectively;
- adapt the measures and conditions attached to project approval in the light of new information or take action to manage unanticipated impacts if necessary;
- ensure that the expected benefits of the project are being achieved and maximized;
- gain information for improving similar projects and EIA practice in the future.

To achieve these objectives, the management plan should specify any arrangements for planned monitoring, surveillance and/or auditing activities, including methodologies, schedules, protocols for impact management in the event of unforeseen events etc. The main components and tools of EIA implementation and follow up as part of an environmental management plan include [5]:

- ***Monitoring activities:***

Measure the environmental changes that can be attributed to project construction and operation, check the effectiveness of mitigation measures, and ensure that applicable regulatory standards and requirements are being met, e.g. for waste discharges and pollutant emissions.

- ***Surveillance activities:***

Oversee adherence to and implementation of the terms and conditions of project approval.

- ***Auditing activities:***

Evaluate the implementation of terms and conditions, the accuracy of EIA predictions, the effectiveness of mitigation measures, and the compliance with regulatory requirements and standards.

Further details on the main elements of environmental management plans for desalination projects are specified in chapter B.11 on p. 47.

A.2.10 Step 10 – Review of the EIA and decision-making process

The purpose of review is to verify the completeness and quality of the information gathered in an EIA. This final step shall ensure that the information provided in the report complies with the Terms of Reference as defined during scoping and is sufficient for decision-making purposes. Review is a formal step in the EIA process and serves as a final check of the EIA report that will then be submitted for project approval.

The review may be undertaken by the responsible authority itself, another governmental institution or an independent body. Participation of collaborating and advisory agencies in the review process is strongly recommended, as is the involvement of the public and major stakeholders in public hearings about the outcomes of the EIA.

The review should follow a systematic approach. This will entail an evaluation and validation of the EIA methodology and procedure, and a check for consistency, plausibility and completeness of the identified impacts, proposed alternatives and suggested mitigation measures. The review process can be based on explicit guidelines and criteria for review. If these are not available, it may draw on general principles, objectives and terms of references or use the following questions [5]:

- Does the EIA report address the Terms of Reference?
- Is the requested information provided for each major component of the EIA report?
- Is the information correct and technically sound?
- Have the views and concerns of affected and interested parties been considered?
- Is the statement of the key findings complete and satisfactory, e.g. for significant impacts, proposed mitigation measures, etc.?
- Is the information clearly presented and understandable?
- Is the information sufficient for the purpose of decision-making and condition setting?

The response to the last question is the most significant aspect for review and will largely determine whether or not the EIA can be submitted to the competent authority as it is or with minor revisions for decision-making.

The competent authority will form its own judgment on the proposed project based on the EIA report, the analysis of stakeholder interests and statements from collaborating agencies, and decide on approval or rejection of the proposed project. The competent authority will typically impose conditions if the project is approved, such as mitigation measures, limits for emissions or environmental standards to be observed.

Part B

Outline and contents list of an environmental impact assessment report for desalination projects

In addendum to the methodological approach proposed in Part A of this document, a modular outline for an EIA report is presented in the following. The EIA report is the primary document for decision-making, which organizes and synthesizes the information and results obtained by the studies and consultations undertaken during the EIA process.

The following contents list (checklist) gives an overview on a range of thematic issues that may be relevant to individual desalination projects. The structure of the list widely reflects the methodological approach of Part A and includes environmental concerns as well as socio-economic and human health implications.

As the list shall serve as a reference source and blueprint for preparing an EIA report, it tries *to be inclusive rather than exclusive* by raising a *wide range of potentially relevant issues* for different desalination projects and environments. By screening the information, it can be decided on a case by case basis which issues may be relevant for a specific desalination project and which are of minor or no importance.

Front matter to an EIA report (sections B.1 – B.2)

The front matter comprises all the material that appears before the actual body content of the EIA report, including

- the title pages,
- the table of contents,
- list of figures and tables,
- preface,
- acknowledgments, etc.

An executive summary of the main findings and results often precedes the full report as part of the front matter.

B.1 Title pages

The front page(s) of an EIA report should briefly define the project, and for transparency reasons also identify the main stakeholders involved in the project and EIA by specifying:

- the name, location, size, nature (e.g. Build Operate Transfer – BOT) of a project;
- the names and contact details of all consultants and institutions who participated in investigations and/or carried out the EIA, also giving their accreditation status;
- the names and contact details of the company or consortium planning the project (e.g. government, public-private partners);
- the financial sponsor of the desalination project and the EIA study (e.g. project proponent, government authorities).

Other useful information that may be included in the front matter of an EIA report:

- copyright or confidentiality statement, other restrictions;
- table of contents, list of figures, tables and appendices;
- preface and acknowledgements to contributors;
- list of abbreviations and glossary.

B.2 Executive summary

The executive summary sums up the essential points and results of the EIA in a concise and non-technical manner. It is a crucial part of the EIA – in fact, it is often the only part of the comprehensive document that decision-makers and the general public will read.

It is strongly advisable to prepare the executive summary such that a layman without any background in desalination or the project can quickly and fully understand the important outcomes of the EIA and pass a considered opinion on the environmental impacts and alternatives presented. For this purpose, executive summaries of EIA statements should:

- be short (up to 5 pages as a rule of thumb), 'stand alone' without requiring references to the rest of the report, clear and simple without oversimplifying or eclipsing facts;
- briefly cover all relevant issues and impart all essential information of the project, in particular provide an overview of the main impacts (possibly in the form of a table), distinguishing between those which can be mitigated and those which cannot;
- inform the reader of the major factors considered in decision-making, include the major conclusions and findings of the EIA study, and identify the areas of remaining controversy and explain unresolved issues.

Considering these recommendations, it may be necessary to prepare more than one executive summary depending on the audience.

Project background information (sections B.3 – B.6)

A coherent EIA report should cover the main activities and results of the pre-EIA stages and all technical and legislative information concerning the project and the EIA process. As a first action, a new project is typically screened in order to determine if a full EIA is required (cf. Step 1, p. 8). In the introduction to the EIA report, the rationale and purpose of the EIA should therefore be stated as identified in the screening decision (▸ *for more details cf. chapter B.3 below*).

If the screening decision is positive, the scope and content of the EIA will be defined during the scoping phase (cf. Step 2, p. 9), which usually ends with the preparation of the Terms of Reference. It is recommended to briefly outline the scope and methodology of the EIA also in the EIA report, including an overview on the studies that are undertaken and the investigation and evaluation methods used. An account of the public participation process and considered alternatives may be included (▸ *for more details cf. chapter B.4, p. 22*).

Moreover, the national EIA laws need to be consulted in the early planning stages of a project in order identify applicable regulations and procedures (cf. Step 3, p. 14). Other policies, permitting and regulatory issues which may apply or relate to the project, such as water quality standards or nature conservation laws should also be investigated and pointed out in the EIA report (▸ *for more details cf. chapter B.5 , p. 23*).

Finally, a technical description of the proposed project (cf. Step 4, p. 15) over its entire life-cycle should be included in the EIA report. The technical details should be reduced to those aspects relevant to the EIA (▸ *for more details cf. chapter B.6, p. 27*).

B.3 Introduction to the EIA

The introduction of an EIA report should convey a general idea of the project and the EIA process by briefly describing:

- the rationale behind the decision for the new desalination project;
- the rationale behind the decision for the EIA study by referring to the screening decision and by summarising the main arguments;
- the general purpose of the EIA, such as to:
  - provide a guide for project site selection, construction, commissioning, operation, maintenance and decommissioning;
  - assess and minimize the environmental, socio-economic and public health implications throughout the life-cycle of the project;
  - identify aspects of uncertainty, need for further research and information gaps;
  - elaborate alternatives and impact mitigation methods.

B.4 Scope and methodology of the EIA

B.4.1 Scope of the EIA

The scope of an EIA study is typically defined by:

- the EIA legislation text, which usually contains general regulations;
- standard guidelines, which may be specific to certain projects or activities;
- the Terms of Reference as established during scoping for a specific project (cf. Step 2, p. 9).

To describe the scope of an EIA study, a reference to the applicable regulations or official documents should be given and their requirements briefly outlined, particularly:

- which environmental compartments, socio-economic aspects and human health implications are being investigated in the EIA;
- which project components are included in the EIA in addition to the desalination unit (e.g. chemical storage facilities, intakes, outfalls, connecting infrastructure like water pipelines, power lines, access roads etc.).

B.4.2 Methodology of the EIA

National standards or guidelines may stipulate the EIA methodology to be followed for a certain type of project or activity. For a specific project, the EIA methodology may also have been a matter of debate during the scoping phase, when the Terms of Reference describing the content and extent of the EIA are established.

In either case, a reference to the applicable regulations or official documents should be given and their requirements briefly outlined in the EIA report. If no conditions have been imposed on the methodology, EIA practitioners may adopt an individual approach, which should be briefly described in the EIA report. The EIA methodology in general includes:

- methodologies used for investigating the environmental baseline and the potential impacts, such as environmental sampling techniques, laboratory analysis, statistical data analysis, controlled field or laboratory experiments, computer models, etc.;
- methodological approaches for evaluating the impacts, such as criteria for the identification of significance of impacts, for balancing the effects against each other, for evaluating the combined risk of all impacts, etc.

B.4.3 Public involvement

Public involvement is an essential process in the planning, decision-making and implementation of development projects, and mandated by national and international organizations. The main goals, particularly for community water supply projects, are to involve the directly or indirectly affected population in decision-making and to establish trust and partnership. This requires that the public is informed and educated about the purpose and implementation plans of the proposed project. Benefits and drawbacks should be explained, including environmental, socio-economic and public health implications. Public involvement furthermore aims to gain all possible views and opinions to ensure that important aspects are not overlooked in decision-making. Invariably, this information from the public is in the form of subjective opinions, influenced by socio-economic, cultural and political factors. The information therefore needs to be scientifically analyzed in order to develop an objective picture of public priorities of the expected benefits and potential impacts of the desalination project.

An effective way of ensuring that participants understand how their views have been addressed in the EIA is to summarize the results of the public involvement process in the EIA report.

B.4.4 Gender effects

The consideration of gender aspects in the EIA process is highly recommended to ensure that gender-specific effects which may perpetuate gender inequality are identified and mitigated. The scope and approach of the EIA in this regard should be briefly outlined in the beginning of the EIA report.

The actual evaluation of gender-specific effects is usually integrated in that part of the EIA which deals with socio-economic impacts (cf. B.7). However, gender-specific effects may also be summarized in a separate chapter if significant gender effects are anticipated. When socio-economic impacts are investigated, it should therefore be kept in mind that desalination activity has the potential to affect men differently than women, especially where traditional role models and lifestyles prevail.

In many societies, water is at the core of women's traditional responsibilities. These may encompass the collection of sufficient water for the whole family, usage of water for household tasks such as food preparation or maintaining sanitation, or caring for family members who fell ill due to the use of contaminated water. The quantity and quality of water that is available in households is therefore a decisive factor for women. Providing access to sufficient and clean water by desalination might dramatically reduce women's workloads, and free up time for other social, educational or economic activities.

B.4.5 Considered alternatives

The consideration of alternatives to a proposal is a requirement of many EIA systems, and should ideally begin in the early EIA stages (cf. Step 2) when the tolerance and disposition to make major modifications to the project is still high. Possible alternatives include alternative location, technology, scale or process, but also the 'no project' alternative, i.e. the use of alternative water supplies, water recycling schemes or water saving techniques.

Possible alternatives to the project or project parts should be briefly listed and described in the EIA to indicate that alternative options have been seriously considered and evaluated. Reasoning should be provided why certain options have been dismissed or selected, leading to the one or two project configuration(s) that are eventually investigated in the EIA.

B.5 Policy and administrative aspects

This chapter in an EIA contains the results of Step 3 (Identification and description of policy aspects, cf. p. 14). It has the following objectives:

- to describe the legal and institutional basis for the EIA;
- to list other regional, national or international policies or agreements relevant to the project, describing them briefly and explaining in which way they relate to the project;
- to list regional, national or international plans or programmes relating to the project;
- to outline any specific permitting requirements and regulatory issues defined by law;
- to identify the various levels of involvement, i.e. involved authorities and stakeholders at local, regional, national, and international level.

B.5.1 Legal and institutional basis of the EIA

This section describes existing national and international EIA laws and procedures relevant to the desalination project. When national procedural guidance is not available, it may be developed by reference to guidelines prepared by international agencies. Two key international developments in EIA policy and institutional arrangements from the last decade are [5]:

- The Rio Declaration on Environment and Development (1992), which calls for use of EIA as an instrument of national decision-making (Principle 17). Moreover, it establishes important principles for sustainable development that should be reflected in EIAs, such as the application of the precautionary principle (Principle 15).
- The UNECE (Espoo) Convention on EIA in a Transboundary Context, which entered into force in 1997 as the first EIA-specific international treaty. It stipulates the responsibilities of signatory countries with regard to projects that have transboundary impacts, describes the principles, provisions and procedures to be followed, and lists the activities, content of documentation and criteria of significance that apply.

Furthermore, the World Bank [6] and some regional development banks[8] have well-established EIA procedures for their lending activities, which oblige borrowing countries to prepare EIAs according to the EIA requirements of the development banks. Although these vary in certain respects, a relatively standard procedure for the preparation and approval of an EIA report is followed. The development banks therefore continue to set important standards in countries that have weak or non-existent domestic arrangements.

National EIA arrangements will be distinctive to some degree and vary from the international standards. A useful starting point to investigate the EIA systems of individual countries is the IIED Directory of Impact Assessment Guidelines [11]. It includes 140 country status reports which summarize the legislative and administrative context of EIAs. For example, the following national and regional EIA systems have been newly established or comprehensively reformed in previous years [5]:

- long-established EIA systems with comprehensive reform, e.g. New Zealand (1991), Canada (1995), Australia (1999);
- new or revised EIA legislation enacted by many developing and transitional countries; e.g. Vietnam (1993), Uganda (1994), Ecuador (1997);
- European Directive on EIA (1997), which requires all member states to be in compliance by 1999 and which is also being transposed into the EIA laws of countries accessing to the EU, and EU Directive on Strategic Environmental Assessment (SEA) of certain plans and programmes (2001) to be implemented by 2004.

The IIED Directory furthermore provides abstracts for 45 international development agencies and 800 bibliographic references for obtaining further information. For general guidance on EIA methodology and practice, also the EIA training resource manual of UNEP is recommended [5].

B.5.2 National or international policies, agreements or programmes

The following major thematic areas may be considered when searching the national or international legal system for relevant agreements. Key *international* conventions and programmes that may be relevant to desalination projects include:

Public participation policy and legal instruments:

- Rio Declaration on Environment and Development (1992);
- EU Protocol Strategic Environmental Assessment, Kiev, Ukraine (May 2003);
- Article 152 of the EU Amsterdam Treaty;
- Articles 6, 7 and 8 of the Aarhus Convention (2000).

[8] African Development Bank, Asian Development Bank, European Bank for Reconstruction and Development, Inter-American Development Bank

- ***Protection of wildlife and biological diversity, coastal seas and oceans:***
- The Convention on Biological Diversity[9] is a key agreement adopted at the Earth Summit in Rio de Janeiro in 1992. It establishes three main goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources. The convention cites EIA as an implementing mechanism.
- The Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention, 1979)[10] aims to conserve terrestrial, marine and avian migratory species on a global scale throughout their habitats. It is an intergovernmental treaty concluded under the aegis of UNEP, which acts as a framework convention for further Agreements (legally binding treaties) and Memoranda of Understanding (MoU) concerning different species and regions. Agreements and MoU that might be relevant for desalination projects are:
  - Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS)[11];
  - Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS)[12];
  - Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA)[13];
  - Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia[14].

[9] http://www.biodiv.org/
[10] http://www.cms.int/
[11] http://www.accobams.org/
[12] http://www.ascobans.org/
[13] http://www.unep-aewa.org/
[14] http://www.ioseaturtles.org/

- Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention)[15], which aims to prevent loss and encourage wise use of all wetlands and their resources. The definition of wetlands includes estuarine and marine environments, such as estuaries, deltas, tidal flats, near-shore marine areas, mangroves and coral reefs.
- European Directives, which deal with the conservation of wildlife and focus on the protection of species and habitats (Birds Directive and Habitats Directive). The sites protected under both directives form the European 'Natura 2000' network, covering 17% of EU territory and including some coastal and marine sites[16].
- The UN Regional Seas Programme[17], which aims to address the accelerating degradation of the world's oceans and coastal areas. Thirteen Regional Seas Programmes[18] have been established so far that engage riparian states in concerted actions to protect the shared marine environments. The programmes are underpinned with a strong legal framework in the form of Regional Seas Conventions, Action Plans and associated protocols on specific problems, such as protocols to prevent pollution from land-based sources.
- Regional seas programmes not under the auspices of UNEP, i.e. OSPAR for the North-East Atlantic and HELCOM for the Baltic Sea.

- ***Control and prevention of emissions and environmental pollution:***
- Convention on Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Basel, 1989)[19], which aims to pro-

[15] http://www.ramsar.org/
[16] http://europa.eu.int/comm/environment/nature/
[17] http://www.unep.org/regionalseas/
[18] Black Sea, Wider Caribbean, East Africa, South East Asia, ROPME Sea Area, Mediterranean, North-East Pacific, North-West Pacific, Red Sea and Gulf of Aden, South Asia, South-East Pacific, South Pacific, West and Central Africa, East Central Pacific.
[19] http://www.basel.int/

tect human health and the environment against the adverse effects which may result from the generation, transboundary movement and management of hazardous and other wastes.

- UN Framework Convention on Climate Change (UNFCCC, New York, 1992)[20] and the Kyoto Protocol, which aim to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent 'dangerous interference with climate' and to adapt to the expected impacts of climate change.
- Global Programme of Action on the Protection of the Marine Environment from Land-based Activities (GPA), adopted through the Washington Declaration, 1995[21]. The GPA shall provide guidance to national and regional authorities in devising and implementing sustained action to prevent and control marine degradation from land-based activities. The UN Regional Seas Programme is used as framework for delivery of the GPA at the regional level.
- Specific protocols addressing land-based pollution have been adopted for the Mediterranean (1980/1996), the South-East Pacific (1983), the Kuwait region (1990), the Black Sea (1992), and the Wider Caribbean (1999).
- Seawater desalination activities in the Mediterranean were reviewed and a guidance document for the management of brine discharges prepared under consideration of the land-based sources protocol for the Mediterranean region [12].

B.5.3 Consistency with relevant management plans and policies

This section of the EIA should include a description of each relevant plan or programme and an analysis of how the project complies with it. For areas with increasing or high desalination capacity, it is recommended to elaborate specific plans for the management of desalination activity, or to integrate desalination activity into existing plans. The most relevant plans or programmes for desalination plants will be:

Integrated Water Resources Management. Useful information sources on IWRM are:

- Global Water Partnership[22] (GWP), a network of Regional Partnerships with the objective to develop action plans based on IWRM. Provides information sources such as a 'ToolBox' for Integrated Water Resources Management;
- UNESCO water portal[23], which provides information on UNESCO-led programmes such as the International Hydrological Programme (IHP) and the World Water Assessment Programme (WWAP);
- World Bank recommendations and resources (e.g. [13]).

Integrated Coastal Zone Management:

- Integrated coastal area management of the UN Regional Seas Programme:
  - Guidelines for Integrated Management of Coastal and Marine Areas - With Special Reference to the Mediterranean Basin [14];
  - Good Practices Guidelines for Integrated Coastal Area Management in the Mediterranean [15];
  - Guidelines for Integrated Planning and Management of Coastal and Marine Areas in the Wider Caribbean Region [16].
- The Integrated Coastal Area Management[24] programme established by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and supporting documents.
- World Bank resources, e.g.:
  - Guidelines for Integrated Coastal Zone Management [17];
  - Coastal Zone Management & Environmental Assessment [13].

[20] http://unfccc.int/
[21] http://www.gpa.unep.org/
[22] http://www.gwpforum.org/
[23] http://www.unesco.org/water/
[24] http://ioc.unesco.org/iocweb/index.php and http://ioc.unesco.org/icam/

- ***Any other plan or programme which includes considerations such as:***
- protection and facilitation of public access to coastal land;
- protection and enhancement or restoration of coastal ecosystems or species;
- management of other uses and activities in a coastal area, such as agriculture, fisheries, recreation, tourism, commercial uses, use of resources, etc.;
- urban, land use and development planning.

B.5.4 Permitting and regulatory aspects

This section should include a review of the relevant permits and regulatory controls that apply to a desalination project in different stages of its life-cycle, including:

- permits needed to begin construction or operation according to agreed conditions;
- renewal of permits at different phases of construction activities based on compliance with the outcomes of the approved EIA for each phase;
- regular renewal permits during operation (semi annual, annual, etc.).

The relevant permits and regulatory controls may be organized by issue, such as:

- public health and safety;
- workplace safety;
- drinking water quality;
- air quality;
- land use and site disturbance;
- conservation of marine and terrestrial biological resources;
- utilities and service system regulations;
- construction activities.

B.5.5 Levels of involvement

Desalination projects relate to a large variety of issues so that different permitting agencies will be involved in the regulatory and permitting process. This process typically includes involvement from all levels of government, with coordination and oversight from regional or federal authorities. To facilitate the permitting process, a 'lead' agency may have been nominated to coordinate the process, to involve other agencies and to inform the project proponent about permitting requirements.

It is important to define and clarify the role of each jurisdiction or agency involved in reviewing and permitting a project early in the process, and to coordinate the information needs of each agency. An overview on the competencies and interrelationships of involved agencies should be given in the EIA to increase transparency of the decision-making process.

B.6 Description of the proposed project

B.6.1 Objectives and goals of the project

This section typically provides a short explanatory statement why the desalination project is needed and it gives some general goals of the project, such as to create a new cost efficient and environmentally acceptable desalination plant for a new water supply; or to create a drought resistant reliable source of water. An outline of the purpose and rationale of a project is a useful introduction to the project description. This should also entail a rather specific goal such as the delivery of a certain volume of freshwater to a particular community for a certain period of time (i.e. stating plant capacity and lifetime).

B.6.2 Project delivery methodology

The desalination project may be delivered using a variety of methods. Delivery methods where the project is built using public funds and the risks are identified and equitably proportioned between the public and private sector are:

- design-bid-construct (DBC);
- design-construct (DC);
- design-build-operate (DBO);
- design-build-operate-transfer (DBO).

Alternatively, the project may be initially built and operated by private capital and the water is purchased from the contractor. The corresponding delivery methods are:

- design-build-own-operate (DBOO);
- design-build-own-operate-transfer (DBOOT).

The methodology selected will influence the project delivery period and some of the project details available at the time of the environmental impact assessment. Notwithstanding the delivery method, the following sections outline the basic components of the project and the minimum technical information required in the development of the project to make an assessment on the potential impacts.

B.6.3 Project implementation status

This section may give a short account of the project implementation status at the time the EIA is submitted to the competent authority for approval, i.e. a brief history of preliminary planning stages, permits already obtained etc. Ideally, an EIA should be conducted in the early planning stages of a project and prior to any action being taken or permits being issued. However, for large projects which often have a planning phase of several years, it may happen that different actions or permitting processes take place at the same time. For example, the workplace safety concept could be approved by the competent authority while the EIA is still in process. Or the project could be split into different sub-projects, which are submitted for approval separately (e.g. the desalination plant and a long water pipeline transporting the water to different communities).

B.6.4 Project location

The EIA should provide a general overview on the project site including e.g.:

- overview maps at different scales and geographical coordinates;
- distances to sites relevant for project planning (e.g. cities, nature reserves, etc.);
- a general classification and habitat description of the coastal and marine environment (a detailed description, however, should follow in subsequent chapters);
- a calculation of plant space requirements, e.g. in terms of square kilometres.

B.6.5 Process and engineering characteristics

This section of the EIA should provide a technical outline of the process and engineering characteristics of the proposed project. It should be restricted to those aspects that are relevant for the evaluation of potential impacts of the project on the environment. Aspects for consideration are listed below. Further details on desalination technology and processes can be found in the WHO guidance document on “Desalination for Safe Water Supply” [18].

Process description:

- functional description and process flow diagrams, indicating the type of process (membrane or thermal), the number of units, chemical addition points etc.;
- process flows and recovery, indicating the quantity of all process flows at each stage of the process as well as operating pressure and temperature;
- other characteristics of process streams (feed water, product water, concentrate), in particular dissolved inorganic species (total dissolved solids (TDS), elemental analysis), nutrients, and suspended solids;
- projected consumption of materials and resources that will be used by the project;
- expected quantities of solid, liquid and gaseous wastes and details on the proposed method of disposal, including the concentrate, cleaning solutions, sludge disposal, screen and filter backwash, sanitary waste, used reverse osmosis membranes, etc.

Power requirements:

This section should contain information on the projected power consumption, the power supply source and power saving devices implemented to reduce power consumption:

- power consumption for desalination process (total MWh and kWh/m^3 distillate):
  - projected total energy consumption for plant operation;
  - thermal energy requirements (e.g. heated steam in cogeneration plants);
  - electrical energy requirements, including requirements for pump stations, high pressure reverse osmosis system, pretreatment system etc.;
- power saving devices:
  - energy recovery systems;
  - low-energy devices (pumps etc.);
- power consumption for construction and transport vehicles;
- energy supply sources:
  - fossil energy (oil, gas, coal);
  - renewable energy (wind, solar, geothermal, biomass);
- energy suppliers:
  - public or private suppliers;
  - from power stations nearby or import.

Based on the projected power consumption and the energy supply sources, an estimate of the emissions of greenhouse gases and other air pollutants should be provided, such as carbon dioxide, sulfur and nitrogen oxides (SO_x and NO_x), fine particulate matter (PM_{10}), etc. The estimate of atmospheric emissions is required in order to investigate potential impacts on local air conditions and climate in chapter B.8.4.

Chemical engineering details

This section should contain information on the usage and properties of chemical additives used in the desalination plant, including all chemicals or formulations used for:

- pretreatment of the intake water against biofouling, scaling, corrosion, etc.;
- cleaning of the plant to remove biofilms, scales, etc.;
- membrane preservation during transport and shut-down;
- product water disinfection and stabilization.

Information on usage should be provided for each substance or formulation, in particular:

- dosing levels and expected discharge concentrations;
- point and time of injection and retention time;
- projected chemical consumption (e.g. total loads in tons per year).

The acceptability of all substances or formulations, including commercial products, that are used in the desalination plant should be evaluated in terms of safety of use, human health and environmental effects. The evaluation should also include any substances produced during the process, for example by corrosion of materials, transformation, side-reaction, or in-situ generation such as the electrolysis of seawater to produce hypochlorite.

For risk characterization, a data set is usually required that covers chemical and physical properties, human health implications and environmental effects of the substance. This kind of information may either be obtained from scientific literature on the substance, or chemical dossiers and data sheets prepared by manufacturers, authorities or independent expert working groups for registration or review of chemicals. Data sheets such as the International Chemical Safety Cards (ICSC)[25] usually also give instructions on storage, transportation, handling, and emergency responses in case of spillages or human exposure, and should thus be stored in a place that is easily accessible at the workplace.

If additional laboratory tests are required for risk characterization, they should be carried out in accordance with existing national standards or internationally recognized guidelines, such as the OECD principles of Good Laboratory Practice (GLP), OECD Testing Guidelines or ISO standards. Data typically required for chemical data sheets and risk characterization of chemicals are:

[25] provided by the International Occupational Safety and Health Information Centre (CIS) of the International Labor Organisation (ILO) under http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/index.htm

- chemical identification: chemical formula, molecular mass, CAS no. or other registration numbers, synonyms, etc.;
- for commercial products: product name and manufacturer contact details;
- for formulations: composition and concentrations of active and inactive substances;
- general usage information: labelling, packaging, storage, transportation, handling, waste disposal etc.;
- physical and chemical characteristics: melting and boiling point, vapour pressure, water solubility, dissociation constant (pK_a), etc.;
- fire, explosion and other hazard information, including emergency responses such as first aid measures, fire-fighting measures, exposure control and personal protection;
- human health hazard data: acute mammalian toxicity, chronic toxicity, effects on skin and eye, developmental and reproductive toxicity, carcinogenicity, mutagenicity;
- information on *acute* aquatic toxicity, i.e. short-term (24, 48, 72 or 96-hours) tests with organisms[26] from three trophic levels, including plants (algae), invertebrates (crustaceans) and vertebrates (fish), and preferably using representative and sensitive organisms or life-cycle stages. Frequently conducted acute freshwater tests are:
  - OECD guidelines 201 (growth inhibition test of algae);
  - OECD guidelines 202 (acute immobilization test of Daphnia);
  - OECD guidelines 203 (acute fish toxicity test);
- information on *chronic* aquatic toxicity, i.e. long-term tests with organisms of three trophic levels, using preferably representative and sensitive organisms or life-cycle stages;
- long-term sediment toxicity tests if substances have a strong potential to adsorb to sediments (e.g. such as heavy metals), using benthic organisms, preferably deposit or suspension feeders;
- information on the potential of chemicals to disrupt endocrine systems of aquatic species, which may result in developmental and reproductive problems;
- information on bioavailability to aquatic and benthic species;
- for substances that have a tendency to accumulate in biota, bioconcentration factors and biomagnification in the food web should also be determined if possible;
- environmental fate and effect under aerobic and anaerobic conditions:
  - biotic and abiotic degradation rates;
  - partition coefficient, octanol/water coefficient;
  - potential of substance for reaction with organic matter.

Mechanical engineering details

This section should contain information on the physical nature of the mechanical systems that will be part of the desalination plant, including:

- seawater intake system;
- pretreatment system;
- desalination system;
- post treatment system;
- concentrate and residuals disposal system;
- product water storage system;
- distribution system;
- chemical storage and handling system.

Civil and structural engineering details

This section should contain information on civil and structural aspects of the desalination plant. Minimum information should include details on location, type, number, materials and method of construction, profile and footprint:

- description of engineering works (offshore, nearshore, onshore);
- excavation and piling;
- structural works;
- site works.

[26] For seawater desalination plants, it should be considered whether the risk characterization can be based on freshwater species, or if tests with representative marine species such as echinoderms (e.g. sea urchins) or molluscs should be preferred. Marine species are not necessarily more sensitive than freshwater species, but some differences in the toxic effects of certain chemicals may exist.

B.6.6 Construction activities

The EIA document should contain a brief description of the anticipated construction activities for the establishment of the desalination system. The construction phase is a temporary condition and the information will be used to assess the potential for the construction activities to alter the physical environment in the vicinity of the plant. This section should include a description of the:

- projected schedule;
- construction techniques;
- access requirements and restrictions;
- waste disposal;
- traffic movements;
- interruption to services and tie-ins;
- projected emissions during construction (atmospheric, terrestrial, aquatic);
- proposed mitigation measures during the construction period.

B.6.7 Commissioning and operation activities

Start-up procedures

The EIA document should contain a brief description of the anticipated commissioning activities for the establishment of the desalination system. The commissioning phase is a temporary condition. The information will be used to assess the potential for the commissioning activities to alter the physical environment in the vicinity of the plant and the extent to which the safety of the plant workers, the public and the environment will be protected. The minimum information required should include a description of the various hazard identification techniques that will be used by the project proponent to protect the safety of the public and the environment. The topics may include:

- hazard and operability studies;
- personnel requirements and operator attendance;
- training and safety;
- storage and handling of hazardous materials;
- disposal and recycling of consumable items;
- emergency response preparedness and security;
- flexibility for process modification.

Decommissioning activities

The EIA document should try to anticipate and describe the planned decommissioning activities of the desalination system after the life-time of the project, or other options of use, such as extension of the system or renewal and prolongation of operation.

Other project details, e.g.:

- ISO 14000 certification;
- post-contractual issues.

Environmental setting, impact assessment and impact mitigation (sections B.7 – B.12)

This part of the EIA report contains the actual impact assessment of the desalination project. It comprises socio-economic, human health as well as environmental implications.
For each of these areas, the following information should be included

- a detailed description of the existing setting (i.e. baseline data);
- a discussion of the expected impacts in the different life-cycle stages of the project, i.e. impacts during construction, commissioning, operation, maintenance and decommissioning as far as these are predictable at the stage of project planning, including a judgement whether or not the project will cause any *significant* impacts;
- a description of impact mitigation measures.

Existing setting

The existing setting describes the present and future state of the environment, including socio-economic and public health characteristics, in the absence of the desalination project ('no project' or 'zero' alternative). It takes into account changes resulting from natural events and from other human activities. Initial baseline studies may be elementary or wide-ranging depending on the project and applying regulations. They should focus on those aspects that may be significantly affected by the project, either directly or indirectly. As with most of the EIA process, establishing the baseline is not an 'on-off' activity. Studies should move from broad-brush to more detailed and focused approaches. The identification of new potential impacts may open up new elements of the environment for investigation, or the identification of effective measures for mitigating impacts may curtail new investigations.

Impacts

The impacts section of an EIA should identify, describe and evaluate all relevant socio-economic, human health and environmental impacts (adverse and beneficial) caused by the project throughout the different life-cycle stages. The prediction of impacts aims to identify the magnitude and other dimensions of identified changes caused by the project, by comparison with the situation before/without the project. The subsequent evaluation and assessment of significance seeks to assess the relative significance of the predicted impacts in order to focus on the important adverse impacts.

Mitigation and avoidance measures

Impact mitigation involves the introduction of measures to avoid, reduce, remedy or compensate for any significant adverse impact resulting from construction, commissioning, operation, maintenance and decommissioning of a desalination plant. Development of mitigation measures includes the following three consecutive steps:

- Prevention: avoid impacts by preventive measures, consider feasible alternatives and identify the best practicable environmental option.
- Minimization: identify customized measures to minimize each of the main impacts predicted and ensure they are appropriate, environmentally sound and cost-effective.
- Remediation: remedy or compensate for adverse residual impacts, which are unavoidable and cannot be reduced further, as a last resort.

B.7 Socio-economic and environmental health aspects

It is essential for an EIA to thoroughly investigate the ways in which a proposed project may change the lives or affect the well-being of the present and future residents in the area potentially affected by the proposal. This assessment can allow for the positive socio-economic and environmental health effects of a desalination project to be realized to the maximum extent possible, while minimizing the negative impacts related to the project.

Understanding the values and concerns present in the potentially affected community is a crucial aspect of the evaluation (cf. also section B.4.3 on Public involvement), and assessment of both quantitative and qualitative aspects is important. Quantitative measures may include increases in population, changes in employment, or housing dynamics, while qualitative measurements might involve perceptions within the population about how a desalination project fits in with the character of the community.

B.7.1 Population, housing and community structure

Existing setting

Provides demographic information for the metropolitan areas, towns or rural areas which will be affected by the project. This includes the communities to which the desalinated water will be distributed (and which will probably benefit from this development), but also communities that may be indirectly affected, or will experience negative effects of the project, for example caused by the redistribution of water resources or environmental degradation. The baseline demographic information can be detailed by providing:

- figures on the current population size, population growth or decline rate, age structure, birth and death rates, and migration rates in the project area and surroundings;
- identification of racial and ethnic characteristics within the affected community;
- a projection of the anticipated future population development and changes to community structure without project realization (zero alternative).

Impacts

Describes and assesses the anticipated changes to demographic development and community structure caused by the project in comparison to the zero alternative, e.g.:

- stimulation of population growth in the community that receives the desalinated water (e.g. due to immigration, improved living standards and health conditions);
- decline in population size in other regions due to drainage of people from disadvantaged areas (in terms of water availability, environmental quality, economic prospects etc.) to more favourable areas;
- relocations and secondary effects on settlement structure;
- displacement of existing housing or people due to the construction of the project and associated infrastructure.

Mitigation and avoidance measures

Mitigation and avoidance measures to avert negative impacts on population and community structure are very specific to the project and regional setting. In general, establishing water security for a certain region or community should not compromise the demands of another community or sub-part of the population. Mitigation and avoidance measures might therefore focus on establishing a fair and equal access to water for all communities.

B.7.2 Economic growth and development activities

Existing setting

Provides an overview on the main economic activities in the communities that will benefit from or may be impaired by the project, such as fisheries and aquaculture, tourism, agriculture or specific industries. This may include statistical data and information on:

- business volume in terms of numbers (e.g. number of tourists) and total revenues;
- importance of an activity for the local, regional or national economy (e.g. share of the domestic gross project);
- information on employment among the affected population and importance of different activities as an employment opportunity and economic base;
- community economic data such as distribution of income and wealth among the affected population, including median household income, median family income, and number of individuals and families below the poverty line;
- a projection of the anticipated future economic development without project realization (zero alternative).

Impacts

Describes and assesses the anticipated changes to economic development and the economic prospects for the population if the project is realized. Identifies which market sectors will benefit and which will be negatively affected by the project. For example, a desalination project could stimulate:

- an increase in tourism, agriculture or certain producing industries if water is diverted to these market sectors;
- a decline in coastal fisheries (e.g. shellfish) or coastal aquaculture if fish stocks or access to fishing grounds are affected;
- subsequent increases or decreases of employment opportunities and income in these market sectors;
- increases or decreases in property values of residential areas or industrial sites.

Mitigation and avoidance measures

Elaborates management strategies which allow different economic activities to coexist or identifies measures to mitigate impacts on market sectors and stakeholders such as compensation, retraining and employment opportunities in new sectors.

B.7.3 Environmental health factors

Environmental health encompasses the assessment, communication and management of potential health risks, due to the exposure of the affected population to environmental physical, chemical and biological hazards, as well as socio-economic, and psycho-social changes, related directly or indirectly to the desalination project.

Existing setting

The existing setting is a baseline picture of the environmental health conditions prior to the construction and operation of the desalination project. It includes a projection of the anticipated future health conditions without project realization (zero alternative). Emphasis should be given to relevant health hazards and the baseline health status of the potentially affected population, including sensitive subgroups, e.g. the elderly and children. The description of the existing setting may include:

Environmental quality

- geographical scope (physio-geography, meteorology, and natural and anthropogenic features of the potentially affected areas);
- population at risk (size, age distribution, sensitive subgroups such as children, elderly, and those with health deficiencies);
- hazardous agents (in air, water, soil, food):
  - biological infectious agents such as viruses, bacteria, parasites, bio allergens, and other disease vectors;
  - chemical agents, in particular toxic chemicals;
  - physical agents such as dust, noise, heat, vibration, etc.;
- ecosystem perturbations due to environmental stresses;
- industrial and hazardous waste;
- water supply and sanitation services;
- solid waste management services;
- air quality management programs.

