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Agenda item 7: Technical Guidelines and related Assessments

Updated Guidelines on the Management of Desalination Activities

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UNEP/MAP
Athens, 2017

Explanatory Note by the Secretariat

1. Since 2003, when the MAP technical report No. 139 was published, the global desalination effort, and in particular the desalination around the Mediterranean, has increased exponentially. Technologies changed as well, together with increased awareness of the possible environmental impacts, in particular on the marine environment.

2. Moreover, the legal framework for the regulation of waste disposal into the Mediterranean evolved because the amendments to the Land-based sources (LBS) Protocol entered into force in 2008 and a number of Regional Plans were adopted containing legally binding measures for the prevention and reduction of specific pollutants. Furthermore the MAP system further evolved with the application of the Ecosystem Approach (EcAp) to achieve and preserve Good environmental status (GES), which as an overarching principle of the MAP system is being streamlined and integrated into environmental assessment and measures.

3. This proposed Desalination in the Mediterranean Guidelines followed the general format of the 2003 guidelines but updated and expanded it with new studies and publications on the global status of desalination and added provisions on future technological improvement of existing mature desalination methods and on emerging technologies and renewable energies (Section 2).

4. The state and trends of seawater desalination in the Mediterranean were updated (Section 3). Questionnaires were sent to the Contracting Parties, asking for information not only on the installed desalination capacity, but on the actual production and in particular, information on operational details of the large desalination plants such as chemicals usage (identity and concentrations), mode of intake and discharge, and brine composition (Section 3). This aspect was not addressed in the previous guidelines.

5. Section 4 on the actual, measured environmental impacts of seawater desalination was greatly expanded to include up to date reports and publications. It is known that in the last 5 years peer reviewed publications addressing actual effects of seawater desalination have been rapidly increasing, providing data that was lacking previously.

6. The section on legal aspects of brine discharge (Section 5) was updated to address the relevant amended provisions of LBS Protocol. A new part, not included in the previous guidelines, was added to address the need to achieve Good Environmental Status.

7. Section 6, on the Environmental Impact Assessment was also updated with recent literature and updated to include BAT and BEP and sustainability issues.

8. Section 7, on Environmental Monitoring, in the proposed guidelines is completely new and was not addressed in the 2003 guidelines.

9. The version of the Guidelines presented in the document has fully reflected the changes made by the Regional Meeting of Experts to review the Draft Desalination and Dumping Protocol Guidelines, held in Loutraki, Greece, on 4-6 April 2017.

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List of Abbreviations / Acronyms

AD	Adsorption desalination
BAT	Best Available Technology
BEP	Best Environmental Practice
CDI	Capacitive deionization
CFCs	Chlorofluorocarbons
CPs	Contracting Parties
CSP	Concentration Solar Power
COP	Conference of the Parties
EcAp	Ecosystem Approach
ED	Electrodialysis
EDR	Electrodialysis reversal
EEA	European Environmental Agency
EIA	Environmental Impact Assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FO	Forward Osmosis
GES	Good Environmental Status
GHG Emissions	Greenhouse Gas Emissions
GWI	Global Water Intelligence (GWI)
IAEA	International Atomic Energy Agency
IDA	International Desalination Association
IMAP	Integrated Monitoring and Assessment Programme
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change

LBS Protocol	Land-Based Sources Protocol
LTD	Low Temperature distillation
MAP	Mediterranean Action Plan
MD	Membrane distillation
MED	Multiple Effect Distillation
MED POL	Programme for the Assessment and Control of Marine Pollution in the Mediterranean Sea
MSF	Multi Stage Flash Distillation
PRO	Pressure retarded osmosis
RO	Reverse Osmosis
RE	Renewable Energies
RED	Reverse Electrodialysis
SW	Seawater
SWIM-Programme	Sustainable Water Integrated Management Programme
TVC	Thermal Vapor Compression
UNEP	United Nations Environment Programme
UNEP/MAP	United Nations Environment Programme\Mediterranean Action Plan
ZLD	Zero Liquid Discharge

1. Introduction

1. The MED POL Programme of UNEP/MAP following approval by the MED POL Focal Point meeting, published in 2003 the MAP Technical Report No. 139: Sea Water Desalination in the Mediterranean. Assessment and Guidelines. At the time, the guidelines, largely used by the Contracting Parties, were up to date and described the need for seawater desalination, the basic technologies, the state and trends of seawater desalination in the Mediterranean region and touched on the environmental impacts and legal aspects of brine disposal.

2. Since 2003, the global desalination effort has increased exponentially due to increase in freshwater demand and improvement of technologies and economic viability. The Mediterranean region followed the global trend and the installed desalination capacity increased from ca. 4 million m3/day (Mm3/day) in 2003 to 12 Mm3/day in 2013. Technologies changed as well, together with increased awareness of the possible environmental impacts, in particular on the marine environment. Moreover, the legal framework for the regulation of waste disposal into the Mediterranean and pollution-related Regional Plans (in the framework of the Land-based sources (LBS) and Dumping protocols and the SAP/MED) evolved to integrate the aspects of the Ecosystem Approach (EcAp) to achieve and preserve Good Environmental Status (GES).

3. Therefore, MEDPOL is now reviewing and updating the 2003 MAP Technical report 139, to better describe the desalination effort around the Mediterranean, and assess its impacts on the coastal and marine environment. The new guideline aims to provide guidance to the Contracting Parties on how to desalinate in a sustainable way and how to monitor the environment. The new guideline builds on previous publications: MAP Technical report 139 (UNEP/MAP/MEDPOL 2003), SWIM report (Khordagui 2013), UNEP and NRC publications (NRC 2008, UNEP 2008) among others, and publications that are cited along this report.

2. Seawater desalination

4. Seawater (SW) desalination accounts for ca. 60 % of the global desalination effort and more than 80 % around the Mediterranean. It is also the most energy consuming desalination type because of the high salt concentration of the feed water. Therefore, the updated guidelines address desalination as seawater desalination, with the understanding that brackish water desalination is common in many world areas but not in the Mediterranean (Khordagui 2013, Lior 2017).

5. An additional point to be considered is the difference between installed desalination capacity and actual desalination production. Most of the statistics on desalination (originating mainly from the International Desalination Association (IDA) and Global Water Intelligence (GWI) reports) address installed desalination capacity. However, the installed desalination capacity may be higher than the production due to changes in desalination needs, usually correlated to climatic variability (draught or rainy years), availability of natural or reused water supply and financial costs.

2.1. The need for seawater desalination

6. Global water use has been growing at more than twice the rate of population increase in the last century (FAO 2012). This, in conjunction with increased incidence of draughts and changes in

precipitation patterns, as a result of climate change, have reduced the availability of freshwater. Two out of every three persons on the globe may be living in water-stressed conditions by the year 2025, if present global consumption patterns continue[1].

7. The water crisis and the dwindling access to potable water in many regions and the ever improving desalination technology prompted the increase in desalination worldwide, in particular seawater desalination. Historically, desalination on a commercial scale started around 1965 having a global capacity of about 8,000 m^3/day in 1970, reaching an estimated 86.6 Mm^3/day at the end 2015[2]. From 1997 to 2008 the compound annual growth rate of desalination was 17%. Desalination grew exponentially at a rate of 14%/year from 2007 to 2012, and the rate declined to 3%/year from 2012 to 2015 (Gude 2016, Lior 2017). Large, mega-size plants turned economically viable and were constructed. Desalination in the Mediterranean countries reflected the global progression and will be discussed in Section 3.

2.2. Brief description of current established (mature) seawater desalination methods

8. Desalination technologies can be divided into two major processes:

a) membrane process (non-phase change), in which semi-permeable membranes are used to separate water from dissolved salts, and
b) thermal process (phase change), in which feedwater is boiled (under suitable operating temperatures and pressures) and the vapor condensed as pure water.
c) Hybrid technologies that include both processes, such as membrane distillation, are starting to being used as well (see below).

9. The thermal processes dominated the desalination industry up to 2003-2005 when membrane technology, in particular reverse osmosis (RO), surpassed it (Gude 2016). Following is a brief description of the established (mature) desalination methods by technology.

