Desalination and Water Treatment 3 (2009) 217–228
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UNEP resource and guidance manual for environmental impact assessment of desalination projects

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Received 14 September 2008; Accepted 25 January 2009

ABSTRACT

The United Nations Environment Programme (UNEP) developed and released a new guidance document on desalination in cooperation with the World Health Organization (WHO). The document assists project designers, consultants, regulators and decision makers to anticipate and address all relevant environmental, socioeconomic and public health 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. This paper gives a short account of the guidance development process and summarizes the main results and recommendations. The UNEP document is divided into three parts. In part A, an introduction to the concept, methodology and practice of environmental impact assessment (EIA) is given and a 10-step EIA approach is proposed. Part B outlines a possible modular structure of an EIA report and gives an overview on a wide range of thematic issues that may be relevant to desalination projects. Part C discusses the potential impacts of desalination plants on the environment, based on a comprehensive literature review, and evaluates the identified impacts in terms of significance and relevance for EIA studies.

Keywords: Desalination; Environment; Socioeconomic; Health; Impact assessment; EIA; UNEP; WHO

1. Introduction

In 2004, the World Health Organization (WHO) initiated a process to develop a guidance document on "Desalination for safe water supply" [1–3] which should supplement and be closely integrated with the main body of the WHO "Guidelines for drinking water quality" [4]. As desalination is applied to non-typical source waters, mainly seawater, brackish water and waste water, and uses non-typical water treatment techniques, the concern had been raised that the existing WHO guidelines might not fully cover the unique factors that can be encountered during the production and distribution of desalinated drinking water. With the worldwide need for desalinated water rapidly increasing, the need for a clear new guidance was evident. It was decided that the new guidance should be equally concerned with health *and environmental* aspects of desalination developments.

The new WHO guidance was developed through the WHO Eastern Mediterranean Regional Office (EMRO). A

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Presented at EuroMed 2008, Desalination for Clean Water and Energy Cooperation among Mediterranean Countries of Europe and the MENA Region, 9–13 November 2008, King Hussein Bin Talal Convention Center, Dead Sea, Jordan.

steering committee consisting of renowned experts in the field of desalination and an oversight committee with representative from different organisations were established, the latter including WHO-EMRO in Cairo, the WHO Water, Sanitation and Health (WSH) Office in Geneva, the United Nations Environment Programme Regional Office for West Asia (UNEP-ROWA) in Bahrain, and the Regional Organization for the Protection of the Marine Environment (ROPME) in Kuwait.

In addition, five technical working groups were formed that addressed five different topic areas:

- Technology: engineering and chemistry
- Health: toxicology of contaminants and nutritional aspects
- Microbiology: sanitary and marine microbiology
- Monitoring: microbiological, analytical chemistry, surveillance, regulatory
- Environment: environmental effects and impact assessments

The technical working groups consisted of a balanced group of more than 35 international expert scientists and engineers with particular expertise in the specialty technical areas. They conducted the scientific analyses and generated the indicated guidance chapters during and in between three working meetings that were held in 2004, 2005 and 2006. The draft document underwent an internal WHO review process and was published on the WHO website for a public commenting period in 2007. The final document was scheduled for publication by WHO in 2008, followed by an Arabic translation by the Kuwait Foundation for the Advancement of Science [2].

Environmental considerations, which are normally not reflected by WHO guidelines, were included into the topic areas because the protection of coastal ecosystems and groundwater aquifers from desalination plant discharges were considered key concerns that should be addressed during the design, construction and operation of a desalination facility. One of the groups was therefore assigned to review the potential environmental impacts and to investigate methodologies for EIA studies of desalination projects. Due to the high relevance of this topic and the amount of material gathered, it was later decided to integrate the results only partially into the WHO guidance and to publish them in a second, standalone document through UNEP.

Independent from these developments, the European Community decided in 2006 to foster the sustainable use of desalination processes in the EU by financing the research project "Membrane-based desalination — an integrated approach" (MEDINA) within the Sixth Research Framework (FP6) [5]. The MEDINA project has the overall objective 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 studies

The MEDINA project builds upon the findings of the WHO environmental working group in order to develop strategies on how to minimize environmental impacts and conduct EIA studies. The new "Desalination — resource and guidance manual for environmental impact assessments" [6] released by UNEP integrates the results from the WHO environmental working group and first results from the EU MEDINA project. In the following, the main results are summarized.

