FINAL REPORT FOR ACTIVITY 1.3.2.1

ASSESSMENT OF POTENTIAL CUMULATIVE ENVIRONMENTAL IMPACTS OF DESALINATION PLANTS AROUND THE MEDITERRANEAN SEA

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1	Final Report ASSESSMENT OF POTENTIAL CUMULATIVE ENVIRONMENTAL IMPACTS OF DESALINATION PLANTS AROUND THE MEDITERRANEAN SEA ACTIVITY 1.3.2.1	Hosny Khordagui	Stavros Damianidis and Vangelis Konstantianos

.....Water is too precious to Waste

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List of Abbreviations

µg	Microgram
AdE	Algérienne des Eau
AEC	Algerian Energy Company
BCF	Bio-Concentration factor
Bm³/y	Billion cubic meter per year = 1 km³/y (one cubic kilometer per year)
BOD	Biochemical Oxygen Demand
cap	per capita
CC	Climate Change
CO_2	Carbon Dioxide (greenhouse gas)
COD	Chemical Oxygen Demand
CoE	Cost of Electricity
Conv.	Conventional
Cr	Chromium
CSP	Concentrating Solar Power
CSP/RO	advanced solar powered reverse osmosis
Cu	Copper
D	Distillate
DES	Desalination
DOM	Dissolved Organic Matter
EC	European Commission
ED	Electro-dialysis
EIA	Environmental Impact Assessment
EU	European Union
Fe	Iron
GDC	General Desalination Company
GHG	Greenhouse Gases (emissions responsible for climate change)
GMMR	Great Man Made River
GWI	Global Water Intelligence
IWRM	Integrated Water Resources Management
kg	Kilogram
kJ	kilo-Joule (thermal energy unit)
KSA	Kingdom of Saudi Arabia
kV	kilovolt = 1000 Volt (unit of tension)
kW	kilowatt (unit of power)
kWh	kilowatt-hour (unit of energy)
kWhe	Kilowatt-hour-energy
KWHtkWht	Kilowatt-hour-thermal
l	Liter
LC	lethal concentration
LC_{50}	Lethal Concentration reducing population by 50% in (usually) 24 hours
m	Meter

m^3	cubic meter
MAP	Mediterranean Action Plan
MD	Membrane Distillation
Med	Mediterranean Region
MED	Multiple Effect Distillation
MED-POL	Program for the Assessment and Control of Marine Pollution in the Mediterranean Region
mg	Milligram
mm	Millimeter
Mm^3	million cubic meters
Mm^3/y	million cubic meter per year
Mo	Molybdenum
MSF	Multi-Stage-Flash Desalination
NDP	National Desalination Plan
ng	Nano gram
ng/l	Nano gram per liter
NGO	Non-governmental Organization
Ni	Nickel
NIS	New Israeli Shekel
NOx	Nitrogen Oxides
O&M	Operation and Maintenance
ONEP	Office National de l'Eau Potable
PCs	Participating Countries
ppb	part per billion = µg/l
ppm	part per million = mg/l
PPP	Public Private Partnership
ppt	part per trillion
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
RES	Renewable Energy System
RO	Reverse Osmosis Membrane Desalination
SHMP	Sodium Hexa-Meta-Phosphate
SMCs	South Mediterranean Countries
SOx	Sulfur Oxides
SW	Seawater
SWIM	Sustainable Water Integrated Management
SWIM-SM	Sustainable Water Integrated Management-Support Mechanism
SWRO	Seawater Reverse Osmosis
T	temperature
t	time variable
TDS	Total Dissolved Solids
THMs	Trihalomethanes
TL	Team Leader

UNEP	United Nations Environment Program
US-EPA	United States Environmental Protection Agency
VLHs	Volatile Liquid Hydrocarbons
SWCC	Saline Water Conversion Corporation

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1 Executive Summary

In most South Mediterranean countries, there is growing concern that the available water resources are now facing or will soon encounter severe chronic shortages of freshwater that might make life difficult. This situation is likely to deteriorate further in view of the increased population, fluctuating economic growth, economic reliance on irrigated agriculture and the unpredictable impacts of climate change (CC).

Fortunately, advances in desalination technology have made it an economically viable alternative source of fresh water in the region. Consequently, in response to shortages of naturally renewable water supplies, many Mediterranean countries are planning to construct and operate large desalination facilities. Direct challenges associated with seawater desalination in the Mediterranean region include the impacts associated with the intakes, outfalls and energy consumption: near-shore seawaters are often important habitat and spawning ground. The larvae and small organisms are most vulnerable to disappearing often due to poorly designed desalination plant intakes causing damage to the near-shore marine ecosystems. The impacts, transport, transformation and fate of the discharged concentrated brine mixed with other chemical additives are far from complete, both generally and in relation to particular sites. Furthermore, the serious greenhouse gas emission from energy intensive plants should be given adequate considerations in support to the international community relentless effort to reduce global warming.

The main objectives of the present study are to identify the current installed capacity and prospects of desalination in the SWIM-SM region; and to conceptually investigate the cumulative environmental impacts of mega desalination plants conglomerating around the Mediterranean Sea. In order to give a more comprehensive and realistic image of the environmental impacts of desalination on the Mediterranean Sea, the scope of the assessment was expanded to encompass all Mediterranean countries rather than Sustainable Water Integrated Management - Support Mechanism Participating Countries (SWIM-SM PCs) only. In an effort to materialize the abovementioned objectives, the author undertook the following actions:

1. Conducted an inventory of the currently operating mega desalination plants including technical details such as utilized technology, production capacity, chemicals consumed, etc.
2. Investigated the prospects of desalination around the Mediterranean basin.
3. Assessed the desalination discharge in terms of volume, pollution load, physical and chemical characteristics, etc.
4. Assessed desalination atmospheric emissions with special focus on CO_2 as the main greenhouse gas (GHG) contributing to CC.
5. Undertook a conceptual assessment of the potential fate, transport, bio-accumulation, bio-magnification and environmental impacts of desalination discharges.
6. Discussed the potential cumulative impacts of brine discharges on the marine eco-system and adapted a nine steps methodology for assessing cumulative environmental impacts of desalination projects.

Following the present study, SWIM-SM is planning to convene a two days regional Expert Group Meeting (EGM) to substantiate and verify the outcomes of the present assessment in terms of structure and content. As a last step, SWIM-SM is planning to convene a high-level techno-political policy dialogue in Brussels to debate the prospects of desalination around the Mediterranean Sea basin in light of experts' opinions and based on the outcomes of SWIM-SM activities from 2011 to 2014 including the present study.

Chapters II, III and IV of the present report introduce the subject, review the status of water scarcity in the region and provide a brief account of the environmental specifics of the Mediterranean Sea respectively.

In order to provide a more comprehensive and realistic picture of the environmental impacts of desalination on the Mediterranean sea, the scope of the present assessment was expanded to encompass all Mediterranean countries rather than South Mediterranean countries only.

Chapter V addresses the current seawater desalination capacity around the Mediterranean Sea. The study revealed that desalination plants have been built, at various scales, in almost all countries of the Mediterranean Region. Starting from 1970 to the year 2013, over 1532 seawater desalination plants had been installed around the Mediterranean Sea. As of 2013, these plants have a total cumulative installed capacity of some 12 million m^3/day. Based on data from GWI-Desal-Data (2013), in the last 13 years (2000 to 2013), the reported installed capacity has dramatically increased by an astounding 560 %. Following the technological developments, Reverse Osmosis (RO) is becoming the most common desalination technology in use in the Mediterranean region accounting for some 82.3% of total installed capacity, or roughly 9.9 Million m^3/day. The second-most common desalination technology in use in the region is Multiple Stage Flash (MSF) with nearly 11.2 % producing some 1.4 Million m^3/day, followed by the Multiple Effects Desalination (MED) with only 6.5 % producing 0.8 Million m^3/day. As of 2013, Spain has the highest installed cumulative capacity of 3.7 Million m^3/day, followed by Algeria with a daily production of 2.4 Million m3/day and followed by Israel with a daily production of 2.1 Million m3/day.

Chapter VI addresses the prospects of seawater desalination in the Mediterranean region. Based on the review of desalination prospects in the Mediterranean region it is projected that most of the planned seawater desalination plants in the region until 2016 will be relying exclusively on RO technology. Analysis and discussions of prospects of seawater desalination in the Mediterranean region in Chapter VI led to the following conclusions revealed the following:

1. Compared to the period extending from 2000 to 2013 exhibiting 560% increase in installed capacity, desalination of seawater will continue to grow but at a slower pace in most of the Mediterranean countries.
2. Emerging and growing disputes on shared transboundary water resources in South Mediterranean (downstream) countries will represent a strong driving force for more desalination to secure drinking water supply within a national security context.
3. RO will be the dominating future seawater desalination technology in the region.

4. Countries that have already bridged most of their water supply gaps through desalination such as Algeria, Israel and Spain are likely to show some slow down in their momentum and might enter into a relatively quieter phase.
5. Persisting regional economic and financial crisis in the Mediterranean might curb the implementation of some of the ambitious national desalination plans in the region.
6. Political instability in some South Mediterranean countries, namely Tunisia, Libya, Egypt and Palestine, might hinder and/or delay the financing and construction of their planned desalination plans.
7. Apart from financing and political instability, the main challenges that South Mediterranean countries will be facing in implementing their future desalination plans are i- reduction in operational cost, ii- diminishment of reliance on fossil fuels and iii- producing environmentally acceptable solution.
8. In case future desalination in the Mediterranean region maintains its total reliance on oil and/or gas, the energy costs and subsequently the cost of desalinated water is predicted to increase due to greater competition for the dwindling fossil fuel reserves.
9. Desalination using solar energy, as an emerging technology, is already capturing the attention and imagination of water and environment officials in Mediterranean countries.
10. Despite the fascination of water planners with Renewable Energy (RE) in desalination, It is projected that desalination by concentrated solar power (CSP) will take a couple of decades before replacing the currently operating fossil fuel desalination plants in the region. This lagging is attributed to the time needed for phasing out and decommissioning desalination plants currently in operation. On the other hand, the opportunity of introducing RE in the National energy mix shouldn't be overlooked.

In chapter VII the report is discussing the environmental aspects of sea-water desalination in the Mediterranean region. The volume of feed water of the currently operating desalination plants and the present pollution loads discharged with brine reject to the near-shore marine environment were estimated. The potential environmental impacts of seawater desalination in the Mediterranean region were also introduced in preparation for chapter VIII discussing fate, transport and bio-magnification.

- Based on the daily volume of desalinated seawater during the year 2013 in the region using various technologies, the author estimated total volume of feed water withdrawn from the near-shore of the Mediterranean to be some 37.4 Million m3/day. By 2030, if same mix of technologies is used at the same ratio, the volume of feed water is speculated to range between 94 to 125 Million m3/day. This volume is roughly equivalent to range from 34.3 to 45.6 Billion m3/year. To put it in perspective and for comparison, the total annual flow of the River Nile to Egypt is 55.5 Billion m3. Withdrawing such large masses of sea waters is posing a serious threat to the near-shore marine environment known for its importance as a habitat for a diversity of marine aquatic lives through impingement and entrainment at the desalination plants intakes.

The most noteworthy adverse environmental impacts of seawater desalination plants are likely to be caused by their intakes rather than their outlets.

Key long term cumulative impact lay with the removal of small life forms such as plankton, eggs and fish larvae. Depletion of marine life may represent the most significant direct adverse effect of seawater desalination. The larger the volume of feed water the more damage will be inflicted on the near-shore marine environment.

- Desalination of saline water is generally an energy intensive process. Depending on the desalination technology and energy sources, large scale water desalination plants in the Mediterranean region are adding significantly to the greenhouse gas emissions held largely responsible for climate change. The production of one m^3 of desalinated seawater, using RO low energy technology will release an average of 2.0 kg CO_2/m^3. Thermal desalination technology such as MSF will generated an average of 10 kg CO_2/m^3. On the average, it is estimated that the production of each m^3 of desalinated water in the Mediterranean region emitted some 3.45 kg of CO_2. Based on these estimates, the study is calculating the total CO_2 emission from all operating seawater desalination plants in Mediterranean Region during 2013 to be equivalent to 15 million metric tons of CO_2/year. By using the same mix of seawater desalination technologies, the study is predicting a total CO_2 emission during the year 2030 to range between 38 to 50 million metric tons/year.

The total CO_2 emitted from desalination of Mediterranean seawater during 2013 is equivalent to putting 3.3 Million new cars on the roads or burning a volume of petrol slightly over 24 Million liters/day.

- The actual mass of salts discharged into the near-shore marine environment is practically equivalent to the salt extracted through desalination to produce fresh water. The real incremental mass of salts discharged in the brine reject during 2013 is estimated to be 172,000.00 tons of salts/year. In the year 2030 the estimated mass of salt to the near-shore marine environment of the Mediterranean Sea will range from 423,000 to 565,000 metric tons/year. During the year 2013, the average salinity discharged from all desalination plants in the Mediterranean was 57.2 g salt for each m3 of desalinated water produced. Where semi-enclosed and shallow embayment's exist in the Mediterranean Sea, these are naturally characterized by a higher salt content due to the elevated rate of evaporation, lack of freshwater discharges, feeble tide waves and restricted dispersion and dilution. These factors when combined with desalination plant brine discharge would suggest that the biota in near-shore semi enclosed areas could either be negatively affected or living on the extreme limits of its environmental tolerance.

- The estimated discharges of polymeric anti-scalants in the near-shores of the Mediterranean Sea is calculated based on the assumption that the average residual polymeric anti-scalants is in the range of 0.5 ppm. The estimated total mass discharged to the near-shore marine environment of the Mediterranean during 2013 is some 12.7 tons/day. When compared to a daily discharge of 62.0 tons of residual polymeric anti-scalants in the near-shores of Arabian Gulf, the daily discharge of 12.7 ton of the polymeric anti-scalants in the Mediterranean Sea is relatively small. By the year 2030, the predicted daily mass of residual polymeric anti-scalants to be discharged in the near shores of the Mediterranean Sea is projected to range from 15 to 20 metric tons/day.
- Chlorine is injected to feed water at desalination plant intakes to control biofouling. Chlorine is proven to be very toxic at concentrations of a few micrograms only. Furthermore, injected chlorine will react with bromide in seawater and natural precursors to form brominated THMs, known for their carcinogenic properties and may be harmful to seafood and possibly to human health. The estimated total residual chlorine discharged from MSF and MED desalination plants into the near-shores of the Mediterranean Sea during 2013 was calculated to be 3.9 tons/day. In the unlikely case the same mix of desalination technologies are used at the same ratio, the predicted daily mass of residual chlorine to be discharged by the year 2030 shall increase to reach between 15 to 20 tons/day. On the other hand, assuming the best scenario that all future desalination plants will be using RO technology only, the predicted daily mass of residual chlorine to be discharged in the near-shores of the Mediterranean Sea shall be similar to the currently discharged 3.9 tons/day. In case some of the MSF and MED plants are decommissioned by 2030, the mass of residual chlorine discharged to the near-shores of the Mediterranean will be lower than the current levels. Compared to the mass of total residual chlorine discharge in the semi enclosed Arabian Gulf estimated at 23.7 metric tons/day, the total mass of residual chlorine presently discharged in the near-shores of the Mediterranean Sea is considered very trivial.
- In thermal desalination plants, it is plausible to find corrosion and elution products in brine waters resulting from the effect of water flow, dissolved gases and treatment chemicals (acids) on the alloys utilized in the construction of desalination pipes and equipment's. The corrosion products often include harmful heavy metals such as nickel (Ni), copper (Cu) and molybdenum (Mo) and less toxic metals such as iron (Fe) and zinc (Zn). The amount of these metal ions is directly related to the REDOX potential, pH and the material in contact with water during the desalination process. In the Mediterranean region, the discharge of trace metals during the year 2013 was estimated to range from 85 to 563 tons/year for Copper, from 11 kg/year to 11 tons/year for Nickel, from 200 kg/year to 2.0 tons/ year for Chromium and from 22 kg/year to 2.2 tons/year for Zinc and 140 tons/year for Iron.

Chapter IX predicts and discusses the potential fate, transport and environmental impacts of brine reject pollutants in the near-shores of the Mediterranean. It also envisages the potential bioconcentration and biomagnification in addition to the potential cumulative impacts of these pollutants in the marine environment of the Mediterranean.

- Quantifying the cumulative environmental impacts of withdrawing large masses of seawater at the intakes of desalination plants in the Mediterranean Sea is an extremely difficult task that should start by ensuring the availability of background levels and composition of near-shore biota, taxonomy and diversity. However, the large and ever augmenting volume of seawater diverted for desalination in the Mediterranean Sea may have serious cumulative impacts on the near-shore marine ecology. On the long term, the cumulative environmental impacts of mega desalination plant intakes in the Mediterranean would result into the entrainment of potentially sensitive small marine species and would also result and mortality from entrainment and impingement will likely contribute to the depletion of fish stocks. The impacts, while small for a single desalination plant, may be considered significant with the cumulative impacts of large number of mega desalination plants and power plants operating simultaneously in a narrow geographic sector of the shore-lines.

- The discharge of brine water particularly in shallow and relatively stagnant nearly-land-locked coastal areas such as bays, harbors, etc. of the Mediterranean Sea might result in pronounced impacts on the surrounding marine ecology. Given the calculated salt concentration in brine reject discharged from different desalination technologies in the Mediterranean (78.00, 46.80 and 42.90 g salt per each m^3 desalinated water from RO, MED and MSF plants respectively), Posidonia oceanica sea grass within the immediate vicinity (mixing zone) of the desalination plants outfalls could be affected by increased mortality rates, including the marine biota this sea grass is sustaining.

- Acids are commonly added in seawater desalination plants as anti-scalants. The extremely large carbonate buffering capacity of the Mediterranean seawater will minimize the impact of acid residues discharged to the near-shore marine environment and renders them negligible. Whenever polyphosphate based additives are used to inhibit the formation of alkaline scale in the condenser tubes of the distillers, a part of this nutritive chemical find its way into the discharge basin. Being a ready source of phosphorus, the additive may cause algae growth near the desalination plant outfall. When polymeric anti-scalants are used and dispersed in the aquatic environment their behavior can be compared to naturally occurring humic substances. Based on this fact, polymeric anti-scalants, similar in nature to humic substances, are likely to complex with metals by chelating and preventing them from precipitating and leading to increase in their mobility. These properties would influence the fate and transport of metals in the marine environment. The presence of polymeric anti-scalants in the marine environment of the Mediterranean sea could maintain trace metals in dissolution leading to their transport for long distances with water masses.

- Concerning trace metals contaminants in desalination brine reject, it is fortunate to note that most of the reported data indicates minimal levels of contamination that are often below the detection limits of the standard analytical procedures. When comparing the mass and nature of heavy metals released with brine water to the amount of heavy metals being released from land-based industrial wastewater, atmospheric fallout and crude oil spills, it is thought over as negligible. However, eclipsing heavy metals releases from desalination plants through dilution of brine reject with cooling waters doesn't change the fact that heavy metals are reaching, accumulating and permanently residing in different compartments of the marine environment. As long lasting pollutants, trace metals will reside in different compartments of the marine environment forever. Their ultimate sink is the marine sediment where they accumulate forming a concealed environmental threat, from which they could be remobilized when environmental conditions change. Any drop in seawater pH value due to the discharge of desalination acidic back-wash effluents (effusion) might lead to the sudden re-dissolution of large amount of the deposited metals in the near-shore sediment and restoring their bioavailability and toxicity. The discharge of heavy metals, even in low amounts, therefore represents a latent threat to the environment through toxicity of marine biota, potential transportation, transformation, bioaccumulation, biomagnification and intrusion into the food cycle.

- When chlorine is injected into seawater at the intake of desalination plants, the chlorine reacts immediately with the bromide ions to form hypobromous acid. Moreover, hypobromous acid is highly reactive and instigates fast chemical reactions with naturally occurring organic precursors leading to the formation of brominated Tri-Halo-Methanes (THMs) chemical species. Furthermore, the presence of certain pollutants of aromatic nature in vicinity of desalination plants outfalls, can lead to the reaction of these pollutants with the discharged residual chlorine to form halogenated organics. Residual chlorine concentrations in MSF effluents and in the mixing zone are acutely toxic for many of the near-shore marine organisms.
- Bromoform as the most dominant THM species formed in seawater as a direct result of chlorination to control biofouling is highly volatile and only moderately soluble in water. Volatilization (followed by oxidation) is the major fate process for the removal of bromoform from the aquatic environment. On the other hand, biodegradation is slow but has a significant effect on the removal of bromoform from sediments. Hydrolysis, adsorption, photo-oxidation, photolysis, hydraulic processes, and bioaccumulation do not appear to reduce bromoform concentrations substantially in the marine environment. Bioaccumulation potential of the THMs appears to be low, compared to many other chlorinated organic compounds.

Chapter X conceptually addresses the cumulative impacts of brine discharges on the near-shore marine ecosystem. The cumulative impacts of desalination in the Mediterranean region can be defined as the impact on the environment which results from the incremental impact of a planned desalination plant when added to other past, present, and reasonably foreseeable future human activities affecting the same environment. Cumulative effects of a desalination plants around the Mediterranean Sea in combination with other existing and future desalination plants were never assessed or foreseen. Currently, there is a lack of integrated information systems and networks to assess the potential cumulative impacts of desalination plants in the Mediterranean Region. The study provides a simple nine steps methodology to assess the cumulative impacts of desalination plants.

2 Introduction

At the global level, the thought of separating salt from water is a prehistoric ancient idea, dating from the time when table salt, not water, was a valuable commodity. It has been technically possible to separate the salt and the water for centuries. With increasing demand for fresh water, water resources officials began to explore ways and means of producing fresh water in remote locations and, particularly, on naval ships at sea. In 1790, United States Secretary of State Thomas Jefferson received a request to sell the government a distillation method to convert salt water to fresh water (Cooley et al. 2006). For long time the dream of desalination for the purpose of general water supply for land-based communities has been curbed by its great construction and operating costs.

Since most Mediterranean countries reached the conclusion that the combination of fast population growth, expanding irrigated agriculture, accelerated economic growth and climate change will culminate into a serious chronic scarcity in freshwater resources. Consequently, the dawn of desalination appeared as a promising technique for tapping into the enormous and infinite water supplies of the Mediterranean Sea. Furthermore, current improvements in desalination technologies, reduced cost of operation coupled with the rising cost and irregularity of conventional water supplies, the glooming disputes on transboundary water rights, are all bringing desalinated water into the center of focus as a strategic water supply option in many Mediterranean countries.