2.2.1. Membrane Processes

10. Reverse Osmosis (RO) uses pressure to force water molecules from the feed solution through semi-permeable membranes that retains the salts and filter particles, producing fresh water and brine. The efficiency of the process is 0.45 for seawater (SW) and 0.75 for brackish water (BW) (World_Bank 2012). The brine produced from SWRO has about twice the seawater salinity.

11. At the various stages of the process chemicals may be added, that are subsequently disposed with the brine at sea or inland: coagulants in the pre-treatment stage (iron or aluminum salts, polymers); biocides (such as chlorine) and neutralizers (sodium sulfite); antiscalants to prevent fouling of the membranes (such as polyphosphates, polyphosphonates, polyacrylic acid, polymaleic acid); cleaning solutions for RO membranes (acidic and alkaline solutions and detergents); and pH and hardness adjustors for the product water (limestone).

12. The successive steps, usage of chemicals, energy recovery and improved efficiency were extensively described (Fritzmann et al. 2007, Greenlee et al. 2009, Elimelech and Phillip 2011, Ghaffour et al. 2013).

[1] http://www.who.int/heli/risks/water/water/en/ (accessed February, 6th 2017)
[2] http://www.iwa-network.org/desalination-past-present-future/

At the current state of the art SWRO plants consume 3-4 kWh/m^3 energy and emit 1.4-1.8 $kgCO_2/m^3$ and 10-100 g NO_x/m^3 of produced water (Lior 2017).

13. Electrodialysis (ED), is an electrochemical separation process in which ions are transferred through ion-exchange membranes by a direct current voltage, leaving desalinated water as the product (NRC 2008). Electrodialysis reversal (EDR), a modification of ED, can operate with highly turbid feed waters.

2.2.2. Thermal Processes

14. Multi Stage Flash Distillation (MSF) uses a series of stages, each with successively lower temperature and pressure, to rapidly vaporize (or "flash") water from the bulk liquid. The vapor is then condensed by tubes of the inflowing feedwater, thereby recovering energy from the heat of condensation (NRC 2008). The process efficiency is 0.25 and the brine produced from SW desalination has about 1.5 the seawater salinity and temperature higher by ca. 5 degrees.

15. At the various stages of the process chemicals may be added, that are subsequently disposed with the brine at sea or inland: antifoaming agents, corrosion inhibitors, biocides (such as chlorine) and neutralizers (sodium sulfite); antiscalants to prevent fouling (such as polyphosphates, polyphosphonates, polyacrylic acid, polymaleic acid); cleaning solutions; and pH and hardness adjustors for the product water (limestone). Thermal desalination plants are subjected to corrosion and subsequent discharge of metals (such as copper) with the brine.

16. Multiple Effect Distillation (MED) is a thin-film evaporation approach, where the vapor produced by one chamber (or "effect") subsequently condenses in the next chamber, which exists at a lower temperature and pressure providing additional heat of vaporization. The process efficiency is 0.34. Compared to MSF it uses less power due to reduced pumping requirements (NRC 2008). Large MED plants incorporate thermal vapor compression (TVC) where the pressure of the steam is used (in addition to heat) to improve efficiency (NRC 2008).

2.3. Future directions of seawater desalination technology – emerging technologies, process improvement and use of renewable energy.

17. The ever increasing desalination industry promoted the research and engineering to develop new technologies, hybrid technologies, to redesign components of existing systems to improve efficiency, reduce energy and chemical consumption and reduce waste and brine discharge. Following is a brief description of the future directions in desalination.

18. Forward osmosis (FO). The FO process is based on the principle that water (solvent) diffuses through a semi-permeable membrane from low concentration region to high concentration region by the natural osmotic process. A semipermeable membrane is placed between a low concentration feed solution and a high concentration draw solution. The chemical potential difference between the two solutions drives water molecules through the membrane from the feed to the draw solution while solutes are retained. The water is then separated and the draw solution reused. The separation process can be expensive depending on the draw solution characteristics (Gude 2016, Straub et al. 2016, Amy et al. 2017).

19. Membrane distillation (MD) is a thermally driven process that utilizes a hydrophobic, microporous membrane as a contactor to achieve separation by liquid-vapor equilibrium. The driving force of MD is the partial vapor pressure difference maintained at the two interfaces of the membrane (hot feed and cold permeate). The hot feed solution is brought into contact with the membrane which allows only the vapor to pass through its dry pores so that it condenses on the coolant side. The process uses lower temperatures and pressures compared to the established thermal and membrane processes and can reach 90% recovery (World Bank 2012, IAEA 2015, Kim et al. 2016, Amy et al. 2017).

20. Adsorption desalination (AD) is a heat-driven adsorption/desorption cycle process. In this process raw seawater is fed into an evaporator at its ambient temperature and an adsorbent is used to adsorb the vapor generated at very low pressure and temperature, under low pressure environment. When saturated, the adsorbent is heated to release the vapor (desorption process) and is then condensed inside an external condenser. There is no need to heat the feed water as in other thermal processes (Kim et al. 2016).

21. Among the emerging processes and technologies are: Pressure retarded osmosis (PRO), Reverse electrodialysis (RED), Low Temperature distillation (LTD), Capacitive deionization (CDI). Most of these technologies are not mature and are not utilized in large scale plants. Close circuit RO is now emerging into the commercial arena. FO and MD are used in niche applications (Amy 2017).

22. Improvements of current technologies: Many improvements are constantly taking place in the ever changing field of desalination, especially in yield improvement and reduction of energy and chemical consumption and brine discharge. Below are a few examples:

a) Zero liquid discharge (ZLD), is a process that recovers water from the concentrates, to eliminate liquid wastes. Most of the emerging technologies can theoretically be employed in zero liquid discharge schemes. ZLD is particularly important in inland brackish desalination (Gude 2016, Tong and Elimelech 2016) and may be feasible in small seawater desalination plants;
b) Improvement of conventional and design of new membranes (membrane engineering) to increase yield, reduce energy consumption and associated GHG emissions are under constant development. Among them are the development of biomimetic membranes, based on aquaporins (a water channeling protein), synthetic water and ion channels, graphene;
c) Renewable energies (RE). RE, solar (concentration solar power (CSP), photovoltaic (PV)), geothermal, wind and marine renewable energy (wave, tide and currents), will eventually replace conventional energy in desalination when economically viable (Gude 2016, Amy et al. 2017). However, IAEA (IAEA 2015) forecasts that in 2030 RE powered desalination will be sufficient only for domestic water supply but will expand to meet industrial supply by 2050.
d) Improvement of diffuser technology to improve the dilution processes during the brine discharge at sea (Portillo et al 2013, Vila et al 2011).

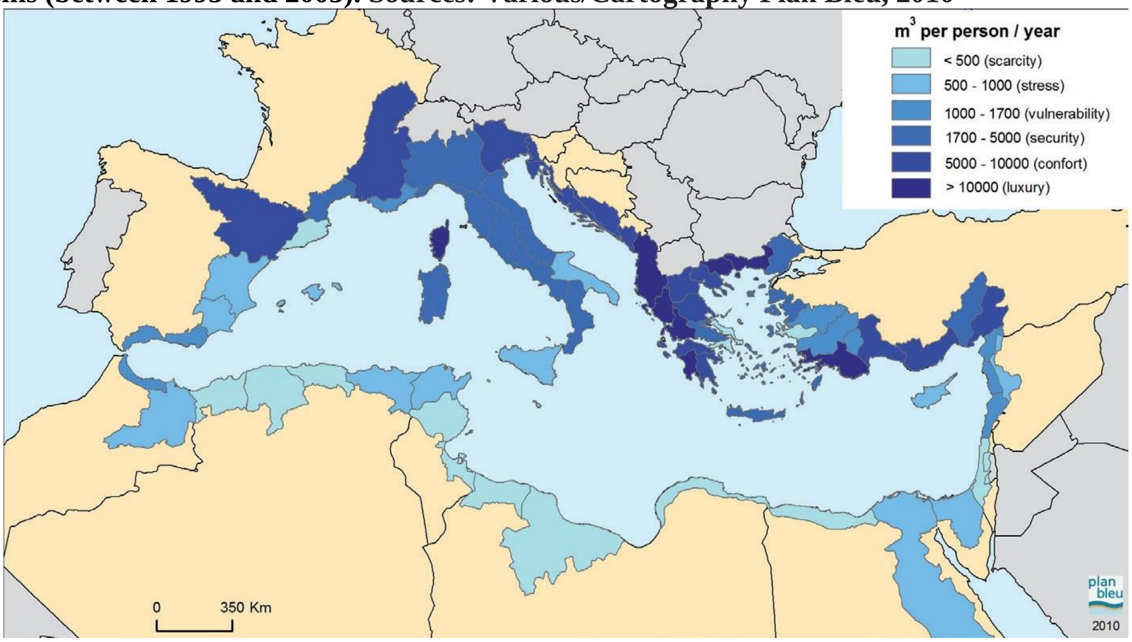
3. The state and trends of seawater desalination in the Mediterranean region