Health of potentially affected population

- morbidity rates of communicable, non communicable, acute and chronic diseases;
- mortality rates, including infant and child mortality;
- life expectancy and DALYs (Disability Adjusted Life Years) distribution;
- biochemical indicators of exposure to environmental contaminants;
- psychological well-being, e.g. due to water stress;
- health and community social services and availability of services;
- socio-economic indicators of the quality of life, e.g. poverty, crime, employment.

Impacts

Key steps are the prediction of potential environmental health impacts and benefits, the evaluation of their significance, interpretation and communication of this information to decision-makers and the public. A prospective assessment will entail the development of a listing of potential impacts and benefits, using screening, scoping and profiling of the existing environmental and public health settings, inputs from environmental health experts, and data from similar desalination projects which are already operating.

Each of the predicted impacts and benefits will be assessed for relevance and significance to the EIA. A variety of methods of varying degrees of complexity could be used to decide if the environmental health impact is trivial and need be taken no further, and which ones will need a full assessment of exposure and health risk.

Environmental health impact assessment includes the following methods:

- inputs from public participation and expert opinion of concerns with possible environmental changes which may impact on public health quality of life;
- comparison of predicted dispersion and levels of environmental contaminants emitted from the desalination project, with applicable public health and safety limits. This may entail the mathematical modeling of the dispersion of contaminant emissions and their distribution and accumulation in air, water, soil, aquatic and terrestrial fauna and flora;
- comparisons of environmental levels of given contaminants, in the potentially affected areas, before and after the operation of the desalination project;
- consideration of the total burden rather than the effect of individual contaminants;
- quantitative assessment of health risk for specific hazards, including where necessary:
  - exposure assessment;
  - identification of exposure – health effect relationship;
  - risk characterization:
    - epidemiological methods (risk calculation for different contaminants at different exposure levels);
    - toxicological methods (carcinogenic and non carcinogenic risk, comparison of the predicted contaminant levels with human health threshold limits)
    - identification of uncertainties in the risk assessment, including sensitivity analysis and establishment of confidence limits on the results.
- Summary of results, including (a) potentially impacted areas, (b) characterization of population at risk, (c) predicted levels and distribution of environmental contaminants and ecosystem perturbations, directly or indirectly related to the desalination project, and (d) prediction of the health risks to the exposed population.

Mitigation and avoidance measures

A first step is the communication of the environmental health assessment to planners, decision-makers and the public. The same message should be given to all with introductory sections that address the interest of each group of stakeholders. Special attention should be given to the presentation of health risk predictions.

In general, the perception of risk depends on such factors as:

- magnitude and probability of the potential damage;
- severity of consequences;
- irreversibility and delayed effects;
- equity;
- impacts on children.

The management of environmental health risk essentially depends on the *comparison of benefits from the desalination project to potential damages*. A decision on what could be an 'acceptable risk', for given benefits, will depend on the psychosocial and cultural characteristics of the affected population. Economic conditions are important factors in deciding on the level and degree of mitigation and reduction of potential health risks.

B.7.4 Water resources use

Existing setting

Describes the current water resources management, or the use of water resources if no management plan has been implemented, and its implications for development and natural water balance by:

- providing figures on current water demand and the main sectors of water use (communities, agriculture, industries etc.);
- quantifying the extracted water volume, the renewable and non-renewable resources (ground-, surface-, rainwater etc.) and the amounts which may be withdrawn from the ecosystem without causing permanent ecosystem damage;
- describing the implications of the current water management for socio-economic development (e.g. incentives or restrictions to growth in certain regions) and the natural water balance and ecosystems (sinking groundwater tables, river flow rates etc.);
- providing figures on the current level of investment in local water infrastructure (stormwater collection and treatment, wastewater collection and treatment);
- providing a projection of the anticipated future use and management of water resources without project realization (zero alternative).

Impacts

Describes and assesses the anticipated changes in water use and water resources management if the desalination project is implemented, such as:

- identification of beneficiaries and disadvantaged stakeholders / groups;
- generation of further demand and stimulation of wasteful use (as salt- and brackish water provide a great reservoir for producing freshwater);
- impact of the desalination project on the ability of communities to develop other water infrastructure in the short, medium and long term;
- disregard for or postponement of water saving measures and techniques;
- disregard for or postponement of water recycling schemes;
- provision of a constant and safe water supply even in times of drought;
- reduced pressure on natural freshwater resources and freshwater ecosystems;
- potential impacts on groundwater aquifers if brackish water is extracted from the ground or waste brine is returned into the ground.

Mitigation and avoidance measures

The purpose of a desalination plant is typically to supplement and diversify existing water supplies by tapping into an additional, drought-safe and largely unlimited water resource. Desalination is thus a mitigation measure to reduce the effects of insufficient or variable water resources, which means that the effects on water resources availability will mainly be intentional and positive.

Negative side-effects which may be associated with increasing desalination activity, such as stimulated demand, changing use patterns, wasteful use or unequal distribution of water resources, deferment of water resource management schemes such as recycling, should be addressed and minimized by implementing an overall water resources management plan.

It is critical that the project proponents demonstrate that the development of the desalination project will not be at the expense of the implementation of sound water management strategies based on conservation, demand management and water recycling.

B.7.5 Land and marine use

Existing setting

The existing setting should provide a description of the pre-construction status of the terrestrial and marine site, including the area of the facility, intake and outfalls, and other plant components. This should include a discussion of existing and future uses of the land and marine environment in the project area. Relevant statistical information and maps may be available from local authorities, or could be obtained by setting up a public enquiry into present uses and activities.

The description may include, if relevant:

- commercial uses (e.g. fishing and aquaculture, navigation, exploitation of oil, gas and other natural resources, agriculture, other industrial and commercial activities);
- recreational uses (e.g. scuba diving, fishing, hiking, use of beaches, boating, etc.);
- infrastructure and buildings at the site and in the vicinity (e.g. pipelines, piers, etc.);
- technical constraints (e.g. proximity of the plant to sewer lines);
- environmental constraints (e.g. presence of endangered species in the project site, highly erosive coastline, etc.)
- existing plans and policies including land use plans and coastal zone management plans, and any planned or potential future development activity in the site;
- a projection of the anticipated future development without project realization (zero alternative).

Impacts

A desalination plant causes air, water and soil emissions and affects the audio-visual characteristics of a landscape in the project site and surrounding area. These impacts may lead to conflicts with recreational or commercial uses or conservation efforts as indicated below. Conflicts can also occur if the project is not compatible with any applicable land use plans, policies or regulations of any entities with jurisdiction over the project.

Recreational conflicts

Alterations to the environmental quality and natural scenery can have potential impacts on human activity by reducing the recreational value of the coastal site for residents and/or tourists. The building complex and supporting infrastructure may furthermore restrict access to beaches, hiking trails, fishing sites, etc.

Commercial conflicts

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 harbours or other activities like commercial fishing or aquaculture.

Nature conservation conflicts

Alterations to the environmental quality can have potential impacts on the ecological value of a project site as a habitat for terrestrial and marine species. The decision to protect or open an area for development is often influenced by the presence or absence of rare and endangered species or biological communities. By changing the ecological value of a site, it may lose its present protection status or may no longer be eligible for becoming a protected area in the future.

Mitigation and avoidance measures

This section recommends various mitigation and avoidance measures which may reduce conflicts between existing activities and the proposed desalination project, such as:

- If possible, desalination plants should be located near other facilities which have similar requirements and repercussions (e.g. in industrial areas where existing infrastructure may be used, where visual or noise disturbance is acceptable, where marine waters have been classified for industrial use, etc.).
- Site development should be optimized to reduce land consumption and avoid impacts on sensitive areas (e.g. by minimizing pipeline length and placing them underground, without accessing recreational areas or ecologically sensitive areas).
- Best available techniques (BAT) and best available practice (BEP) should be applied to limit emissions to the environment and audio-visual effects (e.g. sound proofing, visual screening, limited height of buildings, scheduling of construction activities for time periods that guarantee a low interference with recreation and tourism or breeding and migration of coastal animals, etc.).
- Desalination activity should be reconciled with other interests and activities by including it into a coastal development and management plan (cf. also section B.5.3).
- To the extent possible, construction activities should be coordinated with the affected community, to minimize disruption of commercial or recreational activities.

B.7.6 Utilities and service systems

Existing setting

Includes information on utilities and services affected by the project, such as:

- water conveyance, sanitary sewer and storm water system;
- electricity and natural gas grid;
- traffic on access roads;
- emergency medical services and police and fire protection;
- solid waste disposal.

The EIA should also provide information on public policies and regulations pertaining to these utilities and services (cf. section B.5.4).

Impacts

This section discusses impacts from the project to the above-mentioned aspects including the potential for it to increase the demand for public utilities and services. For example, discharges from the desalination plant to the sanitary sewer system or energy transmissions from power stations to the desalination plant would be disclosed here.

Also, any installation of new supporting infrastructure, such as the expansion of power plant capacities or new electricity lines from the grid to the plant that would result in substantial physical impacts on the environment would be pointed out in this section. Major changes to existing infrastructure would probably necessitate an independent EIA, as their impacts cannot be investigated in full depth within another project's EIA.

Mitigation and avoidance measures

Lists the various mitigation measures that are proposed for the project.

B.7.7 Cultural resources

Existing setting

This section describes and evaluates any existing cultural resources in the vicinity of the proposed project, particularly those that are considered significant to a community, culture, or ethnic group. This encompasses a description of prehistoric and historic resources including paleontological, and archaeological features as well as the potential existence of human remains. Specific examples of cultural resources include fossils, native cultural sites, habitation sites, etc. This description is typically based upon information and maps available from local authorities, or an archaeological survey that was carried out for this or another project in the area. It may also involve a field survey carried out by experts for the particular project. The section often does not disclose sensitive information such as the exact location of sites, to avoid potential disturbances.

Impacts

This section discusses impacts associated with the construction of a desalination plant and its related infrastructure, in particular of ground disturbing activities such as grading and excavation works. These activities may uncover or accidentally discover archaeological, paleontological or human remains through the disturbance of surface and sub-surface soils. This disturbance could lead to direct damage to or removal of sensitive cultural resources, potentially causing permanent loss of scientific information.

Mitigation and avoidance measures

This section lists the various mitigation measures that are proposed for the desalination project to avoid and minimize impacts, and in particular to prevent irreversible damage to cultural resources. This may include a plan for what to do if archaeological specimens are discovered. Examples of typical cultural resource mitigation measures include:

- a cultural resources treatment plan which includes identification of highly sensitive areas, and a protocol for continuous monitoring of construction sites and responding to the accidental uncovering of resources;
- known prehistoric and historic sites should be designated as sensitive areas and if possible avoided;
- all construction workers should be notified and educated about the potential existence of cultural resources on the project site, and should halt any construction activities upon discovery until a qualified expert can assess the situation;
- in particularly sensitive situations, a qualified expert (e.g. an archaeologist) should be present to monitor excavation activities;
- if impacts to cultural resources cannot be avoided, they should be assessed for their significance by a qualified professional who can recommend appropriate mitigation.

B.8 Abiotic environment

An EIA should provide a baseline description and assessment of the abiotic (non-living) environmental properties of the project site, based on literature data and/or field inventory studies. In the EIA report, a summary of the essential aspects may be given, while comprehensive data and more detailed studies may be included in an appendix.

The ‘existing setting’ of the abiotic environment refers to the ambient environment in its present state. It should as far as possible identify any initial level of pollution or environmental degradation, such as pollutant concentrations in air, soil or water. The sources of pollution may either be mentioned in this section or in the previous sections on socio-economic activities, e.g. in section B.7.5 on Land and marine use.

B.8.1 Characteristic landscape and natural scenery

EIAs for desalination projects may include a landscape impact assessment, which is directed towards predicting and evaluating the magnitude and significance of effects that a new facility has on the audio-visual characteristics of the surrounding landscape.

The effects of a desalination project on landscape properties cannot be ‘measured’ and ‘quantified’ as precisely and objectively as for other features of the project site. To assess the magnitude and significance of effects, an expert judgement is typically obtained. This should be based on good practice, follow a structured and systematic approach, and provide reasoned arguments, but even so, people will not necessarily subscribe to the expert opinion. Effects on landscape properties will often be perceived differently by people who judge by their own aesthetics and subjective perception of the project. A landscape impact assessment is typically discussed controversially in the public.

As impacts on landscape and natural scenery are often a major concern of the public, the landscape impact assessment should be taken seriously, as it is the part of the EIA which will help the public to imagine the potential audio-visual impacts arising from the project, and to form an opinion about the project.

Existing setting

This section depicts the pre-construction setting of the project site with regard to natural features such as islands, cliffs, dunes, river mouths, marshes, scenic views, etc. Typically, photos from different perspectives (e.g. from elevations, in different directions) are taken during good weather and visibility conditions to illustrate the landscape properties as they may be perceived by a human observer.

The description of the scenery would also include an assessment of the ambient noise level. It may distinguish between natural sounds caused by wind, waves, animals etc., and those caused by human activity in the site or vicinity, such as by docksides, traffic, etc.

This section would include a projection of the anticipated future development without project realization (zero alternative), but taking other development activities into account.

Impacts

This section evaluates how the landscape will change and how an observer may perceive the scenery if the project is realized, including:

- noise generation;
- obstruction or alteration of scenic views;
- production of glare;
- or any other audio-visual effect that substantially alters the character of the area.

This section typically includes a visualisation of the project from different viewpoints, for example computer generated photomontages or animations, and provides ranges for visibility and audibility of the facility in the form of visibility and audibility maps.

Mitigation and avoidance measures

This section lists the various mitigation measures that are proposed for the project, e.g.

- screens during construction to shield off noise and unsightly views;
- noise reduction measures during operation such as noise barriers;
- landscaping measures such as planting of trees and shrubbery;
- materials of finishes (e.g. reflective or non-reflective materials);
- colors of external appearance;
- lighting of the building complex.

The mitigation and avoidance measures should be designed to blend the facility in with the surrounding natural or artificial landscape features. The different measures such as vegetation and noise barriers should be illustrated by visualisations (photomontages) and their effect on noise levels illustrated in noise mappings.

B.8.2 Terrestrial site (soils, ground- and surface water)

Usually this section includes literature data and the results of field investigations or other studies, such as ground- or surface water modeling.

Existing setting

This section describes the terrestrial part of the project site, such as beach, wetlands, dune system, etc. with regard to:

- topography and geomorphology (e.g. elevation, soil erosion and deposition);
- geology and seismicity (e.g. soil layering, faults, earthquakes);
- soil composition and properties (e.g. content of rocks, sand, silt, humus, organic carbon, pollutants etc., air and water permeability, soil compaction);
- groundwater basins and aquifers (e.g. groundwater levels, flow direction, groundwater composition and quality);
- surface water (e.g. estuaries, lakes, lagoons);
- anticipated future state without project realization (zero alternative).

Impacts

The description and evaluation of impacts would include effects on:

- topography and geomorphology (e.g. potential of plant components to influence erosion or deposition rates, slope stability, land sliding);
- soil composition and properties (e.g. disturbance during construction, soil compaction, permanent surface sealing);
- groundwater (e.g. potential for beach wells to cause saltwater intrusion into aquifers, seepage of contaminants into groundwater due to chemical spills, waste waters, site run-off and contamination of rainwater);
- surface water (e.g. change of flow direction, pollution by chemical spills or waste water).

Mitigation and avoidance measures

This section lists various mitigation measures such as best management practices for project construction and operation activities, e.g.

- minimization of the area affected by soil compaction and surface sealing;
- proper storage of chemicals, control practices and spill prevention plans;
- re-vegetation after construction.

B.8.3 Marine site (seafloor, sediments and seawater)

Concentrate disposal and impacts on seawater quality are central aspects in EIAs for desalination projects. Correspondingly, the part of the EIA that deals with the characteristics of and impacts on the marine site will be more detailed and comprehensive than other sections of the EIA. It usually includes literature data and the results of field investigations or other studies, such as hydrodynamic modeling.

Existing setting

This section describes the intertidal and marine part of the project site with regard to:

- topography and geomorphology (e.g. slope of seafloor, water depth, sediment erosion and deposition processes, distribution of sandy or silty areas (soft bottom) and rocky or stony areas (hard bottom));
- sediment composition and properties (e.g. grain size fractions, content of sand, silt, clay, gravel, shell, organic carbon, levels of pollutants);
- seawater properties (e.g. salinity, temperature, density, oxygen levels, turbidity, nutrient levels and pollutant concentrations, general water quality);
- hydrology of the site (e.g. open water, bay, estuary, including currents, tides, water exchange rate);
- anticipated future state without project realization (zero alternative).

Impacts

The description and evaluation of impacts would include effects on:

- topography and geomorphology (e.g. potential of intake and outfall structures to influence erosion or deposition rates of sediments; stability of seafloor slope etc.);
- sediment composition and properties (e.g. disturbance and resuspension of sediments during construction, sediment compaction and surface covering, introduction of artificial hard bottom substrates into soft bottom habitats, increase in pollutants, etc.);
- hydrology (e.g. changes to currents, water density layers, mixing processes etc.);
- seawater quality (e.g. impacts on physical seawater properties such as changes to salinity, temperature, density, dissolved oxygen levels, turbidity, and impacts on water quality due to the discharge of pretreatment chemicals and cleansers).

An overview of the potential impacts of desalination plants on the marine environment, in particular of reject streams and residual chemicals, is provided in Part C, p. 50ff.

The investigation of impacts typically includes a hydrodynamic modeling study that is carried out as part of the EIA process to simulate the near- and far-field effects of the project on surface water hydrology. Surface water hydrology may be affected by the intake and discharge of large quantities of seawater and effluents. Modeling studies have the main objectives to predict changes to currents and flows caused by the intake, the mixing behaviour of the reject stream in the receiving water body, and the dispersal and dilution of the concentrate and residual chemicals in the receiving water body.

The mixing behavior of an effluent mainly depends on (a) the oceanographic conditions in the receiving water body, (b) the discharge practice and (c) the properties of the reject stream. Therefore, hydrodynamic models usually have to integrate a large number of variable parameters. Furthermore, they require detailed information on the prevailing oceanographic conditions in the discharge site and the planned discharge practice in order to provide reliable information for impact assessment. Parameters which usually require consideration include:

- site-specific oceanographic features:
  - ambient salinity, temperature and density considering seasonal variations;
  - tides, wind- or density-driven currents including flow directions and net flows;
  - bathymetry and shoreline topography;
- processes which may significantly affect chemical concentrations:
  - uptake and transfer into biota;
  - adsorption to particles and sedimentation (transfer into sediments);
  - decomposition and degradation rates;
- discharge practice:
  - outfall location, discharge depth and water depth at the point of discharge;
  - effects of outfall pipelines, seawalls, jetties etc. on the mixing process;
  - single outfall or multiport diffusers, discharge volumes and velocity;
- discharge properties:
  - salinity, temperature and density;
  - residual chemical concentrations.

By using different variations of these parameters, worst-case scenarios can be developed under a number of theoretical conditions. Even with these prerequisites, it may still be considered necessary to verify modeling scenarios with field observations.

Mitigation and avoidance measures

This section lists the various mitigation measures that are proposed for the project. A central aspect will be the design and siting of intakes and outfalls to prevent interference with sediment erosion or deposition processes, to improve mixing of the effluent in the discharge site and to prevent the formation of a widespread discharge plume.

Hydrodynamic modeling can be used as a tool to compare different mixing scenarios in order to identify the best practicable discharge option and thus minimize environmental impacts. The modeling results can further be used to assess if water quality objectives (if established) will be observed in the receiving water body, or to establish spatially restricted mixing zones based on the modeling results.

Another important consideration is the use of chemicals and formulations for pretreatment and cleaning in desalination plants that possess little or no environmental risk. If possible, hazardous substances that minimize impacts on seawater and sediment quality should be avoided or substituted by less problematic substances. If feasible, treatment of residual chemicals should be considered before discharge into surface waters.

B.8.4 Air quality and climate

Existing setting

The description of the existing setting gives a general classification of the climate (e.g. arid, semi-arid, hot, warm, temperate maritime climate) accompanied with basic information on local meteorological conditions for different seasons like predominant winds, air masses and currents, rain patterns, temperatures etc.

This section furthermore lists ambient air quality standards or describes air quality management plans if existing, and assesses the air quality for the area. The assessment of ambient air quality should include an overview on major sources of air pollution in the region and, if air quality monitoring data is available, a matrix of major pollutants with measured concentrations, environmental characteristics and potential health effects. A projection of anticipated future trends in air quality and local climate without project realization (zero alternative) should be provided if possible.

Marine sites are typically characterized by good air quality due to strong and frequent winds blowing from the sea and a good exchange of air masses. However, coastal air quality may be impaired by urbanization, off-gas from coastal industries, major shipping activities, land traffic or natural dust.

Impacts

This section includes a discussion of the potential impacts from the project on air quality and climate, broken down into construction impacts and operation impacts.

Construction-related emissions may include dust generation (i.e. fugitive dust that is transported beyond the project site) or exhaust gas from heavy construction equipment, delivery trucks and construction worker commute.

During operation, the main sources of emissions will be due to the production of electricity (onsite or offsite power plants) and heated steam (thermal plants only), if fossil fuels are used as primary energy source. Another relevant source will be the traffic of transport vehicles and staff to/from the plant. Furthermore, the desalination process strips dissolved gases from seawater, mainly carbon dioxide, oxygen and nitrogen.

Air quality will mainly be affected by emissions of greenhouse gases (mainly CO_2), acid rain gases (NO_x, SO_x), fine particulate matter (PM_{10}) and other air pollutants that are produced when fossil fuels are burned. Significant impacts may occur if the project conflicts with applicable air quality standards or management plans, contributes substantially to other existing or projected air emissions (cumulative impacts), exposes the population to substantial pollutant concentrations or creates objectionable odours.

Mitigation and avoidance measures

Impacts on air quality and secondary effects on human health can be minimized by establishing an air emission reduction and monitoring programme. This may entail:

- use of best available techniques to cut emissions and strip pollutants from off-gas;
- regulations and controls, such as emission limits and air quality standards.

As impacts of desalination plants on air quality are closely connected to energy demand, this section should also investigate and propose energy saving options with regard to technology and process design to reduce overall energy requirements. Energy saving options could include:

- selection of the most suitable desalination process in terms of energy availability and demand (e.g. thermal versus reverse osmosis processes) and optimization of the desalination process with regard to energy efficiency;
- where feasible, implementation of co-generation processes that re-use the low energy steam from electricity plants as a heat source for the desalination plant;
- use of energy saving devices and implementation of energy recovery systems;
- increase of efficiency in electricity production (power plant efficiency).

Furthermore, the potential for renewable energy use (solar, wind, geothermal, biomass) should be investigated to minimize impacts on air quality and climate. This may be in the form of renewable energy driven desalination technologies or as compensation measures such as the installation and use of renewable energy in other localities or for other activities. Major determining factors for renewable energy sources to become a realistic alternative to conventional energy sources are:

- the distribution and overall demand for water in a locality or region (so far, renewable energy is sometimes used in decentralized small-scale units, in rural areas or on islands, whereas larger plants are usually driven by conventional energy);
- the availability of conventional energy sources (availability of national fossil fuel resources, existing power plant capacities and grid connections);
- the environmental potential for renewable energy use;
- ongoing research and development to improve renewable energy driven desalination technologies in order to develop mature and commercial applications;
- demonstration projects to gain experience, knowledge and trust in renewable energy driven desalination technologies and to foster their implementation on a wider scale (e.g. ADIRA project in the MENA region, [19]);
- political incentives to increase renewable energy use for desalination, for example through policies and programmes or financial support.

Even though the use of renewable energy for desalination is still limited and will not solve the world's water and energy problems in the immediate future, it does offer the potential of providing a sustainable source of potable water to some communities, particularly those which have no indigenous sources of fossil fuels. Mature technologies that have reached the commercial stage include [20]:

- solar thermal energy (solar collectors) and distillation (multiple effect distillation);
- geothermal energy and distillation (multiple effect distillation);
- photovoltaics and membrane processes (reverse osmosis, electrodialysis);
- wind energy and membrane processes (reverse osmosis).

B.9 Biotic environment

This section provides a description of the biotic environment in the project site, based on literature data and field inventory studies. Detailed literature or survey data may be included as an appendix. The 'existing setting' refers to the fauna and flora in its present state – i.e. it should identify any initial decline in species abundance and biodiversity, change in distribution of species, or other impairment of a community. The causes of these effects may either be identified in this section or in the previous sections on socio-economic activities, for example in section B.7.5 on Land and marine use.

B.9.1 Terrestrial biological resources

Existing setting

Describes the terrestrial fauna and flora before construction, broken up by:

- sub-ecosystems or habitat type (e.g. dunes, saltmarshes, mangrove forests);
- biological groups and species (e.g. plants, mammals, birds, amphibians).

information to be provided on species-level:

- seasonal abundance and distribution;
- rarity and endangerment status of a species (e.g. threatened or endangered on a local, regional, global level, listed in the IUCN Red List of Threatened Species), as well as protection status (e.g. protected by national law, international conventions).

information on community level:

- the total number of species in the site;
- biodiversity indices;
- the protection status of habitat types and their communities (e.g. by national law as nature conservation area, international conventions such as RAMSAR);
- their rarity in and importance for the overall ecosystem (i.e. wetlands on a rocky coast, mangrove forests as nursery grounds).

The expected large amount of data should be summarized in a short but concise text accompanied by a table listing the various habitats, species, their numbers, status, etc. within the area, while more detailed information can be provided in the appendices of the EIA, where the original field investigation studies and their results may be presented.

Impacts

The prediction and evaluation of impacts is complicated by the fact that these vary between different species as well as individuals of the same group, depending on:

- the type, magnitude, distance and duration of single impact factors;
- the physiology and sensitivity of species and their perception of impacts;
- the life-cycle stage, season, inclination and current activity (e.g. feeding, resting);
- the function and attractivity of the project site (e.g. as feeding ground);
- the ability to adapt or habituate to a certain effect.

The observed effects can be manifold, ranging from acute effects (e.g. death due to poisoning or mechanical impact) over loss of habitat (e.g. destruction or avoidance of previously occupied habitats) to long-term chronic effects (e.g. accumulation of pollutants, stress, reduced fertility etc.) and can impair single species as well as the functioning of entire ecosystems if key species are affected.

For each species, the relevant impact factors should be identified, and their potential effects described and evaluated in the EIA. As the evaluation will typically involve some degree of uncertainty, a precautionary approach should be adopted in the data assessment.

Mitigation and avoidance measures

This section lists the various mitigation measures that are proposed for the project. For instance, these may involve specific drilling and construction practices to minimize impacts.

B.9.2 Marine biological resources

Existing setting

This section describes the marine fauna and flora before construction, usually based on literature data (if available) and site-specific baseline monitoring surveys.

The systematic description of the marine biological resources can be broken down into habitat (i.e. sandy beaches, rocky shores, etc.) or biological communities, in particular:

- plankton (phyto- and zooplankton including eggs and larvae);
- benthos (infauna and epifauna);
- fish species (commercially used species might also be included in chapter B.7.5);
- birds (feeding and resting on the water, nesting sites on land etc.);
- mammals and reptiles (feeding grounds and breeding/haul out sites on land).

Similar to the data requirements for terrestrial biological resources, the description of marine biological resources should include information on the abundance and distribution of single species, their endangerment and protection status, as well as information on the community structure, biological diversity, protection status or importance of habitat types.

Impacts

The discussion of impacts of desalination plants on marine biological resources will mainly involve the following aspects:

- temporary and permanent impacts from construction of intake, outfall or other artificial structures (e.g. seawalls, jetties), such as
  - disturbance of sediments which may affect benthic species;
  - loss of habitat by surface covering;
  - provision of artificial hard bottom substrate for settlement (artificial reefs);
  - resuspension of sediments which may affect pelagic species;
  - emissions of noise and vibrations;

- impacts from impingement and entrainment;
- impacts from reject streams and residual chemicals.

An overview of potential impacts of desalination projects on the marine environment with emphasis on the effects of reject streams and chemical is given in Part C, p. 50ff.

The evaluation of impacts on marine species should involve a risk characterization of the chemicals and formulations that are used for pretreatment and cleaning in desalination plants. This typically entails an investigation of chemicals and formulations in terms of:

- acute and chronic aquatic toxicity;
- long-term sediment toxicity for substances which may accumulate in sediments;
- bioavailability to species, bioaccumulation and biomagnification in the food web;
- environmental fate and effect under aerobic and anaerobic conditions, in particular biotic and abiotic degradation, adsorption potential to suspended matter and transport into sediments, or potential for reaction with seawater constituents.

The information can often be obtained from scientific journals, chemical data banks (e.g. TOXNET[27]) or Chemical Safety Data Sheets. Laboratory tests may be specifically carried out to test the acceptability of substances, formulations, or the whole effluent. Details on toxicity testing are also provided on p. 29f. (section on chemical engineering details).

Mitigation and avoidance measures

This section lists the various mitigation measures that are proposed for the project. This might include design aspects or techniques to facilitate mixing of the effluent in the receiving water body and to reduce the salinity, temperature and other potentially harmful constituents of the effluent, development of an ongoing monitoring programme, or measures to reduce entrainment and impingement of organisms such as use of subsurface intakes (e.g. beach wells), screening techniques, or controlling the velocity of the intake water.

Another important consideration is the use of chemicals and formulations for pretreatment and cleaning that possess little or no environmental risk. If possible, hazardous substances that are toxic, persistent, that tend to bioaccumulate or have other adverse properties should be avoided or substituted by chemicals and pretreatment systems that minimize impacts on marine biota. If feasible, treatment of residual chemicals should be considered before discharge into the environment.

[27] http://toxnet.nlm.nih.gov

B.10 Conclusion and recommendations

This chapter gives a concise account of the main findings and recommendations of steps 5 to 7 (chapters A.2.5 to A.2.7 in Part A, chapters B.7 to B.9 in Part B). It should focus on the key information that is needed for decision-making.

B.10.1 Overview on the main impacts of the project and mitigation measures

An overview of the main direct and indirect impacts (possibly in the form of a table) should be provided, distinguishing between significant impacts which can be prevented or minimized, and those which cannot. Mitigation measures should be listed for significant impacts where possible. Special emphasis should also be given to effects of the project that may become significant when viewed in connection with the effects of past, current or future projects, as well as growth-inducing, wide-ranging or transboundary effects.

Cumulative impacts

Cumulative impacts are two or more individual effects, that when combined are considerable or which compound or increase other environmental impacts. This section is included in most EIAs and usually looks at other proposed and existing developments in a region, as well as other existing and proposed desalination plants.

Growth inducing impacts

The EIA should include a discussion of a desalination project's potential to foster economic and demographic growth in a region. This may include the opening of new business opportunities or the construction of additional roads or housing in the region. Significant adverse environmental effects are not necessarily to be expected, but may result depending on the type, magnitude and location of growth. The proposed project's growth-inducing potential may be considered significant if it could result in significant physical effects in one or more environmental concern areas. For example, additional population growth can lead to increased urban runoff and other water quality impacts, and strains on other natural resources such as land use.

Wide-range and transboundary effects

Effects that may have an impact beyond the immediate vicinity of the plant and discharge site, or beyond regional or national boundaries, should be disclosed here. Such impacts may occur for example due to dispersal of pollutants, or impacts of the project on migratory species that may affect their abundance or survival in other areas (e.g. destruction of breeding sites of endangered migratory birds).

B.10.2 Comparison with alternative project configurations

The original project proposal should be systematically compared with alternative project configurations in terms of adverse and beneficial impacts and effectiveness of mitigation measures. As far as possible, trade-offs and uncertainties should be mentioned.

B.10.3 Identification of the best practicable environmental option

No universally valid standards for environmental quality, acceptable risks, best available techniques or best environmental practice exist. Standards vary regionally, as does the use of desalination with regard to processes, pretreatment systems and discharge options, or the environmental setting, socio-economic background and human health conditions in project sites. The consideration of benefits versus impacts of a desalination project can only be achieved at a local, project-specific level. The 'best practicable environmental option' should be identified in this section, which is the preferred configuration of a specific project under environmental, social, cultural, and public health criteria. It should be economically and technologically feasible. The decision should be transparent and backed by conclusive arguments.

B.11 Environmental management plan

An environmental management plan builds continuity into the EIA process and helps to optimize environmental benefits at each stage of project development. The key objectives of environmental management plans are to [5]:

- identify the actual environmental, socio-economic and public health impacts of the project and check if the observed impacts are within the levels predicted in the EIA;
- determine that mitigation measures or other conditions attached to project approval (e.g. by legislation) are properly implemented and work effectively;
- adapt the measures and conditions attached to project approval in the light of new information or take action to manage unanticipated impacts if necessary;
- ensure that the expected benefits of the project are being achieved and maximized;
- gain information for improving similar projects and EIA practice in the future.

If an environmental management plan has been established, a chapter of the EIA report should briefly outline the details of the plan for each project life-cycle stage, covering the planned monitoring, surveillance and auditing activities and specifying the schedules, methodologies, protocols etc. to be followed. When devising an environmental management plan, consideration should be given to involve the public in the follow up activities, which may range from public disclosure of monitoring and audit reports, over opportunities for review and comment, to the establishment of review committees.

B.11.1 Monitoring

The primary aims of monitoring are to achieve a better understanding of cause-effect relationships between the project and its environment and to improve EIA predictions and mitigation methods for the purpose of an effective impact management [5]. Monitoring refers to the collection of data through a series of repetitive measurements or other systematic observations of environmental, socio-economic and human health parameters. This usually includes a review of available literature data.

Effects or impact monitoring refers to the measurement of environmental parameters in order to detect changes which are attributable to the project, whereas compliance monitoring is the periodic or continuous measurement of environmental parameters to ensure that regulatory requirements and environmental quality standards are being met. Both types of monitoring permit only reactive impact management, since they detect violations or adverse changes after they have taken place. It is therefore important to respond to the outcomes of monitoring by establishing a linkage to impact management, for example by establishing protocols to be followed and actions to be taken if a certain threshold value is exceeded. The monitoring programme should be targeted at the information that is necessary to manage significant impacts and to review the aspects of EIA practice that are of particular importance [5].

B.11.2 Surveillance

Effects and compliance monitoring usually requires reporting of the monitoring data and main findings to the competent authorities and wider public. It permits only reactive impact management after adverse effects or violations of regulatory standards have taken place. For a more pro-active approach to impact management, monitoring activities can be accompanied by regular or periodic site inspections in order to survey the implementation of EIA conditions, such as [5]:

- compliance with conditions imposed by law or by the EIA;
- quality of monitoring activities including sampling, measurements and analysis;
- observation of mitigation measures and general progress;
- discussion of current issues.

Surveillance can be undertaken by the competent authority, independent institutions or experts. Details of surveilling activities, such as scope, frequency and supervisory bodies, should be outlined in the environmental management plan for the desalination project.

B.11.3 Auditing

Auditing describes a systematic process of examining, documenting and verifying that EIA procedures and outcomes correspond to objectives and requirements. It draws upon monitoring data and surveillance reports. The following categories of EIA-related audits can be distinguished [5]:

- impact audits, which determine the project's actual impacts and the accuracy of the predictions made in the EIA;
- implementation audits, which verify that the conditions attached to project approval are implemented as determined in the EIA;
- compliance audits, which verify that project impacts comply with environmental standards and regulatory requirements;
- effectiveness or policy audits, which check the feasibility of mitigation measures and the consistency of EIA practice.

Figure 4: Deployment of a real time monitoring buoy for the Perth seawater desalination plant (by courtesy of 360 Environmental, Environmental Management Consultants, Australia).

B.12 Review of the EIA process

A statement may be included at the end of the EIA document which certifies that the EIA complies with the formal requirements as imposed by national EIA legislative texts and regulations, the Terms of Reference as defined during scoping, or existing general EIA standards. The statement should be provided and signed by the reviewer, which may be the responsible authority itself, another governmental institution or independent body. For more information on the reviewing process, please cf. Step 10 – Review of the EIA and decision-making process on p. 19.

B.13 References of the EIA

Includes all references cited in the EIA and possibly key references for further reading.

B.14 Appendices of the EIA

Relevant studies to be included in the appendix may for example be:

- visualizations of the project and visual impact assessment;
- survey studies of biological resources in the locality;
- survey studies of abiotic characteristics of the locality;
- technical reports on air, soil and water quality;
- hydrodynamic modeling studies of mixing, dilution and dispersal of reject streams;
- laboratory test reports on toxicity, abiotic and biotic degradation of substances;
- technical report on energy requirements;
- surveys regarding human health, socio-economic and cultural resources.

Back matter to an EIA report (sections B.13 – B. 14)

The back matter of an EIA report includes the reference cited in the EIA and possibly key references for further reading. It furthermore contains appendices with additional or more detailed information on the proposed project, cartographic materials and larger figures (e.g. flow-charts), or independent technical reports or surveys that were prepared as part of the EIA process. In this way, more detailed information is easily accessible without burdening the EIA document with too many facts. In the EIA, the relevant information from these studies is usually summarized.

Part C

Potential impacts on the environment

This chapter is considered as a reference source that provides an overview of the potential impacts of desalination projects and references for further reading. *It focuses on the impacts which are specific to desalination projects, and in particular on the impacts of reject streams and chemical additives on the marine environment*. Impacts which are common to many development projects are not covered here but listed in Part B of this document. It is assumed that common effects are sufficiently known and information is readily available from relevant literature.

It must be pointed out that there are still some gaps of knowledge and uncertainties regarding the actual impacts of desalination projects, as monitoring results of operating plants are only available to a limited extent. Also, a wide variety of project- and site-specific impacts may occur.

The following list can thus not be complete nor final, and not every described effect will apply to each individual project. Further research is certainly required, including field and laboratory experiments, and provision of the monitoring results to a wider audience is recommended.

C.1 Ecological risk assessments

EIA studies are often based on a so-called "ecological risk assessment" approach. The objective of this approach is to systematically identify and evaluate the relationships between *stressors* as caused by anthropogenic activity (*exposure analysis*), and subsequent impacts on *receptors* (*effects analysis*).

Stressors can be all single characteristics of a project or activity that lead to an ecological effect. Stressors can be of chemical, physical, or biological nature, such as for example the release of a chemical, the mechanical impact from construction, or the introduction of an alien species. The *receptors* are the different environmental features, usually operationally defined by an ecological entity (e.g. a single species) and its indicators (e.g. population size, biodiversity).

The objective of the *exposure analysis* is to describe the exposure of receptors in terms of intensity, space, and time. To this end, exposure pathways are established, including the stressor source, the spatial and temporal distribution of stressors in the environment, and the extent and pattern of contact or co-occurrence with receptors. The ecological effects analysis then investigates the relationship between stressor *levels* and resulting responses [21].