In the Mediterranean region, desalination has for some time been a major source of water, with the first plant installed in Marsa Alam, Egypt with a capacity of only 500 m^3/day. In 1983, Malta became one of the first places to use the RO process for seawater desalination on a large scale. In Spain and in particular in the Canary Islands the first seawater plants were MSF distillers which were followed by several RO plants (UNEP-MAP, 2003). Today, Spain is the country with the largest capacity of seawater desalination plants in the Mediterranean region with an installed capacity exceeding 3 million m^3/day.

This spectacular emerging interest in desalination in many countries of the Mediterranean region is occurring against the mostly unresolved questions surrounding the potential environmental impacts of mega scale plants on seawater habitat and the discharge of increasing volumes of concentrated reject brine. There is a growing concern that mega desalination plants become "the new dams syndrome" where attention is being diverted from less costly and more sustainable alternatives such as water conservation and demand management. Water resources engineers claim, that desalination yields immediately results delivering the necessary quantities of water with a relatively high reliability, where water saving, water conservation and water demand measures, require long periods to yield results and many measures but above all the cooperation of the consumers, not always given. Furthermore, as one of the recognized climate change adaptation measures of the water sector, desalination (an energy intensive industry) will end-up contributing more CO_2 causing additional global warming. Although it is true that desalination increases the CO_2 emission to the atmosphere it is stated by the authorities, responsible for the supply of those necessary quantities to meet the minimum demand, that this is a necessary measure for the social and economic development of the country. The use for renewable energy for desalination has and is always in the minds of the engineers for avoiding increase of CO_2 emission but the available technologies are not well developed and costs are prohibitive

Although large scale thermal desalination plants continue to be built, most of the world's new and planned desalination capacity in the Mediterranean region is based around the use of membranes which exclude the passage of molecules between two bodies of liquid. The most significant by far of the membrane technologies in use is reverse osmosis (RO). Currently it is now widely used in water desalination of seawater.

Near shore seawaters are often important habitat and spawning ground. The larvae and small organisms are most vulnerable to disappearing due to often poorly designed desalination plant intakes causing damage to the near-shore marine ecosystems. The understanding of the impacts, transport and transformation processes of the discharged concentrated brine mixed with other chemical additives are far from complete, both generally and in relation to particular sites. Furthermore, the considerable greenhouse gas emissions from energy intensive desalination plants is not in line with the international community relentless effort to reduce global warming.

Cumulative impacts result when the effects of one desalination plant are added to or interact with effects of other desalination operations, industrial installations, municipal effluents, etc. in a particular place and within a certain time frame. According to US-EPA (1999), the concept of cumulative impacts takes into account all disturbances since cumulative impacts result in the compounding of the effects of all actions over time. Thus the cumulative impacts of a seawater desalination plant can be viewed as its total effects on the near-shore marine ecosystem or human community of that desalination plant and all other nearby activities affecting the same marine environment. In general terms, cumulative impact assessment entails a more extensive and broader review of possible effects resulting from a combination of activities in a particular location within a given time.

According to Dicki (2007), caution needs to be exercised on the possible cumulative effects of multiple desalination proposals for waters that are partly enclosed. This is particularly true for semi enclosed areas and embayment's where the seawater is relatively shallow and where the dispersal and circulation patterns of waves or currents are relatively low.

3 Water Scarcity and Need for Seawater Desalination in the Mediterranean Region

Southern Mediterranean Countries (SMCs) suffer from enduring stern water shortages. Some 180 million inhabitants suffer water stress and have access to less than 1,000 m^3/year/capita and 80 million inhabitants face water scarcity with less than 500 m^3/year/capita (UNEP-MAP 2009). Intensive abstraction for domestic, agricultural and industrial purposes has led to depletion of surface and groundwater bodies. SMCs have a larger share of their economies directly dependent on water resources. In these countries, the livelihood particularly in rural communities depends directly on the provision of aquatic ecosystem services. Fresh water provides for the use of water mostly for irrigation, domestic human use and aquatic organisms for food and medicines production. Unfortunately, scarce water resources in most of the SMCs are trans-boundary in nature, unequally distributed in space and time, degraded and often poorly managed. This situation is likely to deteriorate further in view of the increased population and rural migration trends, fluctuating economic growth and the unpredictable impacts of climate change forcing many countries to resort to unconventional methods of water resources development.

Fortunately, advances in desalination technology have made it an economically viable alternative source of fresh water. Consequently, in response to shortages of naturally renewable water supplies, many Mediterranean countries are compelled to construct and operate large desalination facilities. Desalination already plays a significant role in the Region's water supply portfolio of several countries of the region including, Algeria, Israel, Spain, Libya, etc. According to the World Bank (2012), it is projected that with the growing water demand gap, desalination will play an ever-larger role in filling the water supply gaps of the Mediterranean Region. The bare truth indicates that SWIM-SM countries are showing an ever growing interest in desalination as a tenable practice for tapping into the vast and infinitely tempting sea-water supplies.

According to the Blue Plan (2010), sea water desalination stands out, in a number of Mediterranean countries facing water scarcity, as a promising option to secure drinking water supply for the population along coastal areas. The major limitations of desalination of sea water are related to its intensive energy consumption per m^3 produced and to the environmental impacts due to the brines discharged into the marine environment. Despite these constraints, desalination plants are currently fast growing and supplying drinking water to an ever increasing number of Mediterranean households.

Figure 1 illustrates the very low per capita share of renewable natural water resources in many of the Mediterranean countries and particularly in the South.

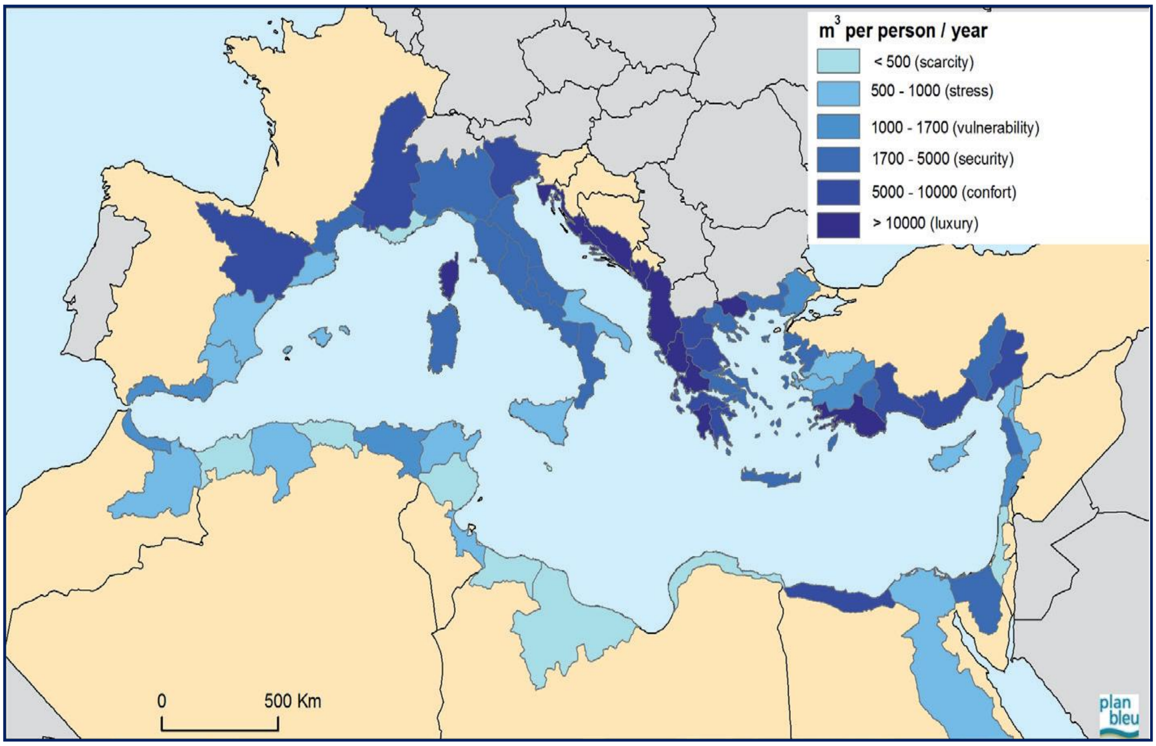


Figure 1: Renewable natural water resources per inhabitant in Mediterranean countries (Source: Blue Plan Notes 2010).

4 Oceanography and Environmental Sensitivity of the Mediterranean Sea

Known as the cradle of civilization, the Mediterranean region has been shaped by human activities for millennia. The Mediterranean Sea covers an area of 2,700,000 km^2. It extends approximately 3860 km west-east from the Strait of Gibraltar to the coast of the Middle-east.

Due to the small number of major rivers feeding the Mediterranean, evaporation is greater than the inflow of water from rivers and rain producing an annual water deficit of approximately 2500 km^3. This water deficit is resulting in more saline water (**39 parts per thousand** – ppt) compared to the connected Atlantic Ocean of only 36 ppt. The Mediterranean's high salinity and water deficit drives a thermo-haline circulation which leads to a water exchange with the Atlantic Ocean. The general circulation pattern is characterized by a swift current that brings low salinity seawater from the Atlantic through the Strait of Gibraltar at and near the surface. As the water flows east it becomes saltier and mixes with Mediterranean waters. The water current sinks in the eastern part of the Mediterranean Sea before turning westward as a deep water current moving in an anti-clockwise motion and exiting through the lower part of the Strait of Gibraltar into the Atlantic Ocean. The duration of the entire water cycle within the Mediterranean basin is approximately **80 to 100 years (** Millot 2003).

According to UNEP-MAP "State of the Mediterranean Marine and Coastal Environment Report" (2012), the state of the Mediterranean coastal and marine environment varies from place to place, but all parts of the Mediterranean are subject to multiple pressures acting simultaneously and in many cases chronically. The Mediterranean Sea already suffers from a number of water quality impacts including the discharge of raw or inadequately treated industrial and domestic wastewater in addition to diffusive runoff from agricultural uses and sedimentation from terrestrial land development in the basin. At the basin scale, pollutants discharged along the southern coasts are entrained either parallel to the shoreline or seaward. Effluents from the eastern and northern coasts are usually entrained parallel to the coast lines.

UNEP-MAP, Plan Bleu (2009) has indicated that the Mediterranean Sea is home to 7 to 8% of the known marine species, while only representing 0.8% of the planet's ocean surface. Over 50% of the marine species originate from the Atlantic Ocean, 17% from the Red Sea, including ancient species and more recently introduced species following the commissioning of the Suez Canal. According to Michael Hogan (2011), there are more than 1000 species of macro-flora present in the Mediterranean Sea and its arms; approximately twenty percent of these are endemic to the Mediterranean, representing a high level of aquatic plant endemism. Diversity is essentially concentrated in the West of the basin and in shallow depths (between 0 and 50 m deep).

Two remarkable ecosystems, magnoliophyte grassbeds (such as Posidonia, a key Mediterranean ecosystem) and coralligenic concretions can be found in coastal zones. So far, there is no extensive knowledge on marine ecosystems as study programs only cover coastal ecosystems.

The state of biodiversity often reflects the cumulative effects of the pressures affecting the Mediterranean coastal and marine environment. Some 19% of known Mediterranean species are threatened. For instance, the Mediterranean's emblematic monk seal is classified as a species in critical risk of extinction. This is also the case for cartilaginous fish, with 42% of shark species threatened with extinction. More than 63% of the fish and 60% of the mammals listed in the "Protocol Concerning Specially Protected Areas and Biological Diversity" have endangered status, from increasing pressures such as coastal urban development, destruction of ecosystems such as lagoons and grass-beds, increased coastal erosion, industrial pollution, over-exploited marine resources and expansion of invasive species.

Although there is still high diversity in the Mediterranean, some species of reptiles, marine mammals, birds, and fish are reaching dangerously low abundance levels. The Mediterranean also hosts a diverse array of habitats of commercial, ecological, and cultural importance, many of which are under a variety of pressures (UNEP-MAP 2012).

As recorded by WWF (2007), Posidonia oceanica is a sea grass unique to the Mediterranean Sea, which forms "prairie" meadows in shallow waters near the coast. It plays a key role in the natural balance of the Mediterranean ecosystem by stabilizing the sediments and providing a feeding and breeding ground to more than one thousand different species .

Figure 2: Unique sea grass Posidonia oceanica forming "prairie" meadows in shallow near-shores of the Mediterranean Sea.
Source: WWF (2007) Young plants of Posidonia oceanica © WWF-Shoreline

The Posidonia prairies are listed as priority habitats under the European Union's Habitat Directives. For the Posidonia to thrive, two essential conditions are required: sun, for which it needs to grow in shallow waters close to the coast, and a stable level of salinity. The rapid expansion of seawater desalination in Spain has raised concerns about possible impacts from desalination discharges which may counteract conservation efforts for sea-grass meadows along the Spanish coastline under EU and national law.

5 Status of Desalination in the Mediterranean Sea

Desalination plants have been built, at various scales, in almost all countries of the Mediterranean region. Starting from 1970 to the year 2013, over 1532 seawater desalination plants had been installed around the Mediterranean Sea. These plants have a total cumulative installed capacity of approximately 12 million m^3/day. Based on data from GWI-Desal-Data (2013), in the last 13 years (2000 to 2013), the reported installed capacity has dramatically increased by an outstanding 560%. Figure 3 illustrates the cumulative installed capacity of desalination plants in the Mediterranean region in the last 43 years from 1970 to 2013.

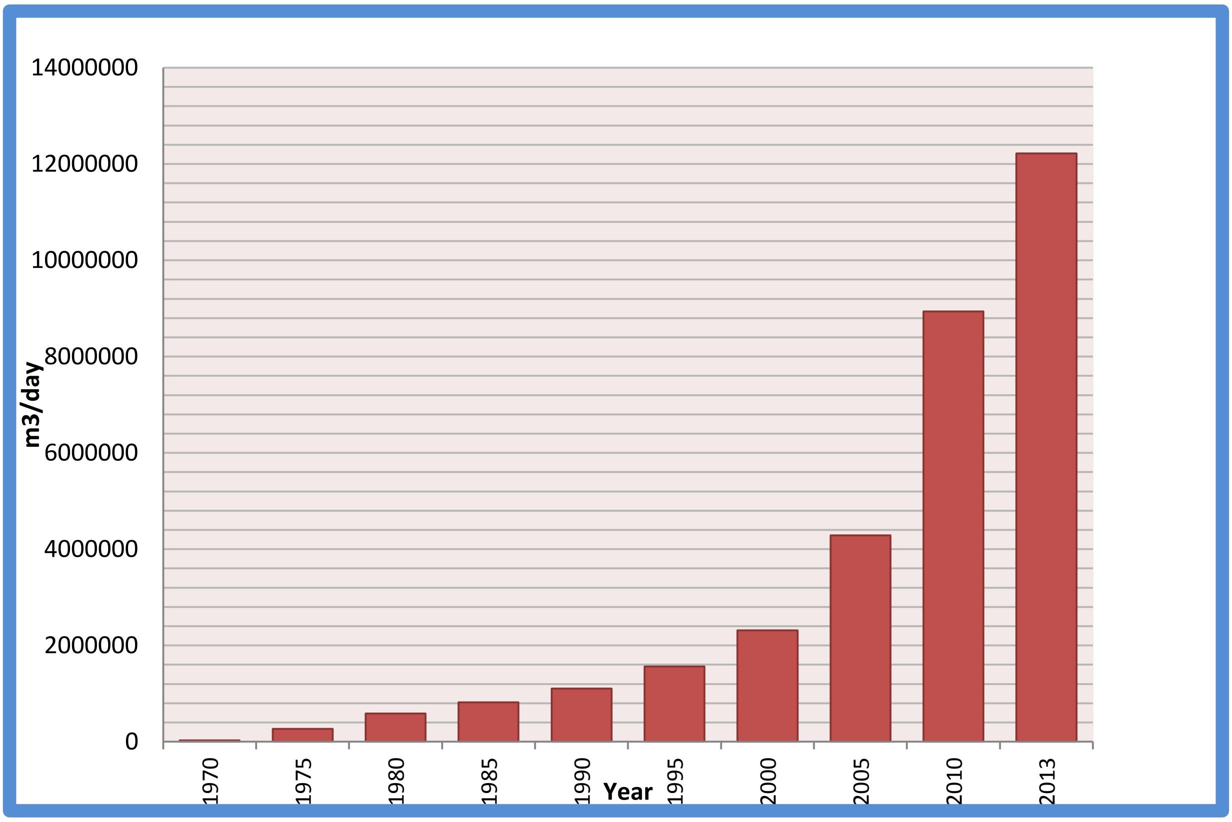


Figure 3: Cumulative installed production capacity of desalinated water in Mediterranean countries from 1970 to 2013 from seawater.

Source of data: GWI-Desal-Data (2013).

Following the technological developments, RO is becoming the most common desalination technology in use in the Mediterranean region accounting for 82.3% of the total installed capacity, or roughly 9.9 million m^3/day. The second-most common desalination technology in use in the region is MSF with nearly 11.2% producing 1.4 million m^3/day, followed by the MED process with only 6.5% producing 0.8 million m^3/day. Figure 4 illustrates the cumulative installed production capacity using different seawater desalination technologies in the Mediterranean region in 2013, while figure 5 represents the percent distribution among the three most common desalination technologies in the Mediterranean Region in 2013 (GWI-Desal-Data 2013).

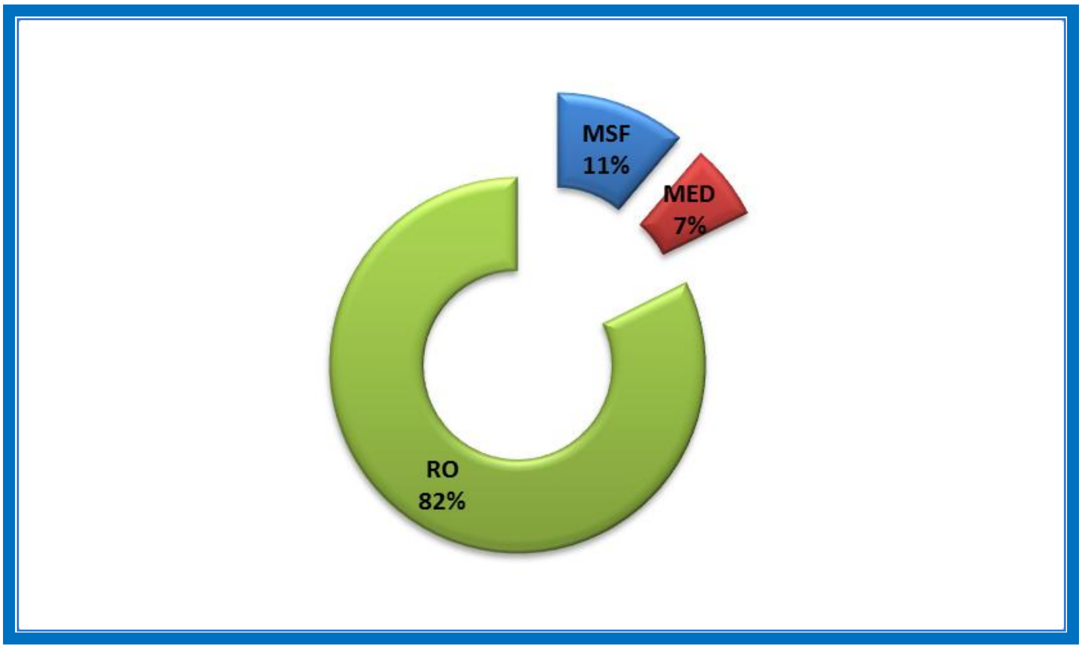


Figure 4: Percent distribution among desalination technologies in the Mediterranean region in 2013.

Source of data: GWI-Desal-Data (2013).

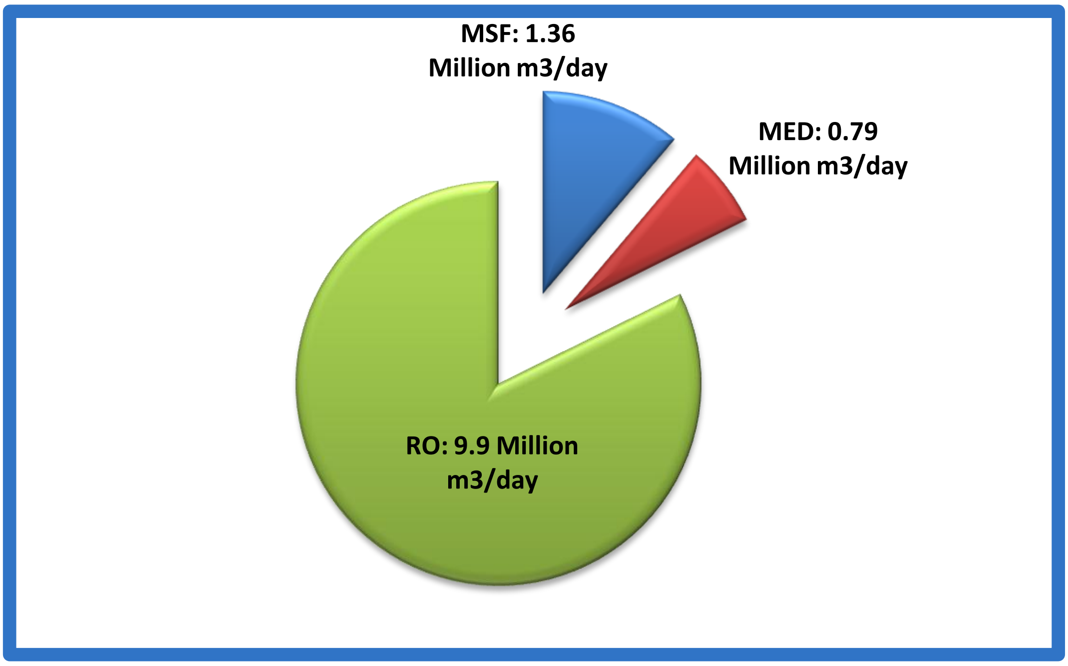


Figure 5: Cumulative installed seawater desalination capacity using different technologies in m3/day for all Mediterranean countries in 2013.

Source of data: GWI-DesalData (2013).

Figure 6 shows the up-to-date total cumulative installed capacity from 1970 to 2013 in the Mediterranean countries with noteworthy desalination production. Spain ranked first as the highest producer of desalinated water with an installed capacity of 3.7 million m^3/day or 31% of the total Mediterranean capacity, followed by Algeria with a daily production of 2.4 million m^3/day or 20% and Israel with a daily production of 2.1 million m^3/day or 18% (GWI-Desal-Data 2013).