2. ABC's to environmental impact assessment (EIA)

EIA studies are widely recognized and accepted as a suitable approach for identifying, evaluating and mitigating potential impacts of development projects on the environment. The main objectives of an EIA are to provide information on the environmental consequences of a project for decision making, and to promote environmentally sound and sustainable development through the identification of appropriate alternatives and mitigation measures. Based on the EIA results, a decision has to be reached which balances the societal and environmental impacts of a project versus its benefits [7].

Detailed EIA studies involving pre- (baseline) and post-installation (operational) monitoring programmes are often required for major infrastructure projects, such as dams or power generation plants. In principle, EIAs for large desalination projects will not differ in terms of complexity and level of detail from those for other infrastructure projects and especially other water supply projects. Depending on the proposed project, it is incumbent on the national authorities to individually define the need, scope and complexity requirements 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 the environment'. This often requires 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 socioeconomic aspects where appropriate. Public participation is therefore another fundamental element of EIAs in many legislative systems, particularly for community infrastructure projects including water supply projects.

In other words, EIAs are multi-stage, multidisciplinary studies, often involving monitoring programs and many different scientists and experts, government agencies, stakeholders as well as the wider public. With the context so broad, difficulties may be experienced in conducting the EIA and accompanying studies, and in analyzing the large amounts of complex information in a structured and consistent way for decision making.

The UNEP guidance document therefore offers a structured 10-step EIA approach (part A), lists a wide range of thematic issues potentially relevant to desalination projects (part B), which can be used for scoping of the project, and gives an overview on the main environmental concerns of desalination projects (part C). Not all of the issues listed in the guidance are unique to desalination projects. Some apply similarly to other water treatment or infrastructure projects. Others, however, may not be relevant to a particular desalination project. The guidance document merely intends to raise a wide range of potentially relevant issues, which may help to anticipate the relevant concerns of a particular desalination project on a case-by-case basis.

2.1. EIA methodology (part A of the guidance document)

An EIA is generally marked by three main phases, which were subdivided into 10 steps (Figs. 1 and 2). The pre- or initial EIA phase includes screening and scoping of the project. The main EIA phase refers to the actual environmental impact assessment, spanning from the establishment of baseline data and the prediction and evaluation of impacts to the identification of appropriate alternatives and mitigation measures. The final EIA phase involves decision making and a review of the EIA process. An environmental management plan is often established for the time following the EIA, which includes specifications for environmental monitoring during installation and operation of the plant, and which shall ensure compliance with any obligations that were imposed as part of the project permit. In the following, the 10-step process as proposed in the UNEP guidance is outlined. In practice, this process may deviate from the outlined procedure, as single steps may not always be clearly delimitable, some steps may overlap, or it may be necessary to change the sequence of steps. The EIA procedure should generally be understood as a continuous and flexible process.

2.1.1. Screening (step 1)

Screening is the process by which a decision is taken on whether or not an EIA is required for a particular

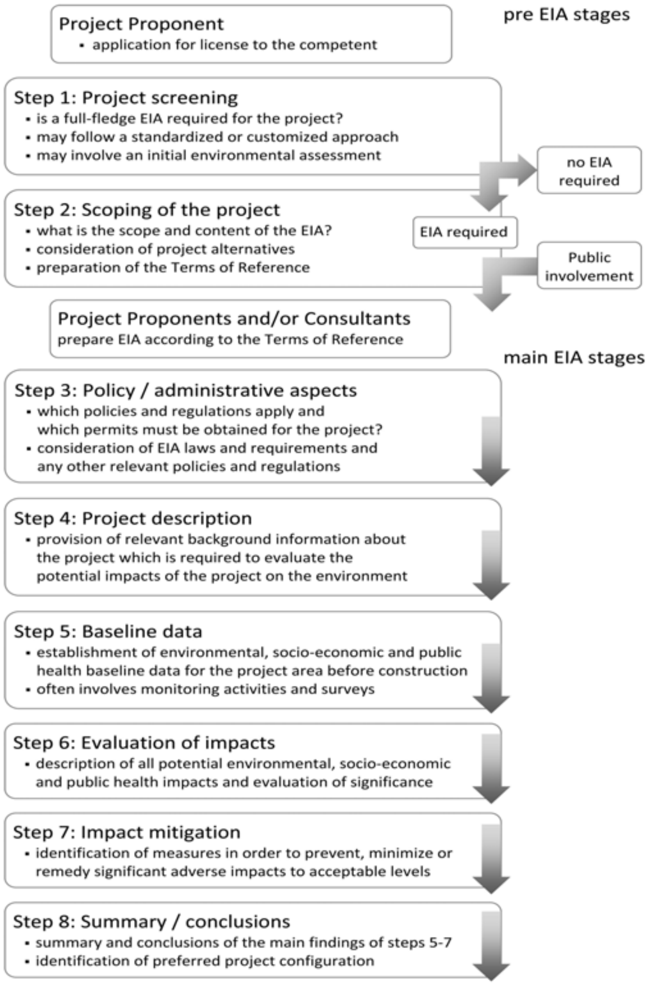

Fig. 1. Pre- or early EIA phases (scoping and screening) and main EIA phase.