In essence, the ecological risk assessment approach is based on an analysis of how exposure to stressors is likely to occur and on an analysis of the significance of the associated impacts. The result is a list of stressor-response relationships, often also termed cause-effect relationships.

As ecosystems are diverse and complex systems, these relationships are often interrelated and have a netlike rather than a linear structure, as one stressor may lead to multiple exposures and may also cause secondary (indirect) effects. The establishment of single cause-effect relationships should therefore be understood as a simplified conceptual model which is used to systematically predict and investigate the key relationships between stressors and receptors.

The level of detail and accuracy of the cause-effect relationships depends on how well information on stressor sources, exposure opportunities, characteristics of the ecosystem at risk and ecological effects is available. Risk assessments are typically conducted at a time when not all necessary information is available, in which case the process helps to identify missing data.

On this basis, an analysis plan is usually developed that includes a delineation of the assessment design and a framework for further investigations, including data needs and techniques for data collection. In the following analysis phase, the ecological effects predicted in the cause-effect relationships are further investigated and refined.

The cause-effect relationships are typically summarized in a *risk matrix* (preference matrix or Leopold matrix), in which the columns represent the various stressors (or causes) of a proposed project and the rows represent the various environmental receptors (or media such as water). In the fields where rows and columns intersect, the potential ecological effects are listed. The risk matrix provides the basis for *risk characterization*. In this step, the stressor-response relationships are integrated into an overall risk estimation and description, which takes the significance and likelihood of effects into account as well as the limitations of the method and the analysis, such as scientific uncertainties and assumptions. Risk characterization is to be distinguished from risk management and decision making, which involves the selection of a course of action in response to the identified risks and other factors (e.g. social, legal, political, or economic) [21]. The stressors and receptors provide the system boundaries for EIA studies. Stressors are usually classified according to life cycle stage and project components. In the following, stressors and receptors relevant to desalination projects are listed.

C.1.1 Stressors

Stressor sources of desalination projects can be subdivided into the following life cycle stages and key elements:

- construction
- commissioning
- operation
- maintenance
- decommissioning / demolition

The key elements of a desalination system are:

- the intake system, including the
  - inlet with screens
  - seawater supply pipeline to the shore
  - pumping station or submersible pump
- the desalination system, including the
  - pretreatment line
  - desalination units
  - product water storage
  - pumping / high pressure system
  - post-treatment line
  - storage facilities
  - car park, gates, etc.
- the outfall system, including the
  - outfall channel or tunnel
  - diffuser system
  - pumping station or submersible pumps

The main auxiliary infrastructure includes:

- the water distribution pipeline
- the energy supply source and transmission line
- access roads to the facility

C.1.2 Receptors

An environmental assessment should address the effects of a project on fauna, flora, soil, water, air, climate and landscape, including all direct and indirect effects and the interactions between single factors. Based on this definition the following categories will used for describing the potential impacts of desalination projects on the environment:

- Landscape and natural scenery
- Air quality and climate
- Soils
- Seafloor and sediments
- Ground- and surface water quality and hydrology
- Seawater quality and hydrology
- Terrestrial flora and fauna, which can be further subdivided into different functional and taxonomic groups, i.e. plant communities and habitat types such as salt marshes, dune vegetation and coastal scrubs, or taxonomic groups such as invertebrates, mammals, amphibians, reptiles, and birds including migratory and resting seabirds.
- Marine flora and fauna, which can be further subdivided into the different functional and taxonomic groups, i.e. phyto- and zooplankton, benthos such as macroalgae, seagrasses, benthic invertebrate species, demersal fish species, pelagic fish species and turtles, marine mammals and seabirds.

Furthermore, potential impacts on human beings, material assets and the cultural heritage need to be evaluated where relevant. *Socio-economic, cultural and environmental health aspects were considered in Part B*, which identifies a wide range of potentially relevant issues associated with the construction and operation of desalination projects and also the distribution of the product water, including impacts on population, housing and community structure, economic growth and development activities, water resources, land and marine use, utilities and services, environmental health factors and cultural resources.

This chapter (Part C) contains only the analysis and description of *strictly environmental impacts* of desalination projects, limited to the most common abiotic and biotic environmental factors. Stressor sources are categorized by life-cycle stage and potential impacts on relevant receptors (as outlined above).

C.2 Construction activities

For a systematic description and investigation of impacts, the construction activities can in general be subdivided into three main categories. These are the construction works:

- at sea for the intake, the outfall and the seawater supply pipeline to the shore,
- at land for the desalination facility, pumping station etc., and
- for connecting infrastructure, e.g. product water pipelines or power transmission lines.

Construction activities and ecological effects will differ for the offshore and onshore sites. The offshore structures, the desalination facility and the connecting infrastructure each form a structural entity, which is also relevant for the investigation of alternative technologies, sites or routes. Moreover, the permitting process for the project and connecting infrastructure are often carried out independently from each other, e.g. separate EIAs may be required for the project and the water supply pipeline in which different technologies, sites and routes are evaluated.

C.2.1 Intakes and outfalls

Intake types

Intake structures can be subdivided into open intakes and sub-(non)-surface intakes. For open intakes, the inlet structure can be located at the shoreline, typically near the surface or shallow water, or further offshore and in deeper water layers (submerged intakes). The seawater transmission pipeline from the offshore intakes to the shore can either be placed on or below the seabed.

In contrast, below ground intakes are completely embedded in the seafloor, either in the beach sediments onshore, such as vertical and radial beach wells or infiltration galleries, or in the offshore marine sediments, such as horizontally drilled drains (HDD). Beach wells are typically drilled 30 to 50 m deep into the seabed, whereas infiltration galleries consist of perforated pipes arranged in a radial pattern in the saturated sand onshore. Both are mainly used for smaller seawater reverse osmosis (SWRO) systems. Favorable conditions for beach wells are geologic formations with a high transmissivity and a certain sediment thickness, whereas unfavorable conditions include beaches with high volumes of mud and a low degree of “flushing”, such as a beach in a shallow bay environment, where beach wells may become blocked [22]. An overview on relevant issues of beach-wells intakes is given in [23].

Open intakes are still the most commonly used intake system for large desalination plants, although horizontally drilled drains are reported to be used successfully in some larger SWRO plants and in different geological formations, both rocky and granular [24]. By mid 2004, however, there were only four SWRO plants with capacities larger than 20,000 m^3/d throughout the world using beach wells for intakes according to [23]. Two desalination plants using horizontal drills (NEDODREN® technology) with a capacity of 25,920 m^3/d and 172,800 m^3/d are listed in [24]. Horizontal drain pipes were also considered for the 200,000 m^3/d plant in Barcelona, Spain, but an open intake was finally preferred over wells for several reasons, such as assuring a greater water availability. Also, it was found that both well water and open water would require similar pretreatment, as the open intake provided only a slightly worse water quality [25].

Screens, such as fine mesh screens, travelling or drum screen, are usually placed in front of the open intakes to reduce the amount of debris and the number of organisms that are taken into the plant with the feedwater. In some cases, a breakwater basin may be constructed for the intake (Figure 5).

Figure 5: Open intake basin with breakwater.

Outfall types

The most widely used method of concentrate disposal is surface water discharge via a single open outfall or a diffuser system. Options for co-discharge exists with power plant cooling water. Large distillation plants are typically cogeneration plants, i.e. they are co-located to power plants and receive thermal energy (steam) from the low-temperature end of the electricity generating turbine. Co-location is also an option for SWRO projects and is proposed/practiced for some large projects (e.g. Carlsbad and Huntington Beach projects in California [26, 27], Tampa Bay plant in Florida [28], Ashkelon and Hadera plants in Israel [29, 30]). Co-discharge with wastewater treatment plant effluents is another option (e.g. Santa Barbara SWRO plant [31], proposed City of Santa Cruz' SWRO plant in California [23]). However, there are several issues associated with the practice of blending SWRO concentrate and wastewater treatment plant effluents, such as toxicity of the combined discharge.

Brine disposal via a subsurface discharge structure involves discharge into a beach well or percolation gallery beneath the beach or seafloor. Mixing occurs in the groundwater table and the discharge plume is slowly dissipated into the surf zone. Percolation galleries are in some locations considered as an effective way to minimize environmental impacts where suitable hydrogeological conditions exist. This practice is for example used for the Marina Coast Water District desalination plant with a capacity of 1,000 m^3/d and will also be used at the proposed Sand City facility with a capacity of 1,700 m^3/d in California [23]. It seems to be mainly an option for smaller SWRO plants.

Alternatives to surface or subsurface disposal include sewer discharge, deep well injection, evaporation ponds or zero liquid discharge (ZLD). These methods are mainly used for inland brackish water reverse osmosis (BWRO) plants but normally not for SWRO plants [32].

Construction activities

Different construction methods can be used for installing the intake and outfall pipelines. A basic distinction is between open-trench techniques, involving submarine excavators or jet streams for embedding the structures in the seafloor, or trenchless techniques. Alternatively, the structures can be placed above ground and moored to the seafloor. The construction impact, though temporary and confined to the location of the works, may be significant. The severity of the impact is a function of the level of disturbance to the environment and of its natural sensitivity, which in turn is dependent on the specific nature of the habitat and on the specific communities [33].

Open trenches were for example used for the three intake pipelines of the Ashkelon plant in Israel. Each pipeline had a length of 1,000 m and a diameter of 1.6 m. A trench of 6 m depth was excavated by a marine excavator and the sand from the trench placed on the seabed. The sand was used for re-filling of the trench in order to restore the seabed to "its former state" [29]. This kind of construction activity probably disturbs the layers of sand and clay along the excavated ditch. Sediment material may become resuspended during the laying of the pipes, and rocky areas and reefs may suffer mechanical blows [33]. A similar open-trench construction technique was used for laying the three 1.8 m diameter, 1.3 km long intake pipelines of the Hadera SWRO plant in Israel [30].

Assuming that each trench would be 2 m wide, about 36,000 m^3 of material (a volume equal to 1090 standard 20-ft containers) would be moved for the construction of three pipelines and temporarily stored on the seabed. Spoil deposition will likely double the size of the impacted seafloor area. Open trench techniques may result in a disturbance of the natural sediment layers, cause sediment compaction where machinery movements take place or where spoil is deposited, and affect the local benthic fauna. Effects such as sediment compaction and disturbance of benthic ecosystems normally require a longer recovery time than the restoration of the seabed to its former topography.

Trenchless techniques are conducted by horizontal drilling from an onshore site, e.g. by horizontal drilling of several radial drains (e.g. NEDODREN® technology [34]) or tunnel boring and lining the tunnel with concrete segments [35]. In the first case, the porous drains for the intake are completely embedded in the seafloor (i.e. in a permeable stratum in the marine subsoil) and the working area is minimized to two small areas, one on land and one offshore [34]. The pipeline is reamed by means of a pushing-reamer. The detritus coming from the bore is carried out to the exit point on land, thus preventing that it affects the sea area [24]. In the second case, one or several intake structures protrude above the seafloor, which are connected to the tunnels by drilling through the seabed, usually from a jack-up barge. For example, the internal diameter of a tunnel for a 100 GL/a SWRO plant (274,000 m^3/d) is expected to be about 3 m and approximately 4 m for a 200 GL/a plant [35].

Similar to open trench techniques, considerable amounts of material are produced by trenchless construction operations but the spoil is usually carried out to the exit point on land. For example, a tunnel with a length of 500 m and a diameter of 3 m would result in the displacement of at least 3,500 m^3 of material or about 100 standard containers (20-ft).

Soil and material stockpiles, fuels, lubricants, solid and liquid wastes stored within the active construction area may have detrimental effects on the environment without appropriate material management plans. Contaminants could be released into soils, sediments or water bodies, or the placement of construction materials, including equipment, pipes, shoring and spoils, could temporarily impede or redirect flows during heavy rainfall and stormwater runoff.

The magnitude of construction impacts largely depends on the design of the intake and outfall systems and the construction methods used. The most environmentally acceptable intake appears to be a sub-floor ocean intake, however, this requires specific geological conditions which are not present at all sites [23]. In general, horizontal drilling or tunneling from the shore will minimize the disturbance of the coastal ecosystem, while underwater construction activities such as digging or the use of jet streams will generally have a larger physical impact on sediments, water and marine life. However, noise emissions and groundborne vibrations may be higher when drilling, blasting or pile driving is necessary for construction pipes in rocky undergrounds.

Impacts will also depend on the selection of the site and pipeline routes and the length and diameter of the pipe. These factors require thorough consideration, as for example a longer pipeline may evade some sensitive ecosystem but would affect a larger area. Another important factor is the season in which construction activities are carried out, as species abundance and vulnerability may vary over the course of a year. For example, seals come ashore for moulting and birthing and many fish species spawn in coastal waters in a certain time of the year.

Potential impacts on receptors

Seafloor and sediments

Disturbance of sediments

Construction activities may cause a displacement or disturbance of sediments and sediment layering, or a compaction of sediments.

Artificial structures

When placed above the ground, the intake and outfall structures and pipelines can act as an artificial breakwater. A breakwater may change wave and current patterns and thereby interfere with dynamic sediment processes, such as erosion or deposition, which may cause a redistribution of sediments along the shoreline. In front of the breakwater, sediments are normally trapped while in the backward side scouring occurs. Furthermore, a prominent breakwater may also intercept sand which is transported along the shore with coast-parallel currents. As the breakwater deprives the down drift shore of sediment, erosion may occur in other locations due to reduced sediment supply.

Accidental spills

Accidental spills of chemicals, oils or fuels, or the leakage of these substances from underwater construction machinery may cause localized sediment contamination.

Seawater quality and hydrology

Resuspension of sediments

The disturbance of sediments may lead to a resuspension of material into the water column and a temporarily increased turbidity in the vicinity of the construction site (Figure 6).

Nutrients and pollutants deposited in the sediments may become resuspended along with the sediments. Water quality may thus be affected by increased levels of suspended matter, nutrients or pollutants, or by reduced oxygen levels potentially caused by a resuspension of anaerobic sediments.

Artificial structures

Above ground structures such as pipelines or breakwaters normally cause wave refractions and changes to longshore currents.

Accidental spills

Accidental spills or leakages may impair seawater quality.

Marine flora and fauna

Mechanical impact

The construction of intake and outfall structures and the laying of pipelines above or below the seabed may lead to a destruction of benthic habitats. The mechanical impact is usually lethal for benthic organisms in the immediate construction site. Studies of biological communities in nearshore soft-bottom habitats have demonstrated that such communities often take one to three years to recover from disturbances, such as for example caused by boat anchors. Rocky substrate also can sustain adverse environmental effects caused by the laying of pipelines and other construction activities when blasting is required [23].

Resuspension of sediments

Furthermore, the disturbance of sediments may have short term indirect effects on marine life. These can be manifold, including potential impacts on filter-feeding organisms or the gills of fish from sediment plumes, impacts on light penetration and photosynthesis due to increased turbidity, potential effects of eutrophication due to the remobilization of nutrients, the potential ingestion and accumulation of pollutants from contaminated sediments, or the effects associated with the resettling of sediments which may cause the burial of benthic fauna and flora or fish spawn.

Disturbance and temporary habitat loss

Construction activities may cause a significant disturbance of sensitive wildlife, e.g. of marine mammals or seabirds, through noise emissions, vibrations and sediment plumes. Where noise impacts on sensitive wildlife are expected, consultation of an expert may be recommendable. Especially dredging and drilling may produce low frequency noise emissions under water, including structure-borne sound emissions and vibrations, which can travel over considerable distances. Under water construction machinery emits sound waves mainly in the low frequency range. For example, dredging systems emit sound waves in the frequency range between 20 Hz and 1 kHz with sound levels of 150 to 180 dB (re 1 µPa, in 1 m distance) [36].

Depending on the sound level, distance from the noise source and hearing ability of the potentially affected individuals, noise emissions can have different effects. Most likely are behavioral responses such as to stop foraging, to start directed movements away from the noise source and avoidance of the construction area. Other potential effects include the masking of communication or echolocation sounds, or potential impacts on hearing abilities that may be caused by very loud noises such as caused by ramping or blasting. In addition, low-frequency sounds and loud sounds can generally be perceived by the sense of touch as vibrations (see also Box 1).

⏩ *Permanent habitat alteration*

Structures above the seafloor provide hard-bottom substrates to which sessile, epibenthic animals can attach, such as algae, anemones, mussels. The prolific growth of such an artificial reef often attracts other reef-dwelling invertebrate species for food or shelter, such as echinoderms (e.g. starfish, sea urchins), crustaceans (e.g. shrimps, lobsters), or marine snails (abalone, limpets), and often shows increased densities of pelagic and benthic fish species. In a sandy environment, the introduction of hard-bottom substrates may lead to placement impacts, i.e. the small-scale loss of habitat for the native benthic infauna due to sediment sealing.

Indirect effects may result from the introduction of new species to a certain location, due to the reef effect, which may alter the existing community structure and local predator-prey relationships.

Furthermore, changes in sediment transport attributed to artificial breakwaters may lead to the degradation of nearby or down-drift sandy habitats, such as seagrass beds, which may be affected by changed erosion and deposition patterns.

⏩ *Accidental spills*

Accidental spills or leakage of lubricants could affect marine life in the vicinity of the spill.

Figure 6: Construction of a sheet pile trench for the Perth seawater desalination plant with minor plume development (by courtesy of Water Corporation of Western Australia).

Box 1: Noise emissions

Noise is defined as an unwanted or undesirable sound. Although sound levels are relatively easy to measure, it is much more complex to evaluate impacts in terms of subjective perception and response. These will depend on many variables, including the sound level and frequency, the distance of the individual to the sound source, the type of sound (e.g. fluctuating or constant), background noise levels, the hearing abilities of the species and the individual, or other factors that may influence if individuals tolerate or even habituate to a noise source, such as attractiveness of an area as feeding or breeding grounds for wildlife species.

When investigating potential impacts on marine organism, the physics of sound propagation under water must be taken into account. The speed of sound in seawater varies approximately between 1460 m/s and 1555 m/s depending on salinity, temperature, and pressure as a function of water depth, and is thus more than four times faster than in air. As the sound waves propagate through a medium, they lose energy (transmission loss). In an unbounded medium such as deep ocean water, spherical spreading occurs, while in shallow coastal water, the propagation of sound is bounded by the sea surface and the seafloor, so that a cylindrical spreading occurs. The transmission loss is smaller for cylindrical spreading than for spherical spreading. It can be calculated by $TL = 10 \log_{10} R$ in decibels [dB], with R being the distance from the source. For cylindrical spreading, it can be approximated that a doubling of the distance causes a reduction of the sound level by 3 dB [37]. Depending on the frequency spectrum, salinity, temperature and pressure, the transmission loss may differ from this nominal value. For example, deep-frequency sound waves have lower transmission losses and can travel greater distances than high frequency sound, while e.g. high seawater temperatures in summer could increase transmission losses.

The noise emissions from construction are audible for marine species within range, depending on their specific auditory frequency ranges and hearing thresholds. While humans can generally hear sounds with frequencies between 20 Hz and 20 kHz, marine organisms have different hearing abilities. For example, audible frequencies range between 1 kHz and 150 kHz for harbor porpoises, with highest sensitivity in the range from 16 kHz to 140 kHz and hearing thresholds of 32 to 46 dB re 1 µPa in this frequency range [38, 39], or between 75 Hz and 60 kHz for harbor seals, with highest sensitivity in the range from 10 to 30 kHz and a hearing threshold of 60 to 70 dB re 1 µPa in this frequency range [40]. In principle, fish species can also detect sound waves, but the audible frequency seems to be limited to low frequencies between 30 Hz and 1 kHz [41]. Low-frequency sounds and loud sounds can also be perceived through the sense of touch as vibrations.

Some further explanations: The sound pressure is the sound force per unit area, while the sound intensity is the acoustical power per unit area in the direction of propagation. Both sound pressure level (SPL) and sound intensity level (SIL) are measured in the logarithmic decibel (dB) scale. The A-weighted scale dB (A) is used to evaluate noise disturbances to humans. It weighs the frequencies of the measured sound levels in a way that corresponds to the way the human ear perceives the sound. In contrast, the linear weighted scale dB (linear) uses equal weights for all frequencies and is often used to investigate impacts of noise on wildlife. The equivalent sound level Leq is used to “quantify” the noise level of a fluctuating sound over a specific period of time in order to compare it with threshold levels. It is a sound-energy average which takes maximum noise levels, number and duration of noise events into account. The reference sound pressure levels are 20 µPa in air and 1 µPa in water. Due to these differences, 100 dB in air is not the same as 100 dB in water. The conversion factors from air to water are +26 dB for SPL and +62 dB for SIL. For example, a noise of 100 dB re 20 µPa (at 1 m distance) in air would be equal to a noise of 162 dB re 1 µPa in water.

C.2.2 Desalination plant

Land requirements

Desalination plants usually consist of a set of buildings that house the pumping station, the pretreatment and post-treatment line, energy recovery units and desalination units. Normally also part of the complex are storage water tanks, office buildings, a car park, fence and gate. In [42], the area required for SWRO plants is given with approximately 10,000 m^2 (1 ha) for 5,000 to 10,000 m^3/d product water. It is not possible to establish an exact correlation between plant size and land use. However, taking this estimate as a rough rule of thumb, the area of land required for a large SWRO plant of 100,000 m^3/d capacity would be between 10 and 20 ha. The following examples illustrate the land requirements of some large SWRO projects:

- Plant with 548,000 m^3/d (200 GL/a) capacity: 20 to 40 ha, which includes an operational buffer area [35].
- Plant with 500,000 m^3/d capacity: about 30 ha, of which about 20 ha would be covered in impervious surfaces such as buildings, roads, and hardstand areas, plus an additional 15 ha area which would become a conservation area (total of 45 ha) [43].
- Plant with 274,000 m^3/d capacity: about 10 ha [33].
- Plant with 189,000 m^3/d (50 mgd) capacity: about 1.6 ha, of which about one quarter would be required for the desalination facility and another quarter for the pretreatment area [26]. The facility will be constructed within the 38 ha compound of a power generation plant, which might explain the comparatively lower land use.

Construction activities

Construction generally comprises the initial earthwork activities (site grading, excavation), the laying of foundations, construction of facilities, and landscaping measures (e.g. pavings, planting with trees, grass etc.). The area affected depends on the size and architectural design of the facility. Additional corridors must usually be allowed for access and maneuvering of machinery.

Construction activities will typically involve all kinds of heavy machinery, including several bulldozers, excavators, graders, compactors, cranes, etc., as well as forklifts, loaders, and trucks for hauling away debris and excavated soils, and delivering construction materials and plant components. For instance, it is estimated that construction of a 189,000 m^3/d facility will require a 24 month period when the desalination facility, the pump station, and the intake and discharge pipelines are constructed simultaneously. Construction would require a crew of up to 80 workers on site. It would involve about 13,360 truck trips and the handling of about 40,000 m^3 of soils (or 1,200 standard 20-ft containers). The greatest amount of equipment operating at the site would be during the earthwork phase, when 3 excavators, 3 backhoes, 3 loaders, 2 graders and 2 compactors would be operating on site, and in the building structure phase, when 3 cranes, 2 cement mixers, 4 forklifts, 1 aerial lift, 1 generator set and 4 welders would be needed. Other types of equipment used during different phases would include pumps, pavers, rollers, pile drivers, trenchers and a drill rig [26].

Potential impacts on receptors

Landscape and natural scenery

Aesthetic impacts of construction

The construction activities can temporarily impair the aesthetic landscape properties and the natural scenery in the construction site and nearby areas within visual and acoustic range. The impacts will vary in terms of intensity and duration depending on construction phases (day-night-differences, working week vs. weekend, busy and more quiet construction periods). Causes of annoyance may be the ‘hustle and bustle’ caused by the movements of construction machinery and increased traffic on roadways, the emissions of dust, exhaust fumes and noise, or the stockpiling of soil, debris, equipment and materials if exposed to public views.

Construction-related clearing of mature vegetation and lack of screening of the project site may intensify visual disturbance.

Aesthetic impacts upon implementation

Following construction, exposure of certain features of the plant facilities and exterior mechanical equipment could potentially result in degradation of the visual character or quality of the site. The degradation could represent a potentially significant impact if it has a substantial adverse effect on scenic vistas or the existing visual character of the site [26]. The significance of impacts therefore depends on the existing scenic features and the architectural design of the facility. Prominent features of the plant may include for example the main building when exceeding a certain height, storage tanks, air conditioning, plumbing lines, duct work and transformers. Significant aesthetic impacts can also be related to the production of glare on metallic or glass surface, exterior lighting and noise generation which adversely affect the day and nighttime views in the area.

Air quality and climate

Air quality may be affected by construction-related emissions. The main emission sources are fugitive dust generated by demolition of structures and site grading and trenching, and exhaust generated by construction equipment, trucks and worker vehicles.

Fugitive dust is the main contributing factor to increased levels of particulate material (PM_{10} and $PM_{2.5}$), but diesel exhaust also contributes to an increase in PM-levels in the construction site.

Other air pollutants resulting from exhaust emissions which may affect air quality include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen and sulfur oxides (NO_X and SO_X), and reactive organic compound (ROC, an ozone precursor substance).

Estimated daily emissions generated during construction on site for a 189,000 m^3/d desalination facility in California were as follows:

- 132 kg of CO
- 21 kg of ROC
- 176 kg of NO_X
- 15 kg of SO_X
- 14 kg of PM_{10}

Based on these results, it was concluded that construction activities may result in NO_X-emissions that temporarily and locally exceed the established emission threshold during peak activities [26].

The emissions are project-specific, however, they illustrate the order of magnitude of construction-related air emissions and indicate that construction causes a localized and temporal, but measurable increase in air pollutants. Project-specific emission estimates, based on the specific emission factors of construction vehicles and fuel type, existing background levels and other emission sources in the vicinity need to be taken into consideration when evaluating if project-related construction activities may violate any existing air quality standards.

Soils

Surface sealing and compaction

If the plant is built on a previously undeveloped site it will have certain placement impacts. Impacts of construction activities on soils include the surface sealing caused by buildings and asphalt and soil compaction by construction machinery, which may reduce air, water and nutrient exchange, reduce the permeability of soils and may impair natural soil processes.

Erosion

Where vegetation has been cleared und where underlying earth is temporarily exposed, the soil may be prone to erosion by runoff rainwater, wind, or wave action near the coastline, which may in turn aggravate the natural recovering process of the vegetation or restoration efforts.

Deposition of excavated material

Debris and excavated material from the construction site must be stored temporarily (if used for refilling) or must be disposed of which may require the identification of a separate soil disposal site.

Accidental spills

Accidental spills of chemicals, oils or fuels, or the leakage of these substances from storage tanks, or the loss of lubricants or fuel by machinery etc. may cause localized soil contamination.

Contaminated soils

When the desalination plant is constructed in a site that was previously occupied by other industrial facilities or used for other industrial purposes, excavation activities may lead to an exposure of contaminated soils or groundwater that, when eroded by wind and rain, could create a potential hazard [23, 26, 44].

Ground- and surface water quality and hydrology

Surface water runoff

Construction activities or certain features of the plant facilities may affect urban runoff and storm water discharge, e.g. by altering or impeding the flow. Loose soils and material, including liquid or solid contaminants, may be washed away by the runoff if not properly managed, and a contamination of the runoff water could have a short-term effect on surface water quality downstream of the project site [26].

Groundwater table

Depending on groundwater levels and the floor elevations of the desalination plant facilities, the groundwater table may be affected by construction activities.

Terrestrial flora and fauna

Clearing of vegetation

A clearing of vegetation or draining of coastal wetlands may be necessary in the construction site when the site is opened up for development. The impact depends on the ground area required and the existing site vegetation, which can be in a natural state or may already show levels of degradation, such as reduced plant coverage or species diversity. Often, an already developed site within an industrial complex is chosen, for example within the compounds of an existing power plant (e.g. [26, 27]) or a site which has already been classified for industrial use (e.g. [44]).

The clearing of vegetation results in a direct loss of this vegetation. The loss will be permanent for all areas covered in impervious surfaces (until project demolition and site restoration) or may be temporal in areas that suffered degradation from the operation of machinery (if re-growth of natural vegetation is allowed or enforced). Often, the natural vegetation is replaced by lawn, flower beds or other gardening measures. The clearing of the natural vegetation also may lead to weed infestations from adjacent areas [45].

Disturbance and temporary habitat loss

The noise levels and general disturbance during construction may scare away sensitive wildlife. The clearing of vegetation means a habitat loss for terrestrial and avian species, which may be minimized and temporary, when re-growth of natural vegetation is allowed or enforced. Potentially affected terrestrial taxa include amphibians (e.g. frogs, salamanders), reptiles (e.g. tortoises, snakes, lizards), mammals (e.g. small rodents, bats) and birds (e.g. breeding seabirds, resting migratory birds).

Edge effects

"Edge effects" may be caused by dust, erosion or run-off and may adversely affect the vitality of the terrestrial habitats [26], including the plant communities and associated fauna in the nearby areas.

Permanent habitat alteration

A permanent loss of natural habitat occurs in all areas covered in impervious surfaces and altered by gardening measures, which makes these areas usually unusable for the local fauna and flora.

Barrier effect

Prominent project features could proclude linkages and movement corridors of wildlife [26].

Accidental spills

Accidental spills or leakage of lubricants could affect terrestrial plants and animals in the vicinity of the spill.

Seawater quality and hydrology

Surface water runoff

Due to the normally close proximity of desalination plants to the sea, loose soils and materials, including liquid or solid contaminants, may be washed into the sea by runoff from the construction site if not properly managed, which could have a short-term effect on seawater quality [26].

C.2.3 Auxiliary infrastructure

The construction of major auxiliary infrastructure, such as water conveyance facilities and offshore pump stations, power transmission lines and access routes, will involve all kinds of heavy machinery such as excavators, cranes or drilling equipment. It will furthermore require the movement of considerable amounts of material and a considerable work force. Construction impacts of auxiliary infrastructure are in the following reduced to *underground* water pipelines. The connection to the power grid can also be made by a *ground* cable but overhead lines are more common.

The impacts are similar in type and nature to the impacts caused by the construction of the desalination facility but may vary in terms of magnitude (depending on the proximity of the facility to the water and power grid, the road system, the selected routes and the construction methods used).

The construction of auxiliary infrastructure causes an additional (cumulative) disturbance to soils, vegetation and fauna along the construction corridors. The impacts can either be evaluated as part of the EIA for the desalination facility, or as a separate EIA if the infrastructure is considered an independent project (depending on the legislative system).

Water transfer pipelines

Construction can be carried out by open-cut and trenchless-techniques. Construction mainly consists of the following consecutive steps: trenching or tunneling, pipe laying, backfilling, compaction, and reinstatement of the previous state (e.g. pavement, vegetation) [26].

For example, for the Melbourne Seawater Desalination plant it is estimated that a construction corridor of 15 to 20 m will be required for a pipeline with a diameter of 1.7 to 2.5 m to allow for trenching, spoil management and access for pipe laying. The pipeline will have a length from 20 to 90 km [35]. An area between 30 and 180 ha will temporarily be disturbed by construction of the water transmission pipeline, in relation to an area of 20 to 40 ha required for the desalination plant itself.

Both open-cut and trenchless construction activities are being considered for the Carlsbad seawater desalination project [26] for different sections of the pipeline. The pipeline is expected to have a maximum diameter of 1.2 m and a maximum length of 25 km. The majority of the pipeline will be constructed by open trench construction techniques, which requires a corridor of maximal 9 m for construction activities and lay-down of equipment, or an area of about 23.5 ha. Trenchless construction activities include micro-tunneling, horizontal directional drilling, or auger boring [26]:

- Micro-tunneling involves the excavation of two jacking and receiving pits, which are vertical excavations with shoring and bracing systems (one on each side of the area to be crossed). A micro-tunneling machine, equipped with either an auger or slurry material removing device, is lowered into the jacking pit and creates a tunnel connecting the jacking and receiving pits. The pipeline can then be installed within the underground tunnel [26].

- Horizontal directional drilling involves the drilling of a pilot hole at a prescribed angle from one end to the other utilizing a pilot drill string. This hole is then enlarged to a suitable diameter for the pipeline by "pre-reaming": a reamer is attached to the drill string and pulled through the pilot hole by a drilling rig. Large quantities of slurry are pumped into the hole to maintain the integrity of the hole and to flush out cuttings. The pipeline is then connected to the reamer and pulled through the tunnel by a drilling rig, again circulating high volumes of drilling slurry. The likely size of the impacted area for this technology would be about 6 m by 12 m at the front of the tunnel and 4.5 m by 4.5 m at the end of the tunnel [26].

- Auger boring forms a bore hole between shafts by means of a rotating cutting head. Spoil is transported back to the drive shaft by helical-wound auger flights rotating inside a steel pipe casing that is being jacked in place simultaneously. The cutting head completely removes the spoil and does not compress the surrounding soil, so that soil heave is not a problem [26].

It is estimated that the construction of the 25 km pipeline can be completed within a 20 month period, assuming that seven segments are constructed simultaneously. For illustration, this would require a crew of up to 200 workers, up to 108 truck trips per day handling about 11 m^3 of soils per truck. Due to forward progression of construction activities along the pipeline route, the intense construction phase would last only two to three days at any one location [26].

Single effects may last longer than this period, for example vegetation re-growth will require a certain time to return to the original state.

Potential impacts on receptors

Landscape and natural scenery

Aesthetic impacts of construction

The construction activities can temporarily impair the aesthetic landscape properties and the natural scenery along the construction corridor and nearby areas within visual and acoustic range. The impacts will vary in terms of intensity and duration depending on construction phases (day-night-differences, working week vs. weekend, busy and more quiet construction periods). Causes of annoyance may be the 'hustle and bustle' caused by the movements of construction machinery and increased traffic on roadways, the emissions of dust, exhaust fumes, noise emissions and vibrations, or the stockpiling of soil, debris, equipment and materials if exposed to public views.

Aesthetic impacts upon implementation

The pipeline will normally not cause any long-term impacts, as it is usually placed underground. Only associated off-site pumping stations may be visible to public views, which are similar in height and dimensions to a one-story, single-family home [26].

Air quality and climate

The construction of auxiliary infrastructure can cause a localized and temporal but measurable increase in air pollutants. The main air pollutants are PM_{10} and $PM_{2.5}$ from fugitive dust and diesel exhaust, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen and sulfur oxides (NO_X and SO_X), and reactive organic compound from exhaust emissions.

Estimated daily emissions generated during construction of a water transfer pipeline for a major desalination facility were as follows:

- 91 kg of CO
- 12 kg of ROC
- 130 kg of NO_X
- 11 kg of SO_X
- 17 kg of PM_{10}

Based on these results, it was concluded that construction activities may result in NO_X-emissions that temporarily and locally exceed the established threshold during peak activities [26].

These figures are project-specific, however, they illustrate the order of magnitude of construction-related air emissions and show that construction of auxiliary infrastructure causes a localized and temporal, but measurable increase in air pollutants. Project-specific emission estimates, existing background levels and other emission sources need to be taken into consideration in order to evaluate if project-related construction activities may violate any air quality standards.

Soils

Soil compaction

Maneuvering of heavy construction machinery and trenching may cause soil compaction and reduce air and water permeability of soils.

Erosion

Where vegetation has been cleared, the soil may be prone to erosion by runoff rainwater and wind, which may in turn aggravate the natural recovering process of the vegetation or restoration efforts.

Deposition of excavated material

The disposal of debris and excavated material from the construction site may require the identification of a separate soil disposal site.

Accidental spills

Accidental spills of chemicals, oils or fuels, or the leakage of these substances from storage tanks, or the loss of lubricants or fuel by machinery etc. may cause localized soil contamination.

Ground- and surface water quality and hydrology

Surface water runoff

Construction activities may temporarily affect urban runoff and storm water discharge, e.g. by altering or impeding the flow. Loose soils and material, including liquid or solid contaminants, may be washed away by the runoff if not properly managed, and a contamination of runoff water could have a short-term effect on surface water quality.

Terrestrial flora and fauna

Clearing of vegetation

A clearing of vegetation will be necessary along the trench. In environmentally sensitive areas, trenchless construction may be utilized. The impact depends on the ground area required, the construction method and the existing site vegetation, which can be in a pristine state or may already show levels of degradation, such as reduced plant coverage or species diversity. The clearing of the natural vegetation may lead to weed infestations from adjacent areas [45].

Accidental spills

Accidental spills or leakage of lubricants could affect terrestrial animals in the vicinity of the spill.

Habitat alteration and loss

The noise levels and general disturbance during construction may scare away animals. The clearing of vegetation means a habitat loss for terrestrial and avian species. The habitat loss may be minimized and temporary, when re-growth of natural vegetation is allowed or enforced. Potentially affected terrestrial taxa include amphibians (e.g. frogs, salamanders), reptiles (e.g. tortoises, snakes, lizards), mammals (e.g. small rodents, bats) and birds (e.g. breeding seabirds, resting migratory birds).

C.3 Commissioning

It may be necessary to discard the membrane storage solution and rinse the membranes before plant start-up, to discard the water from the pretreatment line until the necessary feed water quality is reached, or to discard the product water until the desired product quality is reached.

The discharge from the pretreatment line does not require any special treatment before discharge. Its salinity is identical to that of the seawater. The pH is usually about neutral and is thus slightly reduced compared to ambient seawater, which is slightly alkaline (about 8.3). It does not contain any harmful chemicals, if the discharged water comes from a point located downstream the dechlorination unit. Similarly, the permeate does not have any characteristics which would avoid it from being discharged directly to the sea [46]. If the storage solution contains a biocide or other chemicals which may be harmful to marine life, precautionary measures should be taken before discharge.

Potential impacts on receptors

Seawater quality and hydrology

The discharge of membrane storage solutions may affect water quality. Sodium bisulfite, which is a reducing agent, also prevents biological growth by oxygen depletion and may be used for disinfection or long-term storage of membranes [47, 48]. When discharged to the sea, it may affect dissolved oxygen levels in the discharge site.

Marine flora and fauna

The discharge of membrane storage solutions may affect marine life when it contains biocides or oxygen scavengers.

C.4 Operation

The operation of a desalination plant necessitates the following activities which may have an environment effect:

- intake and pretreatment of the feed water,
- the discharge of the concentrate and other waste streams resulting from the process,
- energy use, and
- handling of hazardous materials.

The activities are discussed in further detail in the following sub-sections.

C.4.1 Intake of seawater

Desalination plants can receive feedwater from open seawater intakes, below-ground intakes or from the cooling water discharge conduits of power plants (cf. also section C.2.1, p. 52). The co-location of seawater desalination plants with power plants provides certain advantages [49]:

- it allows for the use of existing intake and outfall structures, which reduces construction impacts on the marine environment,
- it reduces land use and landscape impacts as the facility is constructed in an industrial area, and does not require additional power transmission lines,
- the intake water is pre-heated which reduces the required energy demand by 5 to 8%,
- it re-uses the cooling discharge water and thereby avoids additional seawater intake,
- it allows for the mixing of the concentrate and the cooling water before discharge, which significantly reduces salinity of the RO concentrate.