The percent distribution of desalination production capacities are exhibited in Figure 7 in which Spain comes on top with 31% of the total cumulative installed capacity around the Mediterranean Sea followed by Algeria with 20%, then Israel and Libya with 18% and 11% respectively.

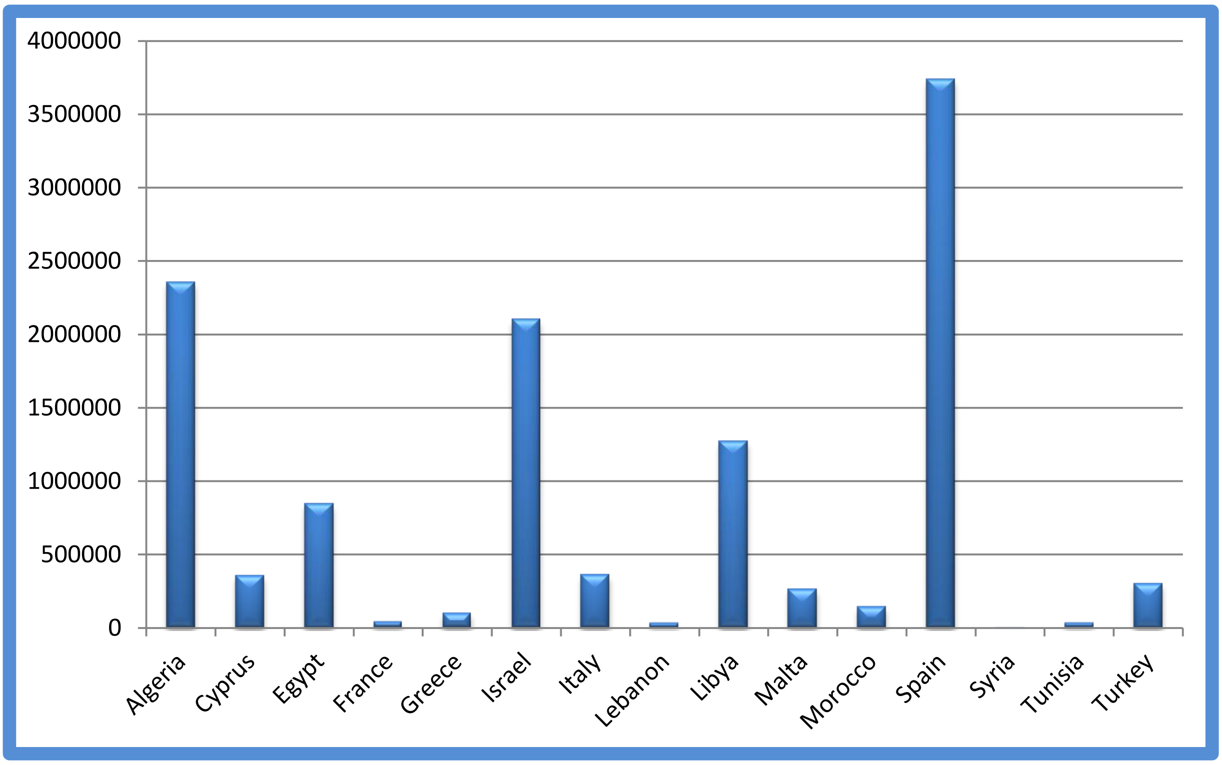


Figure 6: Current cumulative installed desalination capacity (1970 to 2013) in Mediterranean Countries in m3/day.

Source of data: GWI-Desal-Data (2013).

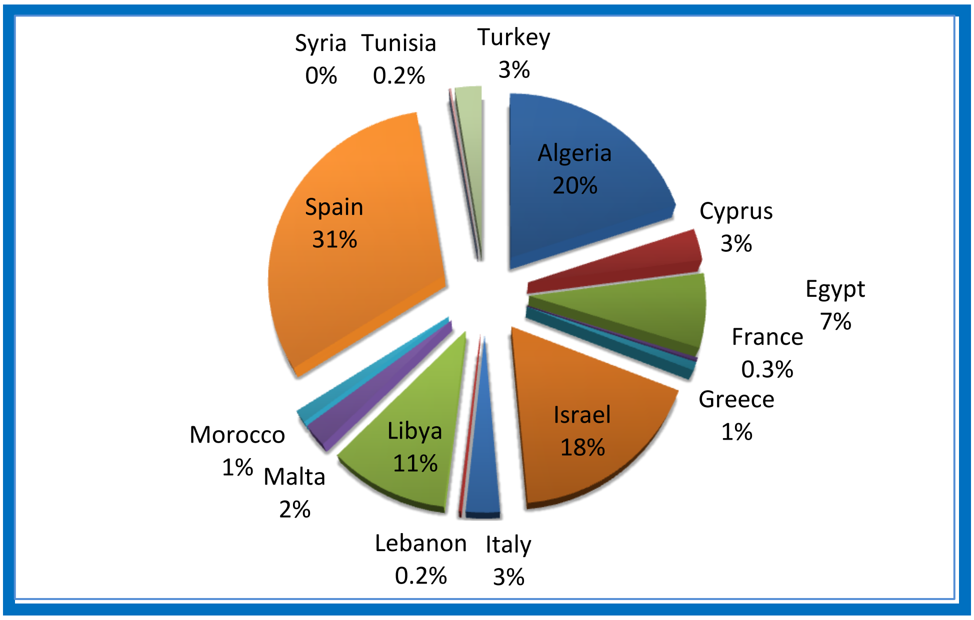


Figure 7: Percent desalination capacity among countries in the Mediterranean region.
Source of data: GWI-Desal-Data (2013).

The nearly 12 million m^3/day of desalinated water, produced around the Mediterranean Sea, is predominantly consumed by municipalities to deliver high quality drinking water. Figure 8 displays the desalinated water average consumption among various sectors in the Mediterranean Region.

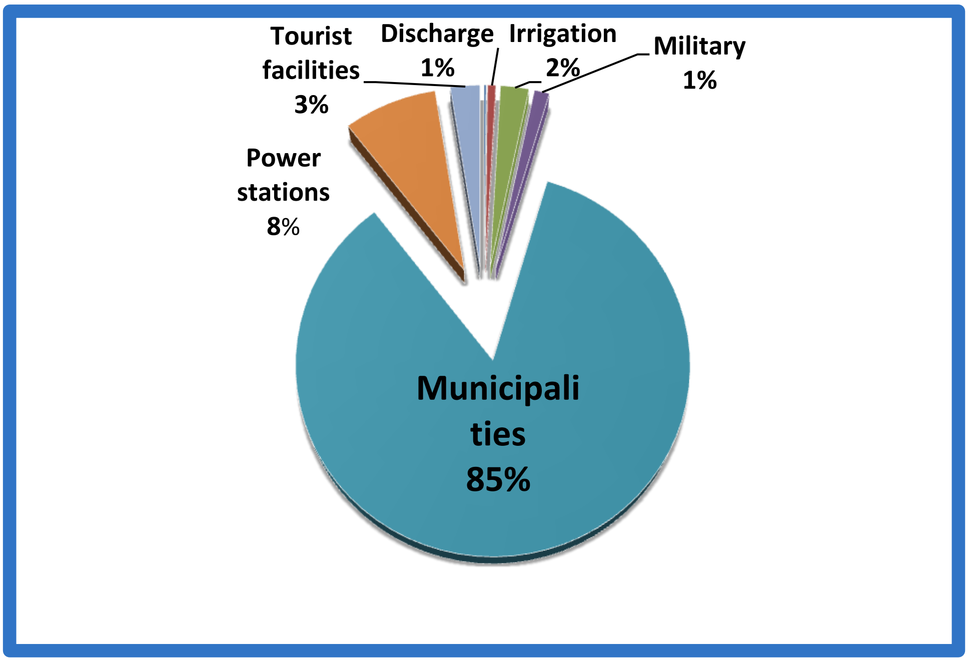


Figure 8: Average distribution of desalinated water according to uses in the Mediterranean region.
Source of data: GWI-Desal-Data (2013).

In the following discussion, more details will be provided on the four major producers (namely, Spain, Algeria, Libya and Israel) of desalinated water in the region.

In Spain, the first desalination plant was introduced in the Canary Islands, where water scarcity and poor quality of groundwater resources prevented the expansion of tourism. A large number of mostly small-scale MSF and MED plants were built in the 1970s. Through the 1980s and 1990s, there was a slow expansion of desalination in the Canaries, as well as in the south-eastern corner of the Iberian peninsula. The desalination strong market was later launched by the Socialist government in 2004 as an alternative approach to the previously planned water transfer from the river Ebro to the Valencia Region. The program involved the creation of around 650 million m³/yr of additional desalination capacity, plus an additional 400 million m³/yr from wastewater reuse and other water saving measures. Figure 9 illustrates the evolution of installed desalination capacity in Spain from 1970 to 2013.

The main desalination technology applied in Spain is the RO process. About 82% of the total desalinated water is produced from RO plants, while the rest is equally distributed between the other production

technologies such as MSF and MED processes.

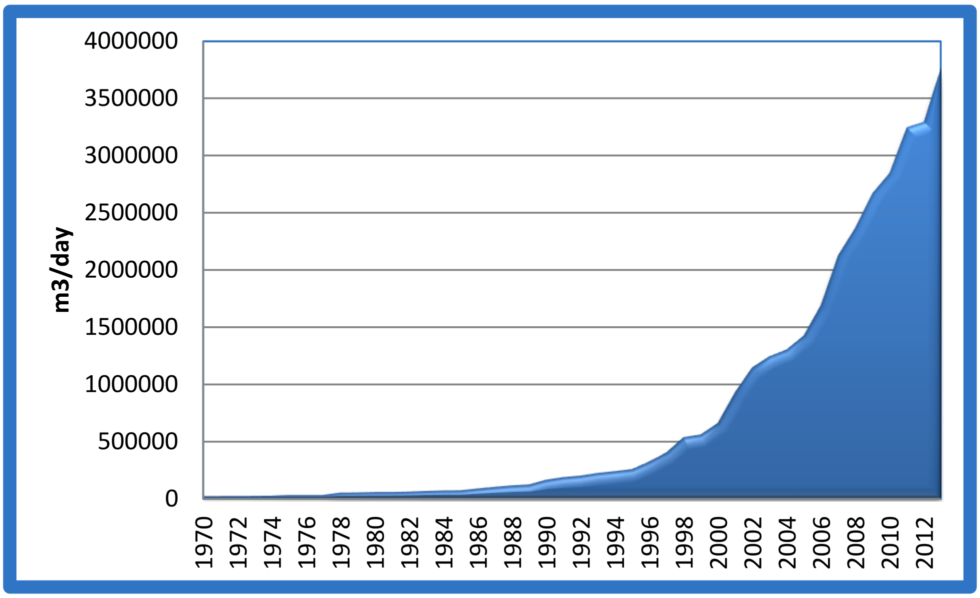


Figure 9: Spain's installed seawater desalination capacity from 1970 to 2013 in m3/day.
Source of data: GWI-Desal-Data (2013).

In Algeria, desalination plants are usually contracted under build-own-operate (BOO) arrangements. These are run by special project companies which are set up as joint ventures between Algerian Energy Company (AEC) and the winning contractor. The project company sells water to Sonatrach and Algerienne des Eau (AdE) on a take-or-pay basis under the terms of a 25-year water purchase agreement.

Algeria developed **a** 2006 – 2025 investment plan for the water sector which is a capital-intensive program of a US$150 billion budget, approximately 75% of which was planned to be invested from 2006 to 2010. One of its five strategic priorities is to increase water supply through desalination and construction of dams. The fluctuation in revenues from oil and gas, which sustain these investments, posed a threat jeopardizing the progress of state-funded water projects.

According to AEC, Algeria's largest operational desalination facility is the El Hamma plant. It has a capacity of 200,000 m³/d and went online in 2008. Algeria's total desalination capacity, including private and industrial plants, was 575,300 m³/d in 2009. In 2005, Algeria launched an ambitious desalination program of large-scale seawater reverse osmosis (SWRO) plants, with plans to build 13 plants along the country's 1,400 km of coastline and a total capacity of 2.26 million m³/d. Ten plants with a total capacity just over 2 million m³/d have now been contracted out, four of which were online by March 2010. As of 2014, the country's total desalination capacity is higher than 2 million m³/d. Figure 10 exhibits the cumulative seawater desalination installed capacity in Algeria from 1970 to 2013.

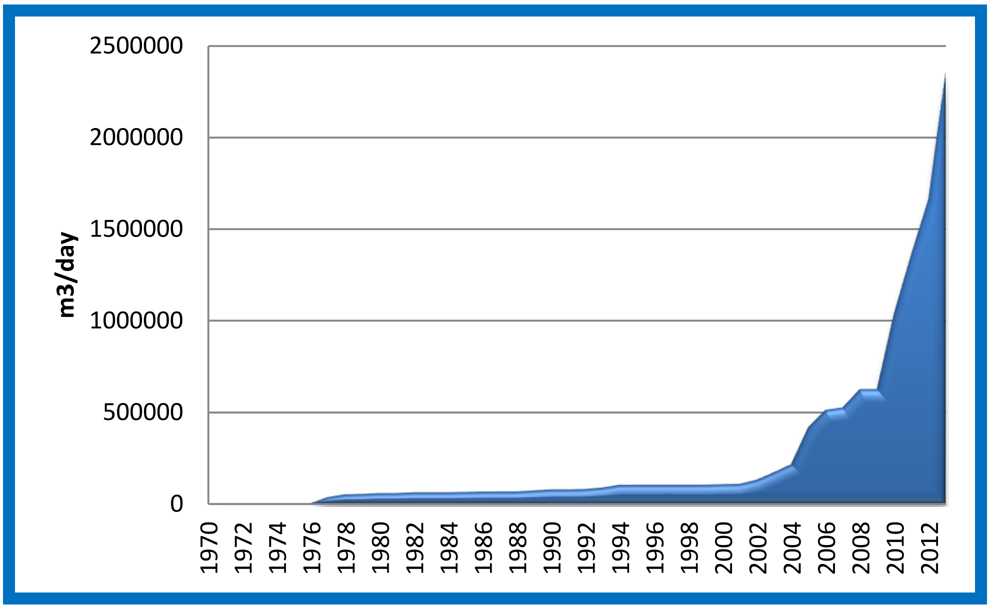


Figure 10: Algeria's cumulative seawater desalination installed capacity from 1970 to 2013.
Source of data: GWI-Desal-Data (2013).

<u>**In Israel**</u>, mega desalination is a key element in the country's long term strategy to tackle water scarcity. The government is investing more than 2 billion New Israeli Shekel (NIS) in reformulating the national water system towards a greater reliance on desalination. Approximately 100 km of water pipelines were constructed to carry output from five desalination plants (Ashdod, two plants at Soreq, Hadera and Hefetz Haim) towards the east and south of the country. According to Mekorot, by 2012 most drinking water in Israel is desalinated.

Desalination is a sound solution for Israel's water shortage, given that its cost has decreased substantially to approximately 3 NIS/m³ and that it provides high quality water. Figure 11 illustrates the increase in seawater desalination capacity in Israel from 1970 to 2013 in m^3/day.

The main desalination plants in Israel are:

- **Ashkelon:** One of the largest SWRO plants in the world. Operational since 2005, Ashkelon has a total maximum capacity of 326,144 m³/d of water, 15% of which is for domestic consumption. It has been expanded by another 41,000 m³/d.
- **Palmachim:** Built by Via Maris in 2007 through a build-own-operate (BOO) contract, this SWRO plant provides 82,190 m³/d of water. It is being expanded to 123,000 m³/d with $22 million of financing
- **Hadera:** This SWRO plant had a capacity of 368,000 m³/d when originally constructed. An extension came fully online by May 2010, which added 88,000 m³/d, bringing the total installed capacity to 456,000 m³/d. The European Investment Bank took part in financing the construction of this plant by committing €150 million. The Hadera plant is more energy efficient than Ashkelon, and the water quality is higher.

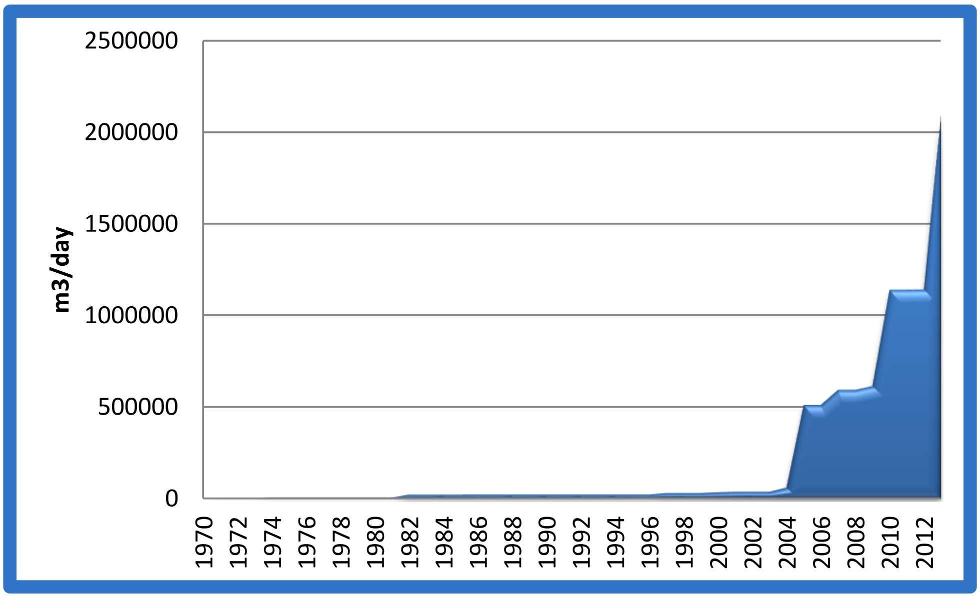


Figure 11: Increase in seawater desalination capacity in Israel from 1970 to 2013 in m^3/day. Source of data: GWI-Desal-Data (2013).

Figure 12: Ashkelon 320,000 m3/day desalination plant in Israel. The largest desalination facility on the Mediterranean Sea.
Source: http://www.water-technology.net/projects/israel/

Libya is ranked the fourth country in terms of capacity of seawater desalination plants in the Mediterranean with 10.6% of the total capacity. In the early 1970s, Libya started operating plants of more than 10,000 m^3/day capacity. By the end of 1999, the total capacity of desalination plants was in the range of more than 0.6 million m^3/day. Since the inception of the Libyan desalination program, thermal technology has dominated its market, though membrane technology has also been lately employed in a limited number of applications. Figure 13 illustrate the cumulative installed desalination capacity in Libya from 1975 to 2013 in m^3/day.

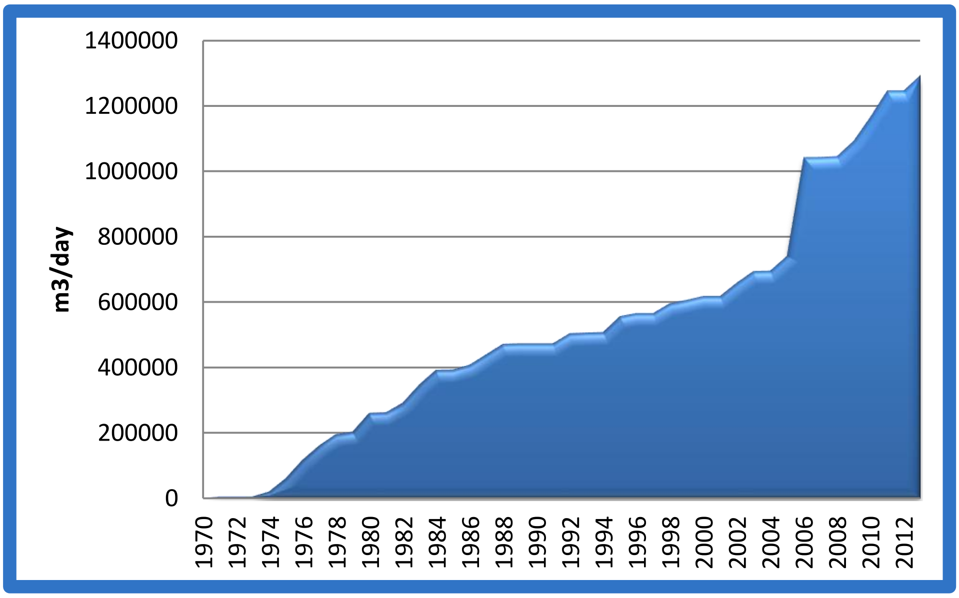


Figure 13: Cumulative installed desalination capacity in Libya from 1975 to 2013 in m3/day.
Source of data: GWI-Desal-Data (2013)

6 Prospects of Desalination in the Mediterranean region

According to Plan Bleu (2010) the seawater desalination market in the Mediterranean is set for high growth in the coming years. By 2030 the Mediterranean region is projected to multiply its desalination capacity by threefold, or even fourfold, thus reaching 30 to 40 million m^3/day exceeding the current 12 million m^3/day installed capacity.

Based on GWI-Desal-Data (2013), the Mediterranean region will witness an incremental increase in seawater desalination production of slightly more than one million m^3/day each year during the period extending from 2013 to 2016 to reach some 15 million m^3/day.

In Algeria, the government has earmarked a budget for the 2010 - 2014 plan of $15-16 billion to develop nonconventional water resources including desalination. Amongst the plan's main projects is the construction of four new desalination plants; the total capacity of the seawater desalination program will total 2.5 million m^3/d. The current BOO program is expected to meet the needs of the entire coastal population until 2030, so the desalination market in Algeria is likely to enter a much quieter phase beyond 2030.

In Israel, the National Desalination Plan (NDP) outlines an increase in desalinated water up to at least 550 million m^3/yr by 2013, and up to 750 million m^3/yr by 2020.

In Morocco, desalination has been used as a last resort because of its cost, particularly in the southern provinces where the population tends to be sparse and concentrated along the coast where conventional fresh water resources are limited. However, in a context of increasingly limited resources and growing demand, Morocco has committed to increasing its desalination capacity nearly tenfold (1000%) by 2015. This will primarily be done by the Office National de l'Eau Potable (ONEP), which currently has a relatively small desalination capacity, although there are other non-ONEP desalination plants in the country. In its 2010 nonconventional water resources strategy, the Moroccan government is planning to substantially increase its desalination capacity, including the construction of large-scale SWRO desalination plants under BOT agreements.

In Tunisia, desalination activity goes back to at least 1971. Tunisia plans to add another 286,000 m^3/d of desalination capacity by 2020, with SWRO accounting for the large majority of it. With financial support from the Japanese Government, a new 1,800 m^3/day RO inland desalination plant using brackish groundwater feed water is under construction employing Photo Voltaic (PV) cells.