23. The renewable natural water resources per inhabitant in the countries surrounding the Mediterranean Sea ranges from scarcity (<500 m^3/person year) to comfort and luxury (>5000 m^3/person year) (AQUASTAT[3], Plan Bleu, 2010).

[3] http://www.fao.org/nr/water/aquastat/water_res/index.stm

24. There is an imbalance between the northern and southern shores of the Mediterranean, the latter considered as one of the most water-scarce regions of the world. As a result, most of the desalination effort around the Mediterranean is concentrated in the southern and eastern shores and in Spain. In 2013, over 1532 seawater desalination plants had been installed around the Mediterranean Sea with a total cumulative installed capacity of about 12 Mm^3/day. Seawater desalination by reverse osmosis accounted for ca. 80 % of the production. Nearly all the desalinated water produced is consumed by municipalities as drinking water (Khordagui 2013).

Figure 1. Renewable natural water resources per inhabitant in the various basic Mediterranean Basins (between 1995 and 2005). Sources: Various/Cartography Plan Bleu, 2010



25. In 2014, the European Environmental Agency with UNEP/MAP published a report compiling the pollution levels in the region, in particular the major drivers of environmental changes and their implications on the protection of the marine environment which didn't address desalination (EEA-UNEP/MAP 2014). However, in UNEP/MAP State of the Mediterranean report in 2012, desalination was mentioned as a new pressure and a key sector affecting the marine and coastal environment in the Mediterranean (UNEP/MAP 2012).

3.1. Evolution of seawater desalination in Mediterranean countries from 1999 to 2013

26. The total desalination capacity around the Mediterranean in 1970 was 0.025 Mm^3/day.

27. By the end of 1999, it had increased by almost 2 orders of magnitude to a total capacity of close to 2 Mm^3/day, with 41% produced by RO (UNEP/MAP/MEDPOL 2003). Spain was the bigger producer of desalinated water with 33% of the total capacity, mainly from RO process. Libya was the second producer, with 30% or the total capacity, mainly from MSF process. Italy, Malta, Algeria and Cyprus accounted for 18, 6, 5 and 2% of the total capacity, respectively (UNEP/MAP/MEDPOL 2003).

28. In 2007, the total desalination capacity in the Mediterranean was 4.0 Mm^3/day (14% of the total global capacity). Spain was the main producer, with 35% of the total capacity in the Mediterranean followed by Libya, with 20%. Algeria, Israel, Italy, Malta and Cyprus accounted for 19, 10, 7, 5 and 4% of the total capacity, respectively (Lattemann et al. 2010a, Lattemann et al. 2010b). The main process utilized was RO.

29. In 2011, the capacity was increased to 11.6 Mm^3/day in the Mediterranean countries, however this estimate may include desalination in the Atlantic and Red Sea. Spain was the main producer (41% or the total capacity in the Mediterranean) followed by Algeria and Israel with 15 and 10%, respectively. Libya accounted for 7% of the total production and Italy and Egypt, 6% each (Cuenca 2013).

30. The potential environmental impacts of desalination around the Mediterranean Sea was assessed within the EU Program SWIM- Sustainable Water Integrated Management, Activity 1.3.2.1 (Khordagui 2013), as well as the installed capacity. In 2013, the total cumulative installed desalination capacity was about 12 Mm^3/day. From 2000 to 2013 the installed capacity increased by 560% (40%/year). RO was the most common desalination technology in the area (ca. 82%) followed by MSF (11%) and MED (6.5%). In 2013, Spain was the main producer (31% of the total capacity) followed by Algeria, Israel and Libya with 20, 18 and 11%, respectively.

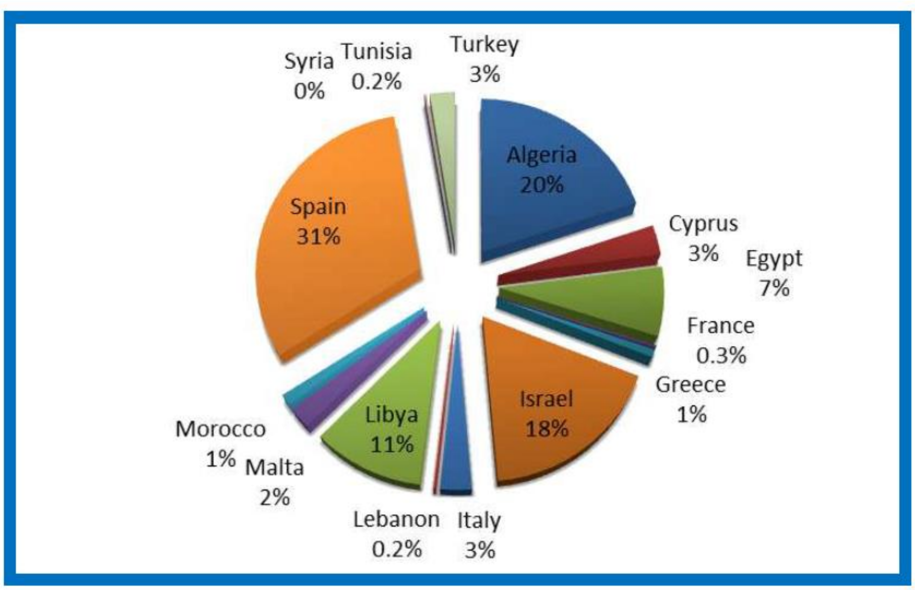


Figure 2. Relative contribution of each Mediterranean country to the total desalination capacity of 12 Mm3/day in 2013. Figure from Khordagui (2013) compiled with data from GWI Desal Data.

3.2. Installed capacity for seawater desalination in the Mediterranean and actual production

31. The SWIMM report (Khordagui 2013) is the most updated collective report on the state of desalination in the Mediterranean region. In order to revise and amend the current knowledge, partially filled questionnaires were send to the Contracting Parties, asking for their collaboration in completing

them. The Questionnaire includes general questions (installed desalination capacity, actual production, the contribution of seawater desalination to the actual production and future plans) and specific questions (number of plants that desalinate more than 10,000 m^3/day, their location, process used details on chemical usage and discharges to the environment). A questionnaire template for collecting information and data related to desalination activities is contained in Annex I to the updated Guidelines to be used for assessment purposes.

4. Environmental impacts of seawater desalination with particular reference to the marine environment

32. This section addresses the impact of seawater desalination on the marine environment following the start of plant operations, based on Kress and Galil (2015) and on additional published reports and peer reviewed literature cited along the text. The possible effects during the construction and operating phases are described in sections 5 and 6. The main impacts of seawater desalination on the marine environment are associated with two components: intake of seawater (feed water) into the desalination plant and brine discharge. However, the number of articles publishing quantitative effects *in situ* or in lab experiments is small and limited in scope (Roberts et al. 2010), but growing in the last years. Those suggest that desalination effluents impact the marine biota at the vicinity of the outfall, but are not definitive because of conflicting results. The results are site specific, depending on the sensitivity of the receiving environment, the desalination process, size of plant and discharge composition and hindered by the lack of long term studies. GHG emissions may also affect the marine environment through ocean acidification but will not be discussed in this section.