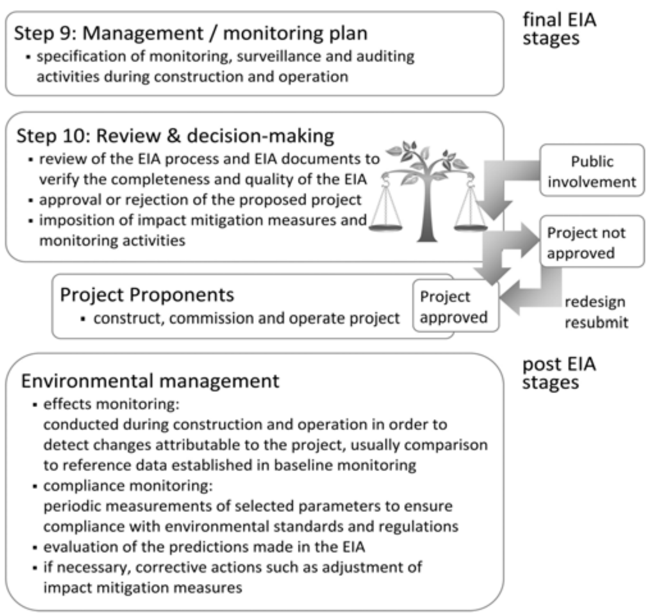

Fig. 2. EIA decision phase and follow-up activities.

project. It shall ensure that a full EIA is only performed for projects with a significant adverse impact on the environment or where the impact is not sufficiently known. Screening therefore involves a *preliminary* environmental assessment of the expected impacts of a proposed project and of their relative significance. This requires a certain level of basic information that is *readily* available about the project and its location, e.g. from literature or other sources [7].

Screening can either be carried out by a standardised or by a customised procedure. In the standardised approach, projects are classified by legislation into categories which are either subject to or exempt from EIA. This may include mandatory (positive) lists for projects that always require an EIA, lists which define thresholds and criteria for EIA, or exclusion (negative) lists. For example, an EIA may be mandatory for large electricity and water co-generation plants, or for desalination facilities with a production capacity above a certain threshold, but not for small systems as used for hotels, small residential communities or recreational areas. A class screening can be undertaken for small-scale projects that are routine and replicable, if there is a reasonably sound knowledge of the environmental effects and if mitigation measures are well established.

In case that project lists and thresholds are not defined by the applicable EIA laws, a customised screening approach should be followed, using indicative guidance. Screening checklists are for example provided as part of the European EIA legislative system (including directives 85/337/EEC and 97/11/EC) [8], which were included in the UNEP guidance for easy reference. The lists include a number of questions referring to the project and its environment. They can be quickly answered by qualified and experienced personnel as found in environmental authorities or consultant companies. Answers should be given based on the information that is *readily* available on the project and its environment at this stage. The lists shall help to provide an answer to the question if the project is *likely* to have a *significant effect* on the environment, which is always a discretionary decision. As a general rule, the greater the number of potential concerns and the greater the significance of the effects, the more likely is an EIA required. Uncertainty should always point towards an EIA, as the process will help to clarify the uncertainty.

After a formal decision has been made whether an EIA is required or not, an official screening document is typically prepared by the competent authority which records the results and underlines the decision. It may be extended into a short screening report, which also includes the results of the preliminary assessment, and can be used for public dissemination in the scoping stage of the EIA.

2.1.2. Scoping (step 2)

Scoping is the process of determining the contents of the EIA study. The terms of reference (TOR), which are elaborated in this process, provide clear instructions to the project proponent on the information that needs to be submitted to the competent authority for EIA, and on the studies to be undertaken to compile that information. Scoping is a crucial step in EIAs because it identifies the issues of importance on which the EIA should focus, and eliminates those of little concern.