In Palestine, given the non-existence of alternative fresh water resources, a mega desalination plant was deemed an absolute necessity to address the serious water deficit threatening the wellbeing of 1.6 million Palestinians residing in the Gaza strip. The proposed mega seawater desalination is considered as the only long-term solution to address the water poverty in the strip. The plan consists of the construction of a 100 million m^3/year = 274,000 m^3/day desalination facility and distribution system in Gaza over two phases. The estimated cost is in the range of US$ 450 million. The plan has been approved and financing is underway.

In Libya, the shift in the country's technological and financial approach to desalination over the past two years indicates that this sector has long been viewed as a secondary option in the country. Alerted by the potential decline in the quality and/or quantity of water from the Great Man Made River (GMMR), the government planned in April 2010 a multi-million m^3/d desalination program.

The government plans have given desalination projects new impetus under the auspices of the General Desalination Company (GDC). The fast expanding desalination market will be aimed basically at domestic supply. The following Figure 14 shows the Ministry of Public Utilities' plan for water supply up to 2015. The plan shows the ambitious objective of the country to quadruple (400%) its desalination capacity. Given the current political instability in the country, it is very unlikely that this plan will be fulfilled as planned.

In Egypt, the desalination sector remains emergent. Desalination is mainly used for additional drinking water supply in coastal towns aimed at the tourism and municipal sectors. It is expected that desalination will be further explored where it is feasible in the new cities located near to the coast lines. As Egypt attempts to disperse its growing population, 16 new cities are under construction and are designed to house a population of 6.8 million people by 2017. Another 41 additional cities are being planned, and are expected to house a total of 7 million people when completed.

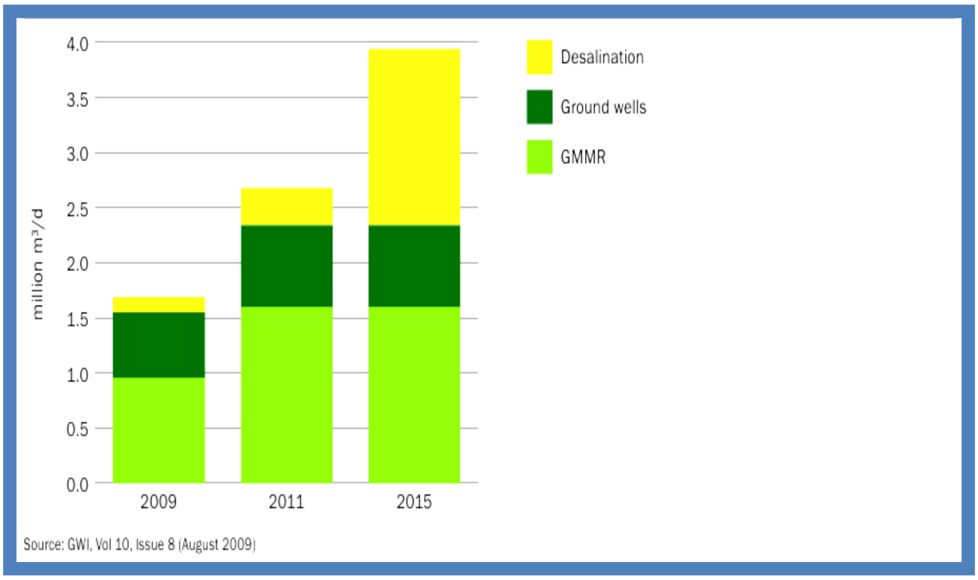


Figure 14: Desalination plans for the year 2015 in Libya

In 2010, the former president of the country issued a decree preventing any water transfer from the Nile valley to governorates located East or West of the country to supply water for the new settlements. In conformity with the decree, touristic resorts, North Coast summer compounds and new settlements are expected to generate their own water supplies using nonconventional techniques including desalination. It is likely that the desalination of seawater and brackish water using RO may well soon be considered viable in Egypt. It is projected that desalination production will grow with the construction of large number of small and medium scale desalination plants away from the Nile Valley to supply new settlements and touristic resorts particularly in the North Coast of Egypt on the Mediterranean Sea.

In Spain, as a result of the severe economic downturn that hit the country in 2008, the total spending on water infrastructure in Spain's 2010 budget was reduced by over 19%, decreasing from €4.22 billion to €3.4 billion. This crisis has also affected the willingness of banks and construction companies to supply private finance for the construction of new desalination plants. Desalination projects have turned to alternative funding sources such as European Investment Bank for loans to finance desalination and wastewater projects. Given the current economic crisis, plans for additional desalination plants might be hindered for the coming few years in Spain.

In Italy, the future scope for desalination is mainly in the drier regions of southern Italy such as Apulia and Basilicata, as well as in Sicily and Sardinia. Apulia is the only region where definite plans for the construction of desalination plants have been made. Sicily is also said to be considering new desalination plants as a serious option, but no clear plans have emerged yet.

The current trend in desalination technology in the Mediterranean region is mainly controlled by the characteristics of feed seawater, cost of construction and operation, maturity of the technology, available energy, percent recovery, etc. Figure 15 depicts the trend in seawater desalination technology where RO is already predominating and taking over other technologies.

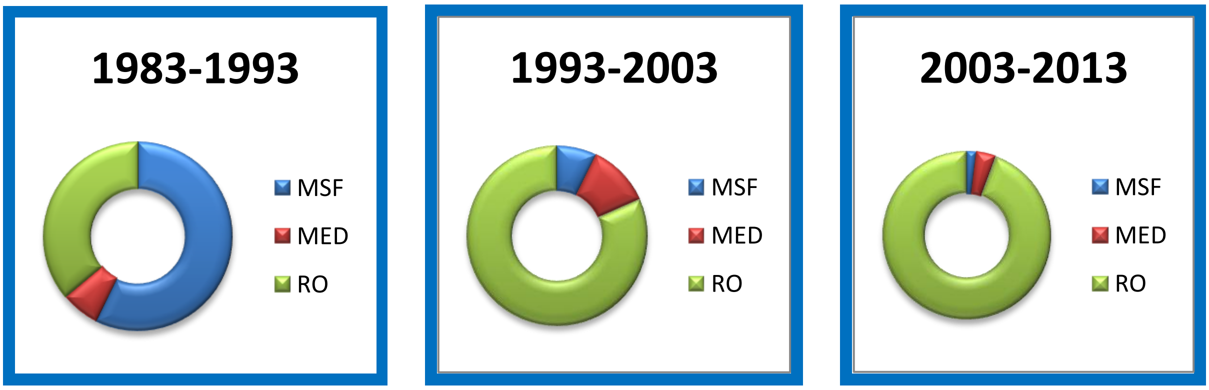


Figure 15: Trends in the market share of desalination technologies in the Mediterranean region during the last three decades.

Source of data: GWI-Desal-Data (2013).

Based on the discernable trend exhibited in Figure 15 and the above discussions, it is possible to deduce that RO technology will shape the future of desalination industry through further development and dominance of the desalination market in the Mediterranean region. According to GWI-Desal-Data (2013), 100% of the planned seawater desalination plants in the Mediterranean region until 2016 will be exclusively using RO technology.

Renewable energy (RE) in the form of solar energy, particularly concentrating solar power (CSP) has tremendous potential to provide energy needed for desalination of seawater and thus reducing CO_2 emissions significantly. CSP is a very promising area of technology for renewable desalination, but probably more so for the medium to large capacity ranges of desalination plants. In this regard, renewable energy technologies such as CSP, PV and Wind power not only contribute to the reduction of greenhouse gases, but would also stabilize electricity cost. In fact, once RE plants are installed, their levelized electricity cost (LEC) is known and constant (i.e. no longer prone to market prices fluctuations). RE technologies can be divided in dispatchable and non-dispatchable. CSP belongs to the first category: its advantages are that the thermal storage is integrated in the plant, so that the generation of electricity on-demand is possible. In contrast, PV and Wind power are non-dispatchable, i.e. their power production patterns directly depend on the momentarily available solar and wind resources. Despite this disadvantage, PV and Wind power are typically characterized by slightly lower LEC than those of CSP. In the end, a combination of renewable dispatchable and non-dispatchable RE plants as well as conventional plants for backup purposes would provide the cost optimal power mix. The relative sophistication of CSP plants make them less suitable for autonomous desalination units in remote and rural areas. So far, CSP-powered desalination is expensive and significant developments are still needed to enable CSP-powered desalination fill the water scarcity gap in the region. Presently, two options are available to combine CSP with seawater desalination. The first choice is to combine a CSP plant to drive a thermal desalination unit using the exhaust heat of the steam cycle. The second choice is to exploit the electricity generated by the CSP plant with an RO unit. According to World Bank (2012), technological innovations are expected to reduce costs of CSP-thermal desalination to approximately US$ 0.9/m^3 by 2050. Furthermore, CSP will also bring considerable environmental advantages.

Many existing and currently planned fossil fuel desalination plants will be operational for years to come (some 20 years for RO and up to 35 years for MSF) before phasing out. Fossil-fueled desalination plants will not be totally decommissioned until 2041–43 (World Bank 2012), therefore, demand for CSP-desalination technology will grow steadily at first before taking off to meet the expected growing water demand beyond 2030.

General Outlook of Desalination Prospects in the Mediterranean:

Based on the above discussion, the following projections can be made on the prospects, pace and future shape of seawater desalination in the Mediterranean region:

1. Compared to the period extending from 2000 to 2013 exhibiting 560% increase in installed capacity, desalination of seawater will continue to grow but at a slower pace in most of the Mediterranean countries.
2. Emerging and growing disputes on shared transboundary water resources in South Mediterranean (downstream) countries will represent a new strong driving force for more desalination to secure drinking water supply within a national security context.
3. RO will be the dominating future seawater desalination technology in the region.
4. Countries that have already bridged most of their water supply gaps through desalination such as Algeria, Israel and Spain are likely to show some slowdown in their momentum and might enter into a relatively quieter phase.
5. Persisting regional economic and financial crisis in the Mediterranean might curb the implementation of some of the ambitious national desalination plans in the region.
6. Political instability in some South Mediterranean countries, namely Tunisia, Libya, Egypt and Palestine, might hinder and/or delay the financing and construction of their planned desalination plans.
7. Apart from financing and political instability, the main challenges that South Mediterranean countries will be facing in implementing their future desalination plans are i- reduction in operational cost, ii- diminishment of reliance on fossil fuels and iii- producing environmentally acceptable solutions.
8. In case future desalination in the Mediterranean region maintains its total reliance on oil and/or gas, the rising energy costs and subsequently the price of desalinated water is predicted to increase due to greater competition for the dwindling fossil fuel reserves.

9. Desalination using solar energy, as an emerging technology, is already capturing the attention and imagination of water and environment officials in Mediterranean countries.
10. Despite the fascination of water planners with renewable energy (RE) in desalination, it is projected that CSP-desalination will take a couple of decades before replacing the phasing out the currently operating fossil fuel desalination plants in the region. . On the other hand, the opportunity of introducing RE in the National energy mix shouldn't be overlooked.

7 Environmental Aspects of Desalination in the Mediterranean Region

The record of environmental impacts of seawater desalination plants is extensive and in many aspects, such as energy consumption or land use, desalination plants exhibit similar negative impacts as those attributed to other coastal industrial development projects. In addition to emission of regular fuel combustion products, desalination technologies produce two types of discharge. One discharge during the regular operation called *effluent* and a second type, called *effusion*, generated during the maintenance cycles for cleaning, backwashing and purging the system.

Most of the concern from desalination is focused on the impacts of the effluent on the near-shore marine environment. Depending on the desalination technology in use, the effluent is characterized by elevated salinity and temperature , release of residual biocides, coagulants, antiscalants, antifoaming agents, heavy metals from corrosion or intermittently used cleaning or backwashing agents. Emission of this mixed wastewater into the near-shore marine environment might adversely affect water- and sediment quality, reduce biodiversity, impair marine biota or the vital functions of coastal ecosystems.

Furthermore, thermal desalination facilities such as MSF and MED are designed to burn crude oil, gas-oil or heavy fuel oil to generate steam for power production and distillation. The products of combustion most commonly released by fossil fuel are ash particles, carbon dioxide (CO_2), carbon monoxide (CO), water vapor, sulfur dioxide (SO_2), and nitrogen oxides (NOx). Fortunately, fast advancement in RO as a desalination technology reduced the overall energy consumption. Since most of the energy used, so far, in desalination is derived from fossil sources, emitted global warming gas CO_2 becomes a problem of great urgency.

Air emissions and associated global warming will not be the main focus of this study. Instead, the attention shall center on the impacts of issues such impingement and entrainment at the desalination plants intakes and their brine discharge. This chapter shall identify the problem, its causes, assess its magnitude and describes the aspects of brine discharges on the near-shore marine environment of the Mediterranean Sea. The environmental effects, bioaccumulation, biomagnification, fate and transport of discharged desalination pollutants are all elaborated in chapter VIII.

7.1 Environmental Aspects of Desalination Plants Intakes

All seawater desalination plants require large volumes of feed-water, to be processed to produce fresh water as a final product. In mega desalination plants, substantial masses of seawater are required; the pumping of the feed-water into the plant can result in significant environmental impacts due to impingement and entrainment.

As a common practice, screening racks with 10-cm bar separation are installed at the desalination plant intakes to prevent large fish and floating objects from reaching the pumping pool (fore-bay). Once within the vicinity of the plant intakes, the fin-fish and macro-invertebrates are exhausted trying to swim against the created seawater flow and vortex. They are then subjected to high doses of chlorine typically ranging from 2.5 to 5.0 mg/l added to combat biofouling on the screens and within the unit processes of the plants. At the pumps, travel-rotating screens or drums are installed to screen small objects such as small fish and other debris. The mesh size of the screen range between 0.5 and 1.0 cm^2. These factors combined ensure that the mortality of impinged organisms is almost complete.

The concern with desalination of seawater is that the near-shore marine environment is an habitat for a diversity of marine aquatic life. Appropriate intake design can mitigate many of the potential impacts on larger life forms but the key long term cumulative impact may be with the removal of small life forms such as plankton, eggs and fish larvae. According to Panktraz (2004) depletion of marine life "may represent the most significant direct adverse effect of seawater desalination".

Based on the daily volume of desalinated seawater in the Mediterranean Sea region using the three recognized technologies (RO, MSF and MED), the estimated total volume of water withdrawn from the near-shore of the Mediterranean Sea for desalination is as follows:

1. Volume of sea water entering the desalination plant as feed-water to RO desalination plants assuming 50% recovery is 19.9 million m^3/day.
2. Total volume of feed-water entering the MSF desalination plant, assuming 10% recovery, is 1,357,597 m^3/day desalinated water x 10 = 13.6 million m^3/day.
3. Total volume of feed-water entering MED desalination plants, assuming 20% recovery, is 790,711m^3/day desalinated water x 5 = 3.95 million m^3/day.
4. Total estimated volume of water entering the desalination plants of the Mediterranean = 37.4 million m^3/day.
5. According to Plan Bleu (2010), the seawater desalination market in the Mediterranean region is set for high growth to reach by the year 2030 some 30 to 40 million m3/day. Assuming the best scenario that all future desalination plants will be using RO technology, the estimated total volume of feed-water will range from 60 to 80 million m3/day equivalent to an annual flow of 22 to 29 billion m3/year.
6. In case future desalination plants will be utilizing the three presently used technologies at the same ratio to desalinate a projected volume of 30-40 million m3/day in the year 2030, then the predicted daily volume of feed-water entering the desalination plants will be ranging from 94 to 125 million m3/day equivalent to an annual inflow ranging from 34.3 to 45.6 billion m3/year

Figure 16 displays the estimated daily volume of feed water withdrawn from the near-shores of the Mediterranean Sea as related to the production of desalinated water using different desalination technologies in million m^3/day during the year 2013.

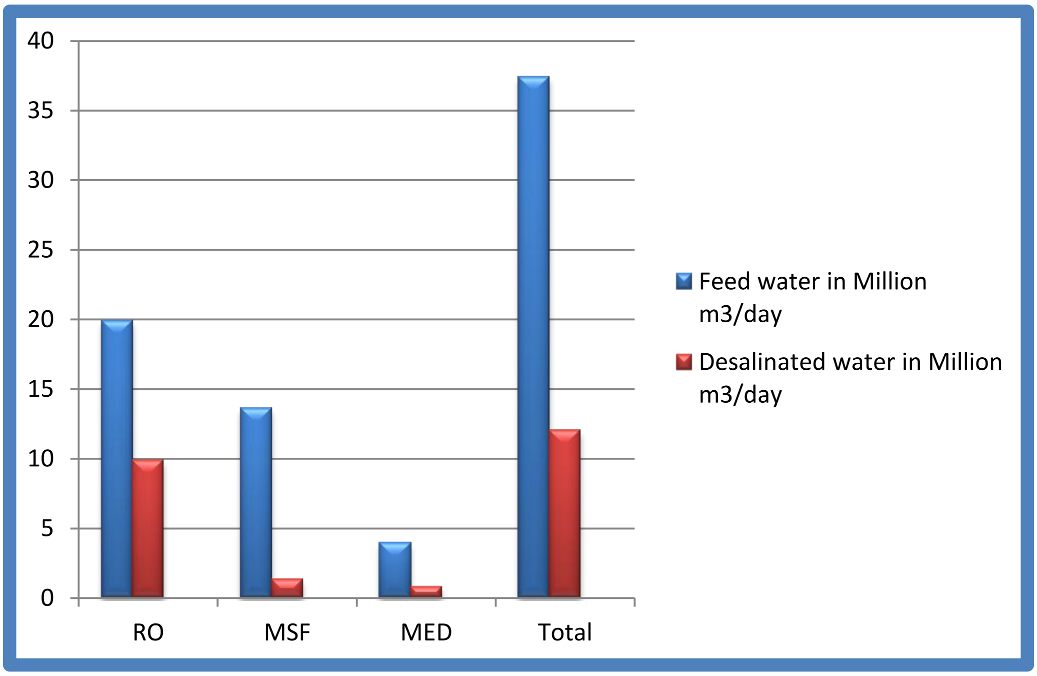


Figure 16: Estimated daily volume of feed water withdrawn from the Mediterranean compared to production of desalinated water using different desalination technologies in million m3/day during the year 2013.

According to projections, by the year 2030, the annual total volume of feed-water entering the desalination plants around the Mediterranean Sea for processing is ranging between 34 to 45 billion m^3/year. This colossal volume of water entering desalination plants around the Mediterranean Sea is equivalent to the flow of some of the largest rivers in the world. While it is relatively simple to assess the levels of entrainment and/or impingement for a specific desalination project, it is very intricate and complex to estimate the actual ecosystem impacts, especially when cumulative effects with other nearby projects exist.

According to the predicted production of 30-40 Million m^3/day of desalinated water by the year 2030 in the Mediterranean, the estimated annual total volume of feed-water needed to desalinate such a volume of water will range from 34 to 45 Billion m^3/year. For comparison, the annual flow of the River Nile to Egypt is 55.5 Billion m^3.

7.2 Environmental Aspects of Energy Use in Desalination

Desalination of saline water is generally an energy intensive process. Depending on the desalination technology and energy sources, large scale water desalination plants have the potential to add significantly to the greenhouse gas emissions held largely responsible for climate change. In many instance, desalination plants emitted pollutants such as NOx, SOx, particulates, etc.

Based on the fact that the generation of one Kilowatt-hour energy (kWhe) in power plants will generate, on the average, 0.58 kg of CO_2, Cuenca (2012), estimated the amount of CO_2 emitted for the production of one m^3 of desalinated seawater, using RO low energy technology, by 2.00 kg CO_2/m^3.

When using thermal desalination technology such as MSF the Kilowatt-hour thermal (kWht) is equivalent to more than 2.54 kWhe. Therefore, the production of thermally desalinated seawater will generated an average of 5 times the CO_2 generated by using RO desalination technology (i.e. 10 kg CO_2/m^3).

CO_2 Emissions from desalination in the Mediterranean Basin.

1. *Estimated total CO_2 emission from online RO desalination plants in Mediterranean region*: The total amount of CO_2 currently emitted from the desalination of some **9,926,161.00 m^3/day** in the Mediterranean countries using RO technology is in the range of **19,852,322 kg of CO_2/day = 19,852.32 metric tons of CO_2/day**. This sum is equivalent to **7,246,345 metric tons/year**.
2. *Estimated total CO_2 emission from online MSF desalination plants in Mediterranean Region*: The current production of desalinated water using thermal MSF desalination in the Mediterranean countries is calculated to be **1,357,597.00 m^3/day** resulting in the emission of **13,575,970 Kg of CO_2/day = 13,576.00 metric ton/day**. This is based on the assumption that thermal desalination will require KWHe that is equivalent to 2.54 KWHt. This sum is equivalent to **4,955,240 Metric Ton/year**.
3. *Estimated total CO_2 emission from MED desalination plants in Mediterranean Region*: The current production of desalinated water using thermal MED desalination in the Mediterranean countries is calculated to be **790,711 m^3/day** resulting in the emission of **7,907,110.00 Kg of CO_2/day = 7,907.11 metric ton/day**. This is based on the assumption that thermal desalination will require KWHe that is equivalent to 2.54 KWHt. This sum is equivalent to **2,886,095 Metric Ton/year**.
4. *Estimated total CO_2 emission from all online desalination plants in Mediterranean Region*: It is safe to assume that the current CO_2 emissions from all desalination plants operating in the Mediterranean Region for the year 2013 is equivalent to **15,087,680 metric Ton of CO_2/ year.**
5. According to Plan Bleu (2010), the sea water desalination market in the Mediterranean Region is set to reach by the year 2030 some 30 to 40 million m^3/day. Assuming the best scenario that all future desalination will be using only RO technology, the estimated total CO_2 emissions during the year 2030 will range from **22.75 to 29.0 Million metric tons/year**.
6. In case future desalination plants will be utilizing the mix of the three presently used technologies at the same ratio to desalinate the projected volume of 30-40 million m^3/day in the year 2030, then the predicted total CO_2 emission during the year 2030 will range from **38 to 50 Million metric tons/year**.

Figure 17 depicts the CO_2 emitted on a daily basis from seawater desalination in the Mediterranean region during the year 2013 as related to the daily volume of produced desalinated water.