4.1. Intake of seawater

33. The main effects associated with source water (seawater) withdrawal are entrainment and impingement of marine organisms (NRC 2008, UNEP 2008). They are also the least studied and known effects, in particular the impact on the population level.

34. Entrainment is the transport of small planktonic organisms with the flow of seawater into the desalination plant. It is generally recognized that the entrained flora and fauna that enters the desalination plant will perish during the different stages of the desalination process, including biocide application. This is in contrast with cooling waters from power stations, where a lower mortality has been reported (Mayhew et al. 2000, Barnthouse 2013). Entrainment can be reduced by locating the intakes away from biologically productive areas, such as in deeper water farther offshore, or by using underground beach wells although the latter are difficult to implement for large-scale desalination plants (NRC 2008, Elimelech and Phillip 2011).

35. Impingement occurs at open intakes when organisms sufficiently large to avoid going through the installed intake screens are trapped against them by the force of the flowing seawater into the desalination plant. Impingement of jellyfish at the intake have been known to block intakes and reduce production[4]. Impingement can be reduced through a combination of appropriate screens and low intake velocity. The

[4] http://gulfnews.com/news/uae/general/jellyfish-choke-oman-desalination-plants-1.355525

US-EPA recognizes intake flow velocity of 0.152 m/sec as BAT for impingement reduction. The EU funded ProDes project suggested a maximum intake velocity of 0.1 m/sec[5].

4.2. Brine discharge

4.2.1. Brine dispersal (Abiotic impacts)

36. Brine is defined here as the hypersaline discharge from a membrane based plant and as the hyper saline and warm discharge from a thermal desalination plant, without the chemicals used in the process. Brine dispersion may vary significantly depending on site characteristics, effluent volume, mode of discharge, and the prevailing hydrographic conditions. Nevertheless, salinity and temperature are higher than reference at the discharge sites but as mentioned, the area affected is highly variable (Fernandez-Torquemada et al. 2009, Holloway 2009, McConnell 2009, Drami et al. 2011, Kress and Galil 2012). Studies of the effect of thermal desalination in the enclosed Gulf showed an effect on water temperature and salinity and a regional increase in salinity (Purnama et al. 2005, Lattemann and Hopner 2008, Uddin et al. 2011).

37. Brine discharge may increase seawater stratification that together with higher salinity and temperature may reduce oxygen levels in the water. This concern was raised during the EIA of the Perth (Australia) SWRO, but although monitoring showed slight water stratification close to the diffuser, no significant effect was found on dissolved oxygen concentrations (Holloway 2009).

38. An additional abiotic impact of brine discharge may be aesthetic due to the discharge of turbid brine. This effect was described for the Ashkelon (Israel) SWRO that until 2010 discharged in pulses backwash containing iron hydroxide used as coagulant in the pre-treatment stage. The iron hydroxide formed a conspicuous “red plume” (Safrai and Zask 2008, UNEP 2008, Drami et al. 2011).

4.2.2. Brine (salinity and temperature) effects on biota

39. Salinity and temperature have long been perceived as inhibitory environmental factors for survival and growth of marine biota (Murray and Wingard 2006, Wiltshire et al. 2010) and therefore, both are expected to affect the biota near desalination brine discharge areas.

i. <u>Laboratory and mesocosm studies</u>

40. Laboratory and mesocosm experiments on *Posidonia oceanica,* a seagrass endemic to the Mediterranean Sea of particular habitat importance, and included in Annex II of the SPA Protocol, have shown that at certain conditions, increased salinity affected physiological function, leaf growth and survival rates (Fernández-Torquemada et al. 2005, Ruiz et al. 2009, Sandoval-Gil et al. 2012, Marín-Guirao et al. 2013).

41. Two other Mediterranean seagrasses, *Cymodocea nodosa* and *Zostera noltii,* also included in Annex II of the SPA Protocol, were proved sensitive to increases in salinity (Fernández-Torquemada and Sánchez-Lizaso 2011) while other seagrasses’ tolerance to hypersalinity stress varied (Walker and

[5] http://www.prodes-project.org/fileadmin/Files/D6_2_Legislation_Guidelines.pdf

McComb 1990, Koch et al. 2007, Sandoval-Gil et al. 2012) (Walker et al. 1988, Koch et al. 2007, Sandoval-Gil et al. 2012a, Sandoval-Gil et al. 2012b).

42. Stressful combinations of temperature and salinity substantially reduced larval performance and development of the barnacle *Amphibalanus improvises* (Nasrolahi et al. 2012), while salinity was shown to affect the silica structure of diatoms (Vars et al. 2013).

43. Hypersalinity decreased embryos survival of the giant Australian cuttlefish *Sepia apama* and reduced mean weight and mantle length (Dupavillon and Gillanders 2009). Whole effluent toxicity testing (WET) performed using locally relevant species as part of the EIA for the Olympic Dam SWRO plant, Australia, attributed toxicity to increased salinity (Hobbs et al. 2008). On the other hand, no significant effect was found in 18 common species during an extensive EIA performed for the Carlsbad SWRO plant (Southern California) (Le Page 2005).

44. Recently, a mesocosm experiment on the impact of high salinities (5% and 15% higher than ambient salinity) on microbial coastal populations of the Eastern Mediterranean found that after ca. 12 days of exposure, chlorophyll a and primary productivity increased and the composition of the microbial population changed. The latter was dependent on the initial, seasonal dependent, population and on the intensity of the salinity enrichment (Belkin et al. 2015).

ii. *In situ* studies

45. A field survey of a shallow *P. oceanica* meadow in Spain showed it to be affected after 6 years of exposure to RO brine (Sánchez-Lizaso et al. 2008), in agreement with the laboratory studies. Also in Spain (southeastern Mediterranean coast) brine discharge was shown to change the benthic community (Del Pilar Ruso et al. 2007, Del Pilar -Ruso et al. 2008, de-la-Ossa-Carretero et al. 2016). Echinoderm disappeared near the outfall of the Dhekelia SWRO in Cyprus (Argyrou 1999). However, no effect of brine discharge was found in the northwest Mediterranean (Raventos et al. 2006) nor in southwest Florida (Hammond et al. 1998). Moreover, in some instances, results of monitoring of the benthic community were inconclusive due to a shift in sediment particle size that can induce changes in community composition (Shute 2009, Riera et al. 2011, Riera et al. 2012).

46. *In situ* studies detected changes in microbial communities and functioning in the Mediterranean and Red Sea (Drami et al. 2011, van der Merwe et al. 2014a, Belkin et al. 2017). The photophysiology of the algal symbiont of the coral *Fungia granulosa* was not influenced by rapid and prolonged changes in salinity but varied with changes in light conditions (van der Merwe et al. 2014b).

4.2.3. Effect of chemicals used in the desalination process and discharged with the brine

47. Impacts of chemicals discharged with the brine on the marine environment are scarcely known. The co-occurrence of stressors: salinity, temperature, chemicals and co-discharged waste effluents (such as cooling waters from power stations) also confound the discussion of results in the few existing studies, preventing the establishment of a cause-response relationship.

48. Chlorine is used in both desalination and power plants to prevent fouling. In RO plants the residual chlorine is oxidized to prevent damage to the membranes, in thermal desalination plants, as in power plants, residual chlorine may be discharged with the brine. Residual chlorine reacts swiftly with seawater to form toxic complexes such as bromoform (Taylor 2006) shown to accumulate in the liver of the european seabass, *Dicentrarchus labrax* . In the same study it was impossible to separate the effect of bromoform from temperature on *Mytilus edulis*.

49. Corrosion products (metals) from thermal desalination plants, in particular copper, a common material in heat exchangers, were shown to accumulate in the vicinity of outfalls. Many of the studies state that the presence of copper does not mean an adverse effect because copper is a natural compound found in nature (Lattemann and Hopner 2008). However, earlier studies found that copper affected echinoderms, tunicates and Florida seagrass and micro-organisms (Chesher 1971, Brand et al. 1986). Recently, higher than natural concentrations of copper and zinc in sediments and bivalves was reported at the brine discharge of two SWRO in Taiwan (Lin et al. 2013).