However, a major argument against co-location is that it might lead to a continued operation of coastal power plants using once through cooling (OTC) systems, which are not considered to be best available technology (BAT) in terms of environmental impacts in some countries.

In California, for example, power plants with OTC systems are required to prepare comprehensive plans for reduction of impingement and entrainment of marine organisms. Measures include the replacement of OTC systems with air-cooling towers or water close-circulation cooling towers. Desalination plants to be co-located with power plants have executed long-term agreements with their power plant hosts to reserve the right to use the existing outfall and intake systems [50]. Without power plant cooling water discharges, however, the desalination plant cannot receive preheated intake water and dilute the concentrate before discharge. This may result in a slight increase of the projected energy demand (by 5–8%) and may necessitate the implementation of other impact mitigation measures to disperse the concentrate, such as retrofitting with a diffuser system.

Potential impacts on receptors

Ground- and surface water quality and hydrology

Groundwater flows

A concern of below ground intakes which requires site-specific hydrological investigation is their possible influence on groundwater aquifers, e.g. by changing flow directions, causing saltwater intrusion into freshwater aquifers, or conversely freshwater intrusion into coastal aquifers when the freshwater moves from the land towards the ocean [23, 51].

If a desalination plant is constructed further inland, there is a need for pipes to transport the seawater. Leakage from the pipes may result in penetration of salt water into groundwater aquifers or surrounding soils [33].

Seawater quality and hydrology

Influence on mixing processes

The intake of large quantities of seawater may affect water circulation, especially in areas that are characterized by weak natural currents and waves. When the feed water is taken from the cooling water discharge conduits of power plants, no additional effects occur above those already caused by the power plant.

Marine flora and fauna

Entrainment

Open seawater intakes usually result in the loss of eggs and larvae of fish and benthic invertebrate species, spores from algae and seagrass, phytoplankton and zooplankton, as well as smaller marine organisms when these are drawn into the plant with the seawater. The intake velocity of the feedwater can be reduced to velocities of about 0.1 m/s, which is comparable to background currents in the oceans [35], in order to allow mobile organisms to swim away from the intake under these flow conditions.

This mitigation measure, however, is not effective against the intake of plankton organisms which drift passively with currents. Due to the pretreatment in desalination system, which among other steps involves chlorination, it must be assumed that the survival rate of organisms within the desalination plant is minimal.

The mortality caused by entrainment may affect the productivity of coastal ecosystems, but effects are difficult to quantify. Although plankton organisms show temporal and spatial variations in species abundance, species diversity and productivity, it can be assumed that the common native species will be prevalent in coastal surface areas. Furthermore, plankton species have rapid reproductive cycles. Due to these circumstances it seems unlikely that the operation of a single desalination facility will have a substantial negative effect on the ability of plankton organisms to sustain their populations.

The entrainment of eggs and larvae from common invertebrate and fish species will also unlikely adversely affect the ability of these species to reproduce successfully. The reproduction strategy of these species is to produce a large number of eggs and larvae, of which only a small percentage reaches maturity due to natural mortality (such as starvation of larvae or failure to settle in a suitable location).

For example, a sea urchin may release about 1 million eggs of which about 1% may be fertilized, and 1% of the larvae may become mature adults. Even under this scenario, the offspring will account for 100 individuals. Similarly, more than 99% of the fish larvae do not become reproductive adults as a result of natural mortality [26].

The question is if entrainment causes a significant additional source of mortality which may have a substantial negative effect on the ability of a species to sustain its population.

Entrainment effects may be significant depending on local conditions, such as the existence of cumulative sources of mortality (other power or desalination plants), locally present endangered species or species of commercial interest (e.g. some fish species). Entrainment caused by direct seawater intakes may also be a major concern in marine protected areas [23].

While it is relatively simple to quantify the levels of entrainment for a specific project, it is very difficult and complex to estimate the actual ecosystem impacts, especially when cumulative effects with other projects may occur.

▸▸ *Impingement*

Open seawater intakes usually result in the loss of larger marine organisms when these collide with screens at the intake (impingement of fish, jellyfish, turtles etc.). Impingement mortality is typically due to suffocation, starvation, or exhaustion due to being pinned up against the intake screens or from the physical force of jets of water used to clear screens of debris ([23] after [52]).

For coastal power stations using once through cooling water, the impacts of impingement are typically assessed solely on impacts to commercially and recreationally fished species. Impacts on fish species can be significant, causing fish mortality equivalent to the take of a fishery.

For instance, an assessment for the Huntington Beach power plant examined the impingement impacts of eleven power plants located on the southern California coast. The estimated combined total impingement mortality from the once-through cooling systems were estimated to amount to 8–30% of the recreational fishing totals for Southern California ([23] after [53]). However, it should be noted in this context that power plants typically require much larger feed volumes than desalination plants.

Impingement effects may also be a significant source of mortality for endangered or protected marine species, such as sea turtles or sea snakes.

C.4.2 Pretreatment of seawater

Open seawater often contains higher and more variable amounts of organic and inorganic material than intakes embedded in the seafloor. As open intakes have to cope with more variable and sometimes deteriorating surface water quality, pretreatment is generally more complex and extensive than for below-ground intakes. These naturally prefiltrate the incoming seawater and thereby reduce bacterial numbers and suspended material. Chemical and physical pretreatment may become unnecessary under these conditions or may be reduced to acid addition for scale control.

The seafloor sediments might, however, also have unfavorable effects on feedwater properties, for example by having increased carbonate or hydrogen sulfide contents, or elevated levels of iron or manganese. If the intake water is drawn from cooling water discharges, it might contain residual pretreatment chemicals (e.g. biocides), corrosion by-products and increased temperature values.

The different intake options are normally evaluated and the intake water quality analyzed in order to design and optimize the pretreatment system. The pretreatment system thus depends on the intake type (e.g. open or sub-surface) and the intake water quality. Most desalination plants use a conventional pretreatment system (outlined below) but alternative designs using micro- and ultrafiltration membranes (MF, UF) will likely become more prominent in the future.

Conventional steps in SWRO plants operating on surface water include (cf. Figure 7):

- Control of biofouling, usually by chlorination, and dechlorination with sodium bisulfite,
- Removal of suspended material by coagulation and media filtration,
- Control of scaling by acid addition (lowering the pH of the incoming seawater) and/or dosing of special 'antiscalant' chemicals,
- Cartridge filters as a final protection barrier against suspended particles and microorganisms before the RO units.

Conventional steps in most distillation plants include (cf. Figure 8):

- Control of biofouling, usually by chlorination,
- Control of scaling by 'antiscalant' dosing,
- Reduction of foaming by 'antifoam' addition,
- Deaeration or use of oxygen scavengers to inhibit corrosion.

In the following, the conventional pretreatment steps in SWRO and distillation plants are briefly outlined before potential impacts are considered in sections C.4.4 and C.4.5.

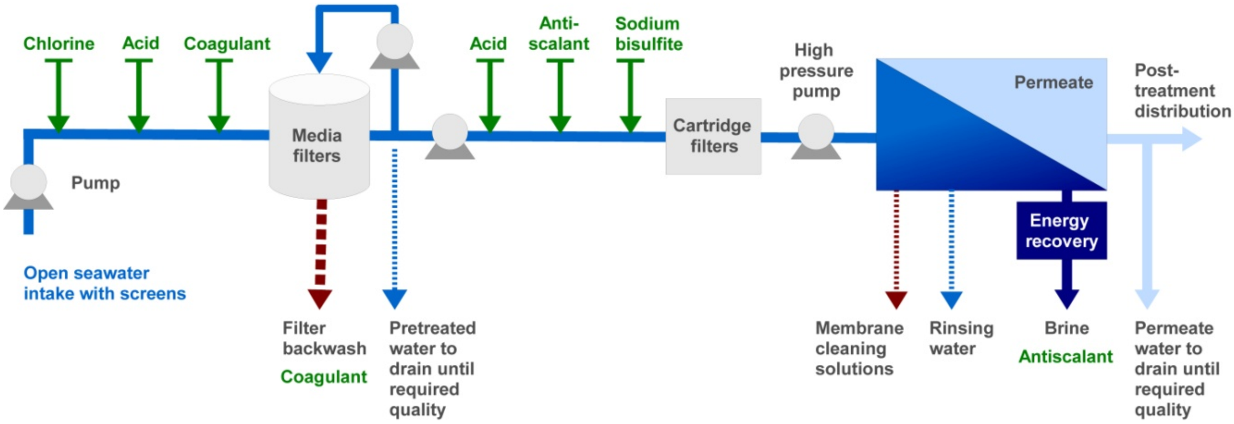


Figure 7: Flow-scheme of a SWRO system showing the conventional pretreatment and chemical dosage steps (green) and the different waste and side streams (the broken lines showing intermittent flows) (adapted from [46, 47]).

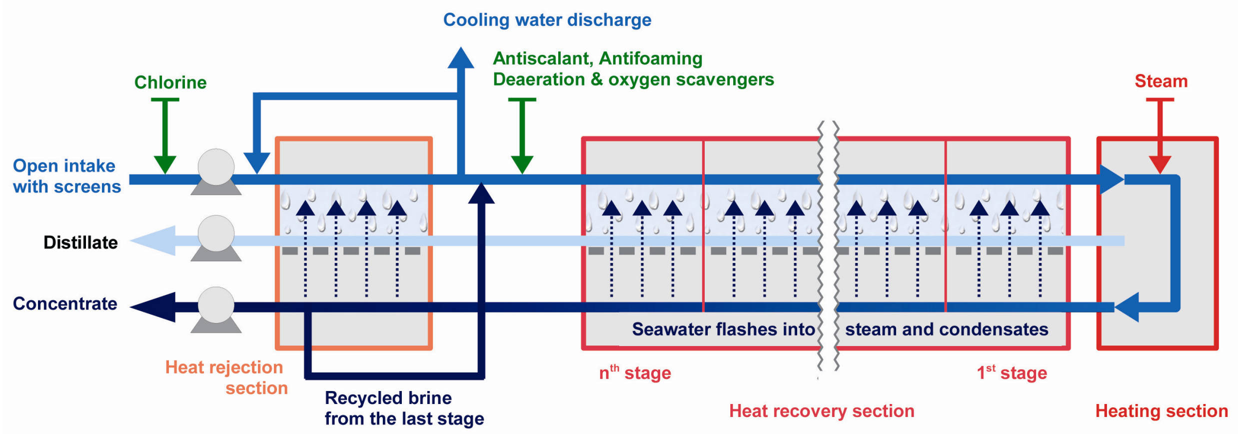


Figure 8: Flow-scheme of a MSF distillation plant showing the conventional pretreatment and chemical dosage steps and the different waste and side streams (adapted from [47]).

Control of biofouling

Seawater contains dissolved and particulate organic matter and microorganisms that may cause biofouling on RO membranes and the heat exchanger surfaces of distillation plants. Biocide dosing is usually carried out in desalination plants that receive water from an open intake, as the concentration of organic matter and the biological activity is higher in surface waters than in water from subsurface wells and drains.

Chlorination–dechlorination

In most desalination plants, chlorine is added to the intake water to control and reduce biofouling inside the plant. Chlorine dosage depends on the raw water quality. It may be unnecessary for beachwell water, whereas in severe cases of biofouling, continuous chlorination and intermittent shock treatment with increased chlorine concentrations may become necessary. To allow for a sufficient reaction time within the plant, chlorine is usually injected at the plant's intake, either as chlorine gas or hypochlorite salts, or is formed by electrolysis of the incoming seawater. Chlorination leads to the formation of hypochlorous acid (HOCl) and hypochlorite ions (OCl^-):

$$\begin{matrix} NaOCl \\ Cl_2 \end{matrix} + H_2O \rightarrow \begin{matrix} NaOH \\ HCl \end{matrix} + OCl^- + H^+$$

In the presence of bromide (Br^-), which is like chloride a natural component of seawater, hypobromous acid (HOBr) and hypobromite (OBr^-) ions are rapidly formed [28]:

$$OCl^- + Br^- \rightarrow Cl^- + OBr^-$$

[28] In freshwater, chlorine content is usually expressed as free available chlorine (FAC), which is the sum of Cl_2, HOCl acid and OCl^-. In wastewater, where high levels of ammonia are present, chloramines are primarily formed, which also have oxidizing capacity and are referred to as combined chlorine. The term total residual chlorine (TRC) refers to the sum of FAC and combined chlorine, while total residual oxidant (TRO) also includes other oxidants such as bromine species formed in seawater chlorination. However, the terms chlorine or residual chlorine are also often used in seawater for simplicity reasons.

Hypobromous acid has also disinfecting properties but efficiency depends on the amount of undissociated species (HOBr) present, i.e. on pH. HOBr is readily available in seawater (at about 85%) at a natural pH of about 8.

In distillation plants, dosing concentrations and resulting chlorine levels of 0.4 to 4 mg/l have been reported. This concentration may be increased periodically to 6 to 8 mg/l for shock treatment. The initial chlorine concentration is reduced inside the desalination plant due to the oxidant demand of the seawater, mainly caused by reactions with organic seawater constituents and abiotic degradation (decomposition).

Residual chlorine levels between 200 and 500 µg/l have been reported for distillation plant reject streams [47]. While this level ensures that the entire plant from intake to outfall is protected from biofouling, it also means that residual chlorine is discharged to surface waters, where it may harm aquatic life.

In RO plants, chlorination typically yields a concentration of 0.1 to 1 mg/l in the intake water [47]. Residual chlorine is neutralized before the water enters the RO units to avoid membrane damage, as RO membranes are typically made from polyamide materials which are sensitive to oxidizing chemicals such as chlorine. Sodium bisulfite (SBS) is predominantly used for dechlorination:

$$NaHSO_3 + OCl^- \rightarrow NaHSO_4 + Cl^-$$

As a consequence, chlorine concentrations will be very low to non-detectable in the reject streams of RO plants. De-chlorination with SBS may reduce dissolved oxygen levels in the reject stream as a side effect if SBS dosing is not properly adjusted.

If oxidant-resistant RO membranes are used, dechlorination is not required and residual chlorine in the reject stream could affect non-target organisms in the discharge site. However, only one manufacturer currently produces RO capillary membranes for SWRO using cellulose acetate, which can be sanitized with chlorine [54].

Following discharge into warm, sunlit surface waters, a further decline in residual chlorine levels by up to 90% can be expected [55]. Environmental concentrations in the discharge site of distillation plants can therefore be estimated to range between 20 and 50 µg/l. This is consistent with observed concentrations between 30 and 100 µg/l in the mixing zones of large distillation plants, which may extend as far as 1 km from the plant's outlet [56, 57].

Although environmental levels are quickly decreased by self-degradation and dilution following discharge, the potential for adverse effects is still high. Chlorine is a very effective biocide and its toxicity has been confirmed by many laboratory studies. Based on toxicological data from a wide spectrum of marine species, the U.S. EPA [58] recommends long-term and short-term water quality criteria for chlorine in seawater of 7.5 µg/l and 13 µg/l, respectively. These are estimates of the highest concentration in surface water to which an aquatic *community* can be exposed without resulting in an unacceptable effect. The toxicity to *individuals*, however, depends very much on species sensitivity and life cycle stage. The European environmental risk assessment for hypochlorite has determined a predicted no effect concentration (PNEC) for saltwater species of 0.06 µg/l total residual chlorine [59]. The PNEC is derived from fish, invertebrate and algae toxicity data.

Considering these data, the establishment of stringent discharge regulations seems appropriate for desalination plants. From a regulatory viewpoint, aquatic pollutants are typically regulated at the point of discharge as well as within the receiving water. The former encourages source control principles, such as effluent treatment, while the latter is associated with the concept of a mixing zone, where the numerical water quality standards may be exceeded. Mixing zones can extend over considerable areas in the water body, depending on the effluent volume and the hydrology of the water body. In order to meet mixing zone regulations, properly sited outfalls with optimized high efficiency mixing designs are typically needed [60].

A major disadvantages of the current practice of chlorination is the formation of organohalogen compounds. The number of by-products can hardly be determined due to many possible side reactions. A major component, however, are the trihalomethanes (THMs) such as bromoform. Very few studies investigated coastal THM concentrations near distillation plants. In two cases, increased levels up to 9.5 µg/l near the outlet [61] and up to 83 µg/l [56] were reported. These findings are in line with bromoform levels of 15–20 µg/l as observed near coastal power plants that use chlorine for disinfection. Concentrations of other halogenated organics are considerably lower and usually in the nanogram per liter range. Substances of anthropogenic origin in coastal waters, especially mineral oil or diesel fuels, may give rise to compounds like chlorophenols or chlorobenzenes [61-64]. However, THMs such as bromoform account for most of the compounds.

Dechlorination will considerably reduce the potential for by-product formation, but even the presence of low concentrations below acutely toxic levels could be harmful to marine life. Studies investigating the toxicity of chlorinated-dechlorinated seawater observed increased mortality of test species [65, 66] and chronic effects [67] of dechlorinated seawater and the observed effects were assumed to be due to the presence of halogenated organics formed during chlorination. Furthermore, sufficient evidence exists that some compounds have carcinogenic and mutagenic properties [64], which makes it difficult to establish a "no-effects-threshold".

⏩ *Alternative to chlorination*

Alternative chemical methods have been investigated to control biofouling in SWRO plants, including monochloramine (NH_2Cl), ozone (O_3), or copper sulfate ($CuSO_4$). None of these has gained wide acceptance over chlorine use. For seawater applications, there is also a growing interest in the use of chlorine dioxide, which is already applied in some of the desalination plants in the Gulf region [68] and is also used in the Tampa Bay SWRO plant in Florida [28].

Chlorine dioxide is – like chlorine – a strong oxidant, but requires a shorter contact time and dosage. Unlike other oxidants such as chlorine or ozone, it does not readily react with bromides to form bromine, or with ammonia to form chloramines. Furthermore, it does not favor addition and substitution reactions, and therefore chlorination by products such as halomethanes. However, the untreated discharge of a biocide to surface water could also be harmful to non-target organisms.

Non-chemical options for disinfecting the intake water include UV-light of 200–300 nm wavelength and prefiltration membranes (UF and MF, see also next section). UV-light destroys the DNA, cell membranes and enzymes of microorganisms by forming free radicals in water which are mainly responsible for the breakdown of the organic material. Storage, handling and disposal of toxic chemicals are therefore avoided. UF/MF pretreatment usually requires chemically enhanced backwash and periodic cleaning [48] of the membranes and is therefore not entirely chemical free.

Control of suspended matter (RO only)

The removal of suspended material from the RO feed stream is necessary as solids can cause irreversible damage to the membranes. Of concern are clay and silt (≤ 63 µm), plankton, bacteria (≤ 3 µm) and smallest colloids of less than 1 nm particle size. RO membranes are not robust enough to operate directly on open seawater without pretreatment (unless in very good water quality). Conventional pretreatment technology relies on a combination of chemical treatment and media filtration to achieve the required conditioning of the water. An alternative is membrane filtration pretreatment [54].

Coagulation and granular media filtration

For granular media filtration, the dosing of a coagulant is required. Coagulants are metal salts which form dense suspended flocks as they react to hydroxides in aqueous solutions.

Mainly ferric chloride ($FeCl_3$) and ferric sulfate ($FeSO_4$) salts are used for coagulation:

$$FeCl_3 + 3\,HCO_3^- \rightarrow Fe(OH)_3 + 3\,Cl^- + 3\,CO_2$$

The coagulants neutralize the negative surface charge of the suspended particles and adsorb and enmesh colloid particles within the flocks. By this process, the particles are aggregated into larger, heavier and more filterable solids [54].

Dosing of sulfuric acid to establish slightly acidic pH values and addition of coagulant aids such as polyelectrolytes can enhance the coagulation process. Polyelectrolytes are organic substances with high molecular masses (like polyacrylamide) that help to bridge particles together. The dosage of coagulants and coagulant aids is normally correlated to the amount of suspended material in the intake water. It can range between < 1 and 30 mg/l for coagulants and between 0.2 and 4 mg/l for polyelectrolytes [47].

The particulate material is retained when the seawater passes through the filter beds. The filters are backwashed on a period basis, using filtered seawater or permeate water, in order to clean the filters from the particulate material, which contains the natural suspended material and the coagulant chemicals.

The backwash water can either be discharged into the sea, or may be treated and the sludge disposed in a landfill. Several levels of treatment may be required depending on the feedwater quality and the volumetric sludge production, including clarification, thickening and sludge dewatering prior to disposal. A worst-case scenario would require a thickener followed by a sludge dewatering system (using a belt press or centrifuge) in a separate building with odor control (e.g. as in the Tampa Bay SWRO facility). Small sludge amounts may be dewatered in a simple and relatively inexpensive sludge drying bed onsite or the liquid sludge may simply be hauled to a landfill without treatment [69]. The clarified backwash water, which still contains about 1% of the particulate material, is normally discharged into the sea [26].

It seems that there is a tendency for removal of the solids and land deposition despite the cost increase, but it is difficult to substantiate this statement as examples for both practices exist.

Plants with a sludge separation step are for example the Perth and Sydney projects (Australia), Carlsbad (California), Chatan (Okinawa) and Javea (Mediterranean coast of Spain) SWRO projects with capacities between 24,000 m^3/d and 189,000 m^3/d [26, 43, 70, 71].

Examples where the sludge is discharged to the sea are the Ashkelon plant in Israel and the Hamma plant in Algeria [72, 73] with capacities of 320,000 m^3/d and 200,000 m^3/d, respectively. However, the Ashkelon plant and new SWRO plants in Israel plan to collect the backwash water from the beginning of each washing cycle in a storage tank and then to discharge it continuously in order to avoid turbidity peaks [74]. The Hadera SWRO produces about 1,500 m^3 per hour of filter backwash water, which is discharged along with about 19,000 m^3 per hour of concentrate into a power plant cooling water conduit with an approximate flow of 160,000 m^3 per hour [30].

Practices on the Canary Islands reviewed in [42] indicate that the concentrate and other reject products such as chemical additives, pretreatment and membrane cleaning solutions, and waste water are usually discharged into the sea.

Large RO plants may accumulate relatively large amounts of sludge as they process large volumes of seawater. As the dosage of coagulants and coagulant aids is correlated to the amount of suspended material in the feedwater, it can be assumed that a low dose of 1 mg/l coagulant and 0.2 mg/l coagulant aid may be required to remove a low natural background concentration of 1 mg/l suspended matter. A correlation of sludge volume and capacity can thus be established: a SWRO plant (operated at 35% recovery) would produce 6.3 kg sludge per day per 1,000 m^3/day capacity, which amounts to e.g. 630 kg/d for a 100,000 m^3/day plant. The sludge produced would consist of the natural suspended matter and the pretreatment chemicals [12]. This correlation is established for low dosages and good water quality.

Under more difficult conditions of operation, the sludge production can be larger. For example, the estimated amount of sludge produced and transported to a landfill for a SWRO plant in Okinawa, Japan, is 1860 kg/d (or 46.5 kg per 1,000 m^3/d) [70].

▸▸ *Ultra- und microfiltration membranes*

The use of ultra- und microfiltration membranes (UF/MF) prior to RO, often characterized as an integrated membrane system (IMS), is an emerging area in SWRO applications. UF and MF membranes have a general removal capability of 0.01–0.02 micron and 0.1–0.2 micron respectively. The use of UF/MF systems can save about one third in plant area size compared to conventional pretreatment. It eliminates the step of coagulation, and reduces RO cleaning frequency and replacement rate [54]. However, the UF/MF membrane pretreatment system also requires periodical cleaning and membrane replacement, i.e. it is not entirely chemical free.

A comparative life cycle analysis between conventional and membrane based pretreatment revealed that membrane based pretreatment reduces the overall environmental burden of the desalination process. However, most reduction stems from associated reduction in overall energy demand, while the reduction of usage of chemicals during operation of the desalination plant showed only minor effects on the environmental load [75]. Energy consumption in MF is relatively low and comparable to a beachwell intake, while pressures of 1 to 5 bar are required in UF with corresponding increases in energy demand in UF systems [76].

Extensive pilot plant tests on membrane pretreatment have been conducted for RO plants in Ashkelon, Tampa Bay and Trinidad. Although the tests were successful, plant operators continued to use media filtration due to slightly higher cost for membrane pre-treatment. In Ashdod, MF and UF pretreatment has been incorporated. The use of MF/UF are assumed to be more robust and reliable in handling fluctuations in feedwater quality with comparable unit water cost [23].

A membrane filtration system which was considered for the Carlsbad seawater desalination plant [26] would require cleaning by three different processes: (a) membrane backwash, (b) chemically enhanced backwash (CEB) using chlorine, acid and base conditioning on a daily basis and (c) membrane cleaning using the same chemicals as for RO membrane cleaning on a monthly basis. The membrane backwash, containing the natural solids from the sea, can either be discharged into the sea along with the concentrate, or dewatered and transported to a landfill. The CEB and membrane cleaning waste can be conveyed to a scavenger tank for initial treatment and then disposed of to the sewer for final treatment.

Cartridge filter system

As a final barrier, the feed water is usually passed through 5 micron cartridge filters before it enters the RO units. The cartridge filter is used in combination with both conventional and membrane pretreatment systems. The particles retained on the cartridge filters will be removed with the filters on a periodic basis, e.g. every six to eight weeks, and typically disposed of to a sanitary landfill [26].

Control of scaling

The desalination process increases the concentration of all water constituents in the reject stream. Depending on the source water and the process recovery rate, different salts can precipitate and form scales if solubility limits in the brine solution are exceeded. In BWRO systems, the main concern is calcium carbonate scale formation ($CaCO_3$). Less frequently observed are calcium sulfate and silica scales, and only occasionally barium sulfate or ferrous salt scales [54]. Calcium carbonate is also the main scale forming species in SWRO systems, whereas solubility limits for sulfate scales and silicates are generally not exceeded in the reject streams due to the high ionic strength of seawater. In distillation plants, the main scale forming species are calcium carbonate and magnesium hydroxide ('alkaline scales') and sulfate scales due to high operating temperatures.

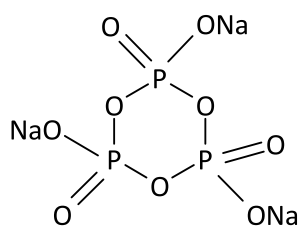
Calcium carbonate scale formation is easily controlled either by dosing of sulfuric or hydrochloric acid, the dosing of special scale inhibitors, or a combination thereof. Acids must be added in relatively high concentrations of 20 to 100 mg/l to the feed stream as acid reacts stoichiometrically with calcium carbonate:

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$$
$$HCO_3^- + H^+ \rightarrow CO_2 + H_2O$$

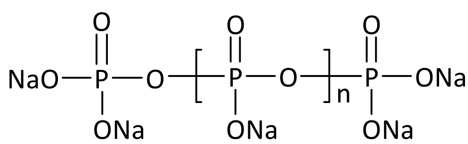
Resulting pH values are usually between 6 and 7, with the natural pH of seawater being approximately 8.3. As acid is depleted by reaction with calcium carbonate, pH values will be closer to ambient at the point of discharge if overdosing is avoided.

In contrast, antiscalants prevent scale formation in non-stoichiometric doses of 1 to 2 mg/l by retarding the nucleation process of scale crystals and by impairing crystal growth. The main types of antiscalants are organic polymers (mainly polyacrylic acid and polymaleic acid), phosphonates and polyphosphates (Figure 9) [47].

Polyphosphates

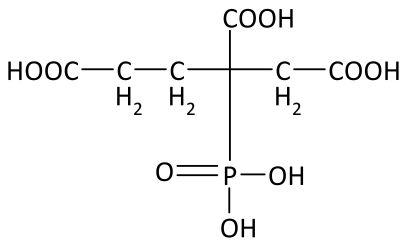


Sodiumhexametaphosphate
SHMP $(NaPO_3)_6$

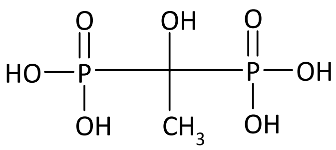


Pentasodiumtriphosphate
STP $(Na_5P_3O_{10})$

Phosphonates

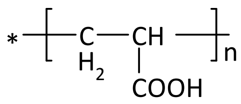


Bayhibit, PBTCA

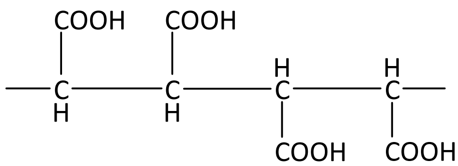


Etidron, HEDP

Polycarboxylic acids



Polyacrylic acid (PAA)



Polymaleic acid (PMA)

Figure 9: Chemical structures of common antiscalants (adapted from [47]).

Control of foaming (distillation plants only)

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 likely as dosage levels are low and discharge concentrations are further decreased by dilution in the environment.

C.4.3 Corrosion

Increases in metal concentrations in the discharge may result from two effects:

- from the concentrating effect of the desalination process, which also increases natural metal ion concentrations in the concentrate (e.g. by a factor of two at 50% recovery) and
- from corrosion processes, such as pit corrosion in stagnant solutions.

The first effect stems from metals of natural origin to which marine organisms are adapted. Similar to elevated salinity, the discharge of elevated metal levels can be harmful and the discharge should be in compliance with the existing water quality standards.

For example, in a pilot study for a SWRO plant in Florida, metal concentrations were calculated for the point of discharge into marine waters after the brine is diluted with power plant cooling water. Three metals (nickel, iron and copper) were found to be relatively close to the state's water quality standards, which were therefore adopted as effluent limitations and included in the proposed permit [77]. Nickel and copper may also stem from the power plant cooling water when copper-nickel alloys are used for heat exchangers.

In SWRO, stainless steel with a high corrosion resistance or non-metallic materials prevail, such as concrete or plastic. Stainless steels are by definition all iron-carbon alloys with a minimum chromium content of 10.5%. Different types of stainless steels are available:

- Austenitic stainless steels have a minimum chromium content of 16%, and a maximum carbon content of 0.15%, and contain major amounts of nickel and manganese.
- Ferritic stainless steels contain a maximum of 27% chromium, typically some molybdenum, aluminum or titanium, but usually very little or no nickel.
- Duplex stainless steels combine the benefits of austenitic and ferritic steels, with high chromium content (19–28%), some molybdenum and nickel.

- Super-austenitic stainless steels, such as 254SMO (see below), have a minimum molybdenum content of 6%, which makes it very resistant to chloride pitting and crevice corrosion.

Table 1: Composition of 254SMO super austenitic steel in % [23].

C	Cr	Cu	Mn	Mo
0.02 (max)	19.5 – 20.5	0.5 – 1.0	1.0 (max)	6.0 – 6.5
N	**Ni**	**P**	**Si**	**S**
0.18-0.22	17.5-18.5	0.03 (max)	0.8 (max)	1.01 (max)

When appropriate construction materials are used and the plant is designed properly, e.g. by eliminating dead spots and threaded connections, corrosion is minimal [23]. The corrosion resistance is generally considered good when the corrosion rate is less than 0.1 mm/a [78]. Significant amounts of corrosion by-products are therefore not to be expected in the concentrate discharge of SWRO plants.

In distillation plants, copper-nickel alloys are commonly used for heat exchanger surfaces, while other construction parts like brine chambers are often made from stainless steels. The corrosion of copper-nickel alloys can result in elevated copper levels in the concentrate. Copper levels in MSF reject brines between 15 and 100 µg/l were reported [47].

The toxicity of metals generally depends on chemical and physical processes in seawater that affect metal speciation (solution, precipitation, complex formation, adsorption etc.), which in turn affects bioavailability of metals. It further depends on the sensitivity of individual species and organisms in their different life-cycle stages. Impacts of metal discharges are difficult to predict, and should be evaluated in the context of natural background levels.

In general, trace amounts of stainless steel alloys in reject streams will pose relatively little risk to the marine environment, whereas elevated copper concentrations can be a matter of concern.

Dissolved copper levels in the environment are usually decreased by precipitation, complex formation, and adsorption processes, which lead to a transportation of the element into suspended material and finally into 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 (such as shellfish) feed on suspended or deposited material, with the risk that heavy metals are enriched in their body tissues (bioaccumulation) and passed on to higher trophic levels (biomagnification).

The U.S. EPA recommends a maximum copper concentration of 4.8 µg/l in seawater for brief exposure and 3.1 µg/l for long-term exposure [58]. Values of the same order of magnitude were determined for European saltwater environments: a predicted no effect concentration (PNEC) of 5.6 µg/l was established [79], while the water quality objective for the Mediterranean is 8 µg/l [80]. However, these values must be seen in the context of natural background levels, which may range between 0.1 µg/l in oceanic water and 100 µg/l in estuaries [81].

As copper is an essential micro-nutrient for most organisms, it might only become toxic if excess amounts become biologically available. The risk lies in long-term accumulation in sediments and marine biota. This is especially of concern in areas of high desalination activity, such as for instance in the Arabian Gulf. A conservative estimate of copper discharges from distillation plants into this sea area is 292 kg per day, based on a copper contamination level of the reject brine of 15 µg/l [82].

C.4.4 Discharge of the concentrate

The 'waste stream' mainly contains the natural ingredients of the intake seawater: The RO process filters the inorganic salts and other dissolved or suspended substances from seawater. The water is transported under high pressure through the semi-permeable RO membranes, while the contents of the source water are retained by the membrane and concentrated into a 'waste stream' that is returned to the sea. In distillation plants, water is extracted by evaporation. The process increases both the salt content and the temperature of the remaining brine.

Environmental concerns arise due to the increased concentration of inorganic salts and the increased temperature of the waste stream, which may increase ambient salinity and temperature in the discharge site and may negatively affect local ecosystems.

Furthermore, the chemical pretreatment of the feedwater (cf. section C.4.2) produces waste streams that require appropriate management, and are in some cases discharged into the sea along with the concentrate. As seawater is a highly corrosive medium, which is further aggravated by the high salinity of the concentrate and the use of pretreatment chemicals such as acids or chlorine, the waste stream may also contain small amounts of metals that pass into solution when metallic parts inside the plant corrode (cf. section C.4.3).

The discussion of potential impacts is therefore subdivided into concerns related to the physical properties of the waste stream (this section), and concerns related to the chemical pollutants that are added during the desalination process (cf. section C.4.5, p. 93). However, potential synergistic effects of increased salinity, temperature and residual chemicals might occur.

Salinity

The salinity of the concentrate is largely a function of the plant recovery rate, which in turn depends on the salinity of the source water and the process configuration. RO plants have higher recovery rates than distillation plants, and typically recover between 40% and 65% of the intake water as product water. The rest, i.e. 60% to 35%, is discharged into the sea. The salinity of the reject stream usually ranges between 65 to 85 for SWRO plants [18]. A reject salinity up to 90 has been reported in one case [83].

Although the brine blow-down in distillation plants may have a salinity of almost 70, too, which is the operational upper limit to prevent sulfate scaling [84], it is effectively diluted with a threefold amount of cooling water[29]. Dilution results in a salt concentration that is rarely more than 15% higher than the salinity of the receiving water [85], while the RO brine may contain twice or more the seawater salt concentration[30].

Temperature

The brine and cooling water discharges of distillation plants are increased in temperature. Differences of 5 to 15°C above ambient seawater temperature have been reported [57, 86], whereas the temperature of the RO concentrate is close to ambient values.

Density

In surface water, density is a function of salinity and temperature. The density difference between reject stream and ambient seawater, as a function of salinity and temperature, primarily determines spreading and mixing of the plume in the receiving water body. Density calculations and modeling studies can be carried out to analyze the project- and site-specific spreading behavior of a plume.

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[29] Thermal plants have lower recovery rates than RO plants. As they use cooling water for temperature control, the seawater flow rate to thermal plants has to be 3-4 times higher than the feed to RO plants for the same amount of product water extraction. The cooling water is discharged along with the concentrate, so that mixing of both reject streams takes place before surface water discharge.

[30] In oceanography, the UNESCO definition of Practical Salinity Units (psu) is used, which is the conductivity ratio of a seawater sample to a standard KCl solution. Salinity is therefore given as a dimensionless value. As salinity reflects the amount of total dissolved solids (TDS) in ocean water, it was traditionally expressed as parts per thousand (ppt or ‰). A salinity of 35 ppt equals 35 g of salt per 1,000 g of seawater, or 35,000 ppm (mg/l), or in approximation 35 (psu).

Table 2: Calculated salinity of RO plant reject streams for feedwater salinities between 20 and 40 and recovery rates between 20 % and 65 %, assuming a permeate salinity of 0.3. The salinity values are derived by the equation $R_S = (F_S \cdot F_F - P_S \cdot P_F) / R_F$ where R_S is the salinity and R_F the flow rate of the reject stream, F_S the salinity and F_F the flow rate of the feed stream, and P_S the salinity and P_F the flow rate of the permeate stream.

Salinity / Recovery	20	25	30	31	32	33	34	35	36	37	38	39	40
20 %	25	31	37	39	40	41	42	44	45	46	47	49	50
25 %	27	33	40	41	43	44	45	47	48	49	51	52	53
30 %	28	36	43	44	46	47	48	50	51	53	54	56	57
35 %	31	38	46	48	49	51	52	54	55	57	58	60	61
40 %	33	41	50	51	53	55	56	58	60	61	63	65	66
45 %	36	45	54	56	58	60	62	63	65	67	69	71	72
50 %	40	50	60	62	64	66	68	70	72	74	76	78	80
55 %	44	55	66	69	71	73	75	77	80	82	84	86	89
60 %	50	62	75	77	80	82	85	87	90	92	95	97	100
65 %	57	71	85	88	91	94	97	99	102	105	108	111	114

Reject streams of RO plants have a higher density than ambient seawater due to the high salt content, whereas the discharge from distillation plants can either be positively, neutrally or negatively buoyant depending on salinity and temperature values of the effluent.

Oxygen content

As oxygen becomes less soluble in seawater with increasing temperature and salinity levels, the desalination process may result in reduced dissolved oxygen levels. More pronounced, however, are the effects of pretreatment, i.e. the deaeration of the feedwater in thermal plants to prevent corrosion and the dosing of a reducing agent (sodium bisulfate, SBS) to remove residual chlorine from the RO feedwater, which may reduce oxygen levels as a side-effect.