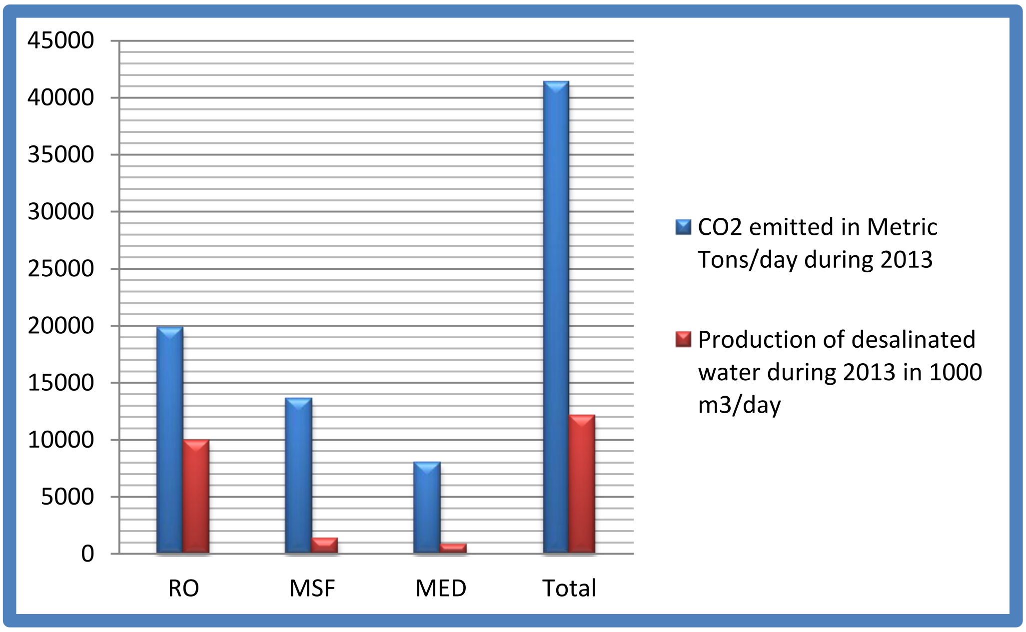


Figure 17: CO2 emitted on a daily basis from seawater desalination in the Mediterranean region during the year 2013 as compared to the daily volume of produced desalinated water.

Each m³ of desalinated water currently produced using the three major desalination technologies in the Mediterranean region results into the emission of an average 3.45 Kg of CO_2/m^3. During the year 2013, the estimated total mass of CO_2 emitted from desalination operations in the Mediterranean is some 15 million metric tons.

The total CO_2 emitted from desalination of Mediterranean seawater during 2013 is equivalent to putting 3.3 Million new cars on the roads or burning a volume of petrol slightly over 24 Million liters/day.

The given indicative figures point out that energy consumed to produce desalinated water has an important impact on the global environment and the Mediterranean countries commitments to the international climate change conventions. These alarming figures should also be considered in the national strategic plans of countries of the region for adaptation of the water sector to climate change. Resorting to desalination for adaptation of the water sector to climate change should not be on climate change mitigation expense.

Using the same calculations as the Australia Institute for water (2005), some 15 million metric tons of CO_2 equivalent emitted on a yearly basis from desalination industry in the Mediterranean Region - in a more colorful terms - is equivalent to putting another 3.3 million cars on the roads around the Mediterranean basin or burning a volume of petrol slightly over 24 Million liters/ day.

7.3 Environmental Aspects of Brine Reject in the Mediterranean Region

The desalination process separates saline water into two streams: A low dissolved solid concentration stream (fresh water or desalinated water), and another stream containing the remaining dissolved solids (brine reject or blow-down). To extract, separate and concentrate the salts in the reject brine solution in desalination plants, intensive thermal or electrical energy is required. During the process of desalination, the physical and chemical properties of the brine reject change significantly. The characteristics of the reject brine were found to be a direct function of the quality of the feed water, the desalination technology used, the percent recovery, the chemical additives used within the process, the construction material and proficiency of the operators.

In most of the cases, concentrated brine is negatively buoyant in seawater, giving it the tendency to sink and spread along the sea-bottom, displacing normally saline water. Higher concentration saline water can have a distressing effect on sea-bottom aquatic life with potential impacts on coastal ecosystems including their biodiversity.

Science and technology didn’t provide an ultimate universal solution to the disposal of brine into the near-shore marine environment devoid of drawbacks. Surface or submerged discharge of brine water has to be carefully designed to protect the near-shore marine environment through efficient diffusion and dilution. In this connection, outfalls for discharge of brine in the Mediterranean Basin need to be installed in a sufficiently large distance from Posidonia Oceanica beds and other sensitive ecosystems characterizing the near-shore Mediterranean Sea and considered as environmentally important to provide shelter and nursing ground for many marine forms of life.

The damaging effects of brine discharge can be mitigated by adequate dispersal, diffusion, dilution and mixing. In many instances, brine effluents are blended with cooling water discharges, to dilute them before disposal. In case disposal of concentrated brine is practiced, it should be coupled with adequate dilution, mixing and dispersal in a restricted (delineated) near-shore mixing zone of low biological sensitivity or biodiversity. The mixing zone is the area around the discharge location in which the brine and its constituents are diluted to ambient or given threshold values. The brine discharge should be regularly monitored according to the regulatory monitoring regime.

7.3.1 Environmental Aspects of Brine Thermal Discharge

The temperature of the brine water effluent resulting from thermal desalination processes is typically 5 to 8°C above the feed water temperature. However, 10 to 15°C above the naturally occurring temperatures in summer and winter seasons were also reported within the mixing zones. Effluent from thermal desalination plants is likely to be positively buoyant on the seawater surface due to its elevated temperature. The brine temperature from desalination plants using RO technology is about ambient values and does not require further evaluation. According to the US-EPA regulations, the allowable increase in the weekly average temperature beyond 300 meters from the point of discharge is 1° C. In addition, the daily average temperature cycle should not change, in frequency or amplitude. If the environment is open and well mixed, then the effects will only be noticeable within 300 meters from the discharge point (Khordagui, 2002).

7.3.2 Environmental Aspects of High Salinity in Brine Reject

The salinity of the Mediterranean is relatively high in the range of 39 g/l relative to 36 g/l for the Atlantic Ocean and lower than the Arbian Gulf average of 42 g/l. The salinity of the discharged brine from desalination plants depends on the recovery rate and can easily exceed double the natural seawater levels (ESCWA, 1993). The recovery rate of RO plants usually lies at 40-64 % (Lattemann, et al., 2008) with an average recovery of 50%. This average level of recovery will result in the discharge of brine at the outlet with double the concentration of the seawater at the intake. As for the MSF desalination plants, the recovery rate is in the range of 10% only and it is often diluted with power generation cooling water before discharging to the sea. Therefore, the discharge salinity usually is practically about 1.05 times higher than the feed water salinity (Höpner, 1999).

It is important to note that higher recovery reduces the volume of brine water discharged, yet it will increase the salt content by the same ratio. Reciprocally, lower recovery will reduce the salt content and increase the volume of brine water discharged..

1. **Estimated total mass of salt discharged from RO desalination plants on the Mediterranean Sea in 2013:**
   - Salinity of the Mediterranean seawater is 39 gm/l equivalent to 39 Kg/m^3
   - Daily production from RO desalination plants is 9,926,161 m^3/day.
   - Volume of sea water entering the desalination plant as feed-water assuming 50% recovery is 19,852,322 m^3/day.
   - Volume of brine discharged is 19,852,322 m^3/day x 0.5 = **9,926,161 m^3/day**.
   - Mass of salt discharged in the brine is = 0.039 Kg of salts/m^3 x 9,926,161 m^3/day = 387,120 Kg of salts/day x concentration factor of 2.0 = **774,241 Kg of salts/day**.
   - Mass of salt discharged on an annual basis is some **283,000 Tons** of salts/year.
2. **Estimated total mass of salt discharged from MSF desalination plants on the Mediterranean Sea in 2013:**
   - Salinity of the Mediterranean seawater is 39 gm/l equivalent to 39 Kg/m^3
   - Daily production from MSF desalination plants is 1,357,597 m^3/day.
   - Total volume of feed-water entering the desalination plant, assuming 10% recovery, is 1,357,597 m^3/day x 10 = 13,575,970 m^3/day.
   - Volume of brine discharged is 13.6 Million m^3/day x 0.9 = 12.24 Million m^3/day.
   - Mass of salt discharged in the brine is = 0.039 Kg/m^3 x 12.24 Million m^3/day = 477.360 Kg salts/day x concentration factor of 1.1 = **525,096 Kg of salts/day**.
   - Mass of salt discharged on an annual basis is **192.000 tons of salts/year**
3. **Estimated total mass of salt discharged from MED desalination plants on the Mediterranean Sea in 2013:**
   - Salinity of the Mediterranean seawater is 39 gm/l equivalent to 39 Kg/m^3
   - Daily production from MED desalination plants is 790,711 m^3/day.

- Total volume of feed-water entering MED desalination plants, assuming 20% recovery, is 790,711m^3/day x 5 = 3.95 Million m^3/day.
- Total volume of brine discharged is 3.95 Million m^3 of feed water/day x 0.8 = 3.16 Million m^3/day.
- Mass of salt discharged in the brine is = 0.039 Kg/m^3 x 3.16 Million m^3/day = 123,351 Kg salts/day x concentration factor of 1.2 = **148,021 Kg of salts/day**.
- Mass of salt discharged on an annual basis is **54,000 tons of salts/year**

4. **Estimated total mass of salt discharged from desalination plants into the near-shores of the Mediterranean Sea during 2013:**

- 283,000 ton/year from RO desalination + 192,000 tons/year from MSF desalination + 54,000 ton/year from MED Desalination = **529,000 tons of salts/year.**

5. **Projected total mass of salt discharged from desalination plants into the near-shores of the Mediterranean Sea during the year 2030:**

- According to Plan Bleu (2010), the sea water desalination market in the Mediterranean Region is set for high growth to reach by the year 2030 some 30 to 40 million m^3/day. Assuming the most likely scenario that all future desalination will be using RO technology, the estimated total mass of salt discharged during the year 2030 will range from **850,000 to 1,132,000 tons/year**.

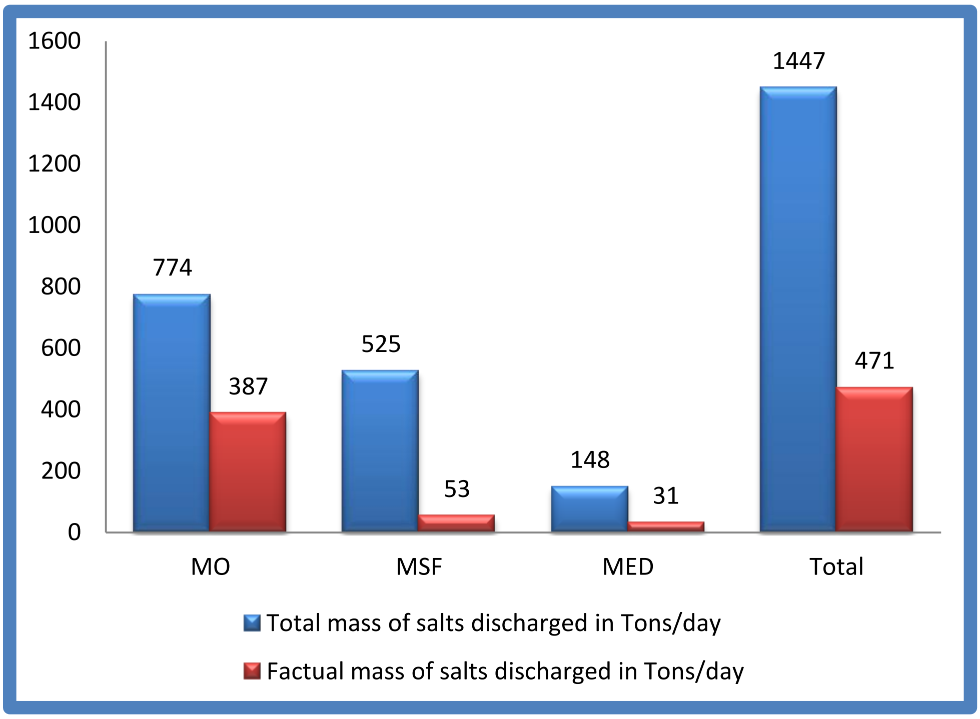
6. **Factual mass of salts discharged to the near-shore marine environment of the Mediterranean Sea:**

The actual mass of salts discharged into the near-shore marine environment is practically equivalent only to the net salt extracted through desalination to produce fresh water. Any other volume of water rejected in the form of brine to the marine environment is basically seawater with identical salt concentration as in the effluent without any additional increment to the salt content. Based on this fact, the real incremental mass of salts discharged in the brine reject during 2013 is calculated as follows:

- The real incremental increase in the total mass of salts discharged into the near-shore of the Mediterranean from RO desalination plants is: 9,926,161 m^3 of fresh water production/day X 0.039 Kg salts/m^3 = **387.12 tons of salts/day**. This would be equivalent to **141,299 ton of salts/year**.
- The real incremental increase in the total mass of salts discharged into the near-shore of the Mediterranean from MSF desalination plants: 1,357,597 m^3 of fresh water production/day X 0.039 Kg salts/m^3 = **53.00 tons of salts/day**. This would be equivalent to **19,345 ton of salts/year.**
- The real incremental increase in the total mass of salts discharged into the near-shore of the Mediterranean from MED desalination plants is = 790,711 m^3 of fresh water production/day X 0.039 Kg salts/m^3 = **31.00 tons of salts/day**. This would be equivalent to **11,315 ton of salts/year**.
- The total incremental increase in salt content in the rejected brine from all desalination plants is **141,299 ton of salts/year** from RO technology + **19,345 ton of salts/year** from MSF technology + **11,315 ton of salts/year** = **172,000.00 ton of salts/year**.

- According to Plan Bleu (2010), the sea water desalination market in the Mediterranean Region is projected to grow to reach some 30 to 40 million m^3/day by the year 2030. Assuming the most likely scenario that all future desalination will be using RO technology, the predicted incremental increase in total salts discharged during the year 2030 will range from **423,000 to 565,000 metric tons/year**.

The total and factual masses of salts discharged on a daily basis to the near-shores marine environment of the Mediterranean Sea are depicted in Figure 18. The projected mass of salts to be discharged during the year 2030 in case desalination capacity reaches 40 Million m^3/day as



expected, will be in the range of 1570 Metric Tons/day.

Figure 18: Total and factual masses of salts discharged on a daily basis to the near shores marine environment of the Mediterranean Sea in Metric Tons during the year 2013.

Salt Concentration in Brine Reject from various Desalination Technologies in the Mediterranean:

- With an estimated 50% recovery, the average salinity discharged from RO desalination plants in the Mediterranean is **78 g salt for each m^3**.
- With an estimated 10% recovery, the estimated average salinity discharged from MSF desalination plants in the Mediterranean is **42.9 gm salt for each m^3**.
- With an estimated 20% recovery, the average salinity discharged from MED desalination plants in the Mediterranean is **46.84 gm salt for each m^3**.
- During the year 2013, the average salinity discharged from desalination operations in the Mediterranean is **57.2 gm salt for each m^3**.

7.3.3 Environmental Aspects of Anti-Scalants in Brine Reject

The chemical analysis of sea water indicates that scales such as alkaline scales can form in thermal desalination plants. These scales occur when the bicarbonate ion breaks down by heating as follows:

$$2HCO_3^- = CO_2 + H_2O + CO_3^{2-} \quad \text{......... (1)}$$

The resulting carbonate ions can react in either one of the following ways:

$$Ca^{2+} + CO_3^{2-} = CaCO_3 \quad \text{.................. (2)} \quad \text{or}$$

$$CO_3^{2-} + H_2O = 2OH^- + CO_2 \quad \text{.............. (3)}$$

Consequently, heating will cause the original bicarbonate content of the seawater to give an equivalent concentration of carbonate or hydroxyl ions. The solubility product of $CaCO_3$ and $Mg(OH)_2$ governs the respective concentration that can exist in solution, respectively. At temperature below 82°C, reaction (2) predominates and $CaCO_3$ deposition prevails. Above 82°C, hydroxyl ion formation is favored, leading to Mg $(OH)_2$ precipitation.

7.3.3.1 Environmental Aspects of Acid Addition

In order to control calcium carbonate scaling, concentrated sulfuric acid (H_2SO_4, 93%) is added to the feed water to remove the bicarbonate ions. The addition of sulfuric acid breaks down the bicarbonate alkalinity and prevent the calcium carbonate scales from forming according to the following reaction:

$$HCO_3^- + H^+ = CO_2 + H_2O \quad \text{................ (4)}$$

The addition of H_2SO_4 leads also to the formation of mainly insoluble calcium sulfate and to a lesser extent barium and strontium sulfate scales according to the following reaction:

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2 \quad \text{........ (5)}$$

The solubility of the sulfate salts in seawater decreases with the increase of temperature and concentration of Ca^{2+}. Another problem connected with the precipitation of $CaSO_4$ is that the compound is not readily removed from the heat exchanger tubes by normal acid wash.

RO plants often use sulfuric acid at 20-100 mg/l in order to avoid scaling. This practice leads to the decrease of the feed water pH to 6-7. The brine reject could be treated with lime prior to discharge to the sea to re-establish its pH to ≈ 8.3.

7.3.3.2 Environmental Aspects of Polyphosphate Scale Inhibitors

A threshold scale inhibitor such as mixtures of sodium hexa-meta-phosphate (SHMP) and surface active agents like lignin sulphonic acid derivatives and esters of polyalkyl glycols are added in desalination plants at a dose ranging from 4 to 6 ppm to hamper the growth of carbonate and/or sulfate crystals. These polyphosphates are effective only at temperatures lower than 90°C. They are commercially available under various trade names such as Hagevap, Albrevap, Salvap, etc. According to MEDRC (2010), *polyphosphates* are on the retreat because of two main disadvantages. (1) Their reduced stability at temperatures higher than 90°C which makes them impractical for most thermal applications and their environmental impacts in the surrounding near-shore marine environment. (2) The greatest environmental impact of polyphosphate in reject brine on the near-shore marine environment lies in its nutritional value which may lead to eutrophication.

7.3.3.3 Environmental Aspects of Polymer Scale Inhibitors

For high temperature scale inhibition, other agents have appeared on the market under commercial names such as Belgard EV, Belgard EV2000, Flocon 247. These are mainly polymers of organic acids such as maleic anhydride and acrylic acids applied at doses ranging from 2-4 mg/l.

The estimated discharges of polymeric anti-scalants in the near-shores of the Mediterranean Sea is calculated based on the assumption that similar doses of 2.0 ppm are applied at the intakes of MSF, MED and RO desalination plants. The levels of residual anti-scalants at the outlet of desalination plants were reported by Khordagui (1997) to range between 0.8 and 1.00 ppm. Morton et al (1996) reported 0.53 ppm. An arbitrary value 0.5 ppm will be used to estimate the total mass of these anti-scalants polymers currently discharged with the brine reject on a daily basis in the near-shores of the Mediterranean.

1. **Estimated total mass of polymer anti-scalants discharged from RO desalination plants on the Mediterranean Sea in 2013:**

- Daily production from RO desalination plants is 9,926,161 m^3/day.
- Volume of sea water entering the desalination plant as feed-water assuming 50% recovery is 19,852,322 m^3/day.
- Volume of brine discharged is 19,852,322 m^3/day x 0.5 = 9,926,161 m^3/day.
- Mass of anti-scalants discharged in the brine is = 0.5 gm of anti-scalants/m^3 x 9,926,161 m^3 of brine discharged/day = 4,963,080 g of anti-scalants/day = **5 tons/day**.
- Mass of anti-scalants discharged from RO plants on an annual basis in the Mediterranean is some **1,825 tons/**year.

2. **Roughly Estimated total mass of polymer anti-scalants discharged from MSF desalination plants on the Mediterranean Sea in 2013:**

- Daily production from MSF desalination plants is 1,357,597 m^3/day.
- Total volume of feed-water entering the desalination plant, assuming 10% recovery, is 1,357,597 m^3/day x 10 = 13,575,970 m^3/day.
- Volume of brine discharged is 13.6 Million m^3/day x 0.9 = 12.24 Million m^3/day.
- Mass of residual anti-scalants discharged in the brine is = 0.5 gm of residual anti-scalants/m^3 brine x 12.24 Million m^3 of discharged brine reject/day = 6,120,000 gm of anti-scalants/day = **6.12 tons** of residual anti-scalants/day.
- Mass of anti-scalants discharged on an annual basis from MSF desalination plants in the Mediterranean is **2,233.00 tons of anti-scalants/year**

3. **Estimated total mass of polymer anti-scalants discharged from MED desalination plants on the Mediterranean Sea in 2013:**

- Daily production from MED desalination plants is 790,711 m^3/day.
- Total volume of feed-water entering MED desalination plants, assuming 20% recovery, is 790,711m^3/day x 5 = 3.95 Million m^3/day.

- Total volume of brine discharged is 3.95 Million m^3 of feed water/day x 0.8 = 3.16 Million m^3/day.
- Mass of anti-scalants discharged in the brine is = 0.5 gm/m^3 x 3.16 Million m^3/day = **1.58 tons** of residual anti-scalants/day.
- Mass of residual anti-scalants discharged from MED desalination plants in the Mediterranean on an annual basis is **577 tons of anti-scalants/year**

4. **Estimated total mass of residual polymer anti-scalants discharged from desalination plants into the near-shores of the Mediterranean Sea during 2013:**

- The daily discharge of residual anti-scalants from desalination of seawater in the Mediterranean basin is 5.0 Ton/day from RO desalination + 6.12 Ton/day from MSF + 1.58 Ton/day from MED desalination = **12.7 Ton residual anti-scalants/day**.
- 1,825 ton/year from RO desalination + 2,233 ton/year from MSF desalination + 577 ton/year from MED Desalination = **4,635 tons of residual anti-scalants/year.**

5. **Predicted total mass of residual polymer anti-scalants discharged from desalination plants into the near-shores of the Mediterranean Sea during 2030:**

- According to Plan Bleu (2010), the sea water desalination market in the Mediterranean Region is projected to grow to reach some 30 to 40 million m^3/day by the year 2030. Assuming the best scenario that all future desalination will be using RO technology, the daily mass of residual polymeric anti-scalants to be discharged in the near shores of the Mediterranean Sea is projected to range from **15 to 20 metric tons/day** during 2030.
- The annual total mass of polymeric anti-scalants during 2030 might range between **5,475 to 7,300 metric tons/year**.

Based on the daily production of desalinated seawater in the Mediterranean region and assuming an average of 0.5 mg/l residue of polymeric anti-scalants, figure 19 depicts the daily discharge of the chemical from each desalination technology and the total discharges during the year 2013.