As a generalised approach, the scoping procedure may follow four basic steps:

- preparation of a scoping document for public dissemination, including project details and a preliminary environmental analysis,
- organisation of scoping meetings inviting collaborating agencies, stakeholder groups, NGOs, experts and advisers, and announcement of the scoping meeting in public,
- compilation of a complete list of issues during scoping consultations, which are then evaluated in terms of their relative importance and significance,
- preparation of the terms of reference for EIA, defining the scope and information requirements of the EIA, study guidelines and methodologies.

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.

An effective way of dealing with a larger number of desalination projects may be to elaborate a standard scoping procedure and standard TOR. The scoping process will often involve the same representatives of government agencies, NGOs, consultants, etc. A guideline, elaborated in a collaborative effort between these groups, may routinize the scoping procedure and may establish standards for the environmental studies to be undertaken and the information to be submitted in EIAs for desalination projects, but would still allow for project-related specifications.

2.1.3. Policy and administrative aspects (step 3)

An EIA usually takes place within the distinctive legislative system established by the individual country where the project is to be located, as well as within the legislative frameworks of international institutions. It is therefore recommendable to gain a deeper insight and understanding of any national or international regulations that apply to the EIA procedure. Moreover, all thematically relevant laws and policies need to be identified, relating for instance to the conservation of nature and biological diversity, to the control and prevention of pollution, to water resources management, or to land-use and regional planning. In many jurisdictions, more than one permit will be required to realise a desalination project. The main approval process, which authorises the construction and operation of a desalination plant, will not necessarily replace other existing statutory provisions and permits. It is important to clarify early in project planning which permits must be obtained and to contact the competent authorities. The permitting process may be facilitated by nominating a 'lead' agency, which co-ordinates the process by involving other agencies and by informing the project proponent about permitting requirements.

2.1.4. Project description (step 4)

A technical project description should be prepared and included in the EIA report. It forms the information basis for the EIA process and provides all the necessary background information that is required to identify and investigate all potential environmental concerns of the project. The project description should cover the different life-cycle stages of the project including construction, commissioning, operation, maintenance and decommissioning of the plant. It should estimate all resources that are consumed during the different project operations, such as land area requirements during construction, the use of chemicals during plant operation and maintenance, or energy use. It should furthermore include a characterisation of all waste products in terms of quantity and composition, including emissions into air, water, and soils, as well as solid and liquid waste products transported to a landfill or discharged into the municipal sewer or stormwater system. The technical description should be succinct and to the point, making a selection between those technical details that are necessary for the impact assessment and those which are irrelevant in this context.

2.1.5. Establishment of baseline data (step 5)

This step entails the collection, evaluation and presentation of baseline data of the relevant environmental, socioeconomic, cultural and public health characteristics of the project area before construction. This should include any existing levels of degradation or pollution, such as other development activities, noise levels, or sources of emissions. The information requirements of the baseline studies to be undertaken in an EIA for a desalination project are determined during scoping (step 2).

A reference area with similar characteristics may be selected, for which baseline data is established in the same way as for the project site. This allows for a comparison between the reference and the project site during project monitoring in order to detect any changes caused by construction and operation of the project. Reference data from a site with similar environmental characteristics is particularly useful to identify natural variations or other anthropogenic effects not related to the desalination project.

2.1.6. Evaluation of impacts (step 6)

This step of the EIA describes and evaluates the potential impact and benefits of the proposed project on 'man and the environment'. Socioeconomic and cultural considerations include for example the project's effects on the day-to-day lives of the individuals and the community, on the management of natural resources, or on local and regional development. Public health impacts refer to changes in the quality of life and community health, or potential health risks associated directly or indirectly with the desalination project. Impacts on the environment would include all emission to air, soils and water, impacts on landscape characteristics, or any disturbance of species and ecosystems during the different life-cycle stages of the project.

The prediction of impact in an EIA is typically based on conceptual models and tests, such as field and laboratory experimental methods (e.g. whole effluent toxicity tests), small-scale models to study effects in miniature (e.g. different outfall designs), analogue models which make predictions based on analogies to similar existing projects (e.g. other desalination plants) or mathematical models (e.g. hydrodynamic modelling of the discharges). As each of these models only partially covers the range of effects, they are usually used in conjunction with each other, often resulting in a number of studies being carried out by different experts.

The relative significance of the predicted impact should be evaluated, using criteria such as:

- Is the impact direct or indirect, positive or negative?
- Is the impact temporary, long-term or permanent?
- What is its extent, in terms of geographical area, or size of the population affected?
- How severe is the impact, how likely will it occur, is it reversible or can it be mitigated?