For the concentrate discharge, the most widely used method of disposal is discharge into surface water, either via a single open outfall or a diffuser system. Options for co-discharge exists with power plant cooling water or wastewater treatment plant effluents (cf. section C.2.1). When dilution with other waste streams is not an option, multiple outlets with multiple diffusers can be installed, which can achieve a maximal dilution with a minimum salinity increase of 1 unit above background levels outside the mixing zone [35].

Environmental conditions such as wave, wind and tidal action, currents, ambient salinity, temperature and density stratification are other variables which have an effect on the mixing and dispersal of the waste water in the receiving environment.

Similar to beach wells used for the intake of feedwater, desalination plants can also discharge their concentrates by well injection, for example into an injection well on the beach, where the concentrate is diluted through mixing with natural groundwater before dissipating into the surf zone [23] or deep-well injection [32].

Potential impacts on receptors

Ground- and surface water quality and hydrology

Groundwater salinity

A concern of prolonged well injection is a potential effect on the salinity of production wells. For instance, simulation scenarios for coastal aquifers in Egypt showed that a salty plume may develop around the recharge well, which migrates downward due to the high density of the plume and which may thus affect deeper drinking water production wells [87].

If a desalination plant is constructed further inland, there is a need for pipes to transport the concentrate. Leakage from the pipes may result in penetration of salt water and therefore presents a danger to groundwater aquifers or surrounding soils [33].

Seawater quality and hydrology

Increase in salinity

The discharge of large concentrate volumes may lead to an increase in salinity in the discharge zone. When the concentrate is pre-diluted with other waste streams such as cooling water, dissipated by a multi-port diffuser system, or discharged into a mixing zone that can effectively dissipate the salinity load due to strong wave action and currents, the salinity increase can be minimized.

For example, the concentrate of the Carlsbad seawater desalination plant is mixed with power plant cooling water before discharge. In 300 m distance from the outfall, a salinity of 38.2 near the bottom and 35.2 in the mid-water column is expected compared to an ambient salinity of 33.5 [26, 88]. In contrast, a diffuser system was installed for the Perth SWRO project to ensure that salinity would be within 1.2 units of background levels within 50 m of the discharge point and within 0.8 units of background levels within 1,000 m of the discharge point [89].

Increase in temperature

High volumes of reject concentrate and cooling water from distillation plants cause thermal pollution in the discharge site and may change the ambient temperature profiles.

Influence on density stratification

The density difference between concentrate discharge and ambient seawater is a controlling factor for mixing and spreading of the plume in the receiving water body. In surface water, density is primarily a function of salinity and temperature.

Due to the high salt content, the RO reject stream has a higher density than ambient seawater. It therefore tends to sink to the seafloor unless the concentrate is adequately dissipated by a diffuser system at the outfall or discharged into sufficiently turbulent waters. The effluent may otherwise accumulate near the bottom, forming a water mass of elevated salinity ('a bottom hugging plume') which spreads over the seafloor in the vicinity of the outfall pipe.

For example, ambient salinity levels of 36–40 and seasonal temperature variations of 15–30°C (typical for Mediterranean surface water) result in density variations of 1,023–1,030 kg/m^3. A SWRO plant with a feedwater salinity of 36 and operating at 50% recovery would produce a concentrate with a salinity of 72 (Table 2). At 20°C, the density of the concentrate would be 1053 kg/m^3, which is negatively buoyant compared to an ambient density of 1025 kg/m^3.

As increased salinity and temperature have opposing effects on density, the reject streams of distillation plants can either be positively, neutrally or negatively buoyant [86, 90]. Typically, they are positively buoyant due to the influence of large amounts of cooling water discharge of elevated temperature.

For example, seawater salinities of 45 and temperatures of 33°C are characteristic of Arabian Gulf seawater. The reject water of a MSF distillation plant would be negatively buoyant compared to ambient density (1028 kg/m^3) at a salinity of 50 and a temperature increase of 5°C (1030 kg/m^3), and positively buoyant at a temperature increase of 10°C (1027 kg/m^3).

Influence on mixing processes

The discharge of large quantities of seawater of a different density may affect mixing processes and density stratification, especially in areas that are characterized by weak natural currents and waves.

Seafloor and sediments

Increase in pore water salinity

RO reject stream that spread over the seafloor may also diffuse into sediment pore waters due to their increased density and may increase salinity in the interstitial water.

Marine flora and fauna

Effects from increased salinity

Salinity and temperature are vital environmental parameters for marine life. Similar to thermal pollution, increased salt concentrations can be harmful and even lethal to marine life. In general, toxicity depends on the sensitivity of the species to increased salinity, the natural salinity variations of their habitat, and the life cycle stage.

For example, studies on the Mediterranean seagrass *Posidonia oceanica* showed that a salinity of about 45 caused about 50% mortality in 15 days and growth rates were reduced by 50 % at a salinity of 43 (cf. Box 2, Formentera). In contrast, two seagrass species common to Western Australian waters, *Posidonia australis* and *P. amphibolis*, seem to be more adapted to higher salinities. Densest covers of meadows are being observed at salinities between 40 and 50 (cf. Box 2, Perth). The available studies suggest that some seagrasses are more tolerant to hypersaline conditions than others, at least some Atlantic and Pacific species [91].

Some macrofauna taxa such as echinoderms (e.g. sea urchins, starfish), which are strictly marine, seem to be more sensitive to salinity variations than for example organisms found in estuaries, which are able to adapt to a wide range of salinities including fresh, brackish and saltwater environments. Furthermore, young life cycle stages, such as sea urchin embryos, are considered to be more sensitive than adults.

Most marine organisms can adapt to minor deviations in salinity and might tolerate extreme situations temporarily. For example, *P. oceanica* plants that survived in a salinity of 43 over 15 days were able to recover when returned to normal conditions (cf. Box 2, Formentera). However, only few species will be tolerant of high salt concentrations over extended periods of time. Natural salinity values vary between 30 and 37 in the Atlantic Ocean, between 36 and 40 in the Mediterranean Sea, between 37 and 43 in the Red Sea, and can range up to 60 in naturally saline environments of the Arabian Gulf. Salt concentrations that considerably exceed these ambient levels to which the local species are adapted may result in haline stress and can even cause toxic effects. This in turn may lead to a die-off of the sessile fauna and flora in the discharge site. For example, salinity increases near the outfall of the Dhekelia SWRO on Cyprus were reported to be responsible for a decline of macroalgae forests, and echinoderm species vanished from the discharge site (cf. Box 2).

Effects from increased temperature

Thermal discharges that change annual temperature profiles in the discharge site may enhance biological processes by increasing seawater temperatures to favorable conditions in winter, but could result in stress or cause an abrupt decline in activity when critical values are exceeded in summer. Marine organisms could be attracted or repelled by the warm water, and species more adapted to the higher temperatures and seasonal pattern may eventually predominate in the discharge site of the distillation plant.

Effects from decreased oxygen levels

In the event that dissolved oxygen levels are reduced in the discharge site as a result of the desalination plant discharges, the lower oxygen content may be harmful to marine life (see also section C.4.5 on p. 93).

General impacts on ecosystems

The reject streams of SWRO and distillation plants generally affect different realms of the marine environment: SWRO reject streams tend to sink to the bottom and spread over the sea floor, where they may affect benthic communities, whereas the reject streams of distillation plants may affect the pelagic community as a result of surface spreading. However, it must be pointed out that mixing and dispersal processes are largely controlled by site-specific oceanographic conditions. To evaluate plume spreading in a specific project site, the existing conditions should be analyzed by modeling studies, accompanied by salinity and temperature measurements in the project site for density calculations.

Marine organisms normally occur in those environments to which they are adapted and which provide favorable environmental conditions in terms of salinity, temperature, food supply and other biological and abiotic factors. Increased salinities and temperatures may therefore drive mobile animals away from the point of discharge even if no direct toxic effects occur. The consequence may be a lasting change in species composition and abundance in the benthic communities in the discharge site.

For example, observations on the distribution on marine species from naturally hypersaline environments in the Arabian Gulf indicate that salinities above 45 alter the benthic community considerably [92]. This stresses the importance of salinity as a controlling environmental factor and illustrates that salinity thresholds must be established depending on the salinity tolerance of local species.

In the Mediterranean, the major threat lies in the loss of *Posidonia oceanica* meadows (Figure 10), which are classified as a priority habitat type by European Community directive 92/43/CEE. Besides their contribution to fix sand banks, oxygenate the sea water and regulate biogeochemical fluxes along the coast, the seagrass meadows are characterized by elevated biological productivity and diversity. Meadows shelter a high biodiversity of associated algae and vertebrates and they constitute the breeding habitat of numerous species [91, 93]. The large scale loss of *Posidonia* meadows may therefore have far-reaching consequences on water quality, sediment stability and marine ecology.

It has been recommended to avoid discharges of desalination plant concentrate into *Posidonia* meadows, or to dilute the discharge salinity so that it exceeds a value of 38.5 in no more than 25% of the time and a value of 40 in no more than 5% of the time (cf. Box 2, Formentera, Box 3 [94]). Ambient salinities in the Western Mediterranean are between 37–38.

In Western Australian, guidelines for fresh and marine waters specify that the median increase in salinity is to be less than 5% from background, which in marine environments is a change of about $\Delta S = 1.5$. The criteria for the concentrate discharge set for the Perth SWRO plant in Western Australia require that salinity is within 1.2 units of ambient levels within 50 m of the discharge point and within 0.8 units of background levels within 1,000 m of the discharge point [45].

In the U.S., EPA recommendations state that salinity variation should not exceed 4 units from natural variation in areas permanently occupied by food and habitat forming plants when natural salinity is between 13.5 and 35 [26].

For a SWRO plant in Okinawa, Japan, a maximum salinity of 38 in the mixing zone and a maximum increase of 1 unit where the plume reaches the seafloor was established [70].

An overview on the available field and modeling studies on concentrate discharge from SWRO plants is given in Box 2 on the following pages. Box 3 (p. 87) summarizes results from bioassay studies investigating the effects of elevated salinity on marine organisms. Box 4 (p. 91) discusses relevant issues of combined discharge from SWRO and wastewater treatment plants.

Figure 10: *Posidonia oceanica* seagrass meadow (Photo: Alberto Romeo, Creative Commons Attribution and Share Alike license, http://commons. wikimedia.org).

Box 2: Overview on field and modeling studies concerning the concentrate discharge

One of the first papers which noted that the brine and chemical discharges may pose a risk to the marine environment appeared in 1979. It called for a thorough investigation of both the physical and biological components of the environment, prior to construction and on a regular basis for a period of at least one year but preferably for two or three years once the plant is in operation [95].

It took until the 1990's before an increasing number of scientific publications appeared (e.g. [57, 85, 86, 90, 96-100]) which addressed the environmental concerns of desalination plants. In 2001, an extensive review of existing literature sources on effluent properties of desalination plants was carried out and the results analyzed in terms of potential impacts on the marine environment. The authors conclude that more actual data is needed, including *field* investigations, *laboratory* toxicity tests and *modeling* studies. To date, an increasing number of these studies become available [47].

However, the problem remains that only few of these studies have performed a *comprehensive* analyses of the effects of brine discharge on the marine environment, while the majority of studies focus on a *limited number of species* over a *short period of time* with no baseline data [4]. There is still a surprising paucity of useful experimental data, either from laboratory tests or from field monitoring, concludes a recent report of the U.S. National Research Council [101].

Often, the investigations are carried out under immense time constraints, e.g. only 4 months were scheduled for an EIA study for a 200,000 m^3/d SWRO plant in Algeria [72]. This indicates that environmental concerns can be of secondary importance when a ready supply of freshwater is urgently needed. The opposite is also true: comprehensive and time-consuming environmental studies are currently being carried out for some major SWRO projects in Australia, and environmental concerns are the major hurdle in the permitting process of new projects in California.

One of the most comprehensive monitoring programs so far was conducted for the Perth SWRO project in Western Australia. Pre-project studies encompassed modeling the stratification and dissolved oxygen in Cockburn Sound, determining the sediment oxygen demand and contaminant releases, and assessing ecological effects. A peer review carried out by the National Institute of Water & Atmospheric Research (NIWA Australia) concluded that the studies have in general been carried out to a high standard, but that they were constrained to using mostly existing data due to significant time pressure. The reviewers were thus not convinced that the studies addressed all concerns adequately, and did not believe that the conclusions of the reports, namely that there will be no or negligible ecological effects, can be accepted with a high degree of confidence [102]. In response to the review, more extensive studies were initiated, including marine baseline studies, a real time monitoring system before and during operations, and laboratory tests on toxicity [89].

The Perth example underlines that monitoring is a basic prerequisite for implementing a desalination project. This is also true for other projects, especially as desalination projects tend to increase both in number and capacity. However, the Perth example also illustrates the difficulties involved in the design of an adequate monitoring programme and an EIA study. An internationally agreed environmental assessment methodology for desalination plants does not exist so far and its development would certainly be desirable according to the World Bank [103]. Existing monitoring and bioassay studies from recent and earlier studies are summarized below. They show the wide range of approaches and methods that are used to investigate environmental impacts of desalination plants and underline the need for a more uniform assessment framework.

Box 2 (continued): Studies for facilities with a capacity ≥ 100,000 m^3/d

Carlsbad SWRO project, Southern California

The U.S. Navy Coastal Water Clarity Model was used to analyze the dispersal and dilution of the combined discharge from the Encina Power Plant and the Carlsbad SWRO plant under average and extreme conditions [26, 88]. Under average conditions, the concentrate from the desalination plant (about 50 mgd or 189,271 m^3/d with a salinity of 67) will be combined with an average cooling water discharge (526 mgd or 1.9 million m^3/d of ambient salinity, i.e. 33.5), which is reduced under extreme conditions (to 254 mgd or 0.96 million m^3/d). Under average conditions, the end-of pipe salinity would be 36.2 near the bottom and 34.4 in the mid-water column. Across the zone of initial dilution, in 300 m distance from the point of discharge, the salinity would be reduced to 34.4 near the bottom and 34.0 in the mid- water column. Under extreme conditions, the end-of pipe salinity would be 40.1 near the bottom and 36.0 in the mid-water column. In 300 m distance from the point of discharge, the salinity would be reduced to 38.2 near the bottom and 35.2 in the mid-water column.

Based on relevant literature data and plant-specific salinity tolerance investigations (see Box 3 further below), it is concluded that operation of the plant under typical conditions would not result in salinity levels in excess of 36.2 in the zone of initial dilution, and that this would not substantially affect any species. Short-term and episodic salinities levels at or below 40 as potentially caused during extreme conditions would also not have a substantial effect on species within the study area.

Perth SWRO project, Western Australia

The Perth desalination plant (144,000 m^3/d) is located in Cockburn Sound, Western Australia. Pre-construction studies, mostly using existing data, were carried out in 2005 encompassing modeling the stratification and dissolved oxygen (DO) in the sound [104, 105], determining the sediment oxygen demand and contaminant releases [106], and assessing ecological effects [107]. A review report [102] concluded that the findings, i.e., that there would be no or negligible ecological effects, cannot be accepted with a high degree of confidence. It was criticized that a simplified box model was used for modeling the stratification and DO in the Sound and that the results were not validated by observational data. Little confidence was therefore placed in the *actual* values presented, but the basic conclusions, i.e., that the discharge is unlikely to have a major effect on density stratification and DO levels in Cockburn Sound, was considered reasonable. It was furthermore criticized that the analysis of the ecological effects relied too heavily on the modeling results and that the conclusions were too firmly stated given the uncertainty about the type and severity of impacts. The recommendations of the original studies, such as to assess DO levels by an ongoing monitoring program and to conduct a comprehensive survey of the macrobenthos in the sound, were thus fully embraced.

According to [89], the concerns raised by reviewers, scientists and stakeholders led to the establishment of conservative water quality and discharge criteria for dissolved oxygen and salinity. The Western Australian guidelines for fresh and marine waters specify that the median increase in salinity is to be less than 5% from background, which in marine environments is a change of about Δ S = 1.5 [45]. The criteria for the concentrate discharge set by the Western Australia Environmental Protection Authority require that salinity would be within 1.2 units of ambient levels within 50 m of the discharge point and within 0.8 units of background levels within 1,000 m of the discharge point. More extensive marine studies and monitoring requirements were also adopted. The baseline studies included concentrate modeling, water and sediment quality, macrobenthic surveys, sediment oxygen demand and whole effluent toxicity testing [89].

Box 2 (continued): Studies for facilities with a capacity ≥ 100,000 m^3/d

The modeling results[1] show that the desalination discharge, through the use of a diffuser, will influence salinity only in the immediate vicinity of the discharge and in a very limited manner, meeting the proposed water quality criteria. The small changes in salinity predicted to occur over a relatively small spatial scale are assumed not be detrimental to the water quality in Cockburn Sound where greater changes in salinity occur over larger areas naturally, on a daily and seasonal basis. Field testing during the first year of operation, including tracing an environmentally benign dye (Rhodamine) added to the plant discharge, showed that the desalination discharge rapidly mixes with the surrounding waters. Furthermore, a real-time telemetered monitoring system was established which provides feedback on dissolved oxygen levels, conductivity and temperature [89].

In a an earlier literature study from 2002 [45], the capacity of the local marine fauna and flora to tolerate the predicted levels of salinity were evaluated, using one meta-literature source [108] that reviewed available information on seagrass communities in Shark Bay. Shark Bay is a sheltered embayment with salinities naturally higher than those of ambient seawater, which also harbours two seagrass species common to Perth's Coastal Waters, *Posidonia australis* and *P. amphibolis*. Physiological investigations of these species found maximum growth rates at a salinity of 42.5, and densest covers of seagrass meadow in the region occurred at salinities between 40 and 50. It is concluded that the existing data, though limited, indicates that seagrasses and benthic organisms are tolerant and potentially benefit from salinity levels of 40. Due to the small salinity increases caused by the Perth desalination plants, it is furthermore concluded that direct or indirect adverse impacts on seagrass meadows, reef or bare sand environments and associated biota are not to be expected. The extensive real-time monitoring in Cockburn Sound in combination with annual marine habitat mapping [89, 109] will help to detect any real changes in the macrobenthic communities.

Studies for facilities with a capacity < 100,000 m^3/d

Maspalomas, Gran Canaria, Spain

The mixing processes of brine discharges from the Maspalomas II (25,000 m^3/d) plant in the south of Gran Canaria were investigated in [83]. The brine with a volume of 17,000 m^3/d and a salinity of 90 is discharged via two outfalls with a diameter of 30 cm and 60 cm, respectively, which extend about 300 m into the sea. The discharge depth is about 7 m. The location is characterized by a sandy seafloor where no segrass beds are present, since the depth and the marine dynamics impede their development. The study observed a high initial dilution of the brine: the salinity decreased from 75 (measured near the outlet) to about 38.5 (near the seabed) and 37 (near the surface) within 20 m from the outfall, with a decrease to almost ambient salinity values (37) within 100 m distance from the outfall.

[1] The models used included:
3 dimensional (3D) hydrodynamic Environmental Fluid Dynamics Code (EFDC), 1D box model, 3D hydrodynamic and dispersion model Mike 3 (Danish Hydraulics Institute), 3D numerical model Estuary, Lake and Coastal Ocean Model (ELCOM) and 3D Computation Aquatic Ecological Dynamics Model (CAEDM).

Box 2 (continued): Studies for facilities with a capacity < 100,000 m^3/d

Blanes, Mediterranean Sea, Spain

The effect of brine discharge from a desalination plant in Blanes, Spain, on macrobenthic communities were investigated in [110]. The plant has a capacity of about 27,400 m^3/d and a concentrate discharge of about 32,900 m^3/d with a salinity of 60. The concentrate is discharged via a diffuser (perforated pipe). Salinity was found to decrease quickly with distance from the pipe, being back to ambient values within 10 m distance from the outlet pipe. Two controls and one supposedly impacted location were selected and visual censuses were carried out by scuba divers 12 times before and 12 times after the plant had begun operating.

No significant variations attributable to the brine discharge were found. This is explained by the rapid dilution of the brine and the high natural variability that is characteristic of this type of habitat (i.e. the sandy substratum), which is sufficiently large to be able to mask possible alterations caused by the discharge. Any such alterations stayed within the system's own natural variability range. It is noted that the results do not necessarily mean that the brine discharge has no direct effects on the populations present, but only that any such effects cannot be discerned in a statistically significant manner on a short-term basis. The absence of any observed impact could also be the result of e.g. affected area size or species mobility, but apparent effects were also not observed for certain sessile species.

Javea, Mediterranean Sea, Spain

The effect of brine discharge from a desalination plant in Javea, on the Mediterranean coast of Spain, were investigated in [71]. The desalination plant has a capacity of 28,000 m^3/d which will rise to 42,000 m^3/d in the future. The seawater is taken in through 10 beach wells, each with a depth of 200 m. The brine is diluted with seawater, which is specifically taken in for this purpose from a near-by river mouth, in order to reduce salinity below 45. The mixed brine and seawater then flow into a holding tank before being discharged into a channel through 16 diffuser heads. The channel flows into the sea. The salinity of the combined discharge was on average 39.5 and reached often values of 44, depending on the salinity of the river which is influenced by freshwater runoff.

Four surveys (two in summer, two in winter) were carried out to assess the effects of the discharge on salinity in the channel and the nearby sea area. The salinity was measured in surface water, near the seabed, and in sediment pore water. Surface water salinities were increased within the channel but not in the sea outside the channel mouth, whereas an increase in bottom and interstitial water was observed to a maximum of 300 m distance from the mouth of the channel into the sea under calm operations. Monitoring of a seagrass meadow "in the area surrounding the […] channel" and two control sites was carried out over a two year period. It was concluded that seagrass dynamics in the potentially affected and the two control sites was very similar. The salinity increase in the potentially affected site and the distance to the channel mouth were not specified. From presented graphs it can be approximated that bottom salinity in the sea area surrounding the channel mouth ranged between 38 and 40, with ambient values of around 37 in 300 m distance.

Box 2 (continued): Studies for facilities with a capacity < 100,000 m^3/d

Alicante, Mediterranean Sea, Spain

Preliminary effects of brine discharge from a desalination plant in Alicante, on the Mediterranean coast of Spain, were investigated in [111]. The plant has an installed capacity of 50,000 m^3/d and operates at a recovery of 40%, producing a brine discharge of 75,000 m^3/d with a salinity of 68. The feedwater is taken from beachwells. Discharge takes place on the southern shore of the harbor, which has been previously impacted by other activities. Three surveys were carried out over the course of one year, involving a sampling grid of more than 100 salinity sampling stations in the vicinity of the outfall. Salinity depth profiles taken in a distance of 2 km from the discharge point showed increased salinities of 38.5 in intermediate water (12 m) layers in August and near the bottom (16 m) in February and April. Horizontally, it was found that dilution is high in the near field and low in the far field, with bottom water salinity increases higher than 0.5 above average up to 4 km distance from the outfall.

Echinoderms and *Posidonia oceanica* meadows were monitored in three locations (in front of the discharge and two controls in 2 km distance to the north and to the south). Preliminary results from the first year of monitoring showed that echinoderms had disappeared from the meadow in front of the discharge and the southern control site. No decline of the seagrass meadow occurred, but a lower vitality of plants near the discharge was observed. As the salinity increases measured in the meadow in front of the desalination plant discharge were close to the ones that produced significant effects on *Posidonia* growth and survival in other studies [94, 112], potential long-term impacts were deemed possible.

San Pedro del Pinatar (Murcia), Mediterranean Sea, Spain

Monitoring results from a SWRO desalination in San Pedro del Pinatar (Murcia, SE Spain) were presented in [113]. The plant started operation in May 2005, progressively increasing the number of lines in operation to a total of 9 with a maximum production of 65,000 m^3/d at an average recovery rate of 44%. The intake water is supplied by wells that were constructed by horizontally directed drilling. The concentrate has a salinity of about 70. The main discharge pipe, which has a length of 5 km length and discharges at –35 m, was completed 8 months later. Between start-up and completion of the pipe, the brine was provisionally diluted with seawater and discharged near the coastline at –2 m water depth. A monitoring program was established to investigate brine dispersal and potential effects on *Posidonia oceanica* meadows in this time period. The meadows appeared in –4 m water depth and approximately 200 m distance from the discharge point. The seabed in front of the discharge was characterized by sandy sediments with a few patches of rocks. Before the concentrate discharge, salinity oscillated between 37.5 and 38 in the upper limit of the meadow, which increased to more than 39 when the plant began operation in May. As a result, the dilution of the brine before discharge was increased.

No changes in the biological communities (*P. oceanica*, *Dendropoma petraeum* and echinoderms) were detected over the 8 months period of the provisional monitoring program. No information was given on the characteristics of the new discharge site in –35 m water depths and the mode of dilution of the discharge.

Box 2 (continued): Studies for facilities with a capacity < 100,000 m^3/d

Cyprus, Mediterranean Sea

The impacts of the Dhekelia SWRO plant, Cyprus, on marine macrobenthos in the nearby coastal waters were investigated over a two year period (1997-1998) [114]. The production capacity of the plant was increased from 20,000 m^3/d to 40,000 m^3/d in this time, with the facility discharging an equal amount of brine with a salinity of about 70. The concentrate was initially disposed of into the coastal area at a water depth of less than –0.5 m and then via an outfall at –5 m water depth and 200 m distance from the shore. Seasonal and spatial variations in salinity were observed in Dhekelia Bay, which is an enclosed bay with low dispersion rates. Salinities up to 50 were observed in a limited area around the outfall diffuser, with salinities decreasing to ambient values of 39 within 200 m around the outfall.

Before discharge started, the area close to the outfall was characterized by rocky substrate dominated by forests of the brown macroalgae *Cystoseira barbata*, in which other species of macroalgae were also found. Salinity increases seriously impacted the phytobenthic assemblage, with *Cystoseira* forests vanishing from the area around the point of discharge. High salinities also had effects on macrofauna composition in the vicinity of the outfall. While the benthic community prior to the concentrate discharge consisted of 27 % polychaetes, 27 % echinoderms, 26 % scaphopods and 20 % gastropods, the only remaining taxa after construction were polychaetes (71 %) and gastropods (29 %). According to Tsiourtis [115], monitoring results carried out every 6 months for 4 years at the Dhekelia site have shown that the situation around the outfall point is steady and confined to an area within a radius of 200 m.

A larger SWRO plant was constructed in Larnaca in 2002 with a production capacity of 54,000 m^3/d and a similar volume of brine production. Following the experience made in Dhkelia, the discharge pipe was constructed at a length of 1,500 m and at a water depth of –25 m below the surface. According to the Cyprus Department of Fisheries, the first measurements conducted in the site point to good dilution conditions [33].

Studies for facilities with a capacity < 10,000 m^3/d

Antigua Island, Caribbean Sea

A comprehensive study was conducted for a small desalination plant on Antigua Island in the Caribbean. The facility has a capacity of 5,000 m^3/d and produces about 6,800 m^3/d of concentrate. The intake salinity is about 35, and the discharge salinity about 57. The site was chosen for its near shore benthic community, which included expansive areas of seagrass (*Thalassia*), coral heads, and typical tropical fish and invertebrate species. Biological and water quality data was collected before concentrate discharge into the study area began. The discharge increased salinities within 10 m from the discharge point.

After 3 months, a weak positive correlation was observed between the intensity of the discharge plume and abundance of the algae *Dictyota dichotoma*, which may be due to nitrogen enrichment in the plume. The nitrogen enrichment may be due to the concentrating effect of the desalination process, or nutrient increases associated with filter backwashing. After 6 months, abundances of *Dictyota dichotoma* were lower than during the previous survey. Besides this, no discernible effects of the concentrate discharge on density, biomass, and production of seagrass, or on benthic fauna or pelagic fish species was observed during the surveys after 3 and 6 months [116].

Box 2 (continued): Studies for facilities with a capacity < 10,000 m^3/d

Formentera, Balearic Islands, Mediterranean Sea, Spain

The impacts of brine discharges from a small RO plant on seagrass meadows (*Posidonia oceanica*) were investigated in [91] over a time period of 6 years. The plant has a maximum discharge rate of 2,000 m^3/d during summer and receives feedwater from the groundwater table which is potentially enriched in nutrients from agriculture. The discharge characteristics thus differed considerably from ambient seawater, with (on average) salinity values around 50, a reduced pH (7.5), and high concentrations of dissolved inorganic carbon, orthophosphate, nitrates and nitrites. Environmental samples were taken from three transects that were perpendicular to the coastline. Salinity along the "impacted" transect varied between 37.8 and 39.8, and along the two supposedly unaffected reference transects between 37.4 and 37.6. The sediment pore water showed a greater increase in salinity than did the water column, also in some areas where water salinity was unaffected at the time of measurement. It was therefore assumed that the brine influence can extend beyond the areas of increased water column salinity. The authors observed no extensive decline of seagrass meadows, but the meadow near the brine discharge showed characteristics significantly different from those of the reference transects, such as increased nitrogen content in the leaves and a deterioration in plant health (reflected by high frequencies of necrosis marks and low total non-structural carbohydrates) as well as a higher epiphyte load. It is concluded that the effects stem from two factors: increased nitrogen and hypersaline conditions. Based on the observations, a critical salinity threshold of 39.3 is established, which was found to be in good agreement with the salinity threshold of 39.1 established by [112] for *P. oceanica* based on experimental results. A measured change in ecosystem integrity was the absence of echinoderms, holothurians and sea urchins, which are considered to be environmentally sensitive species based on laboratory findings.

The impacts of brine discharges on *P. oceanica* were also investigated in a two year study involving laboratory (15 day tank experiments) and field investigations of effects caused by a SWRO pilot plant on Formentera. It seems that the results presented in the above study [91] and the following results presented in [117] are partly based on the same original study. Results are as follows:

- Salinities of about 50 caused 100% mortality in 15 days. Salinities around 45 caused about 50% mortality. Variable results were observed at salinities of 43, 42.9 and 40, which caused 20%, 55% and 27% mortality, respectively. In the laboratory experiments, mortality was also frequently observed in water of ambient salinity (on average 8.5%).
- At salinities of 48–50, no plant growth was observed. At a salinity of 43, growth rates were 50% of the growth rates at natural salinity. At a salinity of 40–41, growth rates were on average reduced by 14% compared to ambient.
- Plants exposed to a salinity of 43 were able to recover when returned to normal conditions.
- Mortality and diminished growth were also observed when only the basal part of the plants was exposed to hypersaline water.
- The increased nutrient levels of the discharge were assumed to be the cause of some of the observed effects on the meadows.

Based on the results, it was recommended to avoid P. oceanica meadows, or when avoidance is not possible, to dilute the discharge salinity appropriately so that it exceeds a value 38.5 in no more than 25% of the time and a value of 40 in no more than 5% of the time.

Box 3: Overview on salinity tolerance and toxicity studies (bioassay studies)

Carlsbad SWRO project, Southern California

Salinity tolerance investigations [26, 118] were conducted to evaluate the effects of increased salinity on species commonly found in the discharge site of the proposed desalination project and species considered to be sensitive to environmental stress.

In a first comparative study, a collection of 18 marine species was held in an aquarium containing a blend of desalination plant concentrate and power plant effluent with a salinity of 36, which is equal to the salinity that would occur within the zone of initial dilution during 95 % of the time (ambient salinity is 33.5). Organisms were evaluated for overall health based on qualitative parameters (appearance, willingness to feed, activity, gonad production in the urchins) and compared to organisms held in a control tank. The quantitative parameters measured were percent weight gain/loss and fertilization success of the purple sea urchin (*Strongylocentrotus purpuratus*). During the 5-½ month test no mortality was encountered. All organisms remained healthy and showed normal activity and feeding behavior at a salinity of 36. No statistical significant difference in weight gain/loss to the control group was observed, and sea urchin spawning and fertilization was also successful.

The second study was a salinity toxicity study in which selected species of concern (purple sea urchin *S. purpuratus*, sand dollar *Dendraster excentricus*, and red abalone *Haliotis rufescens*) were kept at salinities of 37, 38, 39, and 40 over an extended period of time (19 days). These species were chosen due to their known susceptibility to environmental stress and the objective was to capture the biological effects of increased salinity that might occur during extreme operating conditions in the zone of initial dilution. Survival rate was 100% at the end of the test in all test salinities. General observations showed that all individuals were behaving normally.

In addition to the salinity tolerance investigations, a toxicity testing study was carried out [26, 119], using RO concentrate and diluting it with seawater to a salinity of 36. Standard bioassay test were performed on giant kelp *Macrocystis pyrifera* (48 hours germination and growth test), topsmelt *Atherinops affinis* (7 day survival using 10-day old larva) and red abalone *Haliotis rufescens* (48 hour post fertilization embryonic development test). The results indicate that under worst case discharge conditions, the blend of cooling water and RO concentrate will not exhibit acute or chronic toxicity.

Based on the salinity tolerance and toxicity investigations and results from relevant literature, it is concluded that no significant effects are expected from operation of the SWRO plants under normal and extreme conditions. Species found in the southern California bight have geographical ranges that extend into sub-tropical waters, which have higher salinity and temperature values than those expected to occur during normal and extreme operating conditions of the proposed desalination plant. Many species living in the project area therefore experience a natural salinity range that is comparable or greater to what is predicted for the combined discharge. Fish, plankton and other pelagic species will also have a shorter exposure time than applied in the tests [26, 119].

EPA (1986) recommendations state that, in order to protect wildlife habitats, salinity variation should not exceed 4 units from natural variation in areas permanently occupied by food and habitat forming plants when natural salinity is between 13.5 and 35. The food and habitat forming plants located in the vicinity of the proposed project are found in the subtidal hard bottom habitat located to the north and to the south of the discharge channel. As applied to the proposed project, operational conditions that do not elevate salinities above 38.4 (34.4 upper limit of the natural variation in salinity plus 4 units) in the subtidal hard bottom habitat would appear to be fully protective of the food and habitat forming plants living in the discharge field [26, 119].

Box 3 (continued)

Santa Barbara SWRO plant, California

To evaluate potential impacts of brine discharges from the Santa Barbara SWRO plant in California, three representative benthic species were exposed to elevated salinity levels [120]. Salinity samples were produced by mixing hypersaline brine with laboratory seawater. Brine was produced by freezing and partially thawing laboratory seawater. It is concluded that the desalination waste brine is not toxic to amphipods, kelp spores, or sea urchin embryo at concentrations expected to occur in the field. The single test results were as follows:

- Spore germination and tube growth of the giant kelp *Macrocystis pyrifera* were tested in five different salinities ranging from 34.5 to 43 (the end-point of 43 was much higher than salinities predicted by a dilution model for the discharge site of the plant). During the 48-hour test, no statistically significant effects were observed, i.e. elevated salinity did not affect kelp spore germination or tube length. The highest germination percentage occurred at a salinity of 38.5, the lowest at 36.5. Germ tube length of kelp spores was highest at moderate salinities of 35.5 to 38.5 and lowest at the highest salinity of 43, but the effect was not significantly different from the control.
- Ten day tests with amphipods (*Rhepoxynius abronius*) exposed to salinities of 34.5 to 38.5 did not indicate any salinity effects and survival was only slightly reduced in the higher salinity vessels.
- 48-hour salinity tests with sea urchin embryos produced variable results. A salinity of 36.5 produced a small response, but a severe response was produced at 38.5. Based on the modeling results for the Santa Barbara plant, which predict that salinities greater than 35 outside the zone of initial dilution will occur in less than 10% of the time, impacts on sea urchin embryo are not expected to occur in the field. The test, however, confirms sea urchin sensitivity, which is considered among the most sensitive of marine embryos [120]. The next most sensitive species is the scallop, where embryo development decreased 40% following a 20% increase in salinity [120, 121].

Alicante, Mediterranean Sea, Spain

The effects of salinity on leaf growth and survival of the Mediterranean seagrass *Posidonia oceanica* were investigated by short-term mesocosms experiments [112]. Plants collected from shallow meadows in Alicante with an ambient salinity of 36.8 to 38 were placed in tanks of different salinities between 25 and 57 for 15 days. Leaf growth was at maximum at salinities between 25 and 39 and decreased significantly at a salinity of 39.1 and above. No growth was observed at a salinity of 50. Plants also sustained significant mortality at a salinity above 42 and below 29, with 100% mortality at a salinity of 50. Necrotic tissues were evident in treatments with salinities higher than 42.5 or lower than 33.4. Plants surviving at salinity below 46 for 15 days were able to regain growth when they were returned to normal seawater salinity. Epiphyte biomass was highly variable and did not show a clear response to salinity. The authors summarize that elevated salinity led to a significant reduction in leaf growth at an increase of 1 unit over ambient and increased mortality at an increase of 4 units over ambient salinity values. By comparison with salinity tolerance data for other seagrasses (*Amphibolis antarctica, Posidonia australis, Thalassia testudinum, Halodule wrightii*), the authors conclude that P. oceanica is one of the most sensitive species to high salinity and that meadows may be adversely impacted by salinity increases associated with brine discharge from desalination plants.

Box 3 (continued)

ACSEGURA and CEDEX research programme, Spain

Different studies were conducted within a research program funded by ACSEGURA and CEDEX and the results published in several journal articles [91, 94, 111, 112, 117, 122]. An overview article [122] summarizes the main findings from the research program which consisted of three parts:

- Experimental work in the laboratory: a number of *P. oceanica* shoots were maintained in 300 l tanks during 15 days under different salinity treatments (salinity: 23–57) (see also [112] above).
- Experimental work in the field: 1 m^2 surface plots located in a natural stand of *P. oceanica* were treated in situ over a period of 3 months with two different concentrations of a hypersaline water obtained from a pilot desalination plant (salinity of 39.2 ± 0.8 corresponding to a 1.5 unit increase, 38.4 ± 0.3 corresponding to a 0.7 unit increase over ambient salinity of 37.7 ± 0.1).
- Field surveys: study of the long term impact of desalination plant discharge on a *P. oceanica* meadow in the Balearic Islands (Island of Formentera, see also [91, 117]).

Experimental work in the laboratory:

- A salinity of 39.1 and above had significant effects on plant vitality (e.g. leaf growth). Results were similar when the whole plant or only the basal part was exposed to hypersaline water.
- A salinity of 40 and above had significant effects on plant mortality.
  A salinity of 45 caused 50% mortality after 15 days exposure.
- In some cases, plants exposed to short hypersaline episodes were able to recover their normal growth after being returned to normal salinity.
- Increased mortality of the mysid *Letomysis posidoniae* and the sea urchin *Paracentrotus lividus* (which are often found in the seagrass meadows) was observed at a salinity 40.5-41.