50. Sodium metabisulphite ($Na_2S_2O_5$) is commonly used in cleaning reverse osmosis membranes. Short-term pulses to the marine environment may result in acidification and hypoxia. Toxicity bioassays on the lizard fish *Synodus synodus* in the Canary Islands revealed a high sensitivity to short-term exposure to low concentrations, with total mortality occurring at higher concentrations (Portillo et al 2013).

51. The toxicity found during WET test on the diatom *Nitzschia closterium* was attributed to salinity (70% of the toxic effects) while 30% was attributed to the polyphosphonate antiscalant (Hobbs et al. 2008). In a recent mesocosm study in the Eastern Mediterranean, addition of phosphonate relieved immediately the phosphorus stress of the microbial community and in 10 days reduced bacterial diversity and increased eukaryotic diversity (Belkin et al. 2017).

52. Iron salts used a coagulants in the pre-treatment stage at the Ashkelon (Israel) SWRO and discharged in pulses at sea were found to decrease phytoplankton growth efficiency at the outfall in *in situ* studies while during a mesocosm experiment, the iron addition immediately altered the microbial community composition, enhanced the bacterial production and efficiency and decreased primary production. After 10 days, autotrophic biomass and assimilation number decreased compared to the reference (Drami et al. 2011, Belkin et al. 2017).

4.3. Emerging contaminants

53. The desalination industry is, as stated before, very dynamic, striving to improve yield, to reduce the amount of chemicals used in the process and discharged with the brine, and to use less hazardous substances (green chemistry). Therefore, it is hard to keep up with the changes and the environmental scientist should work in close cooperation with the desalination plants operators to be advised on the changes made in the process. For example, the Hadera (Israel) desalination plant now uses bioflocculation instead of coagulation with iron salts as a pre-treatment step and therefore iron is no longer discharged with the brine.

54. An additional hindrance is that many of the chemicals (mainly coagulants and anti-scalants) are protected by patents; therefore the exact composition is usually proprietary and cannot be divulged. In this case, the active compound should be identified and compiled together with its toxicological properties. It should be mentioned that known pollutants are also used in the process: such as acids, bases, cleaning solutions, metal salts as well as known corrosion products (metals).

55. Based on a review of existing technologies and state of play, the following contaminants emerge from desalination technologies:

Contaminants	Used/produced in desalination process	
	Membrane	Thermal
Fe salts, Al salts, organic polymers	Coagulant	Not used
Heavy metals Fe, Ni, Cr, Mo	Stainless steel Corrosion	Stainless steel Corrosion
Heavy metals Cu, Ni, Ti	Not relevant	Corrosion from heat
Chlorine, other oxidants	Biocide, Used but neutralized with bisulfite prior to disposal	Biocide Residual chlorine
Bisulfite	Biocide neutralizer	Not used
Polyglycol, detergents	Not Used	Antifoaming agent
Detergent, oxidants, complexing agents	Membrane cleaning	Not used
Polyphosphate, Polyphosphonate, organic polymers (polymaleic and polyacrylic acids)	Antiscalant	Antiscalant
Nutrients (phosphorus, nitrogen, carbon)	Antiscalant	Antiscalant
Alkaline solutions	Cleaning (neutralized prior to disposal)	Not used
Acidic solutions	Cleaning (neutralized prior to disposal)	Cleaning
	Not used	Corrosion inhibitors
Limestone ($CaCO_3$)	pH and hardness adjustor of produced water	pH and hardness adjustor of produced water
Salt	Brine	Brine
Temperature	Not applicable	Brine

5. Legal aspects of brine disposal, in relation to the amended LBS Protocol, as well as commitment to achieve Good Environmental Status based on the Ecosystem Approach.

5.1. The amended LBS Protocol and seawater desalination

56. The amended LBS Protocol states that point source discharges into the marine environment should be authorized or regulated and a system of inspection and monitoring put into place. It includes 4 annexes and although desalination is not named as one of the sectors of activity to be considered when setting priorities for the preparation of action plans, the principles outlined in them can be applied to the desalination industry.

i. Annex I lists 19 categories of substances and sources of pollution to be taken into account in the preparation of action plans, most of them relevant to desalination, such as organohalogen and nitrogen and phosphorus compounds, heavy metals, non-biodegradable detergents, thermal discharges, non-toxic substances that may have an adverse effect on oxygen concentration or on the physical and chemical characteristics of seawater.
ii. Annex II describes the elements to be taken into account in the issue of the authorizations for discharges of wastes and provides a check list to be used during the Environmental Impact Assessment procedure (EIA, see chapter 6).
iii. Annex III, atmospheric discharge touches the desalination industry only in the context of energy use and GHG emissions.
iv. Annex IV specifies the criteria for the definition of Best Available Technology (BAT) and Best Environmental Practice (BEP) (See chapter 6).

5.2. Implementing Ecosystem approach (EcAp) to achieve and maintain Good environmental status (GES)

57. The term Ecosystem approach (EcAp) was first applied in a policy context at the Earth Summit in Rio in 1992, where it was adopted as an underpinning concept of the Convention on Biological Diversity (CBD) (Beaumont et al. 2007, UNEP/MAP 2016) and defined as “a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way”. The EcAp requires several elements, based on the DPSIR (driver, pressure, state, impact, response) conceptual framework (Farmer et al. 2012, Borja et al. 2016a, Borja et al. 2016b) :

i. defining the source of the pressures emanating from activities;
ii. a risk assessment and risk management framework for each hazard;
iii. a vertical integration of governance structures from the local to the global;
iv. a framework of stakeholder involvement; and
v. the delivery of ecosystem services and societal benefits (Elliott 2014).

58. It also requires and adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning.

59. Ecosystem Approach is the overarching principle of UNEP/MAP with the ultimate objective to achieve and maintain Good Environmental Status (GES) of the Mediterranean Sea and Coast (UNEP/MAP 2012, 2014a,b, 2016). This principle was incorporated into the work of UNEP/MAP through a series of decisions agreed upon at meetings of the Barcelona Convention COP:

60. Decision IG.17/6 set forth the ecological vision for the Mediterranean: “A healthy Mediterranean with marine and coastal ecosystems that are productive and biologically diverse for the benefit of present and future generations” and outlined a roadmap for the implementation of the Ecosystem Approach, setting out 7 steps including definition of vision and goals, development of 11 ecological objectives, operational objectives and respective indicators, the development of GES descriptors and targets, monitoring programs, and necessary measures to achieve GES. Decision IG.20/4 validated the work done regarding the 11 ecological objectives, operational objectives and indicators for the Mediterranean.

Decision IG.21/3 on the Ecosystems Approach adopted definitions of GES and agreed on regionally common targets and indicators. The latest development related to the implementation of the Ecosystem Approach in the Mediterranean is the adoption of Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and related assessment criteria (IMAP) by the COP 19 (Decision IG. 22/7).

61. The 11 Ecological Objectives are[6]:

i. Biodiversity is maintained or enhanced.
ii. Non-indigenous species do not adversely alter the ecosystem.
iii. Populations of commercially exploited fish and shellfish are within biologically safe limits.
iv. Alterations to components of marine food webs do not have long-term adverse effects.
v. Human-induced eutrophication is prevented.
vi. Sea-floor integrity is maintained.
vii. Alteration of hydrographic conditions does not adversely affect coastal and marine ecosystems.
viii. The natural dynamics of coastal areas are maintained and coastal ecosystems and landscapes are preserved.
ix. Contaminants cause no significant impact on coastal ad marine ecosystems and human health.
x. Marine and coastal litter does not adversely affect coastal and marine ecosystems.
xi. Noise from human activities cause no significant impact on marine and coastal ecosystems.