If possible and where appropriate, secondary effects, the potential cumulative impact with other development activities on the project site, trans-boundary (far-distance) effects and growth-inducing effects should be identified.

2.1.7. Impact mitigation (step 7)

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, minimise 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 standards, which depend on a society's or community's social, ideological and cultural values, on economic potentials and on politics.

The elements of mitigation are organised into a hierarchy of actions [7]. Impact prevention by adequate measures and alternatives is usually given the highest priority. If prevention is not possible, impacts should be minimised as far as possible. All remaining impacts which are significant, but unavoidable, and which cannot be mitigated further, should be compensated or remediated after decommissioning of the project.

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 during the project life time or restoration of the affected site to its previous state after project demolition, and enhancement of resource values at another location, e.g. by habitat enhancement, reforestation or restocking of a certain species.

2.1.8. Summary and conclusions (step 8)

In this step, the main findings and recommendations of steps 5–7 are summarised. The focus should be on the key information that is needed for drawing conclusions from the EIA investigations and 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 minimised, and those which cannot. The identified mitigation measures or alternatives should be given at least for all significant impacts. 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. 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 backed by arguments.

2.1.9. Environmental management plan (step 9)

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 has the objective to identify the actual impacts of the project and to verify that the observed impacts are within the levels predicted in the EIA. Moreover, environmental management has the objective to determine that the imposed mitigation measures or other conditions attached to the project permit are properly implemented and work effectively. If not or if unanticipated impacts occur, the measures and conditions should be adapted in the light of new information. The management plan should specify any arrangements for planned *monitoring*, *surveillance* and *auditing* activities, including methodologies, schedules, and management protocols in the event of unforeseen events [7].

Effects monitoring is typically based on field measurements, such as surveys of species abundances and diversity in the project site. It has the primary objective to measure the environmental changes that can be attributed to project construction and operation. By comparing the data from baseline and operational monitoring, and from the project and reference sites, changes which are attributable to the project can be detected and distinguished from natural variations.

C*ompliance monitoring* refers to the periodic or continuous measurement of a certain parameter in order to ensure that regulatory requirements and environmental quality standards are being met, such as the measurement of salinity levels in the discharge and mixing zone.

Both types of monitoring activities 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 links 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 program should be targeted at the information that is necessary to manage those impacts which were found to be significant.

For a more pro-active approach, monitoring activities can be accompanied by surveillance activities, which involve regular or periodic site inspections in order to survey the implementation of EIA conditions and mitigation measures, the quality of monitoring activities including sampling, measurements and analyses, and in order to discuss current issues with consultants and project developers. Surveillance can be undertaken by the competent authority, or by independent institutions or experts. A formal auditing process may draw upon monitoring data and surveillance reports and document the whole process.

2.1.10. EIA review and decision making (step 10)

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 (step 2) and is sufficient for decision making. The review may be undertaken by the responsible authority itself, another governmental institution or an independent body. Participation of collaborating and advisory agencies, the public and major stakeholders in the review process is recommended.

Following review, the EIA report will be submitted for decision making. The competent authority will form its own judgement on the proposed project based on the EIA report, the analysis of stakeholder interests, statements from collaborating agencies etc., and decide on approval or rejection of the proposed project. The competent authority typically imposes conditions if the project is approved, such as mitigation measures, limits for emissions, or environmental standards which must be observed.

2.2. Outline of an EIA report (part B of the guidance document)

The EIA report is the primary document for decision making. It organizes and synthesizes the results obtained during the studies and consultations of the EIA process. The outline or contents list included in part B of the UNEP guidance document gives an overview on a range of thematic issues that may be relevant to desalination projects. The list can serve both as a reference source in the early stages of the EIA (e.g. during scoping), as well as for drafting the EIA report at the end.

In this regard, the guidance document tries to be inclusive rather than exclusive by raising a wide range of potentially relevant issues for different desalination projects and environments. Some of these may be obvious, others may not, and while some may apply to a specific project, others may not. By screening the information, it can be decided on a case by case basis which issues may be relevant to a specific desalination project and which are of minor or no importance.

The list is subdivided into four sections: front matter, project background information, environmental impact assessment, and back matter to an EIA report. 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.