Experimental work in the field and field surveys:

- Increased plant mortality and lower plant vitality was observed in plots with brine treatment compared to the plots without treatment.
- Close to the discharge point (salinities: 38.4–39.8), a significant reduction in leaf size, an overload of epiphytes, a higher nitrogen and phosphorous concentration in tissues and a higher herbivore activity was observed compared to unaffected areas. The effects are probably caused by eutrophication.
- In the far field (salinities: 37.8–39.3), no eutrophication symptoms were observed. The meadow did not show differences in shoot densities compared to reference sites, however, changes in the structural pattern of the shoot distribution, an increase in the frequency of necrosis marks in the leaves, and a significant lower abundance of the accompanying macrofauna compared to reference meadows were observed. The effects are probably due to salinity stress.

Overall conclusions:

- Due to the high sensitivity of *P. oceanica* and associated fauna to salinity increases, brine discharges into areas containing these ecosystems should be avoided.
- In case that avoidance is not possible, salinity should not exceed 38.5 in any point of the meadow for more than 25% of the observations on an annual basis and not more than 40 in any point of the meadow for more than 5% of the observations on an annual basis. The thresholds require further verification and are only applicable to *P. oceanica* of the Western Mediterranean region.

Box 3 (continued)

Bioassay studies summarized from secondary sources (original not available)

Buceta et al. [20] investigated the effects of brine on local *Posidoni*a seagrass meadows. Salinity increases caused growth reduction, permanent leaf fall, appearance of necrosis in the tissues, structural pattern changes of the meadow, decreased abundance of the accompanying macrofauna and increased mortality rates. The sensitivity of fauna frequently found in the *Posidonia* meadows (in particular *Leptomysis posidoniae* and *Paracentrotus lividus*) has also been investigated. Mortality generally increased with salinity, with statistically significant effects at a salinity of 40 and above, while for salinities close to 45, 50% of the plants died within the first 15 days. It has been recommended that salinity thresholds should not be given in terms of a referential value but as frequency distribution: for instance, the salinity should not surpass a salinity of 38.5 in over 25% of the measurements, or 40 in over 5% of the measurements in no point of the meadow (from [93] based on [94]). Due to the lack of long-term observations, uncertainty remains concerning chronic effects during long-term exposures. Season, temperature, depth variability and light availability as well as other environmental components probably also alter the observed effects. For instance, plants in greater depth seem to be much more sensitive. Also, the detrimental effects of chemical agents (sporadically or permanently found in the effluent brine) remain poorly quantified [93].

Studies were conducted by [123] on the response of several species of decapod crustaceans to osmotic stress gradients, in order to assess their ability to osmoregulate. One of the test organisms was the sand crab *Emerita analoga*, an inhabitant of sandy beaches. The species was found to have a narrow range of salinity tolerance (stenohaline). Tests were run using seawater concentrations of 50, 75, 90, 110, 125, and 150%, corresponding to standard seawater salinities of 17, 26, 31, 38, 44, and 52, respectively. Animals placed in 50% (salinity of 17) and 150% (salinity of 52) seawater concentrations died within about two hours of immersion, while those placed in 75% (salinity of 26) to 125% (salinity of 44) seawater concentrations were able to survive as long as 24 hours, thus demonstrating some ability to tolerate changes for a limited period of time (from [23]).

Bioassay studies were conducted by [124] for the Sand City Plant in California. The studies investigated the effects of saline water (using elevated salinity treatments of 33, 38, 43, and 48) on the survival of two shallow subtidal beach species, the olive snail *Olivella pycna* and the sand dollar *Dendraster excentricus,* which occur in shallow subtidal sands of the Monterey Bay. It was found that salinity concentrations at some level between 43 and 48 would become lethal to young sand dollars (10–15 mm diameter) but not to olive snails (3–4 mm length). The authors discuss other pertinent studies and conclude that measuring chronic effects to growth and reproduction as well as survival may be a better indication of salinity toxicity and therefore require a longer test (from [23]).

Box 3 (continued)

Another series of bioassay tests was conducted on Japanese littleneck clams (*Venerupis [Ruditapes] philippinarum*), juvenile sea bream (*Pagrus major*), and marbled flounder (*Pseudopleuronectes yokohamae*) [125], using hypertonic solutions made from a commercial salt mixture and aerated tap water (from [23]).

- The clams showed unimpaired behavior in a salinity of 50 or less. Lethal effects were observed after 48 hours in a salinity of 60, and after 24 hours in a salinity of 70.
- The juvenile sea bream survived well in salinities of 45 or less. In a salinity of 50, 25% died within 24 hours. In a salinity of 70, all fish died after 1 hour.
- In an avoidance experiment, researchers slowly pumped colored solutions of different salinity concentrations into the bottoms of the tanks holding juvenile sea bream in water of normal (33) salinity, thereby creating two layers of water in the tanks. The sea bream behaved normally in water up to and including salinities of 40. Between salinities of 45 and 70 the fish spent less and less time in the higher salinity water. The fish did not enter water with a salinity of 100.

Hatchability of eggs of the marbled flounder was successful at salinities up to 60 but dropped to zero at a salinity of 70, however, hatchability was delayed with increasing salinity between 31 and 60. Marbled flounder larvae survived with no ill effects in salinities up to 50. At a salinity of 55, mortality began to occur after 140 hours. In salinities between 60 and 100 the number of dead larvae increased in shorter periods of time.

Box 4: Toxicity studies concerning co-discharge with waste water from sewage plants

Direct discharge through an existing wastewater treatment plant outfall has found a limited application to date, especially for medium and large seawater desalination plants [18]. Waste brine is in most cases discharged directly to the ocean. Only for some smaller plants, it is proposed to discharge the brine through an existing waste water treatment plant outfall. For example, the City of Santa Cruz' proposed desalination plant in California would convey its brine discharge into the City's wastewater treatment plant where it will be combined with the advanced secondary treated wastewater [23]. The main benefit of this kind of co-discharge is to allow for mixing of the two wastewaters before discharge, and to accelerate mixing in the environment that stems from blending the heavier high-salinity concentrate with the lighter low-salinity wastewater discharge [18].

A disadvantage is the potential for whole effluent toxicity (WET) of the blended discharge, as the mixing of the two waste streams may lead to synergetic effects not found in the individual waste streams [23]. The studies cited below show that mixing of concentrate and waste water can cause toxic effects on some aquatic species, but that the information is somewhat patchy and the effects not fully understood. Site-specific laboratory toxicity tests of combined effluents in different mixing rations are required in order to detect potential impacts on the receiving environment, using effluents from the treatment plants in question and local fauna and flora species.

Box 4 (continued)

An ion make-up shift (ion ratio imbalance) caused by blending of the two waste streams is considered to be the most likely cause for the toxic effects of the concentrate-wastewater blend on sensitive marine species. Blending therefore requires a careful evaluation taking the advantages and disadvantages of this option into account. Furthermore, reuse of the treated waste water may be preferable over disposal, as treated waste water should be considered as a resource rather than a waste product [12]. Membrane technologies can be applied to both wastewater and seawater to produce a new water supply source. Reuse is thus an option which may eliminate the need for a new desalination project and adverse environmental effects associated with the waste water discharge.

Santa Barbara SWRO plant, California

A 48-hour sea urchin (*Strongylocentrotus purpuratus*) embryo development test (endpoint: normal development) was conducted to investigate the potential interactions between elevated salinity and sewage. A 24-hour composite of secondary effluent from the El Estero wastewater treatment plant in Santa Barbara was collected and mixed with laboratory seawater and hypersaline brine to produce the desired combinations. Wastewater at 5.6% effluent (highest test concentration) and ambient salinity (33.5) had a significant toxic effect on sea urchin development. At lower effluent concentrations there were no effects on development. At higher salinity of 36.5, the proportion of normal embryos *in*creased as the percent of sewage *in*creased. It is concluded that salinity may have altered the chemical speciation of toxicants in the sewage and reduced toxicity, as salinity can reduce the toxicity of some trace metals by increasing the complexation of the toxic, free ion form [120].

Marin Municipal Water District's pilot desalination, California

Bioassay studies conducted for the Marin Municipal Water District's pilot desalination plant involved a 7-day chronic inland silverside (*Menidia beryllina*) test, a 96-hour diatom (*Skeletonema costatum*) growth test, a 48-hour bivalve larvae test, and a 96-hour acute speckled sand dab (*Citharichthys stigmaeus*) test. Tests were performed on the brine concentrate itself and on the brine mixed with effluent from the Central Marin Sanitation Agency sewage outfall. The studies found that a dilution of bay water to brine of 23:1 and of CMSA effluent to brine of 20:1 were necessary to achieve a No Observable Effect Concentration (NOEC) for these organisms [126].

Figure 11: Periodic discharge of filter backwash water from the Ashkelon SWRO plant in Israel (courtesy of Rani Amir, Director of the Marine and Coastal Environment Division, Israel Ministry of the Environment).

C.4.5 Discharge of residual chemicals

The conventional pretreatment methods for conditioning the incoming feedwater in desalination plants were outlined in section C.4.2 on p. 66. This section evaluates the potential impacts of the residual chemicals in the reject streams on the marine environment.

Potential impacts on receptors

Landscape and natural scenery

Coagulants (filter backwash)

The filter backwash may significantly increase turbidity in the discharge site, which may be an aesthetic problem when ferric salts are used as coagulant, as these can turn the mixing zone of the backwash plume into a deep red-brown color (Figure 11, p. 92, [73, 127]). There is also concern that the discharge of ferric coagulants may cause a discoloration of sandy beaches when discharged at sea and dispersed by currents [89].

Seafloor and sediments

Heavy metals

Heavy metals such as copper, which may be present in the discharges of distillation plants, have a tendency for accumulating in sediments. The risk of metal accumulation is potentially high near point discharges, in soft bottom habitats or in areas of restricted water exchange, and where sedimentation rates are high.

Seawater quality and hydrology

Chlorine and chlorination by-products

Seawater chlorination results in two groups of chemicals – the oxidants and the chlorination by-products. The oxidants decompose quickly following discharge which results in a limited dispersal range, whereas some of the by-products are persistent and can be dispersed over longer distances. Both residual chlorine and chlorination by-products were detected in the discharge sites of distillation plants (cf. C.4.2, p. 68f).

Heavy metals

The discharge of concentrate from desalination plants may increase dissolved metal concentrations in the mixing zone of the discharge plume and may thereby affect water quality.

Coagulants (filter backwash)

The filter backwash (if discharged into the sea) may increase turbidity and decrease light penetration in the water column (Figure 11).

Antiscalants

Antiscalants generally have a slow to moderate rate of elimination from the environment and are often classified as *inherently* biodegradable (cf. Table 28, Appendix D.3, p. 143ff.) [47]. As antiscalants exhibit dispersing and complexing properties (they prevent scale formation by dispersing and complexing divalent ions such as calcium and magnesium), it seems plausible to assume that antiscalants can also interfere with the natural processes of dissolved metal ions in seawater following discharge. This may be a concern in sea areas with high installed desalination capacity in combination with the prolonged residence time of antiscalants in the environment. For instance, it is estimated that about 60 tons of antiscalants could be discharged into the Gulf every day from desalination plants based on a typical dosage of 2 mg/l to the feedwater [82].

pH

Acid is normally used to adjust the pH to slightly acidic values in order to enhance the coagulation-flocculation process and can also be used for scale control. The pH value of the concentrate may therefore be slightly acidic (pH 6–7) as compared to ambient levels of around 8. A low residual acidity will be neutralized quickly following discharge into well-mixed waters and a pH effect on the receiving water is unlikely due to the good buffering capacity of seawater, which will neutralize surplus acidity quickly.

Decrease in dissolved oxygen (DO) levels

The use of sodium bisulfite for dechlorination may cause reduced oxygen levels in the concentrate when overdosed. Also, when the feed water is taken from a subsurface intake, it may contain reduced DO levels. These are often less than 2 mg/l, compared to ambient seawater DO levels of 6–8 mg/l. This may result in a concentrate with correspondingly low DO levels, which may not meet discharge and ambient water quality standards [22]. For example, the California Ocean Plan limits the decrease in DO to no more than 10% of the ambient level at the edge of the zone of initial dilution [26].

By turbulent discharge, e.g. through an outfall channel or diffuser system, the concentrate may become saturated again with oxygen. In this case the concentrate may even supply oxygen to the bottom water layers (due to its higher density). The concentrate discharge may consequently have two opposing effects on DO levels: On the one hand, a plume saturated with oxygen could add oxygen to bottom waters, while on the other hand the plume may strengthen density stratification which impedes re-oxygenation of bottom water layers [102].

Marine flora and fauna

Chlorine and chlorination by-products

Chlorine is a highly effective biocide and may affect non-target organisms following discharge even in low doses. Moreover, toxicological studies investigating the effects of chlorinated-dechlorinated seawater on fish and invertebrate species observed chronic effects and increased mortality rates, which may be attributed to the presence of halogenated organics formed during chlorination (cf. section C.4.2, p. 68f).

Heavy metals

Metals may be assimilated by marine organisms, with the risk of bioaccumulation and biomagnification (cf. section C.4.3). The toxicity generally depends on metal speciation (which also affects bioavailability), and the sensitivity of individual species and life-cycle stages of organisms. Impacts of metal discharges are generally difficult to predict, and should be evaluated in the context of natural background levels.

Coagulants (filter backwash)

Coagulant chemicals are commonly used in water treatment and are generally not toxic to aquatic life. Iron is also not considered a priority pollutant, as it is a common natural element in seawater. The discharge of large sludge volumes, however, may cause physical effects. Lower light penetration may reduce primary production, e.g. of seagrass beds, or sedimentation of the material may blanket benthic plants and animals.

Antiscalants

Phosphonate and organic polymer antiscalants have a low toxicity to aquatic invertebrate and fish species, but some substances exhibit an increased toxicity to algae (cf. Table 27, Appendix D.3, p. 143ff). The antiscalant dosing rate in desalination plants (1–2 mg/l), however, is a factor of 10 lower than the level at which a chronic effect was observed (20 mg/l), and it is 10–5,000 times lower than the concentrations at which acutely toxic effects were observed. Two material safety data sheets for commercial antiscalant products note that the observed inhibition of algae growth is due to the product's capacity to bind nutrients and not to its toxicity as such. This gives further evidence that antiscalant may interfere with the natural processes of dissolved metals in seawater following discharge. Some of these metals may be relevant micronutrients for marine algae. No field investigations about the actual environmental fate and interactions of antiscalants have been carried out to date.

Polyphosphate antiscalants are easily hydrolysed to orthophosphate, which is an essential nutrient for primary producers. The use of polyphosphates may cause a nutrient surplus and an increase in primary production in the discharge site, which may lead to oxygen depletion when the organic material decays. Eutrophication was reported at the outlets of some larger thermal desalination plants that used polyphosphates for scale control [57, 98].

Toxic effects from decreased oxygen levels

Decreased oxygen levels may be harmful or even toxic to marine life.

C.4.6 Hazards and hazardous materials

The operation of a desalination plant requires the routine transport, storage and handling of hazardous materials, which is generally closely regulated in order to minimize hazards to personnel, the public and the environment. Under reasonably foreseeable upset and accident conditions, the risk of fire, explosion or release of hazardous materials into the environment is therefore low. However, despite all precautionary measures, a small risk remains that workers, the public or the environment is unexpectedly exposed to hazardous materials. The likelihood of an accident is low, however, in the unforeseen event that hazardous material is released, impacts may be severe.

Potential impacts on receptors

Soils

The release of cleaning chemicals in larger quantities by accidental spills during routine transport, handling and storage may cause localized soil contamination.

Ground- and surface water quality and hydrology

Chemicals may affect water quality if spilled into a water body or washed into ground- or surface waters by rain and runoff after a spill. For example, high and low pH values of strongly alkaline or acidic cleaning solutions could affect the natural pH of the water body.

Seawater quality and hydrology

Chemicals may also affect seawater quality if chemicals are accidentally spilled into the sea or washed into the sea by surface runoff.

Terrestrial flora and fauna

Accidental spills into the ground or surface water bodies may affect the local fauna and flora.

Marine flora and fauna

Accidental spills into the sea may affect the local fauna and flora.

C.4.7 Noise emissions

Desalination plants can produce significant noise emissions. For SWRO plants, noise levels of over 90 dB (A) have been reported [42]. Major sources of noise during operation include (values in dB (A) and 0,9 m distance [26]): the intake pumps (90), the RO high pressure pumps and the energy recovery systems (90), and other pumps and equipment (88), such as the different pumps and equipment of the pretreatment and cleaning systems. The facilities would normally be installed in buildings which may include additional noise attenuation measures, thereby reducing the noise emissions to surrounding areas.

Potential impacts on receptors

Landscape and natural scenery

Noise emissions can permanently impair the aesthetic landscape properties and the natural scenery of nearby areas within acoustic range.

Terrestrial flora and fauna

Increased noise levels during operation may scare away sensitive wildlife.

C.4.8 Energy use

Energy use is a major factor in the environmental assessment of desalination projects. Energy use associated with the operation of a desalination plant includes the electrical or thermal energy produced on site or taken from the electricity grid and used to operate the facility. The total energy demand of the facility comprises the energy for the desalination process, for heating and air conditioning, for lighting and office supplies, as well as the fuel energy used for maintenance visits and employee vehicles.

The specific energy demand refers to the energy demand of the desalination process only.

Reverse osmosis

An external pressure must be applied to the seawater solution, which exceeds the osmotic pressure of the system, in order to reverse the flow through the membranes. A concentration of 1,000 mg/l total dissolved solids (TDS) corresponds to an osmotic pressure of 0.715 bar. For seawater with a TDS of 35,000 mg/l, which has an osmotic pressure of about 25 bars, the theoretical energy demand is 0.7 kWh/m^3 of mechanical work.

A net driving pressure must be applied, which exceeds the osmotic pressure by 25 to 35 bars, in order to obtain a sufficient permeate flux. The required pressure of the feed water is site-specific. It ranges between 50 and 70 bars for seawater applications. Taking the increasing osmotic pressure along the membrane, the process recovery rate, and the efficiency of pumps and motors into account, the RO energy demand is about 7 kWh/m^3 at 50% process recovery.

The use of energy recovery devices (Figure 12, 13) allow for a reduction of the specific energy demand to 2–3 kWh/m^3. Pressure exchangers transfer the concentrate pressure directly to the feed stream. A booster pump compensates for the slight pressure loss [128]. Other devices first transfer the concentrate pressure to mechanical power and then convert the mechanical power back to feed pressure. The efficiency of systems ranges from 70% for turbochargers, 74–82% for reverse running pumps, 80–86% for Pelton turbines, 90–95% for work exchangers to 95% for pressure exchangers [23].

An additional 1–1.5 kWh/m^3 must be added on top of this basic energy requirement for pretreatment and auxiliary equipment, leading to an overall ‘real’ energy consumption of modern SWRO of 3–4.5 kWh/m^3 [129]. The total energy requirement is dependent on the plant and pretreatment design (e.g. process recovery rate, conventional or membrane filtration), the type of RO membranes used (e.g. low energy membranes), the efficiency of pumps (e.g. variable frequency pumps) and motors, and the efficiency of the energy recovery system if such a system is installed.

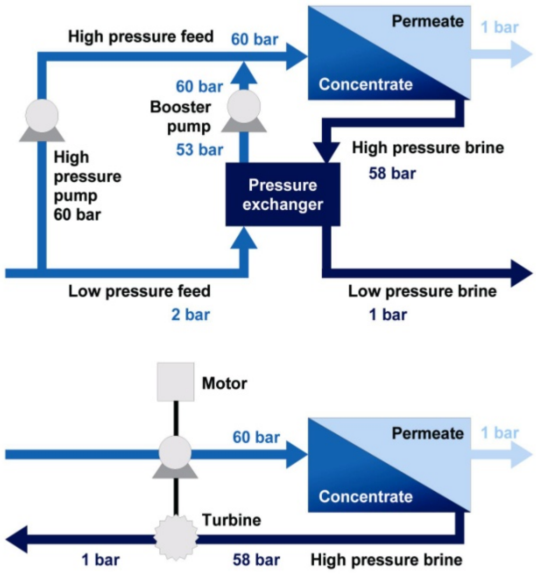


Figure 12: Energy recovery systems: pressure exchanger (top) and classical turbine (e.g. Pelton turbine) [54, 129].

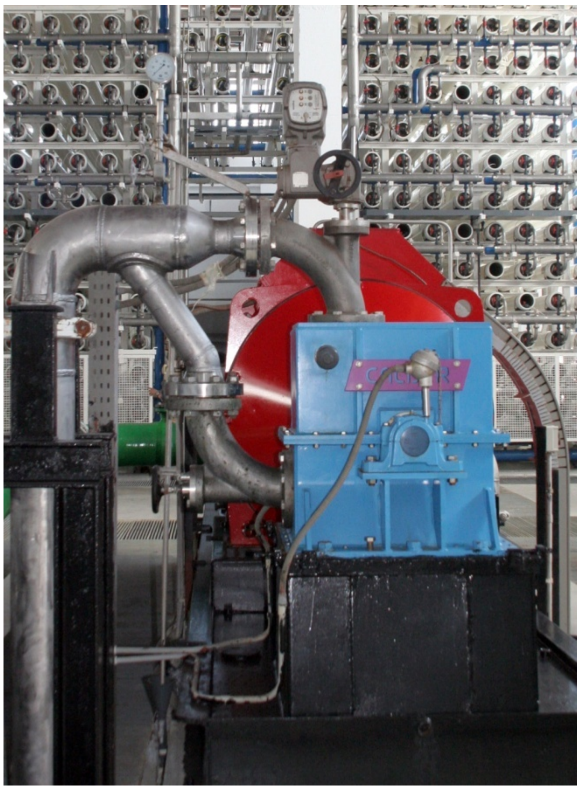


Figure 13: Energy recovery turbine

The Spanish National Hydrological Plan assumes a total energy value of 4 kWh/m^3 under the assumption that plants are equipped with state of the art technologies [93]. For two other SWRO projects, the energy demand is given with 3.9 kWh/m^3 [130] and 4.5 kWh/m^3 [26][31]. Other examples for energy demand, which also include the transfer of water, are 4.2 kWh/m^3 [131][32], 4.5 kWh/m^3 [132] and 5.3 kWh/m^3 [35][33].

The use of state of the art pressure exchanger systems shift the recovery ratio towards lower values, which results in a lower salinity of the reject stream and a reduced scaling potential in the plant, possibly resulting in lower antiscalant pretreatment. Thus, potential environmental effects from high salinity and antiscalants could be reduced, however, a low recovery ratio leads to higher feed water flow rates, which may increase the use of other pretreatment chemicals or entrainment and impingement impacts.

As the treatment and distribution of water from conventional sources and by conventional processes also requires energy, it is necessary to consider both the total energy increase caused by desalination processes as well as the relative increase compared to other water supply options. Furthermore, the chosen reference values may influence how we perceive and evaluate energy demand, for instance if the energy demand is compared to energy usage on a local, regional or national level. Some examples:

- On the Canary Islands, desalination accounts for 14% of all energy demands [133].
- The SWRO plant of Carboneras (capacity of 120,000 m^3/d) on the Mediterranean coast of Spain consumes about one third of the province’s electrical energy [134].
- The Spanish Agua programme will increase desalination capacity in the Mediterranean region from 1.1 million m^3/d in 2005 to over 2.7 million m^3/d until 2010. This will require an additional electricity of 11 GWh/d, assuming an energy requirement of 4 kWh/m^3 [93], and will cause a 1.4% increase over 2005 national electricity generation levels (805 GWh/d, or 294 TWh in 2005 [135]).
- For California, it is estimated that the currently proposed desalination plants with a total capacity of 1.7 million m^3/d would increase the share of desalination to 6% of California’s year 2000 urban water use. The water-related energy use would increase by 5% over 2001 levels assuming an average energy use of 3.4 kWh/m^3 [4]. The total water-related energy use was 48,012 GWh in 2001, representing 19% of the total energy use in California [136]. Another source [50] assumes an average energy use of 2.9 kWh/m^3 to produce 1.7 million m^3/day of new drinking water by desalination in 2030. Desalination would thus increase the water related-energy use of the state by 1,800 GWh/year or about 4% over 2001 levels.
- The Sydney desalination plant with an initial capacity of 250,000 m^3/d is expected to result in a 1.2% increase of New South Wales’ electricity demand if upgraded to a capacity of 500,000 m^3/d [44].

A further reduction in energy demand seems likely in the future. The Affordable Desalination Collaboration (ADC) in California carried out tests using FILMTEC SW30XLE-400i “low energy” membranes. When operated at 43% recovery, the test facility required 1.58 kWh/m^3. The most affordable operating point for a 30 year life cycle is considered at 50% recovery, at which the process required about 1.83 kWh/m^3. Furthermore, the very low energy demand had been achieved at the expense of permeate water quality, as TDS ranged from 190–379 mg/l and Boron varied from 1.04–1.45 mg/l[34].

[31] maximum of 36 MWh during peak production of 50 mgd (Carlsbad SWRO project, Southern California)
[32] at nominal capacity and a recovery rate of 42%, including seawater intake, pretreatment, two RO passes, post-treatment, potable water pumping and all electrical losses (Perth SWRO project, Australia)
[33] 800 GWh/a for a 150 GL/a (410,000 m^3/d) desalination plant (Melbourne, Australia)

[34] http://www.energy-recovery.com/pdf/ adc_sets_low_record.pdf (accessed on 25.11.2007)
http://www.affordabledesal.com/home/test_data.html (accessed on 25.11.2007)

Distillation processes

Large distillation plants are usually co-generation plants, i.e. the desalination plant receives thermal energy from a co-located power plant.

Multi-stage flash (MSF) distillation plants have a maximum operation temperature of 120°C. They require 12 kWh of thermal energy and 3.5 kWh of electrical energy for the production of 1 m^3 of water. These figures are lower for multi-effect distillation plants (MED), which operate at lower temperatures (< 70°C) and require on average 6 kWh of thermal and 1.5 kWh of electrical energy per cubic meter [3].

Table 3: Energy data of MSF, MED and RO [3].

	MSF	MED	RO
Operating temperature	below 120°C	below 70°C	ambient
main energy source	steam (heat)	steam (heat)	electrical energy
Thermal energy demand	12 kWh/m^3	6 kWh/m^3	none
Electrical energy demand	3.5 kWh/m^3	1.5 kWh/m^3	4–7 kWh/m^3

Potential impacts on receptors

Air quality and climate

The energy used for the desalination of seawater is usually produced from fossil energy sources. A main environmental concern associated with the energy demand of desalination processes is therefore the release of air pollutants into the atmosphere, including greenhouse gas (CO_2), acid rain gases (NO_x, SO_x), or fine particulate matter (PM_{10}, $PM_{2.5}$).

Greenhouse gas is relevant in the context of national and international efforts to limit emissions in order to minimise climate change impacts. Significant local impacts on air quality caused by any of the other pollutants may furthermore occur if the emissions conflict with applicable air quality standards or management plans, contribute substantially to other existing or projected air emissions (cumulative impacts), expose the resident population to increased pollutant levels, or create an objectionable odour.

The daily air emissions of carbon monoxide (CO), reactive organic compound (ROC, an ozone precursor substance), nitrogen and sulfur oxides (NO_x and SO_x) and particulate matter (PM_{10}) caused by the operation of a 189,000 m^3/d facility are estimated in [26]. The daily *direct* emissions are associated with landscaping, delivery trucks and employee vehicles. The *indirect* emissions are caused by electricity production to provide the electrical energy for the facility:

Daily indirect emissions:

- 130 kg of CO
- 9 kg of ROC
- 27 kg of NO_X
- 15 kg of SO_X
- 29 kg of PM_{10}

Daily direct emissions:

- 3 kg of CO
- 0.3 kg of ROC
- 3 kg of NO_X,
- < 0,1 kg of SO_X
- 0,1 kg of PM_{10}

It was concluded that operation activities will not exceed any established threshold and will not have an impact on local air quality, neither by direct nor indirect emissions of air pollutants [26]. Carbon dioxide emissions were not considered in this study.

These figures are project-specific, however, they illustrate the order of magnitude of operation-related air emissions of large SWRO projects. Project-specific direct and indirect emission estimates, existing background levels and other emission sources need to be taken into consideration in order to evaluate if project operation may violate any existing air quality standards or management plans.

The air emissions of power generation plants depend on the fuel source (e.g. gas, coal), the technology and efficiency of the plant and any exhaust purification equipment installed (e.g. scrubbers capturing sulfur emissions). When electricity is taken from the electricity grid, the composition of the energy mix must furthermore be taken into account (i.e. the shares of the different fossil energy sources, of nuclear power and renewable energies) when estimating the emissions associated with power production.

As non-carbon dioxide emissions depend on the technology and the fuel type, they are difficult to quantify in general, whereas carbon dioxide emissions from the combustion of fuel can be estimated with a relatively high degree of certainty, as these emissions depend mainly on the carbon content of the fuel. Basic emission factors for carbon dioxide are for instance established as part of the EU emission trading scheme in order to quantify carbon dioxide emissions from fuel combustion (Table 4).

Table 4: Carbon dioxide emission factors [137].

Fuel type	g CO_2 / kWh
Black coal (anthracite)	338
Brown coal (lignite)	404
Light fuel oil	266
Heavy fuel oil	281
Natural gas	202
Petrol	259
Diesel	266

Electricity generation in the EU 25 amounted to 3206 TWh in 2005, of which 28% were produced by coal, 4% by oil, 21% by gas, 30% by nuclear and 14% by renewable energy sources [135]. The European energy mix varies from the energy mix in single countries (Table 5).

Table 5: European energy mix in 2005 [135].

	EU 25		Spain	
Fuel source	[TWh]	%	[TWh]	%
Coal	900	28	79	27
Oil	136	4	24	8
Gas	682	21	80	27
Nuclear	973	30	58	20
Renewables	440	14	44	15
Other	75	2	9	3
Total	3207	100	294	100

For the Spanish energy mix, ENDESA (the leading utility company) specifies an emission factor of 507 g CO_2 per 1 kWh of electricity[35]. If the production of 1 m^3 of drinking water from seawater requires 4 kWh, this results in a CO_2 emission of about 2 kg per m^3. Spain's Agua programme, which will augment Spain's water supply by desalination on the Mediterranean coast, will increase the installed capacity from 1.1 million m^3/d (2005) to over 2.7 million m^3/d until 2010. For the production of this amount of water, a total of 11 GWh/d (4,000 GWh/a) will be required assuming an energy requirement of 4 kWh/m^3 [93]. Based on the above emission scenario, the production of 2.7 million m^3/d would result in 5,475 t CO_2 per day, which represents a 0.6 % increase in national CO_2 emissions compared to pre-2005 levels of 326 million t CO_2 in 2004.

In [138], the most relevant airborne emissions produced by the desalination systems throughout the *entire life-cycle* are given (including natural resources required, manufacturing process, etc.), assuming an energy mix of 43.3% thermal; 40.3% nuclear and 16.4% hydroelectric. For a SWRO plant with an energy requirement of 4 kWh/m^3, typically around 1.78 kg CO_2/m^3, 4.05 g NO_X/m^3, 11.13 g SO_X/m^3 and 1.15 g non-methane volatile organic compounds (NMVOC) per m^3 can be assumed [138].

The desalination approach is in danger of shifting the problem from water to energy [139] or respectively from water to oil and airborne emissions [93] in some parts of the world. In Kuwait, for instance, 90% of the water supply comes from co-generation plants. These produce 443 million m^3 of water and 42,257 GWh of electricity per year, using 462 million GJ of energy, which is 54% of the national fuel use. The plants use mainly heavy oil (78%) and crude oil (20%). The air pollution from cogeneration plants amounts to (in million tons per year):

Due to water production
- 6.96 CO_2
- 0.13 SO_2
- 0.02 NO_x

electricity generation
- 29.58 CO_2
- 0.54 SO_2
- 0.06 NO_x

62% of the total fuel energy (290 of 462 M-GJ) are rejected to the atmosphere (46 M-GJ) and to the sea (243 M-GJ) as cooling water. 60% of the cooling water discharges are attributed to the power plants and 40% to the MSF plants [140].

[35] http://www.endesa.es/Portal/en/our_commitment/sustainabilty/fulfilment_commitments/our_envionment.htm (accessed on 25.07.2008)

Marine flora and fauna

When existing power plant capacities are increased or new plants constructed in order to provide additional electricity for the desalination of seawater, impacts associated with power production could be intensified. For coastal power plants using once through cooling water systems, major concerns are the entrainment and impingement of marine organisms (cf. section C.4.1) and impacts related to discharge of waste heat and residual chemicals (e.g. chlorine).

C.5 Maintenance

Plant operation will result in replacement of worn-out membranes and cartridge filters, pipework and brine chambers. While metallic parts can be recycled, the disposal of some other materials at the end of their effective lives is questionable. Furthermore, the manufacturing process consumes material and energy, with possibly secondary environmental impacts resulting from the production process and the extraction and transport of raw materials. Material and energy flows are normally considered in life cycle analyses [141-143].

The standard life-time of RO membranes is usually 3 to 5 years, as the salt rejection capacity of RO membranes deteriorates over time. Until different polymers are developed and membrane-manufacturing techniques are improved, the improvement in membrane life over the next years can be expected to increase to possibly 10 years. Most commonly, membranes are disposed in landfills. A few companies recover used membranes and clean them for further use in a different application [23]. It is not clear if recycling of the membrane materials is in principle possible or practiced anywhere. The most commonly used RO membranes are thin film composite membranes consisting of polymer material, in which a thin polyamide layer is supported by a polysulfone support layer. The composite nature of membranes probably makes it difficult to separate the single materials for recycling.

Cartridge filters are typically made out of polypropylene and have to be replaced approximately once per year, depending on the intake water quality. Polypropylene is used for a wide variety of applications, including food packaging or textiles. It can be assumed that recycling systems for polypropylene materials have been introduced in parts of the world so that a recycling of the cartridge filters should be a feasible alternative to landfill disposal.

For example, a total of 15,904 FILMTEC SW30HRLE-400i polyamide thin-film composite membranes are being used in the 200,000 m^3/d SWRO plant in Valdelentisco, Spain [144]. Each membrane has an active surface area of 37 m^2, totalling 588,448 m^2 (59 ha) for the entire plant, which have to be replaced and disposed of every 3 to 5 years. In addition, the cartridge filtration stage consists of a total of 300 cartridges made from polypropylene. The cartridge shells are made from carbon steel.

C.5.1 Start-up and shut-down

In addition to the concentrate, desalination plants produce side-streams at plant start-up and shut down (Figure 7 and 8 in section C.4.2).

At start-up, RO plants may discard the water from the pretreatment line until it matches the desired quality, or it may discard the product water if the required quality is not reached. At shutdown, rinsing water is required to reduce the salinity of the water contained in the concentrate zone of the membranes. The rinsing water may contain a biocide.

The discharge from the pretreatment line does not require any special treatment before discharge. Its salinity is identical to that of the seawater. The pH is about neutral and is thus slightly reduced compared to ambient seawater, which is slightly alkaline. It does not contain any harmful chemicals, if the discharged water comes from a point located downstream the dechlorination unit [46].

Similarly, the permeate does not have any characteristics which would avoid it from being discharged directly to the sea. The rinsing waters can either be pretreated seawater or permeate. When a biocide has been added, some precautions have to be taken before discharge [46].

C.5.2 Cleaning

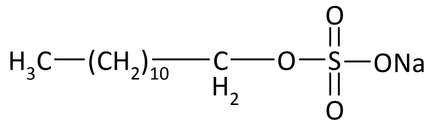
Despite feedwater pretreatment, fouling occurs inside the plant, necessitating periodic plant cleaning. In RO plants, membranes may become fouled by biofilms, accumulation of suspended matter and scale deposits. Initial fouling can be detected by monitoring salt passage, permeate flux and membrane pressure, and needs to be cleaned off periodically to avoid irreversible membrane damage. In distillation plants, fouling is caused by biofilms and scale deposits, which reduce heat transfer and plant efficiency, and may enhance corrosion.

Cleaning intervals have to be established for each plant and are determined by ambient seawater conditions and the efficiency of the pretreatment scheme. Membrane cleaning is typically carried out a few times per year (e.g. cleaning is expected to occur two times a year [26] up to four times a year depending on the degree of fouling of membranes [45]). The membrane trains or distiller units to be cleaned are taken out of service and the cleaning solution is circulated through the system.

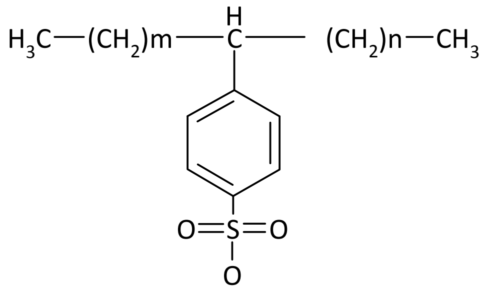
Reverse osmosis

Different cleaning solutions are used in RO plants depending on the type of foulant. Generally, a chemical cleaning is performed with two types of solutions, first with an acidic solution and then with an alkaline solution [46]. The alkaline solutions (pH 11–12) are typically used for removing silt deposits and biofilms, while the acidic solutions (pH 2–3) are used to dissolve metal oxides and scales. The alkaline or acidic solution may additionally contain detergents, oxidants and complexing agents which improve the cleaning process and help to remove biofilms and scale deposits (Figure 14).

Detergents

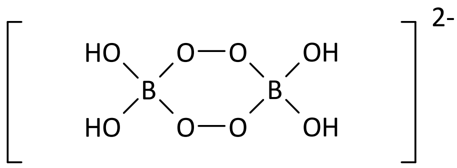


Sodium dodecyl-sulfate (Na-DSS)



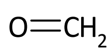
Sodium dodecyl-benzenesulfonate (Na-DBS)

Oxidants

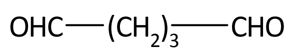


Perborate anion

Biocides

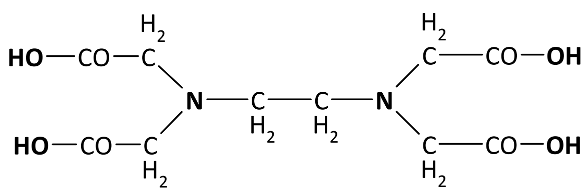


Formaldehyde



Glutaraldehyde

Complexing agents



Ethylene diamine tetraacetic acid (EDTA)

Figure 14: Chemical structures of common RO cleaning chemicals [47].

These additional chemicals are usually generic types or special brands recommended by the membrane manufacturers.

After deposits have been removed, membrane cleaning is often followed by membrane disinfection. For membrane storage, a chemical preservation solution may be required [47]. Major suppliers of SWRO membranes are Dow Filmtec, Toyobo, Toray, Dupont and Hydranautics. The information provided by some of these suppliers on cleaning requirements is summarized in Tables 6 and 7 below.