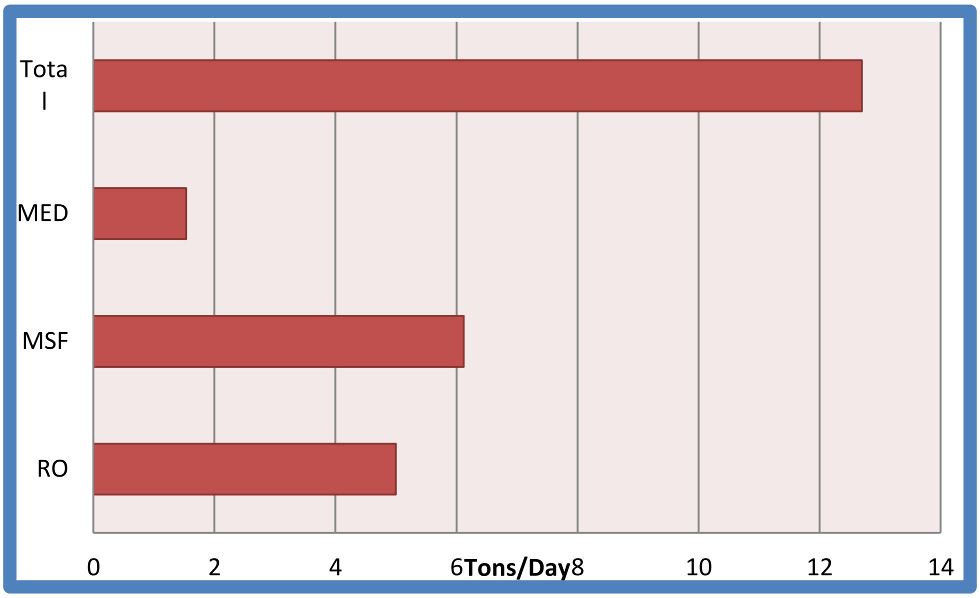


Figure 19: Mass of discharged polymeric anti-scalant from seawater desalination plants around the Mediterranean sea in tons/day during the year 2013.

7.3.4 ENVIRONMENTAL ASPECTS OF TRACE METALS IN BRINE REJECT

In thermal desalination plants, it is plausible to find corrosion and elution products in brine waters resulting from the effect of water flow, dissolved gases and treatment chemicals (acids) on the alloys utilized in the construction of desalination pipes and equipment's. The corrosion products may include harmful heavy metals such as Nickel (Ni), Copper (Cu) and Molybdenum (Mo) and less toxic metals such as Iron (Fe) and Zinc (Zn). The amount of these metal ions is directly related to the REDOX potential, pH and the material in contact with water during the desalination process. Heavy metal discharge as a consequence of corrosion and elution is a main concern in MSF and MED desalination plants because of the high temperatures involved. Depending on the materials used for the heat exchanger tubes and vessels, copper, nickel, iron, zinc and other heavy metals are corroded and discharged (Höpner, 1999). Most of the discharged metals in brine reject (around 80%) are found in their ionic soluble and bioavailable forms. Organically complexed or chelated metals are found at some 15% and particulate metals represents only 5% of the trace metals content.

The prevailing alloy for the heat exchanger tubes is usually made of copper-nickel which has poor corrosion resistance and accounts for the highest heavy metal pollution in MSF and MED plants. In RO plants, non-metal materials and stainless steel are predominating. There are traces of iron, nickel, chromium and molybdenum in the RO effluent, but the concentrations remain insignificant. Stainless steel materials comprise mainly of iron and lower rates of chromium, nickel and molybdenum. The toxicity and overall discharge concentrations are believed to be harmless on the short run. Concentrations might augment through pitting and failing process control.

In UAE, Shams El-Din et al. (1994), observed that the discharged brine from the Um-Al-Nar MSF power desalination plant in Abu-Dhabi carried measurable quantities of Cu, Ni and Manganese (Mn) resulting from the corrosion of metal tubes, water boxes and flash chamber wall material. They also noticed a rise in the concentration of these metals in the brine during the process of acid wash of distillers. In the Kingdom of Saudi Arabia (KSA) heavy metals (Cu, As, Pd, Ni and Fe) determination carried out by Saline Water Conversion Corporation (WSCC, 1997) for seawater feed, the mixing and the recovery zones in the near-shore waters of Al-Jubail desalination plant had extremely low concentration values. According to Mannaa (1994), the principal pollutants present in the brine effluent discharged from dual purpose plants in KSA are metal ions of corrosion origin such as Cu, Ni, Zn and Chromium (Cr).

Oldfield and Todd (1996), revealed an average minimum copper background concentration in the oceans of 0.1 ppb. They concluded that copper contents in brine reject of modern desalination plants with good process control and housekeeping is less than 100 ppb. For an acid treated plant a level of 200 ppb was reported. Copper concentrations in MSF effluents were often reported in the range of **15-100 ppb**.

On the other hand, Ni is contained by up to 30 % in the Cu-Ni heat exchanger alloys and is less toxic than copper. No real data exists about discharge concentrations, but they are believed to be much lower than that of copper. According to Lattemann and Hopner, (2003), Ni concentrations in brine reject are assumed to range between **0.002 and 2 ppb**. The U.S. Environmental Protection Agency (EPA) (2006) calls for a maximum concentration of 8.2 ppb for long term exposure. With proper dilution at the discharge point, most effluents are likely to reach this level after a short distance around the point of discharge.

As for Fe, Mannaa (1994), reported discharge levels of **25 micro gram/l**. Due to its low toxicity in the marine environment, US-EPA does not consider it as a priority pollutant and no criteria was defined for it.

For Cr, Fable and Rigitz (1995) calculated chromium concentration in brine discharge to range between **0.035 and 3.5 ppb**. This calculated concentration is far below the maximum criteria identified by US-EPA (2006) of 1.1 mg/l and the long term criterion of 0.050 mg/l for the toxic hexvalent chromium. Molybdenum was also calculated to range between **0.004 to 0.4 ppb**. Given the low toxicity of molybdenum, no water quality criteria were identified by US-EPA.

Estimation of trace metals discharges in the Mediterranean Sea during the year 2013 from thermal desalination plants:

1. Estimated metals discharged from MSF desalination plants on the Mediterranean Sea in 2013:

At an assumed percent recovery of 10% the daily heavy metals input of MSF plants into the Mediterranean Sea is calculated to be as follows:

- Total volume of feed-water entering the MSF desalination plants, assuming 10% recovery, is 1,357,597 m^3 of produced desalinated water/day x 10 = 13.576 million m^3/day.
- Volume of brine reject discharged is 13.576 million m^3/day x 0.9 = **12.218 million m^3 of brine/day**.

Metal	Reported range in ppb	Minimum possible discharged load in Kg/day	Minimum possible discharged load in Kg/year	Maximum possible discharged load in Kg/day	Maximum possible discharged load in Kg/year
Copper	15-100 Oldfield and Todd (1996)	183	67,000	1,222	446,030
Iron	25 Mannaa (1994)	305	111,325	--	--
Nickel	0.002-2.0 Lattemann & Hopner (2003)	0.024	8.80	24.4	8,906
Chromium	0.035-0.35 Fable & Rigitz (1995)	0.430	157	4.30	1,570
Molybdenum	0.004-0.4 Fable & Rigitz (1995)	0.048	17.5	4.80	1,752

Table 1: Load of metals discharged into the near-shore marine environment from MSF desalination plants on the Mediterranean Sea during 2013.

2. Estimated metals discharged from MED desalination plants on the Mediterranean Sea in 2013:

- Total volume of feed-water entering the MED desalination plants, assuming 20% recovery, is 790,711m^3 of desalinated water/day x 5 = 3,953,555 m^3/day.
- Volume of brine discharged is 4.0 million m^{3}of feed water/day x 0.8 = **3.2 million m^{3}of brine/day**.

Metal	reported Range in ppb	Minimum possible discharged load in Kg/day	Minimum possible discharged load in Kg/year	Maximum possible discharged load in Kg/day	Maximum possible discharged load in Kg/year
Copper	15-100	48	17,520	320	116,800
Iron	25	80	29,200	--	--
Nickel	0.002-2.0	0.0064	2.366	6.4	2,366
Chromium	0.035-0.35	0.115	42	1.15	420
Molybdenum	0.004-0.4	0.0128	4.6	1.28	467

Table 2: Load of metals discharged into the near-shore marine environment from MED desalination plants on the Mediterranean Sea during 2013.

3. Estimated total metal discharged from MSF and MED desalination plants into the near-shores of the Mediterranean Sea during 2013:

Metal	reported Range in ppb	Lowest possible discharged load in Kg/day	Lowest possible discharged load in Kg/year	Highest possible discharged load in Kg/day	Highest possible discharged load in Kg/year
Copper	15-100	231	84,520	1,542	562,830
Iron	25	385	140,525	---	---
Nickel	0.002-2.0	0.030	11.16	30.8	11,272

Chromium	0.035-0.35	0.545	199	5.45	1,990
Molybdenum	0.004-0.4	0.0608	22.1	6.08	2,219

Table 3: Total load of metals discharged into the near-shore marine environment from MSF and MED desalination plants on the Mediterranean Sea during 2013.

Figure 20 illustrates the most likely minimum and maximum range of trace metals discharged into the near-shore of the Mediterranean Sea during the year 2013 in kg/year from MSF and MED seawater desalination plants.

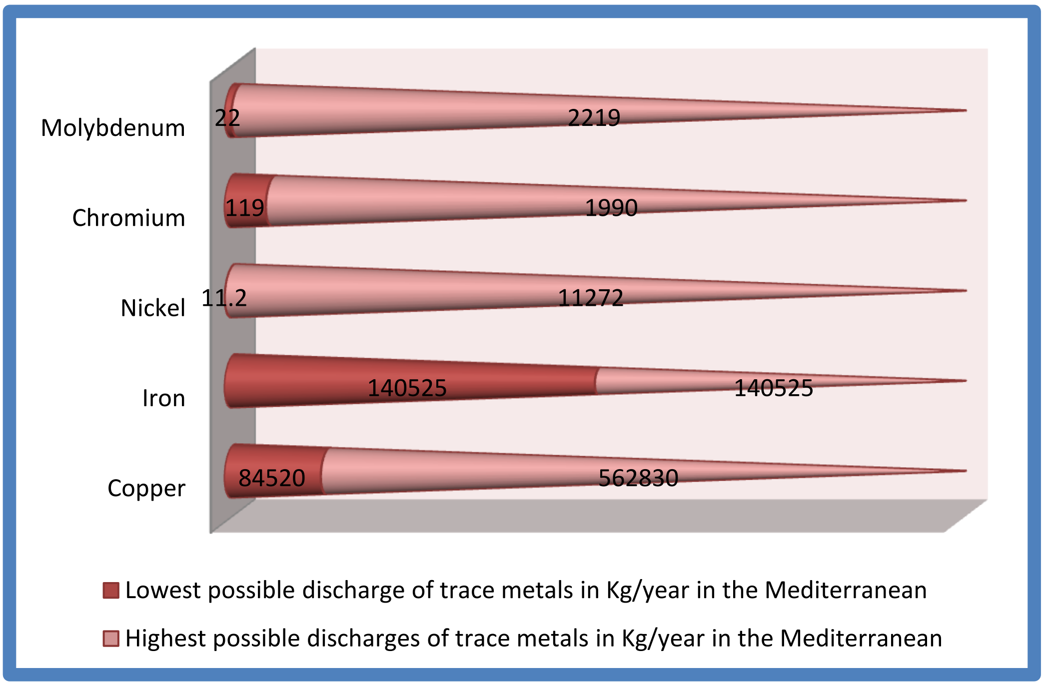


Figure 20: Estimated lowest and highest possible discharges of trace metals in the near- shore Mediterranean Sea from MSF & MED during the year 2013 in Kg/Year.

7.3.5 Environmental Aspects of Antifouling Agents (Chlorine) in Brine

For well over half a century, chlorine has proven to be of immense benefit in controlling biofouling in power and desalination plants, but its adverse toxic effects at trace levels have become evident. Desalination plants including RO use chlorine injection to protect the processes from biofouling. A typical dosage ranges from to 1 to 2 mg/l depending on the chemical and biological composition of the feed-water. Furthermore, shock chlorine doses are commonly applied intermittently at 10-15 mg/l for shorter durations to eliminate any potential formation of biofouling.

In RO Desalination Plants: RO plants often use polyamide membranes that are very reactive to chlorine. Therefore, de-chlorination of the feed water using sodium-bi-sulfite is carried out to avoid damage to the membranes. Nevertheless, trace levels of residual chlorine will still remain in the brine and the problem of the formed toxic halogenated organic compounds such as THMs will persist (Höpner, 1999). In many cases, if sodium-bi-sulfite commonly used for de-chlorination, is overdosed, it may affect dissolved oxygen levels in the reject water and possibly in near-shore seawater. According to WHO (2008), the anti-oxidant dose of sodium-bi-sulfite is usually 2-4 times the dose of the applied chlorine.

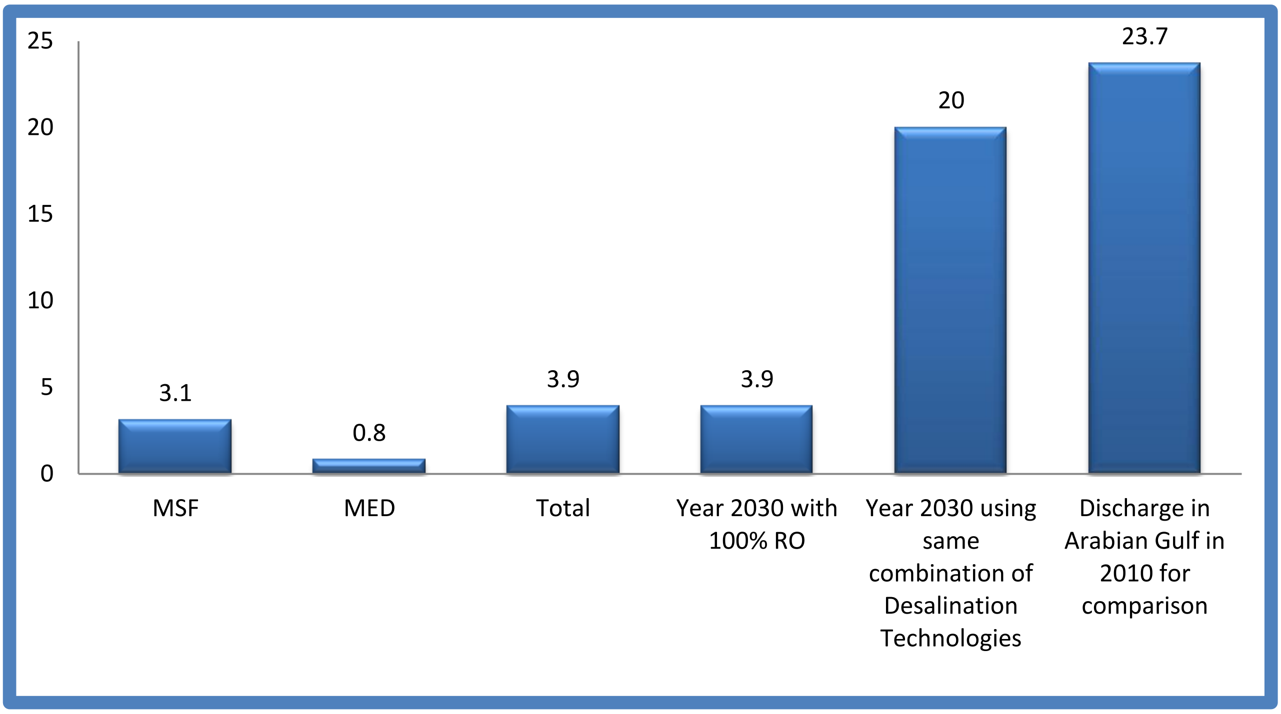
In MSF and MED Desalination Plants: The use and impacts of chlorine are more significant due to the use of larger volume of feed water, and higher doses of chlorine. Furthermore, de-chlorination is not a necessity in MSF and MED desalination plants. As a common practice and in order to ensure chlorine existence within the whole MSF and MED desalination cycle, chlorination doses are adjusted to maintain a constant residual of 0.2 to 0.3 mg/l in brine reject. In many instances concentrations of residual chlorine within the mixing zones, extending from 1.0 to 3.0 Km in diameter was reported at levels reaching 0.1 mg/l.

The mixing zone is the area around the discharge location in which the brine and its constituents are diluted to ambient or given threshold values.

At an assumed percent recovery of 10% and effluent concentration of 250 µg/l, the daily chlorine input of major MSF plants into the Mediterranean Sea is calculated to be as follows:

1. **Estimated total residual chlorine discharged from MSF desalination plants on the Mediterranean Sea in 2013:**
   - Total volume of feed-water entering the MSF desalination plants, assuming 10% recovery, is 1,357,597 m^3 of produced desalinated water/day x 10 = 13.576 million m^3/day.
   - Volume of brine reject discharged is 13.576 million m^3/day x 0.9 = 12.218 million m^3 of brine/day.
   - Mass of total residual chlorine discharged in the brine is assumed at 0.250 mg/l residual chlorine x 12.218 Million $m^3$of brine/day = **3,055 Kg/day**.
   - The mass of total residual chlorine discharged on an annual basis in the Mediterranean Sea from MSF desalination plants is **764 tons/year**.
2. **Estimated total residual chlorine discharged from MED desalination plants on the Mediterranean Sea in 2013:**
   - Total volume of feed-water entering the MED desalination plants, assuming 20% recovery, is 790,711m^3 of desalinated water/day x 5 = 3,953,555 m^3/day.
   - Volume of brine discharged is 4.0 million $m^3$of feed water/day x 0.8 = 3.2 million $m^3$of brine/day.
   - Mass of total residual chlorine discharged in the brine is = 0.250 mg/l residual chlorine x 3.2 Million m^3 of brine/day = **800 Kg/day**.
   - The mass of total residual chlorine discharged on an annual basis from MED desalination plants in the Mediterranean Sea is **292 ton/year**.
3. **Estimated total residual chlorine discharged from MSF and MED desalination plants into the near-shores of the Mediterranean Sea during 2013:**
   - The estimated total mass of residual chlorine discharged into the near-shore marine environment of the Mediterranean Sea from both MSF and MED desalination plants is **3.855 ton/day** or **1,056 ton/year**.
4. **Predicted total residual chlorine discharged from desalination plants into the near-shores of the Mediterranean Sea during 2030:**

- According to Plan Bleu (2010), the sea water desalination market in the Mediterranean Region is projected to grow to reach some 30 to 40 million m^3/day by the year 2030. Assuming the best scenario that all future desalination plants will be using RO technology, the predicted daily mass of residual chlorine to be discharged in the near shores of the Mediterranean Sea shall remain at no less than **3.9 tons/day or 1,420 tons/year if MSF and MED plants are not being decommissioned**.
- In case future desalination plants will be using the present mix of technologies at the same ratio to desalinate 30-40 million m^3/day, then the predicted daily mass of residual chlorine to be discharged in the near shores of the Mediterranean Sea is as follows:
- a- Current volume of brine discharged from RO assuming 50% recovery is = **9,9 Million m^3/day**. b- Current volume of brine discharged from MSF assuming 10% recovery is = **12.24 Million m^3/day**. c- Current volume of brine discharged from MED assuming 20% recovery is **3.16 Million m^3/day**. d- Total volume of brine currently discharged from desalination plants around the Mediterranean Sea is 25.3 Million m^3/day. Ration of RO / MSF / MED is = 39 / 48 / 13. e- The projected total volume of brine to be discharged by 2030 is **84 Million m^3/day**.
- In case similar mix of desalination technologies at the same ratio is used, the predicted daily mass of residual chlorine to be discharged in the near shores of the Mediterranean Sea in the



year 2030 shall increase to reach between **15 to 20 tons/day or 5,500 to 7,300 tons/year**.

Figure 21:Residual chlorine discharge to the near-shore of the Mediterranean Sea from MSF & MED desalination plants in Tons/day during 2013 with projections for the year 2030.

7.3.6 Environmental Aspects of Trihalomethanes (THMs) in Brine Reject

The formation of THMs in brine water is a direct consequence of the chlorination process in which free chlorine reacts with the natural organics occurring in water and seawater and other organic pollutants acting as precursors to form THMs (Khordagui et al. 1983). Shams El-Din et al. (1994), reconfirmed the fact that interaction of chloramines with bromide ion in seawater immediately sets free elemental bromine which reacts with organic precursors in the sea water forming brominated hydrocarbons that are known for their carcinogenic properties and may be harmful to seafood and possibly to human health. Halogenated hydrocarbons including THMs, arise from reaction of chlorine with precursors of natural origin such as humic substances, algae, organic substrates, etc. which will predominantly produce brominated THMs in seawater (Khordagui, 1995).

According to Ali & Riley (1986), out of 20 possible THMs only 4 were consistently detected in brine waters. Brominated species were dominating the formation distribution, with bromoform ($CHBr_3$) accounting for more than 90% of the total THMs followed by dibromochloromethane ($CHBr_2Cl$). The detected levels of total THMs in Kuwait ranged from 90 ppb in the immediate vicinity of the point of discharge to less than 1 ppb within few kilometers seaward (Ali & Riley, 1986). Lower levels were detected by Saeed et al. (1998). Currently, there is some growing concern within the scientific community about possible damage to the near-shore marine ecology into which chlorinated brine is discharged. Except in the immediate vicinity of the brine water point of discharge, it is very unlikely that the concentrations of THMs are significant enough to pose any ecological threat. However, near the point of discharge the relatively high concentrations reported by Ali & Riley (1986) may have some environmental effect. It is important to note that THMs are formed in all desalination technologies including RO desalination. Despite the fact that the feed water to RO membranes is dechlorinated using sulfite, THMs are formed once seawater at the intakes is chlorinated prior to dechlorination. It is obvious that the level of THMs resulting from chlorination in RO desalination is substantially lower than the THMs formed during thermal desalination.

The THMs formation problem can be further complicated by the fact that low boiling point THMs can reach the desalination plant intakes and re-circulate within the system. Once in the intakes, THMs will evaporate in thermal desalination plants with the steam, then co-distill and concentrate in the potable water condensate. The possible appearance of THMs in desalinated water can pose a serious public health threat to the served communities (Khordagui, 1995).