The front and back matter to an EIA report should comprise the usual material that appears before and after the actual body content of a report, such as executive summary, table of contents, references and appendices. All expert reports that were prepared during the EIA, e.g. summarizing the results from hydrodynamic modelling or toxicity studies, would typically be included as original documents in the appendices, while the EIA report reproduces and synthesizes only the key results from these studies. The appendices may therefore contain a dozen or more individual reports. In this way, more detailed information is easily accessible without overloading the EIA document with too many details.

A coherent EIA report should also provide project background information, which covers the main activities and results of the pre EIA stages and all technical and legislative information concerning the project and the EIA process (steps 1–4): In the introductory section to an EIA report, the rationale and purpose of the EIA should be briefly stated as identified in the *screening decision* in step 1, as well as the scope, content and methodology of the EIA as specified in the *terms of reference* during step 2. This may be in the form of a tabular overview summarising the field investigations and studies carried out and the evaluation methods used. Moreover, the applicable EIA laws and procedures should be listed, as well as any other policy, permit or regulatory issue that may apply to the project, such as water quality standards or nature conservation laws (cf. step 3). Finally, a technical description of the proposed project over its entire life cycle should be included in the EIA report, which forms the technical information basis for the impact assessment (cf. step 4). The section of the EIA report containing the results from the actual impact assessment comprises all relevant socio-economic, human health as well as environmental considerations (cf. steps 5–7). It is proposed to include the following chapters and sub-sections into an EIA report where relevant:

1. Socioeconomic and environmental health aspects
- population, housing and community structure
- economic growth and development activities
- environmental health factors
- water resources use
- land and marine use
- utilities and service systems
- cultural resources

2. Abiotic environment
- characteristic landscape and natural scenery
- terrestrial site (soils, ground- and surface water)
- marine site (seafloor, sediments and seawater), air quality and climate

3. Biotic environment
- terrestrial biological resources
- marine biological resources

For each of these topic areas, the following information should be included:

- A detailed description of the existing setting (i.e. baseline), which describes the present and future state of the environment in the absence of the desalination project (*zero alternative*), taking into account changes resulting from natural events and from other human activities, and often involving field studies if sufficient literature data about the project site is not available from previous monitoring studies.

- A discussion of the expected effects on the different life-cycle stages of the project, i.e. 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 these are considered to be significant.
- A description of impact mitigation measures in order to avoid, reduce, remedy or compensate for any significant adverse impact resulting from the project.

In the concluding section, the main results of the EIA process are summarized. It should focus on the key information that is needed for decision making (cf. step 8). If an environmental management plan has been established (cf. step 9), a chapter of the EIA report should also briefly outline the details of that plan, covering the planned monitoring, surveillance and auditing activities, specifying the schedules, methodologies, protocols etc. to be followed, and the responsive actions to be taken in case that violations or adverse effects are detected. Finally, 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 (cf. step 10).

2.3. Potential environmental impact (part C of the guidance document)

This part of the UNEP guidance is intended as a reference guide which gives an overview on the potential impacts of desalination projects and offers references for further reading. It follows the approach of an *ecological risk assessment* by systematically identifying and evaluating the relationships between *stressor sources* as caused by the project and resulting impacts on *receptors*.

Stressors can be all single characteristics of a project or activity that lead to an ecological effect, including chemical, physical, or biological project characteristics, 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 certain species) and its indicators (e.g. population size, biodiversity). The purpose of this analysis is to describe the exposure of receptors in terms of intensity, space, and time [9].

In essence, the ecological risk assessment approach is based on an analysis of how exposure of receptors to stressor sources is likely to occur and on an analysis of the significance of the associated impacts. The result is a list of cause–effect relationships. As ecosystems are complex systems, these relationships often have a netlike rather than a linear structure, in which 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 cause–effect relationships are typically summarized in a *risk matrix* (preference matrix or Leopold matrix) in which the columns represent the various stressors of a proposed project and the rows represent the various environmental receptors. 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 relationships are integrated into an overall risk estimation, which takes the significance and likelihood of effects into account as well as the limitations of the method, such as scientific uncertainties and assumptions. A risk matrix and risk characterization is often developed as part of step 8 of the EIA process and provided in the concluding sections of an EIA report. 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) [9].

For the UNEP report, a categorization of the stressor sources of desalination projects and of the potential environmental receptors was carried out. The stressor sources were subdivided into the life-cycle stages of construction, commissioning, operation, maintenance and decommissioning (demolition), and comprised the following key elements of the desalination system:

1. Intake system, including:
- the inlet with screens
- seawater supply pipeline to the shore
- pumping station or submersible pump

2. Desalination system, including:
- pretreatment line
- desalination units
- product water storage
- pumping/high pressure system
- post-treatment line
- storage facilities
- car park, gates, etc.