Alkaline cleaning solutions usually use sodium hydroxide to achieve a high pH. To improve cleaning efficiency, anionic detergents like dodecylsulfate or dodecylbenzene sulfonate can be added which help to disperse organic particles in solution due to their surface active properties.

For heavy organic fouling, oxidants like sodium perborate or hypochlorite may be used to destroy the biofilm by chemical breakdown. The removal of organic deposits can be enhanced by dispersing the metal ions that bond organic particles together. A chelating agent, typically ethylenediamine tetraacetic acid (EDTA), is recommended by most membrane manufacturers for this purpose [47, 48].

Acidic solutions are used for dissolving scale and metal oxide deposits. They may also contain EDTA as an organic-based chelating agents or tripolyphosphate as an inorganic chelating agent and detergents. The additives are used for complexing and dispersing the divalent (e.g. calcium and magnesium) and trivalent ions (e.g. aluminum), which reduces the hardness of water and helps to remove scale deposits.

Table 6: Proposed cleaning procedure for Hydranautics SWRO polyamide membranes [145].

Foulant	Gentle cleaning	Harsher cleaning
Calcium carbonate scale	Solution 1: low pH solution (target pH of 4) of 2.0% (w) citric acid	Solution 4: low pH solution (target pH of 2.5) of 0.5% (w) hydrochloric acid
Calcium, barium, or strontium sulfate scale	Solution 2: high pH solution (target pH of 10) of 2.0% (w) sodium tripolyphosphate 0.8% (w) Na-EDTA	Solution 4: low pH solution (target pH of 2.5) of 0.5% (w) hydrochloric acid
Metal oxides or hydroxides (Fe, Mn, Zn, Cu, Al)	Solution 1: low pH solution (target pH of 4) of 2.0% (w) citric acid	Solution 5: high pH solution (target pH of 11.5) of 1.0% (w) sodium hydrosulfite
Inorganic colloids	Solution 1: low pH solution (target pH of 4) of 2.0% (w) citric acid	Solution 4: low pH solution (target pH of 2.5) of 0.5% (w) hydrochloric acid
Mixed Inorganic and organic colloids	Solution 2: high pH solution (target pH of 10) of 2.0% (w) sodium tripolyphosphate 0.8% (w) Na-EDTA	Solution 6: high pH solution (target pH of 11.5) of 0.1% (w) sodium hydroxide and 0.03% (w) sodium dodecylsulfate
Biological and natural organic matter	Solution 2: high pH solution (target pH of 10) of 2.0% (w) sodium tripolyphosphate 0.8% (w) Na-EDTA alternatively solution 3: high pH solution (target pH of 10) of 2.0% (w) sodium tripolyphosphate 0.025% (w) Na-DBS	Solution 6: high pH solution (target pH of 11.5) of 0.1% (w) sodium hydroxide and 0.03% (w) sodium dodecylsulfate
Polymerized silica		Solution 7: high pH solution (target pH of 11.5) of 0.1% (w) sodium hydroxide

Citric acid also has chelating properties. In general, different kinds of acid can be used, including citric acid, phosphoric acid and sulfamic acid, to lower the pH value. Sodium hydrosulfite also shows a weak acidity when dissolved in water and is a strong reducing agent. Stronger mineral acids such as hydrochloric acid can be used for heavier fouling [47, 48].

After deposits have been removed by cleaning, disinfection may be carried out to reduce bacterial numbers on the membranes. Oxidants like chlorine and hydrogen peroxide can be used, but often require post-treatment to restore the polyamide membranes. Non-oxidizing biocides like formaldehyde are therefore preferred by some membrane manufacturers. Sodium bisulfite, which is a reducing agent, also prevents biological growth by oxygen depletion and may be used for disinfection or long-term storage of membranes [47, 48].

After the cleaning process is complete and the cleaning agents have been circulated through the membranes, the membranes are rinsed with product water several times. In many cases, the residual membrane cleaning solution and also the first rinse which contains most of the constituents from cleaning are neutralized and diverted to a sanitary sewer for processing. The ensuing rinses are typically disposed with the brine [23]. The Tampa Bay desalination plant in Florida, which experienced fouling problems and required higher than expected levels of membrane cleaning and maintenance, violated their sewer discharge permit due to the presence of membrane cleaning chemicals [4].

Discharge into the sewer may not be the standard practice in all locations, and as little is known on the current practice of waste disposal of most SWRO plants, discharge of the cleaning wastes to the sea may also occur in some locations. It is possible that the cleaning wastes are either discharged by direct blow-down immediately after cleaning, or by storage and continuous blending into the waste stream [47].

Table 7: Membrane cleaning solutions [47, 48].

	Filmtec [146]	Dupont [147]	Toray [148]	Hydran. [149]	Ionics [31]	Trisep [150]	Percentage of chemical in solution*
Low pH (2-3)							**%**
Alkaline scales							
HCl	+	+		+	+		0.5 V%
$C_6H_8O_7$	+	+	+	+	+		2 W%
H_3PO_4	+	+					0.5 W%
$Na_2S_2O_4$	+	+					1 W%
NH_2SO_3H		+					0.2 W%
Metal oxides							
$C_6H_8O_7$		+	+	+	+		2 W%
H_3PO_4	+	+					0.5 W%
$Na_2S_2O_4$	+	+		+			1 W%
NH_2SO_3H	+	+					0.2 W%
SHMP		+					1 W%
High pH (11-12)							
Inorganic colloids (silt)							
HCl		+		+	+		0.5 V%
$C_6H_8O_7$		+		+	+		2 W%
NaOH	+			+	+	+	0.1 V%
Na-DDS	+						0.025 W%
Na-DBS		+		+			0.25 W%
$NaBO_3$		+					0.3 W%
NaOCl		+					0.04 V%
STP		+		+	+		2 W%
SHMP		+					1 W%
Na-EDTA				+	+	+	1 W%
Biofouling							
NaOH	+	+	+		+	+	0.1 V%
Na-DDS	+		+				0.025 W%
Na-DBS		+		+		+	0.25 W%
$NaBO_3$		+				+	0.3 W%
NaOCl		+					0.04 V%
STP		+	+	+	+		1 - 2 W%
TSP		+	+		+		1 W%
Na-EDTA	+	+		+	+	+	1 W%
Disinfection & storage							
Formaldehyde		+	+	+			0.1 - 1 V%
Glutaraldehyde		+		+			0.1 - 1 W%
SBS		+	+		+		1W%
H_2O_2			+				0.20%
Propylene glycol					+		20%
Glycerin					+		20%

+ recommended * may vary between manufacturers

Abreviations (Table 7): HCl hydrochloric acid, **$C_6H_8O_7$** citric acid, **H_3PO_4** phosphoric acid, **$Na_2S_2O_4$** sodium hydrosulfite, **NH_2SO_3H** sulfamic acid, **SHMP** sodium hexametaphosphate, **NaOH** sodium hydroxide, **Na-DDS** sodium dodecylsulfate, **Na-DBS** sodium dodecylbenzene sulfonate, **$NaBO_3$** sodium perborate, **NaOCl** sodium hypochlorite, **STP** sodium tri-phosphate, **Na-EDTA** sodium ethylenediamine tetraacetic acid, **TSP** trisodium phosphate, **SBS** sodium bisulfite.

Discharge practices on the Canary Islands, reviewed in [42], indicate that the cleaning solutions must be neutralized before discharge into the sea. The chemical additives are not considered very important in terms of marine environmental impacts. According to this source, the chemical products are mainly weakly acidic (citric acids) or alkali solutions, sodium polyphosphate and EDTA. In another source [46], it is advised to discharge the alkaline and acidic solution into a stirred buffer tank in order to achieve neutralization before conveying the mixture at a slow rate into the concentrate drain, which discharges the concentrate into the sea.

Distillation processes

The cleaning of distillation plants is comparatively simple and usually involves acid washing at pH 2. Special inhibitors may be added to control corrosion in this highly acidic environment.

Potential impacts on receptors

Marine flora and fauna

The accidental or deliberate discharge of cleaning solutions to surface waters may be harmful to aquatic life in the discharge site due to very high or low pH values and the presence of hazardous chemicals. For example, detergents like dodecylbenzene sulfonate have surface active properties, i.e. they have one lipophilic and one hydrophylic residue and are therefore soluble in water and organic material. Due to this property, they have the potential to disturb the intracellular membrane system of organisms. If complexing agents such as EDTA are released into seawater, they could interact with dissolved metal ions and interfere with natural processes of these elements. EDTA was furthermore found to be poorly degradable and persistent in the environment. Oxidizing or non-oxidizing biocides (e.g. chlorine or formaldehyde) used for disinfection are potentially hazardous, as they are effective biocides that may be toxic to marine life if released to surface water [47].

C.6 Decommissioning

Waste management practices and dismantling of a desalination facility will mainly depend on the requirements and obligations that are attached to a license for constructing and operating a plant. Similar to other facilities, waste disposal and dismantling of a desalination plant has to be arranged on a case by case basis. Plant components and construction materials can either be recycled, reused for other purposes or disposed of in an appropriate way (e.g. deposition in an industrial landfill).

Figure 15: Pretreatment chemicals (top) and pretreatment dosing system (below).

C.7 Evaluation of significance

The objective of an EIA study is to identify and analyze all project-related impacts on the environment, which includes an assessment of the relative significance of the predicted impacts (cf. Part A of this document).

The evaluation of significance allows for a rating of the predicted impacts in terms of priority for impact mitigation. Impacts that were found to be significant have a high priority for impact mitigation and should either be prevented or minimized (if avoidance is not possible) by suitable impact mitigation measures to levels that are less than significant. If an impact remains significant after mitigation, some form of compensation is normally required. For all impacts found to be less than significant, additional (optional) mitigation measures ("nice-to-haves") can be identified, but these normally do not influence the overall outcome of the EIA and project assessment. The evaluation of significance thus allows project planners and regulators to focus on the most relevant impacts, for which impact mitigation measures need to be implemented.

Whether or not an impact is rated to be significant depends on many factors, such as the project size and design, the sensitivity of the environment in the selected site, the availability of impact mitigation measures, but also the definition and perception of significance. No universally valid definition of significance exists, and the perception of significance may vary regionally. For example, entrainment and impingement caused by the intake of desalination plants is perceived as the potentially most significant direct adverse impact in California [151]. In all large Australian SWRO projects, carbon dioxide emissions seem to be the central issue [35, 43-45], and project proponents are encouraged to provide for the use of energy from renewable sources, planting of plantations or rehabilitation of vegetation to offset the emissions [45]. Differences are also observed with regard to the backwash waters from the media filters or the cleaning solutions, which are either discharged or treated (cf. sections C.4.2 and C.5.2).

The following evaluation of significance should thus be understood as an attempt to prioritize impacts—as far as this is possible within the limitations of a general approach. The primary purpose is to provide some form of indicative guidance by identifying aspects that will typically have a high priority for project- and site-specific investigations, and that would typically require some form of impact mitigation.

C.7.1 Methodology

The potential stressor sources identified in the preceding sections (C.2–C.6) are rated in terms of intensity, space, and time (cf. C.1, p. 50ff.). *Space* and *time* refer to the spatial and temporal distribution of the stressor sources. Whether or not an exposure occurs also depends on the spatial and temporal distribution of the receptors in the environment (i.e. the distribution of algae stands or benthic species in the project site).

For the rating of intensity, it is assumed that the receptor is present in the impact area, and that impacts are caused by a large desalination plant as the intensity of impacts generally increases with the size of the facility. Impacts are rated under the assumption that no impact mitigation measures have been adopted so far. The probability criterion gives a rough estimate of the likelihood of exposure, taking the likelihood of stressor occurrence (e.g. of a chemical spill) as well as receptor occurrence (e.g. presence of a mobile species) into account.

A three-stage grading system was used for each criterion (e.g. severe, notable and negligible for the intensity of impacts, cf. Table 8 below). The ratings for intensity, space and time were formally integrated into a single rating for priority/significance[37]. The probability criterion was not formally integrated into this system but used as an indicator. When a result between two ratings was obtained, the next higher rating was usually selected as a precautionary approach.

[37] The average value was calculated (highest rating = 3, medium rating = 2, lowest rating = 1, results were rounded to the next higher/lower value).

Impacts of typically *high priority* for project- and site-specific EIA studies and for impact mitigation are those which fulfill the following criteria:

- Severe alterations of natural properties, functions or processes, which are of
  - long-term duration and far range, or
  - long-term duration and mid range, or
  - medium-term duration and far range.
- Notable alterations of natural properties, functions or processes, which are of long-term duration and far-range.

Impacts of typically *low priority* for project- and site-specific EIA studies and for impact mitigation are those which fulfill the following criteria:

- Negligible alterations of natural properties, functions or processes of
  - short-term duration and localized, or
  - short-term duration and mid range, or
  - medium-term duration and localized range.
- Notable alterations of natural properties, functions or processes, which are of short-term duration and localized range.

Table 8: Significance ratings for evaluation criteria (adopted from [36, 152]).

Impact rating		Description	Significance
Intensity	severe	severe alteration of natural properties, functions, processes	high
	notable	notable alteration of natural properties, functions, processes	medium
	negligible	negligible alteration of natural properties, functions, processes	low
Duration	long-term	continuously or regularly (once per day) over project life, permanent or irreversible effects (including aftermath effects)	high
	medium-term	several years (< 5) of duration, (including aftermath effects) reversible, periodic events (several times per year)	medium
	short-term	less than one year or restricted to construction, reversible	low
Spatial extend	far-range	effects beyond project site and nearby areas beyond 1,000 m distance of origin	high
	mid-range	within the project site and nearby areas within 1,000 m distance of origin	medium
	localized	punctual, within the area of the project site within 100 m distance of origin	low
Probability	definite/likely	highly probable (> 80%) or definite	high
	possible	fair chance of occurring	medium
	unlikely	little or no chance of occurring (< 20%)	low

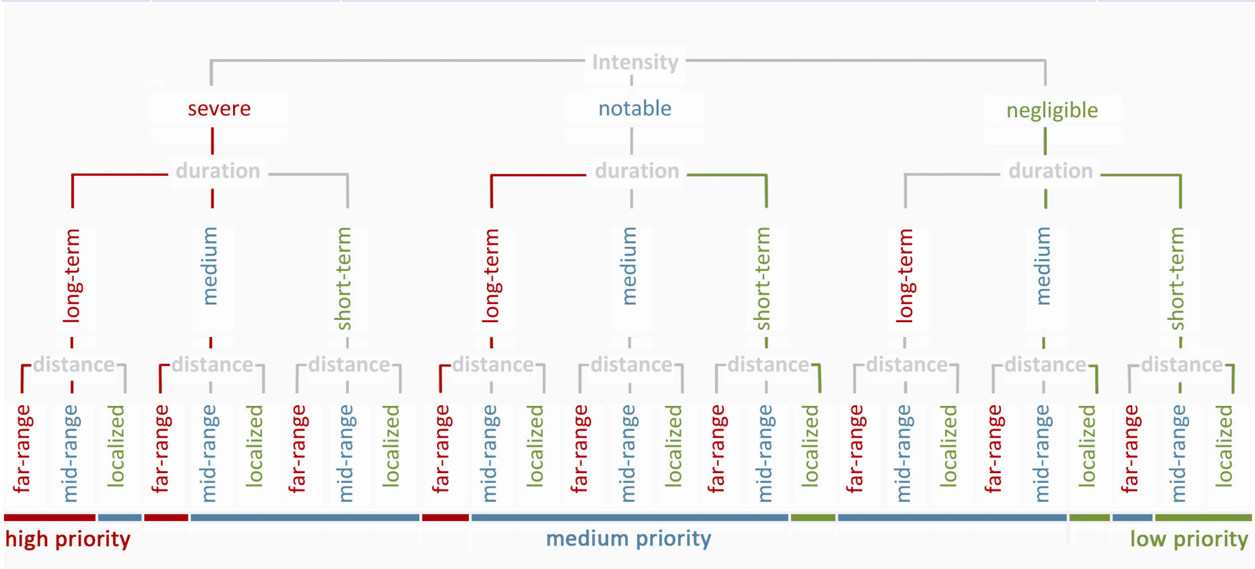


Figure 16: Decision hierarchy used to identify high (red bottom line) and low priority impacts (green).

C.7.2 Evaluation

Based on the evaluation approach described in section C.7.1, the effects of highest priority for project- and site-specific investigations and mitigation were (cf. Tables 9–22, p. 108ff.):

Landscape properties and natural scenery

- aesthetic effects from the discharge of reddish-brown backwash water from media filters (specific to reverse osmosis plants) that may cause a discoloration of the water column in the mixing zone or nearby beaches
- acoustic impacts caused by noise emissions from plant operation

Air quality and climate

- any significant impairment of local air quality by air pollutants
- greenhouse gas emissions

Groundwater quality and hydrology

- any changes in flow directions and groundwater salinity
- any pollution from spills and seepage

Marine sediments

- changed erosion and sedimentation patterns caused by artificial breakwaters
- increases in pore water salinity which may be caused by the concentrate discharge
- the accumulation of coagulant material in sediments near the outlet
- the risk of heavy metal accumulation in sediments if these are present in the discharge, e.g. copper from corroding plant materials

Seawater quality and hydrology

- significant changes in salinity and temperature in the mixing zone of the plume
- formation of a dense bottom water layer with a strengthening effect on density stratification, which may impede re-oxygenation of bottom waters
- increases in turbidity and decreases in light penetration in the mixing zone potentially caused by the filter backwash plume

Terrestrial fauna and flora

- habitat alterations that may cause a long-term to permanent loss of habitat
- noise emissions that may scare away sensitive wildlife within acoustic range
- prominent features that could preclude linkages and movement corridors of wildlife

Benthic macrofauna and –flora

- salinity or temperature increases in the mixing zone that may cause a decline of algae stands or seagrass meadows, or that may be harmful to benthic invertebrate species, depending on exposure and species sensitivity
- any toxic effects of chemicals, e.g. from residual chlorine, chlorination by-products, or heavy metals, alone or in combination with other effects, e.g. synergetic effects between increased temperature and chlorine
- avoidance reactions, which may cause a lasting change in species abundance and diversity in the discharge site even if toxic effects are not observed
- a harmful blanketing of sessile species potentially caused by the filter backwash plume

Marine mammals, reptiles or bird species

- a loss of haul-out sites, nesting grounds or important feeding grounds, for example caused by noise emissions and general disturbance within visible and acoustic range

Most other potential effects were rated as being of “medium priority”, such as for example all construction-related impacts, which are usually severe in terms of intensity, but temporary, localized, and reversible. Medium priority does not imply that these effects are per se negligible – although often not decisive for the project outcome, these effects may also require some form of impact mitigation. Furthermore, impacts which were classified into the medium category can be upgraded or downgraded into the next higher or lower category depending on project- and site-specific conditions. This underlines the necessity for a case-by-case evaluation within an EIA as described in this document.

Table 9: Landscape and natural scenery

Construction	Landscape and natural scenery	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ sediment plume may increase water turbidity	▪ notable	▪ short-term	▪ localized to mid-range	▪ definite
	▪ noise emissions and machinery on land	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
Onshore facilities ▪ Pumping station ▪ Desalination plant ▪ Office buildings ▪ Car park, gates,... ▪ Equipment ▪ Connecting infrastructure	▪ potential impacts within visual and acoustic range due to movements, dust, exhaust fumes, noise or stockpiles exposed to public views	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
	▪ upon completion, visual appearance of buildings, prominent features, plumbing or power lines, glare, and light sources, noises etc. may alter landscape properties	▪ notable	▪ long-term	▪ mid-range to far-range	▪ definite
	▪ potential impacts within visual and acoustic range due to movements, dust, exhaust fumes, noise or stockpiles exposed to public views	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
Operation	**Landscape and natural scenery**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Backwash water	▪ discoloration (reddish plume) near the outlet and surrounding areas possible when $FeCl_3$ is used and potential discoloration of nearby beaches	▪ notable	▪ long-term/ intermittent	▪ mid-range to far-range	▪ likely if dis-charged
▪ Noise emissions	▪ may impair landscape properties within acoustic range	▪ notable	▪ long-term	▪ mid-range to far-range	▪ likely

Table 10: Air quality and climate

Construction	Air quality and climate	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ emissions of air pollutants from construction machinery on land (NO_x, SO_x, PM_{10})	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
	▪ greenhouse gas (CO_2) emissions from construction machinery on land	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
Onshore facilities ▪ Pumping station ▪ Desalination plant ▪ Office buildings ▪ Car park, gates,... ▪ Equipment ▪ Connecting infrastructure	▪ emissions of air pollutants from construction machinery (i.e. NO_x, SO_x, PM_{10})	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
	▪ greenhouse gas (CO_2) emissions	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
	▪ fugitive dust from demolition of buildings and site grading	▪ notable	▪ short-term	▪ mid-range to far-range	▪ definite
Operation	**Air quality and climate**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Chemical storage	▪ accidental spillage or leakage of volatile substances may cause air pollution (e.g. chlorine)	▪ severe	▪ short-term	▪ mid-range to far-range	▪ unlikely
▪ Energy use (depending on the fuel source, plant efficiency and purification equipment)	▪ emissions of air pollutants from trucks and passenger cars (CO_2,NO_x, SO_x, PM_{10})	▪ negligible	▪ long-term	▪ mid-range to far-range	▪ definite
	▪ emissions of air pollutants from power generation (NO_x, SO_x, PM_{10})	▪ notable	▪ long-term	▪ mid-range to far-range	▪ definite
	▪ greenhouse gas (CO_2) emissions from electricity generation	▪ notable	▪ long-term	▪ mid-range to far-range	▪ definite

Table 11: Terrestrial soils

Construction	Terrestrial soils	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ construction in the landing area may affect beachslope stability, dune systems etc. and may cause erosion by wind and waves where vegetation has been cleared	▪ severe	▪ medium-term to long-term	▪ localized	▪ possible
	▪ in case of horizontal drilling: stockpiles of debris from the borehole may have placement impacts and may require an offsite disposal	▪ notable	▪ short-term to medium-term	▪ localized	▪ possible
Onshore facilities ▪ Pumping station ▪ Desalination plant ▪ Office buildings ▪ Car park, gates,... ▪ Equipment ▪ Connecting infrastructure	▪ soil compaction through machinery	▪ notable	▪ short-term to medium-term	▪ localized	▪ definite
	▪ erosion may occur where vegetation has been cleared	▪ severe	▪ medium-term to long-term	▪ localized	▪ possible
	▪ stockpiles of excavated material may have placement impacts and may require a final / offsite disposal site	▪ notable	▪ short-term to long-term	▪ localized	▪ likely
	▪ accidental spillage or leakage of fuel, chemicals, or lubricants may cause soil contamination	▪ severe	▪ short-term to medium-term	▪ localized	▪ possible
	▪ upon completion, surface sealing caused by asphalt and buildings	▪ severe	▪ long-term	▪ localized	▪ definite
Operation	**Terrestrial soils**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Backwash water	▪ backwash sludge may require a final / offsite disposal site	▪ notable	▪ long-term	▪ localized	▪ possible
	▪ spreading on land may affect soil properties	▪ notable	▪ medium-term to long-term	▪ localized to mid-range	▪ possible
▪ Chemical storage	▪ accidental spillage or leakage may contaminate soils	▪ severe	▪ short-term to medium-term	▪ localized	▪ unlikely
▪ Membrane and cartridge replacement	▪ disposal may require an appropriate site for landfill	▪ notable	▪ long-term	▪ localized	▪ possible

Table 12: Ground- and surface water quality and hydrology

Construction	Ground- and surface water quality and hydrology	Intensity	Duration	Spatial extend	Probability
Onshore facilities ▪ Pumping station ▪ Desalination plant ▪ Office buildings ▪ Car park, gates,... ▪ Equipment ▪ Connecting infrastructure	▪ accidental spillage or leakage of fuel, chemicals, or lubricants may cause ground- and surface water pollution	▪ severe	▪ short-term	▪ localized to mid-range	▪ possible
	▪ loose or contaminated soils and other material washed away by runoff or eroded by wind may affect surface water quality	▪ notable	▪ short-term	▪ localized to mid-range	▪ possible
	▪ the groundwater table may be affected by construction (e.g. drainage)	▪ severe	▪ short-term	▪ localized to mid-range	▪ possible
Operation	**Ground- and surface water quality and hydrology**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake of feedwater	▪ intake from aquifers may change flow directions and changes in groundwater salinity	▪ severe	▪ long-term	▪ localized to mid-range	▪ possible
▪ Concentrate discharge	▪ well injection may cause an increase in groundwater salinity	▪ severe	▪ long-term	▪ localized to mid-range	▪ possible
▪ Backwash water	▪ potential seepage from landfill disposal into groundwater	▪ severe	▪ long-term	▪ localized to mid-range	▪ possible
▪ Chemical storage	▪ accidental spillage or leakage may contaminate ground- and surface waters	▪ severe	▪ short-term	▪ localized to mid-range	▪ unlikely

Table 13: Seafloor and sediments

Construction	Seafloor and Sediments	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ sediment layering and structure may be disturbed	▪ notable	▪ short-term to medium-term	▪ localized	▪ definite if excavating
	▪ sediment compaction from machinery	▪ notable	▪ short-term to medium-term	▪ localized	▪ likely if excavating
	▪ surface sealing (if structures placed on the seabed)	▪ severe	▪ long-term	▪ localized	▪ definite
	▪ upon completion, structures may act as breakwaters and change erosion and sedimentation processes locally and in downdrift locations	▪ severe	▪ long-term	▪ localized to far-range	▪ possible
	▪ accidental spillage or leakage of fuel, chemicals, or lubricants may cause sediment contamination	▪ severe	▪ short-term to medium	▪ localized	▪ possible
Onshore facilities	▪ loose or contaminated soils and other material washed away by runoff or eroded by wind may affect sediments	▪ notable	▪ short-term	▪ localized	▪ possible
Operation	**Seafloor and Sediments**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Concentrate discharge	▪ discharge plume may sink to the seafloor and may cause an increase in porewater salinity due to diffusion	▪ severe	▪ long-term	▪ localized to mid-range	▪ likely
▪ Residual chemicals in the concentrate	▪ Heavy metals (if present in the concentrate from corrosion processes) may accumulate in sediments in the discharge site	▪ severe	▪ long-term	▪ localized to mid-range	▪ possible
▪ Backwash water	▪ sedimentation and accumulation of coagulants in sediments or beaches	▪ severe	▪ long-term	▪ localized to far-range	▪ likely

Table 14: Seawater quality and hydrology

Construction	Seawater quality and hydrology	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ resuspended sediments may increase turbidity, pollutant or nutrient levels or decrease oxygen levels	▪ notable	▪ short-term	▪ mid-range to far-range	▪ likely
	▪ upon completion, structures may act as breakwaters and change wave patterns and currents	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible
	▪ accidental spillage or leakage of fuel, chemicals, or lubricants may cause water pollution	▪ severe	▪ short-term	▪ localized to mid-range	▪ possible
▪ **Onshore facilities**	▪ loose or contaminated soils and other material washed into the sea by runoff or eroded by wind may affect water quality	▪ notable	▪ short-term	▪ localized to mid-range	▪ possible
Commissioning	**Seawater quality and hydrology**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Discarded waste streams	▪ membrane storage solutions could affect water quality if discharged	▪ notable	▪ short-term	▪ localized to mid-range	▪ possible
Operation	**Seawater quality and hydrology**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake	▪ open intakes may change water circulation when large volumes of water are extracted	▪ notable	▪ long-term	▪ localized to mid-range	▪ likely
▪ Concentrate discharge	▪ increases salinity in the mixing zone	▪ severe	▪ long-term	▪ localized to mid-range	▪ definite
	▪ large volumes may affect circulation and mixing processes in the discharge area	▪ notable	▪ long-term	▪ localized to mid-range	▪ likely
	▪ increased density may cause sinking of the plume and seafloor spreading	▪ severe	▪ long-term	▪ localized to mid-range	▪ definite
	▪ stratification of the water column may be strengthened	▪ severe	▪ long-term	▪ localized to mid-range	▪ possible
	▪ stratification may impede re-oxygenation of bottom waters ▪ whereas turbulent discharge may add oxygen to bottom layers	▪ severe ▪ positive	▪ long-term	▪ localized to mid-range	▪ possible
	▪ potential enrichment of nutrients, organic matter, pollutants or trace metals	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible

Operation	Seawater quality and hydrology	Intensity	Duration	Spatial extend	Probability
▪ Residual chemicals in the concentrate	▪ residual chlorine and chlorination by-products possibly detectable in the mixing zones (if no dechlorination step)	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible
	▪ sodium bisulfite is a reducing agent and may decrease dissolved oxygen levels if overdosed	▪ notable	▪ long-term	▪ localized	▪ possible
	▪ heavy metals (if present in the concentrate from corrosion processes) may affect dissolved metal concentrations in the mixing zone	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible
	▪ antiscalants may bind nutrients and ions dissolved in seawater	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible
	▪ a weak surplus acidity may be discharged which would be neutralized quickly by ambient seawater	▪ negligible	▪ short-term	▪ localized	▪ possible
▪ Backwash water	▪ increased turbidity and decreased light penetration in the discharge zone	▪ severe	▪ long-term/ intermittent	▪ localized to mid-range	▪ definite if discharged
▪ Chemical storage	▪ accidental spillage or leakage may contaminate seawater	▪ severe	▪ short-term	▪ localized to mid-range	▪ unlikely
Maintenance	**Seawater quality and hydrology**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Cleaning solutions	▪ discharge of acidic or alkaline cleaning solutions may affect the ambient pH seawater in the mixing zone	▪ severe	▪ short-term	▪ localized	▪ likely if discharged
	▪ detergents or complexing agents may interfere with natural processes of dissolved seawater constituents (e.g. metals)	▪ notable	▪ short-term to medium-term	▪ localized to mid-range	▪ possible if discharge

Table 15: Terrestrial flora

Construction	Terrestrial flora	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ construction in the landing area may require a clearing of vegetation	▪ severe	▪ short-term to medium-term	▪ localized	▪ likely
Onshore facilities ▪ Pumping station ▪ Desalination plant ▪ Office buildings ▪ Car park, gates,... ▪ Equipment ▪ Connecting infra-structure	▪ clearing or flattening of vegetation in construction site (impact depending area size or route and site vegetation)	▪ severe	▪ short-term to medium-term	▪ localized to mid-range	▪ likely
	▪ potential weed infestations in cleared areas	▪ notable	▪ short-term to medium-term	▪ localized	▪ possible
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term	▪ localized	▪ possible
	▪ upon completion, permanent loss of land usable by native plants in all areas covered by solid surfaces or landscaped areas	▪ severe	▪ long-term	▪ localized	▪ definite
Operation	**Terrestrial flora**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Chemical storage	▪ potential exposure to harmful substances by accidental spills	▪ severe	▪ short-term	▪ localized	▪ unlikely

Table 16: Terrestrial fauna

Construction	Terrestrial fauna	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ construction in the landing area may disturb wildlife	▪ notable	▪ short-term	▪ mid-range	▪ likely
Onshore facilities ▪ Pumping station ▪ Desalination plant ▪ Office buildings ▪ Car park, gates,... ▪ Equipment ▪ Connecting infra-structure	▪ construction, e.g. through noise and vibrations, may cause behavioural responses and temporary habitat loss	▪ notable	▪ short-term	▪ mid-range	▪ likely
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term to medium-term	▪ localized	▪ possible
	▪ upon completion, habitat alteration or loss of habitat for native species	▪ severe	▪ long-term	▪ mid-range	▪ definite
	▪ upon completion, prominent features could preclude linkages and movement corridors	▪ severe	▪ long-term	▪ mid-range	▪ definite
Operation	**Terrestrial fauna**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Chemical storage	▪ potential exposure to harmful substances	▪ severe	▪ short-term	▪ localized	▪ unlikely
▪ Noise emissions	▪ may scare away sensitive wildlife within acoustic range due, potential habitat loss	▪ severe	▪ long-term	▪ mid-range	▪ likely

Table 17: Marine macroflora

Construction	Marine macroflora	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ habitat destruction by excavation works	▪ severe	▪ short-term to medium-term	▪ localized	▪ likely
	potential impacts from increased turbidity ▪ reduced light penetration ▪ increased sedimentation rates (blanketing)	▪ notable ▪ severe	▪ short-term ▪ short-term	▪ localized to mid range	▪ likely ▪ likely
	▪ potential impacts from remobilization of nutrients or pollutants from sediments	▪ notable	▪ short-term	▪ localized to mid range	▪ possible
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term	▪ localized	▪ possible
	▪ upon completion, structures may act as artificial reefs (attachment of macroalgae)	▪ notable (positive)	▪ long-term	▪ localized	▪ likely
Onshore facilities (Desalination plant)	▪ potential burial by soils or other material washed into the sea	▪ severe	▪ short-term	▪ localized	▪ possible
Commissioning	**Marine macroflora**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Discarded waste streams	▪ may be exposed to residual chemicals that may be present in the discarded water	▪ severe	▪ short-term	▪ localized	▪ possible
Operation	**Marine macroflora**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake	▪ open intakes cause entrainment of spores	▪ notable	▪ long-term	▪ localized to mid range	▪ definite
▪ Concentrate discharge	▪ increased salinity may cause a decline of algae stands and seagrass meadows (depending on exposure levels and species sensitivity)	▪ severe	▪ long-term	▪ localized to mid range	▪ definite
	▪ nutrient enrichment may enhance growth and eutrophication effects	▪ notable	▪ long-term	▪ localized to mid range	▪ possible
▪ Residual chemicals in the concentrate	▪ antiscalants are non toxic at the concentrations used but they may bind nutrients and ions needed for plant growth	▪ notable	▪ long-term	▪ localized to mid range	▪ possible
	▪ residual chlorine levels and chlorination by products may have toxic effects on organisms in the mixing zone	▪ severe	▪ long-term	▪ localized to mid range	▪ likely
▪ Backwash water	▪ coagulants are non-toxic, however, blanketing may impair photosynthesis and could lead to a die-off of seagrass and algae stands	▪ severe	▪ long-term	▪ localized to mid-range	▪ likely
▪ Chemical storage	▪ potential exposure to harmful substances	▪ severe	▪ short-term	▪ localized	▪ unlikely
▪ Energy use	▪ when coastal power plant capacity increases: secondary effects from cooling water	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible

Maintenance	Marine macroflora	Intensity	Duration	Spatial extend	Probability
▪ Cleaning solutions	▪ high or low pH values and residual cleaning chemicals such as biocides may be harmful	▪ severe	▪ short-term	▪ localized	▪ possible if discharged

Table 18: Marine plankton

Construction	Marine plankton	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ potential impacts from increased turbidity (reduced light penetration)	▪ notable	▪ short-term	▪ localized to mid range	▪ likely
	▪ potential impacts from remobilization of nutrients or pollutants from sediments	▪ notable	▪ short-term	▪ localized to mid range	▪ possible
Commissioning	**Marine plankton**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Discarded waste streams	▪ may be exposed to residual chemicals that may be present in the dis-carded water	▪ notable	▪ short-term	▪ localized	▪ possible
Operation	**Marine plankton**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake	▪ open intakes cause entrainment of phyto- and zooplankton	▪ notable	▪ long-term	▪ localized to mid range	▪ definite
▪ Concentrate discharge	▪ may be harmful or even toxic to organisms (depending on exposure levels and species sensitivity)	▪ notable	▪ long-term	▪ localized to mid range	▪ definite
	▪ nutrient enrichment may enhance growth (algae blooms possible ?)	▪ notable	▪ long-term	▪ localized to mid range	▪ possible
▪ Residual chemicals in the concentrate	▪ antiscalants are non toxic at the concentrations used but they may bind nutrients and ions needed for plant growth	▪ notable	▪ long-term	▪ localized to mid range	▪ possible
	▪ residual chlorine levels and chlorination by products may have toxic effects on organisms in the mixing zone	▪ severe	▪ long-term	▪ localized to mid range	▪ likely
▪ Backwash water	▪ coagulants are non-toxic, however, they may lower light penetration and primary production in the water column	▪ notable	▪ long-term/ intermittent	▪ localized to mid range	▪ likely if dis-charged
▪ Chemical storage	▪ potential exposure to harmful substances	▪ notable	▪ short-term	▪ localized	▪ unlikely
▪ Energy use	▪ when coastal power plant capacity increases: secondary effects from cooling water	▪ notable	▪ long-term	▪ localized to mid range	▪ likely
Maintenance	**Marine plankton**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Cleaning solutions	▪ high or low pH values and residual cleaning chemicals such as biocides may be harmful	▪ notable	▪ short-term	▪ localized	▪ possible if discharged

Table 19: Marine benthic invertebrate fauna

Construction	Marine benthic invertebrate fauna	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ habitat destruction (excavation works)	▪ severe	▪ short-term to medium-term	▪ localized	▪ likely
	▪ increased turbidity may affect filter feeding organisms	▪ notable	▪ short-term	▪ localized to mid range	▪ possible
	▪ re-sedimentation may blanket sessile epifauna	▪ severe	▪ short-term	▪ localized to mid range	▪ likely
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term to medium-term	▪ localized	▪ possible
	▪ upon completion, structures may later act as artificial reefs (attachment of sessile hard bottom species or attraction of reef-dwellers)	▪ notable (positive)	▪ long-term	▪ localized	▪ definite
Onshore facilities (Desalination plant)	▪ potential burial by soils or other material washed into the sea	▪ severe	▪ short-term	▪ localized	▪ possible
Commissioning	**Marine benthic invertebrate fauna**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Discarded waste streams	▪ may be exposed to residual chemicals that may be present in the discarded water	▪ severe	▪ short-term	▪ localized	▪ possible
Operation	**Marine benthic invertebrate fauna**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake	▪ open intakes cause entrainment of invertebrate larvae	▪ notable	▪ long-term	▪ localized to mid range	▪ definite
▪ Concentrate discharge	▪ increased salinity may be harmful or even toxic to benthic species ▪ increased salinity may cause avoidance reactions ▪ toxic effects and avoidance can cause a change in species abundance and diversity in the discharge site (effects depending on exposure levels and species sensitivity)	▪ severe ▪ notable ▪ severe	▪ long-term	▪ localized to mid range	▪ definite ▪ likely
	▪ potential enrichment of pollutants in filter feeding organisms	▪ notable	▪ long-term	▪ localized	▪ possible
▪ Residual chemicals in the concentrate	▪ residual chlorine levels and chlorination by products may have toxic effects on organisms in the mixing zone	▪ notable	▪ long-term	▪ localized to mid range	▪ likely
	▪ potential for metal accumulation in filter-feeding and deposit-feeding benthic organisms (bioaccumulation), with the risk of biomagnification	▪ severe	▪ long-term	▪ localized to far-range	▪ possible
▪ Backwash water	▪ coagulants are non-toxic, however, blanketing of sessile animals and ingestion of material by filter- and sediment feeders may occur	▪ severe	▪ long-term	▪ localized to mid-range	▪ likely if discharged
▪ Chemical storage	▪ potential exposure to harmful substances	▪ severe	▪ short-term	▪ localized	▪ unlikely
▪ Energy use	▪ when coastal power plant capacity increases: secondary effects from cooling water	▪ notable	▪ long-term	▪ localized to mid-range	▪ likely