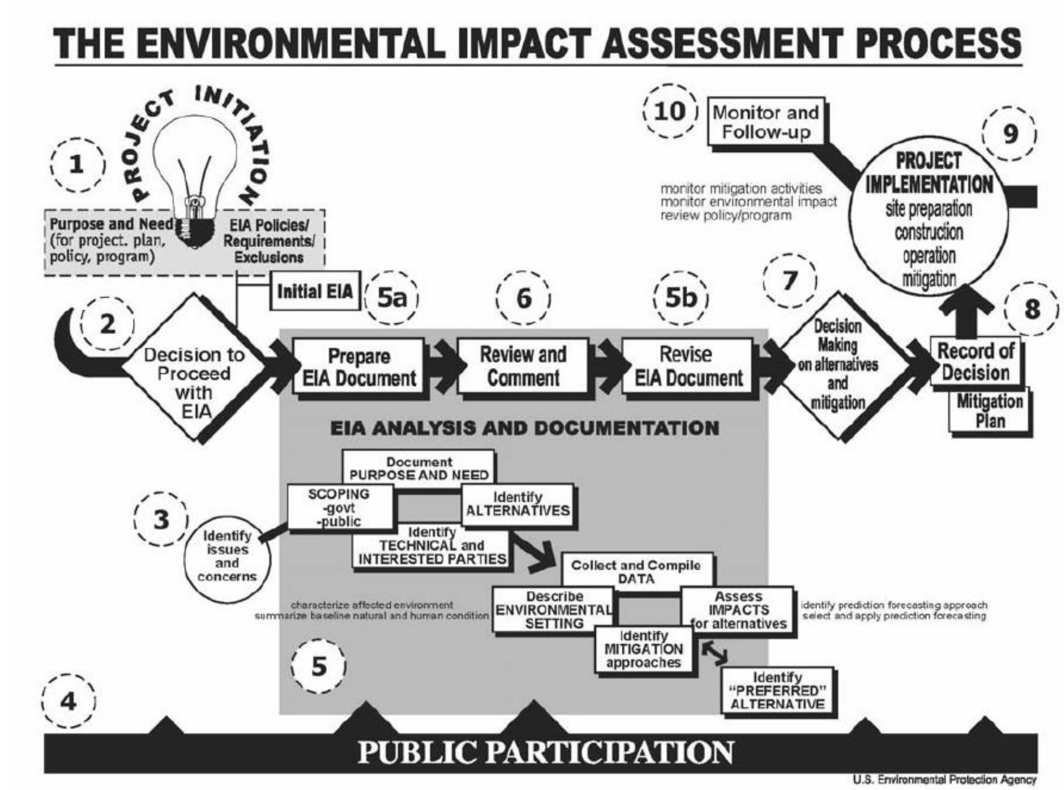
62. Most of the Ecological and Operational objectives are applicable to the desalination industry both at the intake and discharge sites (see chapter 4). Therefore, while examining and monitoring the disposal site, care should be taken to add the parameters that will help define the environmental status prior to the start of operations and to follow long term trends.

6. Environmental Impact Assessment (EIA)

63. Environmental Impact Assessment (EIA) is a process by which the anticipated effects on the environment of a proposed development or project are identified at the design and planning stages. If the likely effects are unacceptable, design measures or other relevant mitigation measures can be taken to reduce or avoid those effects. The EIA should be prepared by professionals and specialists in a multidisciplinary manner, and include engineers, environmental specialists, designers, and be performed within the national regulatory framework in conjunction with the decision makers. Stakeholders input

[6] http://web.unep.org/unepmap/who-we-are/ecosystem-approach

should be encouraged. The EIA procedure has been extensively described in UNEP's guidance manual published in 2008 (UNEP 2008). A succinct depiction of the EIA is given in the following diagram[7].



64. Below is a description of the suggested steps and emphasis for an EIA process concerning the desalination industry. It serves as a general guideline; it is not all inclusive and should be adapted based on the specifics of the project and location of the desalination plant.

6.1. Project description

65. A general description of the purpose and need of the project should be given at the beginning of the EIA document. It should include the following information:

- Proposed location of the desalination plant
- Co-location with other industries (such as power plants)

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7 https://nepis.epa.gov/Exe/ZyNET.exe/50000I6K.txt?ZyActionD=ZyDocument&Client=EPA&Index=1995%20Thru%201999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C95THRU99%5CTXT%5C00000013%5C50000I6K.txt&User=anonymous&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&slide

- The onshore and offshore components of the plant (buildings, pumps, pipelines, brine outfall), planned construction activities and timeline
- Connection to the water supply grid.

6.2. Technology selection and characterization of discharges

66. A detailed technological description of the chosen desalination process should be part of the EIA, including the rational for the choice. It should include the following information:

- The desalination technology chosen and engineering specifications
- Desalination capacity of the plant and future expansion plans
- Energy usage and source
- Area and method of source water intake (open intake, well intake)
- The treatment steps of the source water during the desalination process (among others the pre-treatment, biocide application, anti-scaling measures, cleaning stages, desalinated water treatment)
- Type of discharges and emissions (marine, terrestrial and atmospheric)
- Total volume of discharges and emissions (daily, yearly)
- Area and method of brine discharge (open discharge, co-discharge, marine outfall with or without diffusers)
- Brine discharge pattern (continuous, intermittent, variable)
- Physico-chemical characteristics of the brine (salinity, temperature, etc...)
- Concentrations and loads of discharged substances and their environmental characterization (such as persistent, toxicity, bioaccumulation)

6.3. Brine dispersion modeling

67. The EIA process in choosing the disposal site and methodology should be accompanied by modelling the dispersion of the brine. The models include, among others, near field and far field numerical modeling, circulation models, ecosystem models (Brenner 2003, Christensen and Walters 2004, Botelho et al. 2013, Purnama a

68. nd Shao 2015, Abualtayef et al. 2016)

6.4. Environmental setting description (terrestrial and marine)

69. Existing data on the land and marine habitat from the proposed planed desalination plant site, including the intake and discharge areas, should be compiled and critically analyzed. When no available data exist or when there are only partial or out of date data, surveys should be conducted prior to

construction. The number of surveys and timing (i.e. seasonal) should be decided on a site specific basis. This information (compiled and/or new) will also provide a valuable reference (baseline) to be used for environmental monitoring following the start of operations (see Section 7). It is important that the methodology used in undertaking baseline investigations is documented so that the results of later monitoring can be referenced.

6.4.1 Terrestrial environment description

- Physical landscape characteristics (soil, habitat, geology)
- Current uses
- Archeological and cultural value
- Environmental value
- Proximity to protected areas, occurrence of protected species in the area

6.4.2 Marine environment description

- Oceanographic conditions and water quality in the area
- Current uses
- Sediment composition and bathymetry
- Biota in the seawater and benthic compartments, including endangered and alien species, proximity to protected areas.

6.5. Assessment of possible impacts

70. Assessment of possible impacts should be performed based on existing literature and when needed, complemented with laboratory studies such as toxicity and whole effluent test (WET), mesocosm experiments. As noted in section 4, the effects of seawater desalination on the marine environment are not well documented although the number of publications and the awareness have been increasing in the past years. The impacts emanate during the construction activities at land (building the desalination facility, pumping stations, pipelines, connecting to infrastructure), during the construction activities at sea (installation of intake and outfall), and during the operational phase (feed water intake and brine discharge)..

6.5.1 Possible impacts during the construction phase

71. During the construction phase, the possible impacts originate from the construction activities at land (building the desalination facility, pumping stations, pipelines, connecting to infrastructure) and at sea (installation of intake and outfall). Most impacts are localized and may cease after the construction phase but may be significant during construction (UNEP 2008, Lokiec 2013).

<u>Terrestrial</u>

- Alteration of the natural terrain
- Impact on flora and fauna

- Impacts of construction wastes and excess soil
- Soil and groundwater pollution (fuels, oil)
- Air pollution (dust emission)
- Noise emission during construction work
- Damage to archeologic values and natural preserves

Marine

- Alteration of seabed (composition and bathymetry)
- Sediment resuspension during marine works (increased turbidity)
- Release of nutrients and pollutants (if present) with sediment resuspension
- Impact on the benthic biota due to alteration of the seabed and on benthic and pelagic biota due to increased turbidity and pollutants
- Effect on sensitive marine life due to noise, vibration and light
- Oil pollution from ships involved in the construction works.