3. Outfall system, including:
- outfall channel or tunnel
- diffuser system
- pumping station or submersible pumps

4. Main auxiliary infrastructure, including:
- water distribution pipeline
- energy supply source and transmission line
- access roads to the facility

The following receptor categories were defined:

- landscape and natural scenery
- air quality and climate
- terrestrial soils
- seafloor and sediments
- ground- and surface water quality and hydrology
- seawater quality and hydrology
- terrestrial flora and fauna
- marine flora and fauna, subdivided into macroflora, plankton, benthic invertebrates, nekton, mammals and reptiles
- terrestrial birds and seabirds

In a first step, a comprehensive literature review of the potential environmental effects of desalination plants was carried out (overviews on the potential concerns have been previously given [3,10]). The identified concerns were formally reorganized into cause–effect relationships and then evaluated in terms of intensity, space, time.

Space and time refer to the spatial and temporal distribution of the stressor source. 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, benthic or fish species in the project site). It was therefore generally assumed that the receptor is present in the impacted area. A categorization into far-range, mid-range, localized, respectively long-term, medium-term, and short-term effects was made.

Far-range effects were defined as those effects which are noticeable beyond 1 km of the point of origin. Mid-range effects were considered to be those effects which are limited to the project site and nearby areas and typically do not exceed a range of 1 km. Localized effects would occur only punctually, and are limited in their range to the project site within 100 m distance of origin.

Long-term effects were defined as those effects which occur continuously or regularly (e.g. once per day) over the entire project life, including permanent or irreversible effects. Medium-term effects would be those effects which last for several years, including periodic events that occur several times per year. Short-term effects have a duration of less than one year and are generally reversible.

Concerning the intensity rating, a classification was made into severe, notable and negligible alterations of natural properties, functions, or processes. It was furthermore assumed that the impacts are caused by a large facility, as the intensity of environmental impacts can be assumed to increase with the size and production capacity of a desalination plant. Finally, an attempt was made to include an estimate of the likelihood of the effect (likely, possible, unlikely), taking the likelihood of stressor occurrence (e.g. the likelihood of a chemical spill) as well as receptor occurrence (e.g. the likelihood that a mobile species may be exposed) into account.

The single ratings for intensity, space, time were formally integrated into a single rating, which should reflect the significance of that effect for project and site specific EIA studies and for impact mitigation measures (high, medium, low priority). The probability criterion was not formally integrated into the decision hierarchy but instead used as an indicator. When a result between two ratings was obtained, the next higher rating was usually selected as a precautionary approach.

Of high priority were all effects that have the potential for:

- severe alterations of natural properties, functions or processes, which are of (1) long-term duration and far range, (2) long-term duration and mid range and (3) medium-term duration and far range;
- notable alterations of natural properties, functions or processes, which are of long-term duration and far-range.

Based on this categorization, the effects listed in Table 1 were identified as being of high priority for EIA studies and for impact mitigation.

Most other potential effects were rated as being of "medium priority" for environmental impact assessments, such as, for example, all construction-related impact. Although construction impact is usually severe in terms of intensity, the effects are generally temporary, localized and reversible. The classification as medium priority does not imply that these effects are per se negligible. Although they might not be decisive for the project outcome, they usually also require some form of impact mitigation. Furthermore, the impact which was classified into the medium category in this evaluation may be upgraded into high priority impact or downgraded into low priority impact, depending on project- and site-specific conditions. This underlines the necessity for a case-by-case evaluation, as part of a project specific EIA study and using the criteria from this evaluation or other criteria.

Whether or not an impact is rated 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 perception and definition of significance. No universally valid standard for significance exists. The evaluation that was carried out should therefore be understood as an attempt to prioritize impacts based on general criteria (as far as this is possible) in order to provide a first indicative guidance. 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.