Maintenance	Marine benthic invertebrate fauna	Intensity	Duration	Spatial extend	Probability
▪ Cleaning solutions	▪ high or low pH values and residual cleaning chemicals such as biocides may be harmful, esp. for sessile animals	▪ severe	▪ short-term	▪ localized	▪ likely if discharged

Table 20: Marine nekton

Construction	Marine nekton	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ construction may cause behavioural responses and temporary habitat loss due sediment plumes, noise and vibrations, etc.	▪ notable	▪ short-term	▪ localized to mid-range	▪ likely
	▪ increased turbidity may affect fish gills and re-settling of material may blanket fish spawn	▪ notable	▪ short-term	▪ localized to mid-range	▪ possible
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term	▪ localized	▪ possible
	▪ upon completion, structures may attract species (reef effect), e.g. due to increased food supply	▪ notable (positive)	▪ long-term	▪ localized	▪ possible
Commissioning	**Marine nekton**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Discarded waste streams	▪ may be exposed to residual chemicals that may be present in the discarded water	▪ severe	▪ short-term	▪ localized	▪ possible
Operation	**Marine nekton**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake	▪ open intakes cause entrainment of fish eggs and larvae or small juveniles	▪ notable	▪ long-term	▪ localized to mid-range	▪ definite
	▪ open intakes may cause impingement of nektonic species	▪ severe	▪ long-term	▪ localized	▪ likely
▪ Concentrate discharge	▪ may avoid the discharge area, loss of potential feeding or breeding grounds	▪ notable	▪ long-term	▪ localized to mid-range	▪ likely
▪ Residual chemicals in the concentrate	▪ chlorinated-dechlorinated seawater may still have chronic effects due to the presence of chlorination by products	▪ notable	▪ long-term	▪ localized	▪ unlikely
	▪ residual chlorine levels and chlorination by products may have toxic effects on organisms in the mixing zone	▪ severe	▪ long-term	▪ localized to mid range	▪ likely
▪ Backwash water	▪ coagulants are non-toxic, however, mobile animals may avoid the high turbidity discharge area and high levels of suspended matter may affect fish gills	▪ notable	▪ long-term/ intermittent	▪ localized to mid-range	▪ likely if discharged
▪ Chemical storage	▪ potential exposure to harmful substances	▪ severe	▪ short-term	▪ localized	▪ unlikely
▪ Energy use	▪ when coastal power plant capacity increases: secondary effects from cooling water	▪ notable	▪ long-term	▪ localized to mid-range	▪ likely

Maintenance	Marine nekton	Intensity	Duration	Spatial extend	Probability
▪ Cleaning solutions	▪ high or low pH values and residual cleaning chemicals such as biocides may be harmful, but animals will probably avoid the discharge site	▪ notable	▪ short-term	▪ localized	▪ possible if discharged

Table 21: Marine mammals and reptiles

Construction	Marine mammals and reptiles	Intensity	Duration	Spatial extend	Probability
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ underwater construction may cause behavioural responses and temporary habitat loss due sediment plumes, noise and vibrations, etc.	▪ notable	▪ short-term	▪ localized to mid-range	▪ likely
	▪ haul-out sites of seals or nesting sites of turtles in the landing area may be affected	▪ severe	▪ short-term	▪ localized	▪ possible
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term to medium-term	▪ localized	▪ unlikely
	▪ upon completion, structures may attract species (reef effect), e.g. due to increased food supply	▪ notable (positive)	▪ long-term	▪ localized	▪ possible
Onshore facilities (Desalination plant)	▪ Construction noise may cause a temporary loss of haul-out sites	▪ severe	▪ short-term	▪ localized	▪ possible
Commissioning	**Marine mammals and reptiles**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Discarded waste streams	▪ may be exposed to residual chemicals that may be present in the discarded water	▪ severe	▪ short-term	▪ localized	▪ unlikely
Operation	**Marine mammals and reptiles**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Intake	▪ open intakes may cause impingement e.g. of sea snakes or smaller turtles	▪ severe	▪ long-term	▪ localized	▪ possible
▪ Concentrate discharge	▪ may avoid the discharge area, loss of potential feeding or breeding grounds	▪ notable	▪ long-term	▪ localized to mid-range	▪ likely
▪ Backwash water	▪ coagulants are non-toxic, however, mobile animals may avoid the high turbidity discharge area	▪ notable	▪ long-term/ intermittent	▪ localized to mid-range	▪ likely
▪ Chemical storage	▪ potential exposure to harmful substances	▪ severe	▪ short-term	▪ localized	▪ unlikely
▪ Noise emissions	▪ may avoid the sites of increased noise levels, loss of potential haul-out sites	▪ severe	▪ long-term	▪ localized to mid-range	▪ likely
▪ Energy use	▪ when coastal power plant capacity increases: secondary effects from cooling water	▪ notable	▪ long-term	▪ localized to mid-range	▪ possible
Maintenance	**Marine mammals and reptiles**	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Cleaning solutions	▪ high or low pH values and residual cleaning chemicals such as biocides may be harmful, but animals will probably avoid the discharge site	▪ notable	▪ short-term	▪ localized	▪ unlikely

Table 22: Terrestrial birds and seabirds

Construction	**Birds** (terrestrial and seabirds, migratory birds, penguins)	**Intensity**	**Duration**	**Spatial extend**	**Probability**
Offshore facilities ▪ Intake system ▪ Outfall system ▪ Equipment	▪ construction may cause behavioural responses and temporary habitat loss due sediment plumes, noise and vibrations, etc.	▪ notable	▪ short-term	▪ localized to mid-range	▪ likely
	▪ nesting sites of seabirds or penguins in the landing area may be affected	▪ severe	▪ short-term	▪ localized	▪ possible
	▪ potential contamination by spills or leakages	▪ severe	▪ short-term	▪ localized	▪ unlikely
	▪ upon completion, structures may attract species (reef effect), e.g. due to increased food supply	▪ notable (positive)	▪ long-term	▪ localized	▪ possible
Onshore facilities (Desalination plant and connecting infrastructure)	▪ construction, e.g. through noise and vibrations, may cause behavioural responses and temporary habitat loss	▪ notable	▪ short-term	▪ localized to mid-range	▪ likely
▪ Infrastructure ▪ Equipment	▪ construction, e.g. through noise and vibrations, may cause behavioural responses and temporary habitat loss	▪ notable	▪ short-term	▪ localized to mid-range	▪ likely
Operation	**Birds** (terrestrial and seabirds, migratory birds, penguins)	**Intensity**	**Duration**	**Spatial extend**	**Probability**
▪ Concentrate discharge	▪ may avoid the discharge area, loss of potential feeding or breeding grounds	▪ severe	▪ long-term	▪ localized	▪ likely
▪ Backwash water	▪ coagulants are non-toxic, however, mobile animals may avoid the high turbidity discharge area	▪ notable	▪ long-term/ intermittent	▪ localized to mid-range	▪ likely
▪ Chemical storage	▪ potential exposure to harmful substances	▪ severe	▪ short-term	▪ localized	▪ unlikely
▪ Noise emissions	▪ may avoid the sites of increased noise levels, loss of potential feeding or nesting grounds	▪ severe	▪ long-term	▪ localized to mid-range	▪ likely

Part D

Appendix

D.1 Appendix 1 – Guidance for screening of desalination projects

The following screening criteria and checklists are based on EU guidance [7][37] and were modified for the specific needs of desalination plants. This appendix contains three checklists:

- details on the information needed for screening (D.1.1);
- a screening checklist to determine if a full EIA should be conducted (D.1.2);
- criteria for defining the significance of impacts (D.1.3) to be used in conjunction with the screening checklist.

D.1.1 Information required for screening

During screening, some or all of the following information must be obtained in order to decide whether a proposed project requires a full EIA. The information may be outlined in a short screening report or on a standardized screening form that is submitted to the competent authority. Details on the information requirements for screening may be set out in a state's legislation and/or specific guidance on EIA. As screening is typically carried out early in a project's life, the information will be available only to a certain depth and may be subject to change during project development. Information should thus only be requested if the proponent can reasonably be expected to have it at this stage of project development. Significant gaps of knowledge and uncertainties should be identified and taken into account in the screening decision.

[37] Further guidance is available from the European Commission in the "Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions" http://europa.eu.int/comm/environment/eia/eia-studies-and-reports/guidel.pdf (accessed on 25.07.2008)

Contact details of the project proponent

Name, postal address, telephone and fax number, e-mail address and other contact details of the company and main contact persons.

Characteristics of the proposed project

For further information and explanations on the project description see also section B.6 on p. 27, which outlines the scope and contents of a project description for an EIA report. At the stage of screening, typically less detailed information will be requested than in an EIA report, including:

- objectives and goals of the proposed desalination project (i.e. rationale of the project);
- details on capacity, processes and flows (flow-diagrams), input and output, recovery technologies and rates, wastes, etc.;
- an estimate of consumables and resources used during construction and operation, e.g. of materials, chemicals, water, energy, land;
- process-mechanical engineering details on seawater intake system, pretreatment system, desalination system, etc.;
- civil and structural engineering details on offshore, nearshore and onshore works, excavation and piling activities, etc.;
- electrical engineering details on estimated connected load, power connection or generation details, etc.;
- plans showing the boundary of the project development including any land required temporarily during construction, and the form of the development, e.g. layout of buildings and other structures;
- new access arrangements or changes to existing infrastructure which may be required as a consequence of the project, e.g. new roads, generation or transmission of power, water supply and sewage disposal lines;
- brief work programmes and schedules for construction, commissioning and operation phases, decommissioning, restoration and after-use where appropriate;
- details of any other permits required.

- ***Characteristics of the proposed project site***
- brief description and general classification of the existing environmental, socio-economic and human health setting of the project site;
- maps and photographs showing the location of the project site relative to surrounding natural and man-made features;
- existing land-uses on and adjacent to the site and any future planned land uses, zoning or land-use policies, including nature conservation or sensitive areas.

- ***Characteristics of alternatives considered***
- alternative project configurations (e.g. alternative processes, capacities etc.);
- alternative project locations.

- ***Characteristics of the potential impacts of the proposed project and alternatives***

A brief description and initial assessment of the likely impacts of the project should be given, as far as impacts can be identified at this stage of project planning. Impacts can be manifold, for example a desalination plant may have impacts on fauna and flora, soil, water and air quality, landscape properties, land use, use of resources, as well as cultural, socio-economic and human health effects during different life-cycle stages.

The identification of potential impacts can be achieved by using the screening checklist below (D.1.2). An alternative common approach which ensures that all relevant impacts are identified without overlooking any significant effects is to devise a table or matrix. This may list the main project parameters (over the entire life-cycle) on one axis, and the main environmental, socio-economic and public health parameters on the other. A brief description of the potential impact is provided where the x- and y-rows intersect. A number of cause-effect-relationships is thus established, which can then be checked for potentially significant adverse effects.

The initial assessment of impacts can only be based on the information available, which is typically rather limited at the stage of screening. Gaps of knowledge and areas of uncertainty should be clearly identified. The understanding of cause-effect-relationships will typically evolve with time when more information becomes available in the EIA process.

The following factors should be taken into account when each pair of cause-effect-relationships is examined for potentially significant adverse effects:

- nature of impacts (positive/negative, direct/indirect, cumulative, transboundary);
- time-span of impacts (short-, medium-, long-term, permanent/temporary, frequency);
- extent of the impact (geographical area, size of affected population/habitat/species);
- magnitude and complexity of the impact (severe, reversible/irreversible);
- probability of the impact (certain, high/medium/low probability);
- if mitigation to reduce, avoid or offset significant adverse impacts is possible or not.

- ***Mitigating measures being considered***

In this section, any mitigation measures known at this stage of project planning can be listed.

D.1.2 Screening checklist

The following screening checklist provides a list of questions to help identify where interactions between a project and its environment is likely to occur. It should be used in conjunction with the criteria for evaluating the significance of environmental effects below (D.1.3).

- In a first step (column 1), the following questions should be answered and a brief description of the expected interaction between the project and its environment should be provided.
- In a second step (column 2), it should be checked, using the criteria for evaluating significance (D.1.3), if this will likely result in significant effects, including a brief description and explanation.
- In a third step, the features of the project and of its location indicating the need for EIA should be summarized.

Table 23: Screening checklist

Questions to be considered in screening		▪ please answer with yes / no / unknown ▪ please provide a brief description	▪ will this likely result in significant effects? ▪ please answer with yes / no / unknown and provide a brief explanation why
1.	*Will construction, commissioning, operation, maintenance or decommissioning of the project (in the following 'the project') involve actions which will cause physical changes in the locality, e.g. on topography, land use, changes in water bodies, etc.?*		
2.	*Will the project use natural resources such as land, water, materials or energy, in particular resources which are non-renewable or in short supply?*		
3.	*Will the project involve use, storage, transport, handling or production of substances or materials which could be harmful to human health or the environment, or raise concerns about actual or perceived risks?*		
4.	*Will the project produce solid wastes?*		
5.	*Will the project cause noise and vibration or release of light, heat energy or electromagnetic radiation?*		
6.	*Will the project release pollutants or any hazardous, toxic or noxious substances to air?*		

Questions to be considered in screening		▪ please answer with yes / no / unknown ▪ please provide a brief description	▪ will this likely result in significant effects? ▪ please answer with yes / no / unknown and provide a brief explanation why
7.	*Will the project release pollutants or any hazardous, toxic or noxious substances into surface or groundwater, coastal or marine water, with the risk of contaminating these?*		
8.	*Will the project release pollutants or any hazardous, toxic or noxious substances into the ground, soils or sediments, with the risk of contaminating these?*		
9.	*Will there be any risk of accidents during construction or operation of the project which could affect human health or the environment?*		
10.	*Will the project result in social changes, for example, in demography, traditional lifestyles, employment?*		
11.	*Will the project discourage water resource management initiatives such as water conservation?*		
12.	*Will the project discourage water reuse / recycling?*		

Questions to be considered in screening		▪ please answer with yes / no / unknown ▪ please provide a brief description	▪ will this likely result in significant effects? ▪ please answer with yes / no / unknown and provide a brief explanation why
13.	*Will there be consequential development which could lead to environmental effects, or will there be a potential for cumulative impacts with other existing or planned activities in the locality?*		
14.	*Are there areas on or around the location which are protected under international, national or local legislation for their ecological, landscape, cultural or other value, which could be affected by the project?*		
15.	*Are there any other areas on or around the location which are important or sensitive for reasons of their ecology, e.g. wetlands or other water bodies, dunes, coastal ranges, woodlands etc., which could be affected by the project?*		
16.	*Are there any areas on or around the location which are used by protected, sensitive or otherwise important species of fauna or flora, e.g. for breeding, nesting, foraging, resting, overwintering, migration, which could be affected by the project?*		
17.	*Are there any areas or features of high landscape or scenic value on or around the location which could be affected by the project?*		
18.	*Are there any routes or facilities on or around the location which are used by the public for access to recreation or other facilities, which could be affected by the project?*		

Questions to be considered in screening		▪ please answer with yes / no / unknown ▪ please provide a brief description	▪ will this likely result in significant effects? ▪ please answer with yes / no / unknown and provide a brief explanation why
19.	*Are there any transport routes on or around the location which are susceptible to congestion or which cause environmental problems, which could be affected by the project?*		
20.	*Is the project in a location where it is likely to be highly visible to many people?*		
21.	*Are there any areas or features of historic or cultural importance on or around the location which could be affected by the project?*		
22.	*Is the project located in a previously undeveloped area where there will be loss of greenfield land?*		
23.	*Are there existing land uses on or around the location, e.g. homes or other private property, public open space, community facilities, tourism, recreation, industry, commerce, mining, agriculture, forestry, aquaculture or fisheries which could be affected by the project?*		
24.	*Are there any plans for future land uses on or near the location which could be affected by the project?*		

Questions to be considered in screening		▪ please answer with yes / no / unknown ▪ please provide a brief description	▪ will this likely result in significant effects? ▪ please answer with yes / no / unknown and provide a brief explanation why
25.	*Are there any areas on or around the location which are densely populated or built-up, which could be affected by the project?*		
26.	*Are there any areas on or around the location which are occupied by sensitive land uses e.g. hospitals, schools, places of worship, community facilities, which could be affected by the project?*		
27.	*Are there any areas on or around the location which contain important, high quality or scarce resources, e.g. groundwater, surface waters, forestry, agriculture, fisheries, tourism, minerals, which could be affected by the project?*		
28.	*Are there any areas on or around the location which are already subject to pollution or environmental damage, e.g. where existing legal environmental standards are exceeded, which could be affected by the project?*		
29.	*Is the project location susceptible to earthquakes, subsidence, landslides, erosion, flooding or extreme or adverse climatic conditions e.g. temperature inversions, fogs, severe winds, which could cause the project to present environmental problems?*		

D.1.3 Criteria for defining significance

In order to define what is 'significant', a simple check is to ask whether the effect ought to be considered and might have an influence on the decision. The following list of questions may be additionally used. They are designed so that a 'yes' answer will generally point towards the need for EIA and a 'No' answer to EIA not being required.

Questions to be considered:

- Will there be a large change in environmental conditions?
- Will new features be out-of-scale with the existing environment?
- Will the effect be unusual in the area or particularly complex?
- Will the effect extend over a large area?
- Will there be any potential for transboundary impact?
- Will many people be affected?
- Will many receptors of other types (fauna and flora, businesses, facilities) be affected?
- Will valuable or scarce features or resources be affected?
- Is there a risk that environmental standards will be breached?
- Is there a risk that protected sites, areas, or features will be affected?
- Is there a high probability of the effect occurring?
- Will the effect continue for a long time?
- Will the effect be permanent rather than temporary?
- Will the impact be continuous rather than intermittent?
- If it is intermittent will it be frequent rather than rare?
- Will the impact be irreversible?
- Will it be difficult to avoid, reduce, repair or compensate for the effect?

D.1.4 Summary of features of the project and of its location

A conclusion has to be derived from the answers given to the screening checklist (D.1.2) on the question whether or not an EIA is required for the proposed project. There is no specific rule for deciding whether the results of the screening checklist should lead to a positive or negative screening decision (i.e. that EIA is or is not required).

As a general principle, the greater the number of 'Yes' answers and the greater the significance of the effects, the more likely it is that EIA is required. 'Unknown' answers, indicating uncertainty about the occurrence or significance of effects, should also point towards a positive screening decision because the EIA process will help to clarify the uncertainty.

D.2 Appendix 2 – Guidance for scoping of desalination projects

The following scoping criteria and checklists are based on EU guidance [10][38] and were modified for the specific needs of desalination plants. This appendix contains two checklists:

- Checklist of project characteristics which could give rise to significant effects (D.2.1);
- Checklist of environment characteristics susceptible to significant adverse effects (D.2.2).

The checklists shall help to identify all potential impacts of a desalination project and to select those impacts which are likely to be significant for the more detailed investigation process of the EIA. To decide what is significant, the two scoping checklists should be used together with the criteria for defining significance in Appendix D.1.3 on screening. Less obvious effects, which can also have a significant impact, should not be overlooked, such as:

Secondary and higher order effects

When using these scoping checklists it is important to remember that secondary and higher order effects can occur as a result of a primary interaction between a project activity and the project environment. For example, disturbance and re-suspension of sediments during construction can affect water quality by increasing turbidity, nutrient or pollutant concentrations, which may affect pelagic-living species such as plankton or fish, which may affect fisheries etc. Where a primary effect is identified, the user should always think about whether secondary or further effects on other aspects of the environment could arise as a result.

Effects of different life-cycle stages and time-scales

Users should remember that effects can occur not only permanently and over the long term but also temporarily during construction, commissioning or decommissioning, intermittently during certain phases of project operation (e.g. cleaning cycles), or rarely as a result of abnormal events affecting the project (e.g. accidents, harsh weather conditions, earthquakes, etc.).

Accompanying project-related effects

Accompanying effects are those which could arise indirectly from the project as a result of development activities taking place, e.g. provision of access roads, power supplies, water pipelines, sewage treatment or waste disposal facilities, etc. It may also mean the provision of community infrastructure such as housing for people attracted to the area by the project.

Cumulative effects

Cumulative effects could arise from a combination of the project's effects on the environment with those of other existing or planned developments in the surrounding area. For example, cumulative effects may be caused by two or more desalination facilities, or a desalination and power plant, port, fisheries industry, chemical industry, sewage treatment plant, etc.

D.2.1 Checklist of project characteristics that could cause significant effects

For impact identification, it is recommended to start with the first checklist below by answering the given questions with (column 1):

- yes — if the activity is likely to occur
- no — if it is not expected to occur
- unknown — if it is uncertain at this stage whether it will occur or not

For each activity to which the answer is 'yes' or 'unknown', the second scoping checklist should be used to identify characteristics of the project environment which could be affected.

[38] Further guidance is available from the European Commission in the "Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions" http://europa.eu.int/comm/environment/eia/eia-studies-and-reports/guidel.pdf (accessed on 25.07.2008)

Information on the surrounding environment will be required in order to complete this stage. The characteristics of the project environment that could be affected and the nature of the potential effects should be briefly described (column 2). Please refer to the criteria for evaluating significance of impacts (Appendix D.1.3) to complete column 3. This will help to sort out those impacts which are expected to be significant. The questions are designed so that a 'yes' answer will point towards a significant impact.

Table 24: Project characteristics which could give rise to significant effects

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
1	***Will construction, commissioning, operation, maintenance or decommissioning activities of the project (in the following referred to as 'the project') involve actions which will cause physical changes in the locality (topography, land use, changes in water bodies, etc.)?***			
1.1	*Pre-construction investigations, e.g. boreholes, soil testing?*			
1.2	*Loss of greenfield land due to land cover and surface sealing?*			
1.3	*Changes to topography or shoreline morphology, erosion/deposition rates of soils or sediments, soils or sediment layering, slope stability etc.?*			
1.4	*Changes in land use, creation of new land uses or increases in intensity of land use?*			
1.5	*Clearance and demolition works, e.g. of vegetation, buildings, etc.?*			
1.6	*Temporary sites used for construction works or housing of construction workers?*			
1.7	*Earthworks including cut and fill or excavations?*			
1.8	*Construction of above ground buildings or structures?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
1.9	*Underground works including mining or tunneling?*			
1.10	*Land reclamation works?*			
1.11	*Dredging?*			
1.12	*Coastal or offshore structures, e.g. seawalls, pipelines piers?*			
1.13	*Facilities for storage of hazardous substances or materials?*			
1.14	*Facilities for treatment or disposal of solid wastes or liquid effluents?*			
1.15	*Facilities for long term housing of operational workers?*			
1.16	*Increased volumes of traffic or transportation?*			
1.17	*New transport infrastructure, closure or diversion of existing transport routes?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
1.18	*New or diverted power transmission lines or pipelines?*			
1.19	*Changes to the hydrology of water-courses or aquifers?*			
1.20	*Abstraction or transfers of water from ground or surface waters?*			
1.21	*Changes in water bodies or the land surface affecting drainage or run-off?*			
1.22	*Activities during decommissioning which could have an impact on the environment?*			
1.23	*Influx of people to an area in either temporarily or permanently?*			
1.24	*Loss of native species or genetic diversity, or introduction of alien species?*			
1.32	*Any other actions?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
2	***Will the project use natural resources such as land, water, materials or energy, especially any resources which are non-renewable or in short supply?***			
2.1	*Land especially undeveloped or agricultural land?*			
2.2	*Water?*			
2.3	*Energy including electricity and fuels?*			
2.4	*Any other resources?*			
3	***Will the project involve substances or materials which could be harmful to human health or the environment or raise concerns about actual or perceived risks?***			
3.1	*Will the project involve use of substances or materials which are hazardous or toxic to human health or the environment (flora, fauna, water bodies and supplies)?*			
3.2	*Will the project result in changes in occurrence of disease or affect disease vectors?*			
3.3	*Will the project affect the welfare of people, e.g. by changing living conditions?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
3.4	*Are there especially vulnerable groups of people who could be affected by the project, e.g. hospital patients, the elderly?*			
3.5	*Any other causes?*			
4	***Will the project produce solid wastes?***			
4.1	*Municipal waste?*			
4.2	*Industrial process wastes, in particular hazardous or toxic wastes?*			
4.3	*Sludge from effluent treatment?*			
4.4	*Construction or demolition wastes?*			
4.5	*Redundant machinery or equipment?*			
4.6	*Contaminated soils or other material?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
4.7	*Any other solid wastes?*			
5	***Will the project release pollutants or any hazardous, toxic or noxious substances to air?***			
5.1	*Emissions from combustion of fossil fuels from stationary (on-site and off-site) or mobile sources?*			
5.2	*Other emissions to air from the stationary process, including gases, particulate matter and dust or odours?*			
5.3	*Emissions from materials handling including storage or transport (e.g. fuels, chemicals)?*			
5.4	*Emissions from construction activities including construction equipment, fugitive dust of demolition works, etc.?*			
5.5	*Emissions from any other sources?*			
6	***Will the project cause noise and vibration or release of light, heat energy or electromagnetic radiation?***			
6.1	*From operation of mobile equipment or vehicles, including construction or operational traffic?*			
6.2	*From the stationary process?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
6.3	*From construction or demolition, including piling, drilling, blasting etc.?*			
6.4	*From lighting or heating systems or sources of electromagnetic radiation?*			
6.5	*From any other sources?*			
7	***Will the project lead to risks of contamination of land or water from releases of pollutants onto the ground, surface or groundwater, coastal or marine waters?***			
7.1	*From handling, storage, use or spillage of hazardous or toxic materials?*			
7.2	*From discharge of sewage or other effluents (whether treated or untreated) to water or the land?*			
7.3	*By deposition of pollutants emitted to air?*			
7.4	*From any other sources?*			
7.5	*Is there a risk of long term build up of pollutants in the environment from these sources?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
8	***Will there be any risk of accidents during the different life-cycle stages of the project that could affect human health or the environment?***			
8.1	*From explosions, spillages, fires etc. or from storage, handling, use or production of hazardous or toxic substances?*			
8.2	*From events beyond the limits of normal environmental protection, e.g. failure of pollution control systems?*			
8.3	*From any other causes?*			
8.4	*Could the project be affected by natural disasters causing environmental damage (e.g. floods, earthquakes, landslip, etc)?*			
9	***Will the project result in social changes, for example, in demography, traditional lifestyles, employment?***			
9.1	*Demographic changes, e.g. of population size, age structure, social groups etc.?*			
9.2	*Community changes, e.g. resettlement of people, immigration of new residents, demolition or creation of homes or whole communities, etc.?*			
9.3	*Life-cycle changes, e.g. creation or loss of jobs, income opportunities, activities etc.?*			

Questions to be considered		▪ please answer with yes / no / unknown	▪ which characteristics of the project environment could be affected and how? ▪ please use the second scoping list below	▪ is the effect likely to be significant and why? (use significance criteria)
9.4	*Any other causes?*			
10	***Are there any other factors which should be considered such as consequential development which could lead to environmental effects or the potential for cumulative impacts with other existing or planned activities in the locality?***			
10.1	*Will the project lead to pressure for consequential development which could have significant impact on the environment, e.g.* ▸ *housing development* ▸ *infrastructure (roads, power lines, waste or waste water treatment)* ▸ *industries and commerce* ▸ *tourisms*			
10.2	*Will the project set a precedent for later developments?*			
10.3	*Will the project discourage the development of water management initiatives, such as water conservation and the use of water saving devices?*			
10.4	*Will the project discourage the development of schemes and infrastructure for water recycling / reuse?*			
10.5	*Will the project have cumulative effects due to proximity to other existing or planned projects with similar effects?*			

D.2.2 Characteristics of the project environment

For each project characteristic identified in Table 2 above, it should be considered whether any of the following environmental components could be affected:

- Are there features of the local environment on or around the project site which could be affected by the project, in particular:
  - areas which are protected under international, national or local legislation for their ecological, landscape, cultural or other value?
  - areas which are otherwise important or sensitive for reasons of their ecology, e.g. wetlands or other water bodies, dunes, coastal ranges, woodlands etc.?
  - areas used by protected, important or sensitive species of fauna or flora e.g. for breeding, nesting, foraging, resting, overwintering, migration?
  - areas or features of high landscape or scenic value?
  - routes or facilities used by the public for access to recreation or other facilities?
  - transport routes susceptible to congestion or which cause environmental problems?
  - areas or features of historic or cultural importance?
- Is the project in a location where it is likely to be highly visible to many people?
- Is the project located in an undeveloped area where there will be loss of greenfield land (i.e. undeveloped land used for agriculture or left to nature)?
- Are there existing land uses on or around the location e.g. homes or other private property, public open space, community facilities, tourism, recreation, industry, commerce, mining, agriculture, forestry, aquaculture or fisheries which could be affected by the project?
- Are there any plans for future land uses on or around the location which could be affected by the project?
- Are there any areas on or around the location which are densely populated or built-up, which could be affected by the project?
- Are there any areas on or around the location which are occupied by sensitive land uses that could be affected by the project, e.g. schools, places of worship, community facilities, etc.?
- Are there any areas on or around the location which contain important, high quality or scarce resources which could be affected by the project, e.g. groundwater resources, surface waters, forestry, agriculture, fisheries, tourism, minerals etc.?
- Are there any areas on or around the location of the project which are already subject to pollution or environmental damage, e.g. where existing legal environmental standards are exceeded, which could be affected by the project?
- Is the project location susceptible to earthquakes, subsidence, landslides, erosion, flooding or extreme or adverse climatic conditions, e.g. temperature inversions, fogs, severe winds, which could cause the project to present environmental problems?
- Is the project likely to affect the physical condition of any environmental media?
  - atmospheric environment, i.e. microclimate, local and larger scale climatic conditions?
  - aquatic environment, i.e. hydrological and sediment properties including currents, tides, waves, net flows, levels, flow directions, sedimentation, erosion and resuspension rates etc. in rivers, lakes, groundwater, estuaries, coastal waters, seawater and sediments?
  - terrestrial environment, i.e. soil properties including depths and layering, permeability, compaction, humidity, stability, erosion, deposition, layering, geological and ground conditions etc.?

- Are emissions from the project likely to affect the quality of any of the following environmental media?
  - local air quality and/or global air quality including climate change and ozone depletion?
  - water quality of rivers, lakes, groundwater, estuaries, coastal and marine waters?
  - contamination of soils and sediments?
  - nutrient status and eutrophication of waters?
  - acidification of soils or waters?
  - noise or vibrations, light or glare, electromagnetic radiation or heat?
- Will the availability or scarcity of any resources be affected by the project?
  - fossil fuels?
  - Other non-renewable resources?
  - Infrastructure capacity in the locality - sewerage, power generation and transmission, telecommunications, waste disposal, roads, etc.?
- Is the project likely to affect human or community health or welfare?
  - quality or toxicity of air, water or other products consumed by humans?
  - occurrence or distribution of disease vectors?
  - community cohesion and identity?
  - cultural identity and associations?
  - minority rights?
  - housing conditions?
  - employment and quality of employment?
  - economic conditions?
  - social institutions?

D.3 Appendix 3 – Ecotoxicity data

Table 25: Chlorine toxicity (excerpt partly based on [47, 48]).

Concentration [ppb]	Effect	Test species	Time [h]	Reference
500 ppb	LC_{100}	Larval clam	100	[153]
440 ppb	LC_{50}	Bluegill	96	[153]
208 ppb	LC_{50}	Coho salmon	1	[153]
97 ppb	LC_{50}	Daphnia magna	0.5	[154]
70 ppb	LC_{50}	Coho salmon	96	[155]
65 ppb	LC_{50}	Herring	96	[156]
26 ppb	LC_{50}	American oyster	96	[157]
17 ppb	LC_{50}	Daphnia magna	46	[153]
50-150 ppb	shift in species composition possible	marine phytoplankton	-	[153]
20-40 ppb	photosynthesis may be reduced by 80 %	marine phytoplankton	-	[158]

Table 26: Chlorination by-products (bromoform) toxicity (excerpt partly based on [47, 48]).

Concentration [ppb]	Effect	Test species	Time [h]	Reference
1,000 ppb	LC_{50}	oyster larvae Crassostrea virginica	96	[159]
16-19 ppb	respiration rate increased, feeding rate and size of gonads reduce	adult oysters		[67]

Table 27: Antiscalant toxicity (excerpt partly based on [47, 48]).

Concentration [ppm]	Effect	Substance	Test species	Time [h]	Reference
Polyacrylic acid					
4,300 ppm	LC_{50}	Flocon 100, 36%, neutralized	Bluegill	96	[160]
1,000 ppm	LC_{50}	Flocon 100, 36%, pH 3	Bluegill	96	[161]
Polymaleic acid					
580 ppm	LC_{50}	50%, pH <2	Brown shrimp	96	[162]
10,000 ppm	LC_{50}	Belgard EV, 48%	Brown shrimp	96	[160]
2,500 ppm	LC_{50}	Belgard EV, 48%, neutralized	Bluegill	96	[160]
1,000 ppm	LC_{50}	Sokalan, 44%, pH 7.75	Brachydanio rerio	96	[163]
Phosphonate					
2,700 ppm	LC_{50}	HEDP (diphosphic acid), 10-20%, pH 2.8	Daphnia magna	48	[164]
11,400 ppm	LC_{50}	amino phosphonic acid, alkaline	midge lavae	48	anon./conf.
> 330 ppm	LC_{50}	amino phosphonic acid, alkaline	Rainbow trout	96	anon./conf.
> 300 ppm	LC_{50}	amino phosphonic acid, alkaline	Bluegill sunfish	96	anon./conf.
1,212 ppm	LC_{50}	amino phosphonic acid, alkaline	Channel Catfish	96	anon./conf.
4,575 ppm	LC_{50}	amino phosphonic acid, alkaline	Brown Shrimp	96	anon./conf.
> 150 ppm	LC_{50}	amino phosphonic acid, alkaline	Rainbow trout	14 days	anon./conf.
297 ppm	LC_{50}	amino phosphonic acid, alkaline	Daphnia magna	14 days	anon./conf.
20 ppm	EC_{50}	amino phosphonic acid, alkaline	Selenastrum capricornutum (algae)	96	anon./conf.
20 ppm	EC_{50}	amino phosphonic acid, alkaline	Selenastrum capricornutum (algae)	14 days	anon./conf.
Others					
> 1,000 ppm	LC_{50}	biopolymer with low N and P content	Rainbow trout	14 days	anon./conf.
> 1,000 ppm		biopolymer with low N and P content	Daphnia magna	96	
> 1,000 ppm		biopolymer with low N and P content	Ps. Putida (bacteria)	48	
110 ppm		biopolymer with low N and P content	Scenedesmus subspicatus (algae)	72	

Table 28: Antiscalant degradability (excerpt partly based on [47, 48]).

Degradation rate	Time [days]	Substance	Test	Reference
Polyacrylic acid				
52%	35	Flocon 100		[161]
Polymaleic acid				
18%	35	Belgard EV	Zahn-Wellens test	[160]
Phosphonate				
7-20% biodegradation	30	amino phosphonic acid, alkaline	closed bottle test	anon./conf.
25-38% biodegradation	30	amino phosphonic acid, alkaline	closed bottle test, after acclimatisation	anon./conf.
23% DOC removal	28	amino phosphonic acid, alkaline	Zahn-Wellens test	anon./conf.
90% DOC removal		amino phosphonic acid, alkaline	modified SCAS test, buffered at pH 7	anon./conf.
20% of theoretical CO_2 evolution		amino phosphonic acid, alkaline	modified OECD screening test	anon./conf.
0.5-2 of theoretical $^{14}CO_2$ evolution		amino phosphonic acid, alkaline	modified SCAS test	anon./conf.
Others				
20-60 % biodegradation		biopolymer with low N and P content	OECD test method	anon./conf.

Table 29: Cleaning chemical degradability (excerpt partly based on [47, 48]).

Degradation rate	Time [days]	Substance	Test	Reference
Detergents				
87%	17	Na-DBS (sodium dodecylbenzene sulfonate)	biodegradability tests indicate a decline by 87% in 17 days, improved degradation in warm seawater of 25-30°C	[165]
80%	2-6 days	Na-DDS (sodium dodecylsulfate)		[166]
Complexing agents				
5%	3 weeks	microbial degradation in 3 weeks, aerobic conditions, activated sludge		[167]
	18-20 weeks	half-life of by photolytic degradation in marine environments		[168]

Table 30: Cleaning chemical toxicity (excerpt partly based on [47, 48]).

Concentration [ppm]	Effect	Test species	Time [h]	Reference
Acid				
pH 3-3.5	LC_{50} using H_2SO_4, HCl, or H_3PO_4	Bluegill	96	[169]
pH 3-3.3	LC_{50} using H_2SO_4	salt water prawn	48	[170]
pH 2-2.5	LC_{50} using HCl	starfish	48	[171]
Detergents				
1-10 ppm	LC_{50} Na-DDS (sodium dodecylsulfate)	fish, Daphnia magna and algae		[162]
Oxidants				
8 ppm	NOEC	zooplankton		
25 ppm	NOEC	fish		[162]
11 ppm	LC_{50}	Daphnia magna	48	[162]
12 ppm	EC_{50}	Scenedesmus suspicatus (algae)	96	[162]
51 ppm	LC_{50}	Brachydanio rerio	96	[162]
160-320 ppm	LC_{50}[1]	fingerling trout	24	[150]
Biocides				
0.1 ppm	LC_{50} formaldehyde	Bluegill	96	[159]
6.5 ppm	NOEC isothiazole-derivate[1]	Bluegill		[164]
2.9 ppm	LC_{50} isothiazole-derivate	Daphnia magna	48	[164]
12.1 ppm	LC_{50} isothiazole-derivate	Bluegill	96	[164]
20 ppm	LC_{50} isothiazole-derivate	Sheepshead minnow	96	[164]
Complexing agents				
> 50 ppm	LC_{50}[1]	Golden Orfe	96	[150]
> 100 ppm	EC_{50}[1]	Daphnia magna	24	[150]
10-100 ppm	EC_{50}[1]	algae	72	[150]
100 ppm	NOEC	Bluegill		[159]
159 ppm	LC_{50}	Bluegill	96	[159]

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