7.3.7 Environmental Aspects of Chlorinated Volatile Liquid Hydrocarbons (VLHs)

Volatile Liquid Hydrocarbons (VLHs) are defined empirically as compounds with boiling points ranging between those of *n*-C6 and *n*-C14 (Sauer, 1981 and McDonald et al., 1984). Hydrocarbons within this range include normal and branched alkanes, monocycloalkanes, aromatics and alkyl–substituted analogues. The light aromatics such as benzene and toluene are considered to be the most immediately toxic components of petroleum other than the carcinogenic polycyclic aromatics (Blumer, 1971). Since seawater is used for drinking after desalination, the produced distillate is free of all of the seawater's contaminants except for VLHs that can vaporize and consequently, co-distill during the desalination process (Ali and Riley, 1989; Ali and Riley, 1990 and Latif et al., 1989). The reaction of discharged residual chlorine with VLHs contaminants would lead to the formation of more complex chlorinated VLHs such as chloro-benzene, chlorophenols, etc. (Saeed et al. 1998). This aspect will be discussed in more details in the following section. The presence of traces of benzene or phenol pollutants in the near-shore sea water, for example, can lead to the formation of chloro-benzene and chloro-phenols respectively.

Despite their documented hazard to the aquatic environment and their ubiquity, very little information is available on VLHs in the Mediterranean marine environment. Khordagui (1995) have reported extremely low levels of VLHs in near-shore marine environment of Kuwait. Traces of oil and grease leaking from operating power-desalination plants were found to be the main precursors for the detected part per trillion (ppt) levels of halogenated VLHs in Kuwait's near shore marine environment. The detected levels of chlorinated VLHs at the nano-gram/liter (ppt) should not give reasons for concern.

In the near-shore of the Mediterranean sea, the opportunity for the formation of halogenated VLHs exists. This will be pending the presence of petroleum hydrocarbons pollution (even at trace levels) to blend with brine reject containing residual chlorine in the vicinity of thermal desalination outfalls.

7.3.8 Environmental Aspects of Antifoaming Agents in Brine Reject

Antifoaming agents are surface active chemical agents applied mainly to thermal desalination processes to reduce surface tension and disperse foam causing organics in the water-air interface, which are mainly the product of excretion and decomposition of phytoplankton's in the feed water to desalination plants (Hopner 1999). The commonly used antifoaming agents are polyglycols and fatty acids with typical dosages of about 0.1 mg/l. The dosage depends mainly on the raw water quality and its seasonally changing organic composition. This dose of antifoam is substantially diluted with cooling waters at the desalination plants outfall reducing its concentration to less than half of its original value to 0.05 mg/l. The most common polyglycol often used by desalination industry is polyethyleneglycol. It is soluble in water but very resistant to hydrolysis and sensitive to oxidizing agents particularly at high temperature (Hopner 1999).

Estimation of residual antifoams discharges in the Mediterranean Sea during the year 2013.

At an assumed percent recovery of 10% and effluent concentration of 50 µg/l, the daily antifoaming agents input of major MSF plants into the Mediterranean Sea is calculated to be as follows:

1. **Estimated total residual antifoam discharged from MSF desalination plants on the Mediterranean Sea in 2013:**
   - Total volume of feed-water entering the MSF desalination plants, assuming 10% recovery, is 1,357,597 m^3 of produced desalinated water/day x 10 = 13.576 million m^3/day.
   - Volume of brine reject discharged is 13.576 million m^3/day x 0.9 = 12.218 million m^3 of brine/day.
   - Mass of total residual antifoam discharged in the brine is assumed at 0.050 mg/l residual antifoam x 12.218 Million $m^3$of brine/day = **611 Kg/day.**
   - The mass of total residual antifoam discharged on an annual basis in the Mediterranean Sea from MSF desalination plants is **223 tons/year**.
2. **Estimated total residual antifoam discharged from MED desalination plants on the Mediterranean Sea in 2013:**
   - Total volume of feed-water entering the MED desalination plants, assuming 20% recovery, is 790,711m^3 of desalinated water/day x 5 = 3,953,555 m^3/day.

- Volume of brine discharged is 4.0 million $m^3$of feed water/day x 0.8 = 3.2 million $m^3$of brine/day.
- Mass of total residual antifoam discharged in the brine is = 0.050 mg/l residual antifoam x 3.2 Million $m^3$of brine/day = **160 Kg/day**.
- The mass of total residual antifoam discharged on an annual basis from MED desalination plants in the Mediterranean Sea is **58 ton/year**.

3. **Estimated total residual antifoam discharged from MSF and MED desalination plants into the near-shores of the Mediterranean Sea during 2013:**

- The estimated total mass of residual antifoam discharged into the near-shore marine environment of the Mediterranean Sea from both MSF and MED desalination plants is **711 Kg/day** or **281 ton/year**.

7.3.9 Environmental Aspects of RO Membranes Cleaning Chemicals

RO membrane efficiency is strongly reduced by chemical scaling from impurities in feed water, by biological growth and by physical blockage of the membranes with minute particulates. This phenomenon is often surmounted with chemicals that appear in the discharged effluent.

The conventional pretreatment of feed seawater to prevent fouling of the membranes includes the removal of suspended solids, chlorine injection to prevent biofouling, addition of ferric chloride as a coagulant and sulfuric acid for the adjustment of pH. With increased back pressure, the filtration system is also backwashed with a 12 % biocide solution of sodium hypochlorite. On its way to the RO membranes the pretreated feed-water is further treated with an antiscalant. The dose of antiscalant depends on the quality of the feed water at the intake. A typical dose ranging from 4 to 6 ppm is discharged with the brine. In order to remove deposited metal oxides and scale formations on RO membranes, acids are dozed to lower pH to 2-3. Other cleaning agents such as detergents, biocides and complex forming chemicals are also used either separately or combined depending on the kind of fouling and RO membrane in use. The cleaning intervals depend on the feed water quality and efficiency of the pretreatment system. Practically most of the added chemical agents are discharged with brine to the receiving environment.

8 Environmental Impacts of Desalination Including Fate and Transport of Brine Reject Pollutants in the Near-Shores of the Mediterranean

Conceptually, once discharged to the near-shore marine environment of the Mediterranean Sea, pollutants in the brine reject will be subject to different degradation processes that influence the persistence, partitioning, transport, bio-availability and overall fate of the pollutants. However, regardless of the specific degradation process, what generally occurs is that organic chemicals and organo-metal chelates are reduced in size and complexity. Degradation processes in the marine environment generally take place through one or more of the following processes:

- ***Aerobic biodegradation*** in which the pollutant would breakdown by microorganisms that utilize oxygen;
- ***Anaerobic biodegradation*** is the breakdown of chemicals by microorganisms without the use of oxygen, mostly in marine sediments.
- ***Hydrolysis*** in which the pollutant would breakdown by reaction with water;
- ***Oxidation or reduction*** in which the pollutant exchanges its electrons with another reactive compound found in water;
- ***Photo-oxidation*** is a process by which sunlight through photolysis and oxygen jointly breakdown the pollutant.
- ***Volatilization*** is a process by which low boiling point volatile chemicals such as THMs and chlorinated VLHs will gradually strip from seawater.

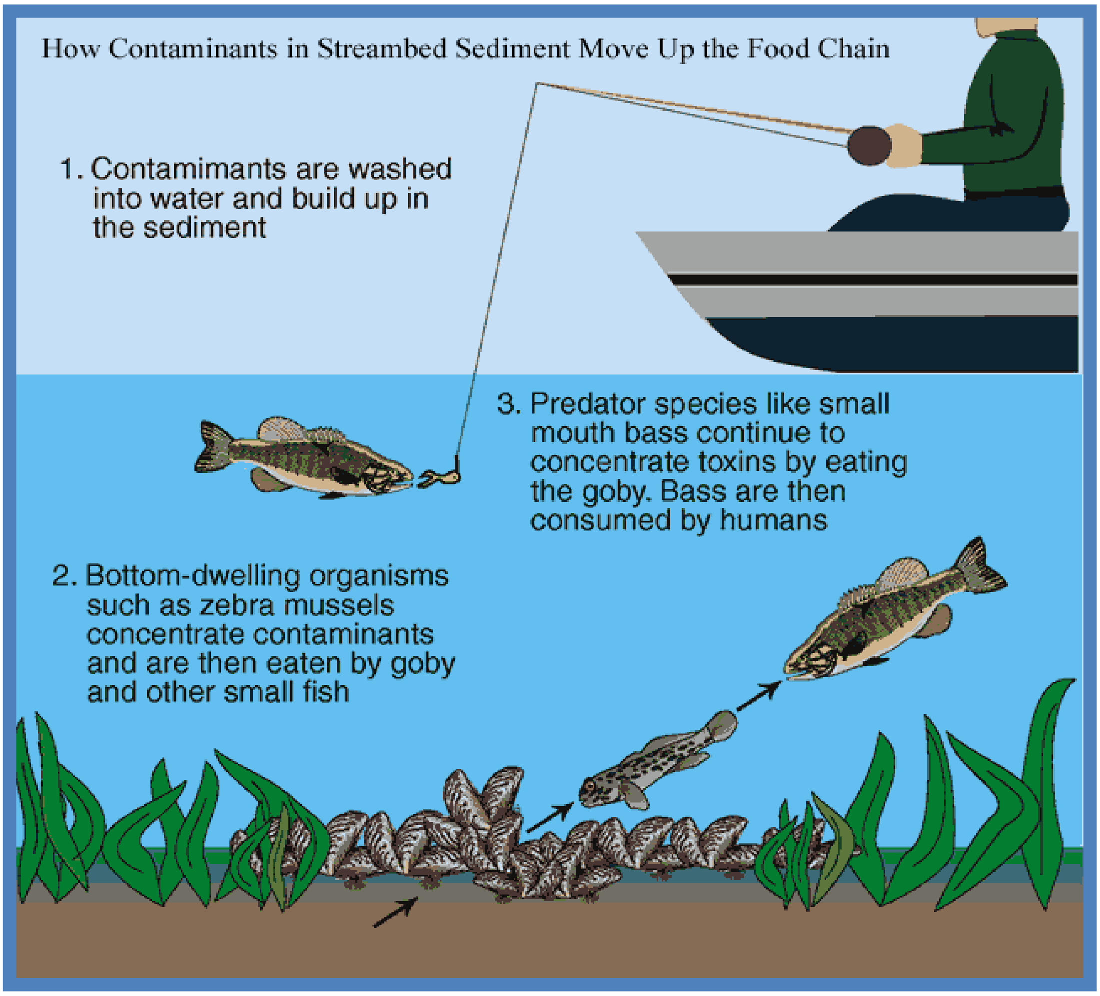
Persistence refers to a water pollutant that is discharged with brine reject and is slow to degrade in the marine environment. Some of these pollutants can ***adsorb*** to sediment and be transported to other locations. Examples of persistent chemicals are trace metals which do not degrade.

Bioaccumulation or bioconcentration refers to persistent chemicals that build up in the tissues of living marine organisms to concentrations that are higher than in the surrounding environment. These pollutants are often lipophilic in nature, which allows them to be taken up and stored in fatty tissues.

Biomagnification refers to persistent chemicals that increase in concentration as they transfer up the food chain so that they accumulate to much higher concentration levels with each successive food chain level.

Characterizing the fate and movements of persisting pollutants discharged in desalination brine reject and which also may bioaccumulate through various environmental media such water, sediments, and biota is a highly complex task, and generally available methods for evaluating the fate and transport pathways have only recently been developed. Many models that estimate the concentrations of persistent and bioaccumulative pollutants over time in the various environmental compartments are being developed. These models simulate both physical and chemical processes such as leaching (dissolution), soil/sediment adsorption, and chemical speciation (oxidation/reduction, precipitation reactions). Some models also evaluate the biodegradation of organic pollutants by bacteria and other organisms in sediment and water. Applying these models requires a large number of site-specific inputs and many measurements of the physical and chemical characteristics of pollutants and the marine receiving environment. It is beyond the scope of this study to discuss the processes that may be modeled in the assessment of pathways to bioaccumulation and biomagnification. Figure 22: Illustrates how contaminants can bioaccumulate, biomagnify and move up the food chain affecting environmental health.

Figure 22: Bioconcentration and biomagification of pollutants in aquatic environment reaching the food chain.



Source: http://water.usgs.gov/nawqa/images/fig23.gif

The brine reject is mixed with the ambient seawater at the point of discharge. Depending on the salinity and temperature of the effluent and the salinity and temperature of the ambient seawater, the effluent will either be positively (less dense than ambient), neutrally or negatively (denser than ambient) buoyant. In case the effluent's density is higher than the ambient seawater, it has a tendency to sink to the bottom of the near-shore seawater. These phenomena will be a function of the design of the brine outlets; water depth; hydrographic circulation regime including eddy currents and tide; wind speed; ambient temperature; salinity; etc. Under worst case conditions, the biota occupying the seafloor could thus be consistently exposed to major stressing factors such as salinity, residual chemicals and trace metals. Together, these factors will cause the effluent to stratify and will reduce the mixing and dilution of the other major contaminants such as trace metals. Consequently, trace metal concentrations will often be much higher than the ambient levels normally encountered, representing a real threat to the biota occupying the deep stratum of the near-shore seawater.

Poor circulation and inadequate dilution in enclosed embayments and harbors can act as a sink, where pollutants in brine reject can remain for long duration causing major deleterious effects to the marine biota. Trace metals can also be effectively adsorbed onto the sediment forming a latent environmental threat.

The MSF and MED desalination plants periodically produce a second type of discharge (effusion) that is low in temperature, pH and salinity but high in trace metals (copper, nickel and iron). When these plants shut down for maintenance, the corroded copper-nickel surfaces becomes dry and oxidized. When service is resumed, the formed loosened copper powder and scale are washed into the sump with the first water circulated sea the system.

It is important to note that effusion or blow-down during commissioning and/or following the start-up of MSF & MED desalination plants after routine maintenance operations might cause more environmental damage than the brine discharged during normal operation.

8.1 Environmental Impacts of Withdrawing Masses of Seawater into Desalination Plant Intakes

The most noteworthy adverse environmental impacts of seawater desalination plants are likely to be caused by their intakes rather than their outlets.

According to the World Wide Fund for Nature (WWF, 2007), "seawater is not just water. It is a lively habitat and contains an entire ecosystem of phytoplankton, fishes, and invertebrates." Unfortunately, the issue of impingement and entrainment losses of sea life is often overlooked in the consideration of specific desalination plants.

According to Melbourne Water & GHD (2007), open seawater intakes usually result in serious loss of eggs and larvae of fish and benthic invertebrate species, spores from algae and sea-grass, phytoplankton and zooplankton, as well as smaller marine organisms when these are drawn into the plant with the seawater. Due to the pretreatment in desalination system, which among other steps involves chlorination, it must be assumed that the survival rate of organisms within the desalination plant is minimal.

For long time the environmental impacts related to the discharge of desalination brine were always considered to be of highest concern. Recently, the desalination intake related impacts are considered to potentially have the most severe environmental impacts that can be attributed to the industry. According to the California Coastal Commission (2004), the most significant direct adverse impacts of a desalination facility are likely to be caused by its intake rather than its outlet. However, the information available about the subject, are sparse when compared to the volume of literature existing on the environmental impacts of brine discharge.

Quantifying the cumulative environmental impacts of seawater intakes of desalination in the Mediterranean Sea is an extremely difficult task that should start by ensuring the availability of background levels of near-shore marine biota, taxonomy and diversity. However, based on experience from around the world, it is conceptually sound to affirm that the large and ever augmenting volume of seawater diverted for desalination from the Mediterranean Sea will have serious cumulative impacts on the near-shore marine ecology.

Impingement:

Impingement occurs when marine organisms become trapped on intake screens due to suction from the seawater intake velocity. According to California Desalination Task Force (2003), mortality of marine organisms owed to impingement is typically due to asphyxiation, starvation and/ or exhaustion due to being pinned up against the intake screens or from the physical force of jets of water used to clear screens of debris (California Water Desalination Task Force, 2003). The single most important factor in impingement, however, is the near-field distribution of fin-fish and macro-invertebrates.

Several cases of massive fish kill were reported in the vicinity of power-desalination plants in the Gulf Region (Khordagui, 1994). Although factors such as intake design, rate of inflow, seasonal changes in seawater temperature, species-specific behavior, and others factors may affect impingement rates. Unfortunately, the mutual interactions of these variables are poorly understood..

For coastal power stations using once through cooling water, the impacts of impingement are typically assessed solely on impacts to commercially and recreationally fished species. For instance, the Huntington Beach power plant examined the impingement impacts of eleven power plants located on the southern California coast. The estimated combined total impingement mortality from the once-through cooling systems were estimated to amount to 8–30% of the recreational fishing totals for Southern California (California Energy Commission, 2005). Impingement effects may also be a significant source of mortality for endangered or protected marine species, such as sea turtles and/or eels.

Figure 23: Massive Pelagic fish kill (Sardinella) in the fore-bay of a desalination plant in the Gulf region.
Source: Khordagui (1994),

Entrainment:

Entrainment occurs only when smaller marine organisms such as fish eggs, larvae and plankton not excluded by screen bars at the intake get drawn into the desalination plant with the feed-water. Since entrainment typically results in confirmed death, a 100% mortality rate can be assumed. Mortality usually occurs as a result of pressure changes within the facility components, exposure to toxic chemicals and high temperature in thermal desalination. According to the Pacific Institute (2006), entrainment has the potential to affect biological population levels by repressing recruitment, which could affect commercially valuable fish populations.

As stated by Demitz (2006), the main question is if entrainment causes a significant additional source of mortality which may have a substantial negative effect on the ability of a species to sustain its population. Entrainment effects may be significant depending on local conditions, such as the existence of cumulative sources of mortality (nearby industrial installations, other power or desalination plants, etc.) that might already be affecting locally present endangered species or species of commercial interest.

Entrainment losses quantified by York and Foster (2005) in 7 desalination plants, have found serious adverse impacts of entrainment. In these studies the losses attributed to entrainment were equivalent to the loss of productivity of thousands of acres of coastal habitat. It was observed that impingement impacts compounded the entrainment losses because often the same species that lose early life stages due to entrainment lose adults and larger juveniles due to impingement.

Many coastal areas of the Mediterranean are highly productive, due to availability of nutrient rich waters. The seawater contains a wide array of small photosynthetic plants and animals that drift without restraint in the water column, collectively referred to as plankton.

On the long term, the cumulative environmental impacts of mega desalination plant intakes in the Mediterranean sea would result into the entrainment of potentially sensitive small marine species and would also result in the depletion of near-shores fish stocks. The impacts, while small for a single desalination plant, may still be considered significant with the cumulative impacts of large number of mega desalination plants operating simultaneously in a narrow geographic sector of the shore-lines.

This phytoplankton grant the foundation of the food web, supplying nourishment for filter feeding species, which in turn are then preyed upon by larger animals in the food chain. The zooplankton that makes up the second "living" portion of the feed-water comprises both fishes and crabs that spend early life stages as plankton in the form of eggs or larvae, as well as other animals such as copepods that spend their entire lives as plankton. In addition to the phytoplankton found in the seawater, spores and seeds from various species of algae, sea-grass, etc. are also present.

Similar to other environmental impacts resulting from desalination plant operation, the extent of environmental degradation due to impingement and entrainment varies significantly among desalination plants. The magnitude of environmental damage caused by desalination plant intakes is usually a function of the design of the intakes, technology used, the actual volumes of sea-water drawn into the desalination plants, and the species composition and abundance of the aquatic organisms in the near-shore sea-water.

Both of these effects (impingement and entrainment) may cause increased mortality rates for plankton of all types as well as small fish. This in turn may result in reduced population and hence reduced biodiversity, production and yield.

An additional indirect consequence resulting from the intake of large volumes of seawater is the dead impinged and entrained marine organisms that are ultimately discharged along with the brine effluent. The high organic content will potentially result in the depletion of dissolved oxygen levels in addition to release of nutrients. MEDRC (2010) provided several technical measures and intake designs capable of reducing the entrainment and impingement impacts of seawater desalination plants.

8.2 Environmental Impacts of Brine Thermal Discharge

In the life of marine organisms, temperature elevations from ambient values cause thermal stress that might result into an eco-toxicological effect such as disturbed enzyme activity, water balance and cellular chemistry. The buoyancy, locomotion and/or respiration of some marine organisms have been found to be disturbed as a result of temperature induced changes in density, viscosity and solubility of gases in the receiving waters. The severity of damage to the biota present in the vicinity of the point of discharge is assumed to be a function of its type, the temperature levels (levels of exposure) and duration of thermal inputs (duration of exposure).

Furthermore, increased temperatures and salinity reduce the level of dissolved oxygen in seawater. Significant drop in dissolved oxygen levels can be toxic to certain marine species. Thermal pollution increases bacterial and aquatic invertebrate activity which in turn will diminish already lowered DO. On the other hand, raising temperature during cold winter seasons can enhance biological activities and growth rate of microscopic plants and fish and increases vulnerability of aquatic life to toxic elements. In warm summer seasons, particularly in South Mediterranean Countries, higher ambient temperature can be mortal to unadjusted and stationary organisms (Danoun, 2007). In general, significant long-term alterations in temperature can be harmful and cause marine organisms to die-off (Höpner, et al., 2008).

The impact of thermal pollution in enclosed areas, harbors and bays might be much more significant and could be manifested by changes in community structure such as types of dominating organisms and by changes in the characteristics of the individual species such as lower tolerance and/or adaptation. In temperate zones of the Mediterranean many marine organisms might be adapting to the relatively high temperature and showing tolerance to slight increases in ambient water temperature.

8.3 Environmental Impact and Fate of Salinity on the Near-Shore Marine Environment of the Mediterranean

In the case of desalination of seawater using RO technology, the higher salt levels characterizing its resulting brine have a higher density and directly affect the benthic species. The rate of dilution of the brine effluent decreases with the density differential between brine and the receiving near-shore seawater. This is particularly true for RO brines which keep critical salinity levels over an extended area of the seawater body.

Environmental studies indicate that exposure of seawater benthic community to constant salinity levels above 45 g/l will alter its existence and reduce the diversity of organisms. Most organisms will tolerate short term exposure to salinity of up to 50 g/l peaks. They can also adapt to chronic variations of 1-2 g/l. However, some organisms have very low tolerance and will not be able to survive. According to Lattemann, et al (2003), corals will not stand salinity exceeding 43 g/l. The typical salinity of brine resulting from RO desalination exceeds these levels and should be considered as harmful to the near-shore marine environment unless it is sufficiently dispersed and diluted.

Turbidity also increases with higher salinity reducing clarity needed for efficient photosynthesis process. The combined effect of high salinity and elevated turbidity will lead to the disappearance of plankton species and reduce the diversity of other stationary marine organisms. The tolerance varies greatly between the different species. The same applies to fish. Less tolerant species will be deprived of their natural habitat and nursing ground and will obviously disappear from the affected areas

Given the calculated salt concentration in brine reject discharged from different desalination technologies in the Mediterranean sea (78.00, 47.00 & 43.00 gm salt/m^3 desalinated water from RO, MED and MSF plants respectively), it is very likely that Posidonia oceanica sea grass <u>within the immediate vicinity</u> of the desalination plants outfalls will be eradicated including all marine biota this sea grass is sustaining.