6.5.2 Possible impacts after start of operations

72. After start of operations the following impacts may occur:

Terrestrial

- Permanent alteration of the coastal habitat environment
- Aesthetic impact due to plant structure, and obstruction of free passage along the seashore due to the location of the plant, onshore pipelines and pumping station
- Emission of GHG and air pollutants in the case of power generation on site
- Noise and light pollution
- Accidental spillage or leakage of chemicals
- Solid waste and sanitary sewage

Marine

- Permanent alteration of the marine habitat
- Changes in hydrography and sediment transport
- Impingement and entrainment of marine biota
- Water quality deterioration and biological effects due to the discharge of brine and chemicals used in the desalination process.
- Facilitating the introduction of non-indigenous species due to changes in habitat, in particular increased salinity and temperature
- Noise and light pollution

6.6. Impact mitigation

73. The EIA should include a description of measures to be undertaken in order to avoid, and mitigate likely negative impacts of the desalination plant on marine and coastal environment. Below is a list of steps to be considered in this regard, during the construction phase and after the start of the operations.

6.6.1 Impact mitigation during construction

74. During construction stage the following steps should be considered to mitigate the possible impacts

- Use of environmental friendly construction methods, such a pipe-jacking instead of open trenches for the installation of pipelines
- Rehabilitation of areas affected during construction
- Design assuring minimal alteration of the natural environment
- Recycling of construction wastes
- Use of containment basins for fuel and oil tanks
- Surface wetting to prevent air pollution by dust.
- At sea, pipe-jacking (as far as possible from shore), and controlled dredging beyond microtuneling technique.
- Covering of the trench after pipeline installation and restoration of the original bathymetry

6.6.2 Impact mitigation after start of operations

Terrestrial

- Minimal energy consumption (power plant fueled by natural gas or renewable energy)
- Acoustic insulation and minimal external lighting
- Minimal use of process chemicals – safety measures for transportation, storage and handling, containers for solid waste and authorized landfill disposal

- Pipelines laid underground

Marine

- Intake and outfall pipelines below the seabed to minimize marine habitat alteration
- Slow suction velocity to prevent impingement (or well drilling)
- Self-cleaning traveling screen for debris collection at the intake system and disposal in authorized waste disposal sites
- Chlorine dosing (shock treatment) into the intake in the direction of the plant avoiding discharge to the sea
- Outfall diffuser system to increase initial dilution and reduce salinity and temperature, or in open discharge, dilution with co-discharge, i.e. cooling water of power plant
- Reduction of brine discharge, increased recovery
- Reduction of use of chemicals in the process
- Land based treatment of backwash
- Use of environmental friendly chemicals
- Treatment of limestone reactors washing together with backwash
- Neutralize inorganic membrane cleaning solution prior to discharge.

6.7. Best Available Technology (BAT) and Best Environmental Practice (BEP)

75. The best available technology and the best environmental practice are defined in Annex IV of the amended LBS Protocol as follows: BAT “means the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste” and BEP “the application of the most appropriate combination of environmental control measures and strategies”.

76. These definitions were further addressed in the IPCC Directive to explain that "available" techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages while "best" shall mean most effective in achieving a high general level of protection of the environment as a whole.

77. It is recognized that BAT and BEP change with time following technological and scientific advances and with changes in economic and social factors. This is true in particular for the desalination industry that is in a constant state of rapid improvement and change due to the large research and engineering effort put into technological development. Therefore, BAT and BEP processes should follow them closely in order to:

- Increase recovery rates (efficiency of desalination)
- Minimize energy and chemical consumption

- Replace chemicals, such iron salts coagulants, antiscalants, with more environmental friendly substances or with processes that do not require the use of chemicals
- Decrease discharges or increase near field dilution
- Reuse brine in novel desalination technologies to further increase freshwater yield
- Promote cleaner production

6.8. Sustainability

78. Sustainability integrates the evaluation of economic, environmental and social impacts in large projects, among them seawater desalination. The impacts are strongly interconnected and should be evaluated in an integrative way. The main goals are to save material and energy resources and reduce waste. Sustainability analysis should be implemented in the planning and design of the project prior to its construction and operation (Gude 2016, Lior 2017).

79. The sustainability evaluation defines indicators that measure economic, environmental economic and social impacts, their relative importance (or weights) and if possible, computes a single composite sustainability index, aggregating the indicators and their relative importance. While the viability of desalination used to be judged mainly on economics and production reliability now it includes environmental and social aspects as well.

80. Following are some of the indicators and considerations that should be taken into account during a sustainability study.

i. Economics
- Water use and demand
- Cost of alternative water sources (conservation of natural resources, rain collection, water treatment and re-use, prevention of water waste due to leaks and faulty pipes, more)
- Total unsubsidized cost of the desalinated water.
- Energy source and process technology
- Labor operation and maintenance cost

ii. Environment
- EIA and BAT approaches
- Effects on feedwater and its domain (intake and brine discharge)
- Resource depletion (brackish water desalination)
- GHG emissions
- Transboundary pollutant transport (brine discharge)

iii. Social

- Impacts on human health (desalinated water quality)
- Land use and rapid unplanned local growth, without accompanying infrastructure
- Social acceptance, confidence in desalinated water supply
- Impact on water consuming sectors such as agriculture
- Impact on recreational activities or other legitimate uses of the sea and the coastline

7. Environmental Monitoring

81. Environmental monitoring is a legal requirement addressed in the amended LBS protocol (article 8) as well as a scientific requirement to follow possible impacts of seawater desalination on the marine environment. The environmental monitoring should follow the baseline survey performed during the EIA (see paragraph 68) but not restricted by it. Monitoring during the construction phase will be different from the long term environmental monitoring needed during plant operations. There are a few publications addressing environmental monitoring at desalination plants (NRC 2008, UNEP 2008, Lattemann and Amy 2012). It is recommended to inform the relevant national authorities as soon as possible when deviations from the permitting conditions are observed during the monitoring survey.

7.1. Monitoring during the construction phase

82. Monitoring during the construction phase should be planned based on the possible effects originating from the construction activities in land and at sea (Section 6.5). The purpose it to assess if an activity is within acceptable impact and if not, introduce mitigation measures as soon as possible.

83. The terrestrial monitoring during construction should include:

i. Monitoring the disposal of construction wastes on site to prevent damage to land not within the area
ii. Monitoring accidental discharge of fuel, oil, other substances and dust, to prevent soil, atmosphere and ground water pollution
iii. Monitor noise and light levels and if needed, limit hours of operations
iv. At the end of construction, the area should be inspected to check if measures were applied to rehabilitate the area that no trenches were left open, that all non-permanent constructions were removed, etc.

84. The marine monitoring during the construction should include

i. Monitoring the water turbidity levels, and if above a pre-determined value, regulate dredging operations
ii. At sensitive areas were the sediments are suspected to be polluted, follow the release of pollutants into the water column
iii. Monitor noise, vibration and light levels that may be a hindrance to marine mammals and other sensitive marine life
iv. Monitor the sediment quality used to cover the pipelines, if not from local source
v. At the end of construction, all marine installations should be mapped in an updated bathymetry map.

vi. Seagrass and macroalgae beds should be monitored for recovery

7.2. Long term monitoring following start of operations

85. Regular monitoring of the marine environment following the start of plant operations should be a long term commitment, throughout the lifetime of the desalination plant and some years beyond, in line with the permitting conditions. These long term data series with proper controls are essential to normalize for natural temporal variability in order to prevent erroneous conclusions on the environmental effects of seawater desalination.

86. The monitoring plan should be based on the EIA document and other environmental management documents performed prior to the plant construction and in line with the permitting conditions. The monitoring data should be analyzed regularly and critically to allow for changes in the monitoring design when needed, to enforce permitting license requirements, and to require mitigation steps when effects are deemed excessive. The data should be published and disseminated to the community to afford feedback to the regulators and scientist performing the monitoring.