Table 1
Effects of high priority for impact assessment and impact mitigation

Receptor	Effects
Landscape properties and natural scenery	• Visual, aesthetic impacts due to the discharge of reddish-brown backwash water from media filters (specific to the reverse osmosis process) that may cause a discoloration of the water column in the mixing zone or may be transported to nearby beaches • Acoustic impacts caused by noise emissions from plant operation
Air quality and climate	• Significant impairments of local air quality due to emissions of air pollutants (NO_X, SO_X, PM_{10}) • Effects on climate due to carbon dioxide (CO_2) 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 locally and in down drift locations which may be caused by artificial breakwaters • Increases in pore water salinity which may be caused by the concentrate discharge • Accumulation of coagulant material in sediments near the outlet potentially caused by the discharge of media filter backwash water • 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 effluent plume • Sinking of the discharge plume and formation of a dense bottom water layer, which may have a strengthening effect on density stratification of the water column and 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, which may strengthen the effect of habitat loss
Benthic macro-fauna and flora	• Salinity or temperature increases in the mixing zone that may cause a decline of algae stands and 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 • Harmful blanketing of sessile species potentially caused by the filter backwash plume
Marine mammals, reptiles or bird species	• 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

3. General considerations for EIA studies

The consideration of alternatives to a proposal is an integral part of many EIA regulations. Alternatives can be generated or refined most effectively in the early stages of project development, when the disposition to consider alternatives or modifications to a project is still high. Alternatives should include project modifications regarding process design or location, as well as different water supply or management options like exploitation of surface and ground waters, long-distance transfers, reclamation and reuse, or water conservation measures.

Public participation is another integral part of EIAs, especially for community infrastructure projects. Public involvement should seek to inform the public and gather different perceptions about the project, addressing the benefits as well as potential public health, environmental and socio-economic impacts. Involving a broad public will furthermore ensure that important issues are not overlooked, thus providing for the comprehensiveness, quality and effectiveness of the EIA. Another benefit of public involvement is that a partnership with the community can be developed, which is critical for the success and sustainability of a project.

A thorough selection of the project site in the early stages of project development is one efficient way of keeping the impacts of a proposed desalination project on its environment at a minimum. Typically, one preferred site and possibly one or two alternatives are identified, for which an EIA including a site-specific monitoring program will be carried out. To facilitate site selection for desalination plants, public authorities may designate suitable areas in regional development plans. Recommendations for site selection, including different criteria such as biological and oceanographic conditions, are given in the UNEP guidance.

Last but not least, EIAs can only give a prognosis of the expected impacts, based on the information that is available for a specific project and its location at a certain time. It is recommended to deliberate carefully about the accuracy of all predictions made in the EIA, which can only be as valid as the underlying data and information. Information gaps and deficiencies should therefore be clearly identified in the EIA and a precautionary approach applied in the evaluation of potential impacts and in decision making.

4. Conclusions and outlook

EIA studies are a widely recognized and accepted approach for identifying, evaluating and mitigating the potential impact of new development projects on the environment. In 2004, Schiffler from The World Bank stated that an “internationally agreed environmental assessment methodology for *desalination plants* does not exist so far and its development would be desirable” [11].

The UNEP guidance document partially fills this gap. It offers guidance for designers of desalination projects, consultants, regulators and decision makers on the methodology, scope and contents of EIA studies specific to desalination projects. Still missing, however, are monitoring studies that improve our understanding of the actual impact of desalination plants on the environment.

In 2008, the US National Research Council of the National Academies attested to a “surprising paucity of useful experimental data, either from laboratory tests or from field monitoring”, despite “numerous papers discussing the potential for negative environmental impacts of effluents from desalination facilities” [12]. The NRC report concludes that there is still a considerable amount of uncertainty about the environmental impact of desalination. Identified long-term research needs include site-specific assessments of the impact of source water withdrawals and concentrate management and the development of monitoring and assessment protocols for evaluating the potential ecological impact of surface water concentrate discharge.

The new UNEP guidance, which is in the center of this paper, combines past results from the WHO environmental working group with first results from the MEDINA project. A remaining task of the MEDINA project is still to develop terms of reference for the collection of relevant data and information (i.e. monitoring protocols) and terms of reference for the evaluation and assessment of these data and information (i.e. assessment protocols). Further results are expected in 2009, the third and last year of the MEDINA project.

Acknowledgements

We would like to extend thanks to all individuals and organizations that made the UNEP publication possible. Houssain Abouzaid and Joseph Cotruvo have been instrumental in initiating, coordinating and guiding the process within the WHO project on “Desalination for safe water supply”. Special thanks go to Khalil H. Mancy, Bradley S. Damitz, Hosny K. Khordagui, Greg Leslie and Klaus Genthner for their dedicated participation in the environmental work group and for co-authoring the original WHO publication. The author received further funding from the European Community in the research project MEDINA, Sixth Framework Programme, project no. 036997.

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