87. Following are the general recommended components of a monitoring study. The specific monitoring should be adapted based on the environmental setting and sensitivity, the desalination technology, including the intake and brine discharge methods, and in accordance with international and national legislation and requirements. The monitoring program should be approved by the national regulators prior to its implementation.

7.2.1. Marine Sampling

88. *Sampling frequency and methods* should be decided based on the site-specific characteristics. It is recommended that at the beginning, monitoring should be conducted at least twice each year at relevant seasons (i.e, winter and summer or spring and fall). It is recommended to include additional surveys during plant cleaning operations.

89. *Sampling stations.* The initial design of the sampling stations should be based on the brine dispersion pattern obtained from the modelling results. Two sampling grids are required: one extensive grid of stations to follow and delimit the brine plume dispersion and spreading at the time of the survey (hereafter dispersion stations), and one smaller grid of stations to sample water, sediment and biota to assess the effects of brine discharge (hereafter sampling stations). The dispersion stations array should be flexible, and updated *in situ* based on the actual brine dispersion (as determined by seawater temperature and salinity measured during the survey) and/or following the examination of the monitoring data[8]. The sampling stations should be positioned in three general areas: impacted areas (within the mixing zone, where salinity and temperature are at the highest), affected areas (beyond the mixing zone but still under the influence of the brine) and reference areas (where no brine is present). Three to four stations are recommended to be sampled at each area.

[8] In situ monitoring stations with instruments recording temperature, salinity, dissolved oxygen and fluorescence should be considered. However it is recognized that this may be difficult to implement due to the high cost of the instrument and maintenance.

90. The *Sampling vessel* should be equipped with accurate global positioning system and be able to accommodate the scientific instrumentation and personnel. During sampling a detailed log should be kept, including the survey date, name of participants, meteorological and sea state condition (air temperature, winds, currents, waves), the exact position of each station (latitude, longitude, depth), time that station was occupied and what was sampled, any unusual occurrence during sampling or at the sea.

91. *Parameters to be measured.* In general, the decision on the parameters to be measured should be based on the expected discharges from the desalination plant, identified in the EIA, and on the ecological and operational objectives and GES definition.

92. At the dispersion stations, continuous depth profiles of temperature, salinity, dissolved oxygen, fluorescence and turbidity should be measured.

93. At the sampling stations, three compartments will be sampled: seawater, sediment and biota.

i. Seawater: The basic parameters include continuous depth profiles as in the dispersion stations, the concentration of suspended particulate matter, nutrients (nitrate, nitrite, ammonium, total nitrogen, phosphate, total phosphorus, silicic acid), metals, chlorophyll-a, substances discharged at sea and identified in the EIA. The following parameters of seawater biota are optional and should be considered based on the area characteristics: microbial population (phytoplankton and bacterial numbers) and composition, primary and bacterial production rates, zooplankton population (number and composition)[9].
ii. Sediment. The basic parameters include sediment size distribution (granulometry), heavy metal (such as mercury, cadmium, copper, zinc, iron, aluminum) and organic carbon concentration, in fauna community structure (number of specimens, taxonomic determination to the species level if possible)[10]. If the discharge area is rocky, the sessile population should be characterized and assessed. If the discharge area is located near seagrass and macroalgae beds, those should be also characterized and assessed.
iii. Biota. In addition to the parameters mentioned in the seawater and sediment samples, endangered species and invasive species identified in the EIA should be monitored.

94. *Sampling methods* should be adequate to allow for the representative collection of the samples. *In situ* measuring instrumentation should be calibrated according to the manufacturer specifications.

95. *Sample collection.* Samples should be marked and assigned unique identifiers. On a long term monitoring program the same station will be occupied repeatedly, therefore the sampling date should be one of the identifiers to prevent confusion. The samples should be preserved adequately following sampling, during transportation and up to the measurement stage in the laboratory.

[9] Genomic tools are seen as a promising and emerging avenue to improve ecosystem monitoring, as these approaches have the potential to provide new, more accurate, and cost-effective measures. The most promising is metabarcoding

[10] Genomic tools are seen as a promising and emerging avenue to improve ecosystem monitoring, as these approaches have the potential to provide new, more accurate, and cost-effective measures. The most promising is metabarcoding

96. *Analytical methods.* The analytical measurements should be performed preferable by accredited laboratories, and if unavailable, by laboratories with quality control/ quality assurance methodologies. The analytical method chosen should be accurate and precise to allow for the assessment of the brine impact, and to follow temporal changes.

7.2.2. Monitoring report

97. The monitoring report should include:

i. An introduction describing the desalination plant technology, monthly production, intake and brine discharge (volume and composition), any malfunction that may have impacted the marine environment (such as unplanned discharge of solid material)
ii. A detailed description of the monitoring survey, including dates, sea state, sampling station locations, identity of samples taken at each station, sampling methods, sampling preservation methods and analytical methods
iii. Results, with tables of all the data collected in situ and in the laboratory
iv. Discussion, including maps of the brine dispersal, assessment of impacts based on the EIA and literature
v. Conclusions
vi. Recommendations for the continuing monitoring such as changes in station number and location, in parameters measured, in the frequency of sampling.

7.2.3. In-plant monitoring

98. In-plant monitoring should include water quality of the source water (seawater intake) and the volume and composition of the brine.

i. Seawater intake: Concentrate in parameters that may affect the desalination process and the quality of the desalinated water.
ii. Brine prior to disposal: Discharge volume, temperature, salinity, concentration of chemicals used in the desalination process and discharged with the brine.

Annex I

Questionnaire

Seawater desalination status in the Mediterranean Region

Questionnaire

Seawater desalination status in the Mediterranean Region

1. Introduction

Seawater desalination has for a long time been a major source of water in parts of the Mediterranean to meet water demands, supplying ca. 12 Mm^3/day desalinated water in 2013. The desalination effort is expected to continue to increase. The MED POL Programme of UNEP/MAP is assessing now the implementation of its desalination guidelines published in 2004 and evaluating the state of play of the desalination section in the Mediterranean. The purpose is to produce an updated guideline and provide the Contracting Parties with adequate technical guidance to reduce to a minimum all environmental impacts. For this we would appreciate your collaboration in completing this short questionnaire.

2. General Questions– Only for plants along or near the Mediterranean Coast

2.1. Country:

2.2. How many desalination plants are in operation in your country along or near the Mediterranean Coast? ________

2.2.1. How many plants desalinate seawater? ________

2.2.2. How many plants desalinate brackish water? ________

2.2.3. How many plants have a production capacity >50,000 m^3/day? ________

2.3. What is the total annual production of desalinated water? __________

2.3.1. What is the total annual production of desalinated water? __________

2.3.2. What is the actual total annual production originating from seawater desalination?

2.4. Are there more desalination plants at the planning/construction stage along the Mediterranean coast? __________

2.4.1. How many? __________

2.4.2. Total planned desalination production __________

2.4.3. Expected year for start of production __________

3. Detailed information for large size plants (>10,000 m^3/day, 3.65 Mm^3/year production) only along the Mediterranean Coast. (Please copy table for additional columns).

	Plant Name	Plant Name	Plant Name	Plant Name	Plant Name	Plant Name
Name						
Year starting to operate						
Location[1]						
Desalination Technology[2]						
Production, m^3/day						
Method of brine discharge[3]						
Co- discharge with brine[4]						
Chemicals used in the desalination process[5]						
Coagulants						
Anti-Scalant						
Biocides						
Water Hardener						
Other						
Chemicals co-discharged with brine[6]						
Is there a marine monitoring program in place?						

[1]Location: city, area
[2]Desalination technology: **RO**-Reverse Osmosis, **MSF-** Multi Stage Flash , **MED -** Multi Effect Distillation, **Other** – please add technology
[3]Method of Brine discharge: **OD**-Open discharge, **MO-** Marine outfall, **Other** – please add details

[4]Co-discharge with brine: Other discharges, for example, cooling waters from Electric power stations
[5]Please name the chemicals: i.e Coagulants – iron salts **(FE)**; anti-scalant- polyphosphonates (Ppho), **If the identity of the chemical is unknown, please add yes or no**
[6]Please name the chemicals discharged with the brine

Annex II

References

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