(Miri, et al., 2005).

The impact of salinity on Posidonia oceanica, a Mediterranean sea grass maintaining a high assortment of species and with important functions for sustaining the marine ecology has been investigated. With a slight increase in salinity of only 39.1 g/l considerable effects on the vitality of the plant were noticed and documented. At salinity levels of 40 g/l and above, Posidonia exhibited some mortality (Sánchez-Lizaso et al. 2008).

Cumulative Impacts of Increased Salinity on *Semi-Enclosed Marine Environment*:

The discharge of brine water in shallow and relatively stagnant nearly-land-locked coastal areas such as bays, harbors, etc. in the Mediterranean Sea might result into much more pronounced impacts on the surrounding marine ecology. Werner and Feo (1995) warned that the unlimited disposal of brine waters in sheltered bays or harbors might lead to serious effects on local marine habitat. One of the earliest works which emphasized the biological impact of a desalination plant was that of Cheshire (1975) who reported adverse effects of brine discharge on the fauna and flora of the Safe harbor, receiving effluents from the Key-West desalination plant in Florida, USA. He reported the near disappearance of a variety of marine organisms during the 15 months course of his field investigations. Sea squirts (*Ascidia nigra*), various species of larvae, bryozoans and sabellid worms were absent during certain periods. Dead shells of various clams and oysters were abundant in the area studied. However, high local salinity levels around desalination plant outfalls, especially from RO plants discharging their high density brine in semi enclosed near-shore areas, clearly exceed natural levels and might pose a real threat for a variety of species (Khordagui 2002).

For Mediterranean seagrass *Posidonia oceanica* meadows, salinity thresholds have been recommended based on field and laboratory experiments by Sánchez-Lizaso et al. (2008). They concluded that salinity should not exceed a value of 38.5 in any point of a sea-grass meadow for more than 25 % of the observations (on an annual basis) and should not exceed a value of 40 in any point of the meadow for more than 5% of those observations. Ambient salinities in the western Mediterranean range between 37 and 38.

Foskett (1977), revealed that larval mortality, slow development rate, failure of osmo-regulatory mechanisms, shrinkage of body cells, malfunction of the endocrine system, etc. are a few of the adverse effects observed in marine organisms exposed to elevated salinity. Gacia, E., et al., (2007) concluded in their studies on the Mediterranean sea-grass *Posidonia oceanica* that a salinity of about 45 gm/l caused about 50% mortality in 15 days and growth rates were reduced by 50 % at a salinity of 43 gm/l.

On the other hand, it is also reasonably sound to assume that some indigenous biota in the

Semi-enclosed and shallow embayment's in the Mediterranean Sea are naturally characterized by a higher salt content due to the elevated rate of evaporation, lack of freshwater discharges, feeble tide waves and restricted dispersion and dilution. These factors when compounded with desalination plants brine discharges would suggest that the biota in many instances is living on the extreme limits of its environmental tolerance in enclosed near-shore areas of the Mediterranean.

near-shore of the Mediterranean would adapt to the naturally prevailing environmental condition characterized by the elevated salinity. These high salt content in addition to the natural cycles of even higher salinity during long dry summer seasons might have several order of magnitudes the impacts of what is being discharged from desalination plants.

Nonetheless, limited environmental impacts were documented in literature associating natural cycles of higher salinity with measurable negative ecological implications. Hence, the slight increase in salinity away from the points of brine reject discharge is projected to be of limited impacts on large semi-enclosed marine ecology of the Mediterranean.

Cumulative Environmental Impacts of Increased Salinity on *Distant Open Seawaters*:

According to Khordagui (2002) there has always been some misconception that the concentrated salt content of the brine water disposed-off by seawater desalination plants will inflict significant damage to the **distant open marine environment.** This might not be the case for the following reasons:

1. The amount of seawater withdrawn for desalination is relatively minute when compared to the water mass of the open sea.
2. The nature and composition of salts discharged with the brine are identical in nature and composition to the salt content of the open sea.
3. The concentration factor of salts in the rejected brine increases on the average by no more than two.
4. In most of the desalination plants the outfalls are specifically engineered and equipped with diffusers to discharge brine where maximum circulation patterns and hydrographic currents can easily disperse and dilute the brine so that impacts from elevated salinity are restricted to the mixing zone.
5. The salt resulting from natural evaporation from the Mediterranean Sea, particularly in the South region, is several orders of magnitude compared to the calculated salt inputs from operating desalination plants.

This fact was substantiated by Hopner (2008) when he ruled out the danger of an overall increase in salt content of the Persian Gulf due to the high natural evaporation rates in the Gulf that generate much more significant overall salinity changes than the totality of desalination activities.

For distant open seawater, it is safe to assume that the risk of a potential increase in salinity due to brine reject from desalination plants in the Mediterranean Sea has been overstated and should not give much reasons for concern. This is, particularly true if near-shore hydrographic circulation patterns are considered in the proper design of the plants discharge outlets.

8.4 Fate and Environmental Impacts of Anti-Scalants Discharged with Brine Reject in Mediterranean Region

8.4.1 Fate and Environmental Impacts of Acids Anti-Scalants

In connection with fate of the added acids, the extremely large carbonate buffering capacity of the Mediterranean seawater will minimize the impact of acids on the environment and renders them negligible. In this connection, Al-Tayaran and Madany (1992) were unable to detect any discernible pattern of pH variation in near-shore seawater in the proximity of Sitra Power & Desalination plant in Bahrain.

In terms of environmental impacts, the drop in pH is probably the most important single variable that influences the fate and transport of metals that might be released due to corrosion and elution from thermal desalination plants to the near-shore marine environment.

- The pH controls metal speciation and potential binding by affecting the species distribution of dissolved ligands (such as phosphate, sulfate, carbonate, humic substances) and the surface charge of binding sites on dissolved organic matter (DOM) and solid phases such as metal oxy-hydroxides.
- As a general rule, at low pH, when surface sites are protonated, the sorption of cationic metals decreases, and, hence, trace metals mobility increases. The converse occurs at high pH, which results in low metal solubility and greater sorption.
- The pH of the cooling water can also affect the nature of the oxidation by-products formed. The lower the pH of the effluent the lower will be the formation of brominated trihalomethanes (THMs), probably due to base-catalyzed hydrolysis of intermediates in the haloform reaction. At desalination sites where the pH is adjusted to reduce scale formation, a reduction in THM formation might occur.
- According to Lattemann, S., et al., (2003), fish are capable of avoiding acidic discharge plumes from desalination plant, less mobile organisms such as star fish, mollusks, horse fish, etc. will be directly affected by acid blow-down.

8.4.2 Fate and Environmental Impacts of Polyphosphates Anti-Scalants

When present with other nutrients, phosphate causes an over abundant growth of algae that is unusual or non-indigenous to the area. This excessive plant growth usually means a reduction in diversity of species, and results in an imbalance of species that might affect the whole food chain. In turn the decay and degradation of large algal biomass means an increase in bio-chemical oxygen demand (BOD) and turbidity of water. Algae bloom often leads to degradation of seawater at desalination plants intakes with subsequent filter problems and a growing need for higher doses of antifouling agents such as chlorine.

In the United Arab Emirates (UAE), Shams El-Din et al. (1994), recounted their 5 years experience with the impact of utilizing polyphosphate based additives to inhibit the formation of alkaline scale in the condenser tubes of the distillers. They revealed that during operation, part of the chemical was lost by absorption on scale crystallites and the remainder found its way into the discharge basin. Being a ready source of phosphorus, the additive caused the flourishing of algae as green mat near the desalination plant out-fall. The increase in the mat thickness was found to cause dissolved oxygen depletion in the receiving near-shore seawater.

8.4.3 Fate and Environmental Impacts of Polymeric Anti-scalants

Shams El-Din et al. (1994) depicted the additives currently in use. The organic polymers based on maleic anhydride monomer were found to not cause any algal growth in the discharge bay of Um-Al-Nar power desalination plant in Abu-Dhabi in the UAE.

Compared to a daily discharge of 62.00 Ton of residual polymeric anti-scalants (MEDRC 2010) in the near shores of Arabian Gulf, the daily discharge of 12.7 Ton of the polymeric anti-scalants in the Mediterranean Sea is relatively minute.
After many years of practice, desalination officials deduced that discharged levels of polymer anti-scalants are way below the concentration levels that might cause any acute or chronic toxicity to marine organisms.

Only one study about Belgard EV has been carried out reporting that no accumulation in algae and fish was detected and that the agent is ecologically safe (Hopner, 1999). Toxic concentrations are usually by an order of magnitude of 1-3 higher than typical dosage levels. However, considerable loads are discharged into the seas. According to MEDRC (2010), an estimated anti-scalant daily load of almost 62,000 kg is discharged into the Arabian Gulf. As claimed by the manufacturers, in their safety data sheets, polymer anti-scalants possess relative low toxicity with high LC_{50} values and were considered safe to the receiving marine environment.

Höpner and Lattemann, (2008) noted that Belgard EV was found to be degraded by 18 % of its original concentration in 35 days. Other agents reach even much higher degradation in the same duration, e.g. Flocon 100 degrades by 52% in 35 days. They recommended the use of polymers with good biodegradability in order to avoid any potential long term environmental degradation effects.

According to Fable and Regitz (1995), when polymer anti-scalants are dispersed in the aquatic environment their behavior can be compared to naturally occurring humic substances. Both have similar chemical composition with high molecular masses and attached carboxyl groups. By similarity in chemical structure, composition and functional groups, it is evident to observe similar properties and behavior in the aquatic environment. Both humic acid and polymeric anti-scalants were observed to be resistant to biodegradation and would have a half lifetime longer than one month. Based on these facts, polymeric anti-scalants, like humic substances, are likely to complex with metals by chelating and preventing them from precipitating and leading to increase in their mobility. These properties would dramatically influence the fate and transport of metals in the marine environment. The presence of polymeric anti-scalants in the marine environment of the Mediterranean sea would maintain trace metals in dissolution leading to their transport for long distances with moving water masses.

Heavy metals chelating with polymeric anti-scalants discharged in the brine water will increase solubility, mobility and transport. However, bioavailability for bioaccumulation and biomagnification will be reduced. These phenomena need further investigations to clearly identify the potential fate, transport and transformation of toxic heavy metals in the presence of residual polymeric anti-scalants in the marine environment.

8.5 Fate and Environmental Impacts of Trace Metals in Desalination Brine Reject

Fortunately, most of the reported data indicates that the levels of heavy metals associated with brine water disposal are minimal and often below the detection limits of the standard analytical procedures. This has been particularly true after blending brine water with large volumes of cooling water used in power production. When comparing the mass and nature of heavy metals released with brine water to the amount of heavy metals being released from land-based industrial wastewater, atmospheric fallout and crude oil spills, it is thought over as negligible.

Many scientists such as Mannaa (1994), Oldfield and Todd (1996), and others, are treating the low levels of trace metals discharged into the marine environment with brine reject as insignificant and do not assume any significant harm to the marine environment. Judging on the environmental effects of trace metals effluent based on concentration in terms of µg/l without giving adequate consideration to the cumulative and persistent nature of metals in the marine environment might eclipse the potential long-term threats these metals are posing to the ecology and future human generations. When addressing the environmental aspects of trace metal discharges, loads in terms of Kg/day or Ton/year might be better expressions than mg/l to reflect their potential lasting and cumulative harm to the environment.

Furthermore, metals such as copper based alloys would react with residual dissolved oxygen in water causing corrosion and pitting and leading to an additional copper contribution to the cooling water in the range from 1 to 4 ppb (Paquin et al. 1999).

Drawing conclusions based on the exclusive impact of each metal while overlooking its synergistic and antagonistic effects and reaction with other chemicals in the brine reject in addition to the physico-chemical and hydrographic characteristics of the near-shore marine environment is an oversimplification and might be misleading. In this connection, environmental transformation, transport, accumulation, bioavailability, bioaccumulation and biomagnification of these metals are important factors that need to be addressed within an integrated context.

Eclipsing heavy metals releases from desalination plants through dilution of brine reject with cooling waters does not change the fact that heavy metals are reaching, accumulating and permanently residing in different compartments of the marine environment.

Routine acid washing will lead to solubility of heavy metals deposited in the sediment within the vicinity of the desalination plants outfalls. The increase in heavy metal solubility will lead to higher bioavailability with higher potential for biomagnification in the food chain.

According to Oldfield and Todd (1996), brine containing corrosion products of desalination plants when discharged into the sea may become part of the liquid phase due to their solubility or remain suspended in the liquid phase. Heavy particles may get settled at the bottom in the sediments. The distribution pattern mainly depends upon the physico-chemical properties of the seawater, the chemical species, weather conditions and geological factors.

Exposure and risks associated with metals in aquatic environments depend on the forms of the metals and on the factors that influence the presence of these forms as well as on the fate and transport of the metals. For heavy metals, the free ions are the primary metal species that might cause toxicity to aquatic organisms in the Mediterranean Sea. The key parameters that can modify the degree of toxicity are those that affect speciation, such as pH and the amount of inorganic and organic ligands that can form metal complexes and so provide alternative binding sites for the metal ion. Metal toxicity will also be affected by other dissolved ions such as sodium and calcium -readily available in seawater- that would compete with discharged heavy metals for binding sites on the gills of fish or on the respiratory surfaces of other aquatic organisms.

As long lasting pollutants, metals will last in different compartments of the marine environment for long time periods. However, their ultimate sink is the marine sediment. The level of metals (primarily in sediments and to a much lesser extent in seawater) reflects the general status of the environment but it does not necessarily reflect the bioavailability or toxicity of these metals.

It is important to note that metal speciation greatly determines the fate, transport and toxicity of metals in the marine environment. Speciation refers to the occurrence of a metal in a variety of chemical forms. These forms may include free ions, dissolved metal complexes or adsorbed metals on solid surfaces such as ocean sediment. Metal species includes also metals that have been co-precipitated in major metal solids or that occur in their own solids. Complexes that incorporate metals play a major role in controlling the availability and fate of metals in the environment. Increasing the fraction of a metal that is complexed increases the solubility of that metal. In other words, metal complexing increases total metal solubility and mobility.

According to Stumm and Morgan 1970, many metal complexes (whether bound to organic or inorganic ligands) are reversible, particularly if environmental conditions change such as decreases in pH. In addition to pH, partitioning and speciation of heavy metals in the aquatic environment are function of several physico-chemical characteristics such REDOX potential, presence of complexing or chelating agents, surface characteristics of sediment particles, hydrographic regime, etc. According to Paquin et al., (1999), organic and inorganic metal complexes are not bioavailable. This phenomenonreduces the toxicity of metals in the marine environment, however, it improves its transport and distribution with seawater masses.

According to UNEP-ROWA and WHO-EMRO (2008), many benthic invertebrates (such as shell-fish) feed on suspended or deposited material, with the risk that heavy metals are enriched in their body tissues (bioaccumulation) and passed on to higher trophic levels (biomagnification).

Environmental studies catered to investigate heavy metals pollution of near-shore marine environment caused by the discharge of brine water have failed to establish or confirm causality. This failure is mainly attributed to the multitude of land-based industrial discharges situated along the coastal lines of the Mediterranean that release much higher levels of more toxic heavy metals than the power-desalination industry to the near-shore marine

Decrease in pH of the seawater due to discharge of acidic back-wash effluents might lead to the re-dissolution of the deposited trace metals in the near-shore sediment of the Mediterranean Sea restoring their bioavailability and toxicity. Re-dissolution of heavy metals represents a latent threat to the marine environment through potential, transportation, transformation, bioaccumulation, biomagnification and evident intrusion into the food cycle.

environment.

In general terms, complex formation and chelation with natural and/or anthropogenic organic substances, co-precipitation and adsorption on iron and manganese hydroxides and scavenging by suspended particles decrease the bioavailability of the heavy metals and reduce their toxicity.

After nearly 20 years of practicing large scale thermal seawater desalination, studies conducted on the near-shores of Kuwait revealed that apart from few cases of contamination with Mercury (Hg), local fish and shrimp species were not dangerously contaminated by other heavy metals (Anderlini, 1982).

The tolerance towards copper pollution is not yet entirely known for all species. Copper can be toxic at higher concentrations, causing enzyme inhibition in organisms and reducing growth and reproduction (Miri and Chouikhi, 2005). Although the discharged concentrations can be high above natural levels in the mixing zone, the risk of acute toxicity is generally low. Instead, there is a higher risk of accumulation and long term effects. Copper compounds tend to settle down and accumulate in the sediments. They can be absorbed by benthic organisms and even be transferred, eventually, into the food chain. With respect to bioaccumulation, the discharged loads instead of the concentrations become the main point of concern.

On the other hand, Nickel is quite mobile in water, but the majority of the load will accumulate in the sediments around the outfall. Adverse effects of accumulation cannot be excluded. It should be kept in mind that the corrosion rates will most likely increase during the process of acid cleaning although no specific data is available.

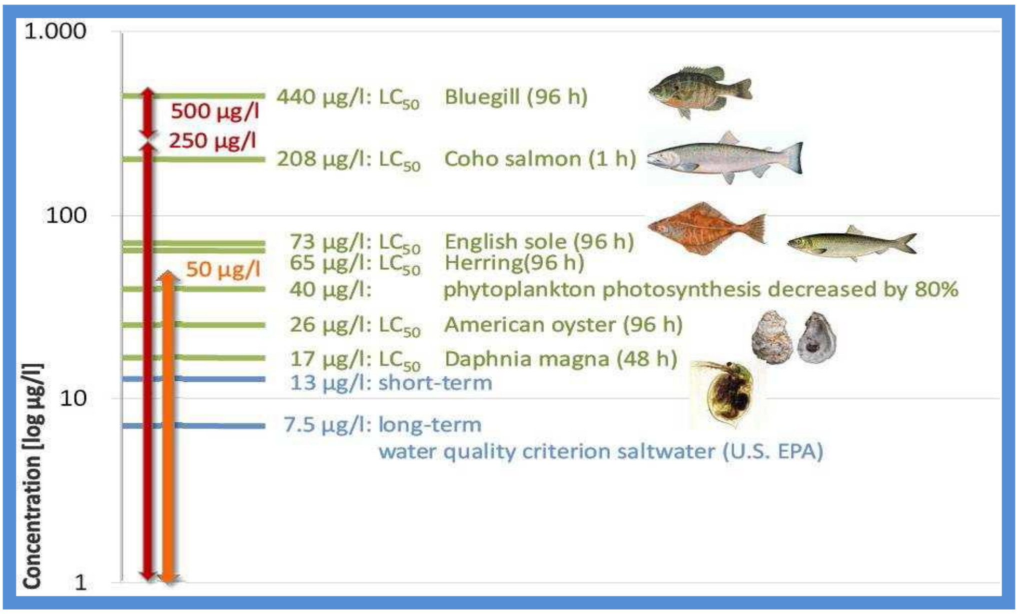
Modeling of heavy metal transport and fate within aquatic systems involves the representation of hydrodynamic transport to simulate movement of water, particulate transport to simulate the movement of particles, and chemical transfers and kinetics to simulate exchange of metal between dissolved and particulate phases and between the water column and benthic sediment. The risk assessor has the option of using independent hydrodynamic transport, sediment transport and chemical fate models, or an integrated model that incorporates all these processes.

8.6 Fate and Environmental Impacts of Residual Chlorine in Desalination Brine Reject

According to Khordagui (1992), when chlorine mixes with seawater at the intake of desalination plants (pH=8.3), the chlorine reacts immediately with the bromide ions to form hypobromous acid. Moreover, hypobromous acid is highly reactive and instigates fast chemical reactions with naturally occurring organic precursors leading to the formation of dangerous brominated Tri-Halo-Methanes (THMs) chemical species. Furthermore, the presence of certain pollutants of aromatic nature in vicinity of desalination plants outfalls, can lead to the reaction of these pollutants with the discharged residual chlorine to form halogenated organics (Khordagui 1995).

Unfortunately, there are no available data on the bioaccumulation of bromine in saltwater organisms. However, it was postulated that, since chlorine does not appear to have any potential for bioaccumulation or biomagnification in freshwater organisms, it is reasonable to assume that bromine will exhibit similar behavior. Additional data are needed to substantiate this prediction (CCREM 1987).

Chlorine is proven to be very toxic at concentrations of a few micrograms only. The photosynthesis process of plankton can be seriously reduced at concentrations of only 20 µg/l. At levels of 50 µg/l the composition of marine organisms can change and their variety is reduced. The known lethal values for fish species range between 20 and several hundred µg/l (Lattemann, et al., 2003). Figure 24 depicts toxic chlorine concentrations for a range of species by means of the LC_{50} indicator. It can be seen that the reported chlorine concentrations in MSF effluents and in the mixing zone are



acutely toxic for many of the examined marine organisms.

Figure 24: Chlorine toxicity levels for a range of marine species

Source: From Höpner, et al., (2008).

8.7 Fate and Environmental Impacts of THMS in the Near-Shore Marine Environment

Due to its low boiling point, bromoform as the most dominant THM species in seawater is highly volatile and only moderately soluble in water (Merck Index 1989). Information is available, mostly, on the environmental fate of chloroform that is similar in structure and chemical characteristics of bromoform. Based on the available data, bromoform does not adsorb onto sediments to any great extent. Consequently, this process is not considered to be an important means of removing bromoform from the aquatic environment (Canadian Council of Ministers of the Environment CCME 1992).

Volatilization (followed by oxidation) is the major fate process for the removal of bromoform from the aquatic environment. On the other hand, biodegradation is slow but has a significant effect on the removal of bromoform from sediments. Hydrolysis, adsorption, photo-oxidation, photolysis, hydraulic processes, and bioaccumulation do not appear to reduce chloroform concentrations substantially in the marine environment. Based on the physical and chemical characteristics of brominated THMs and given the relatively warm temperature of the Mediterranean region, it is very unlikely that brominated THMs formed as the result of seawater chlorination will last in the near-shore marine environment for long durations.

Some of the volatile THMs species were found to be carcinogenic and mutagenic to humans (Cantor, 1983). It has also been known for some time that reproductive tissues and the immature stages of organisms, especially sperm are sensitive to very low concentrations of THMs (Davis & Middaugh, 1978). In addition, Scott et al. (1982), found that when adult oysters (*Crassostrea virginica*) were exposed to seawater containing 25 ppb of $CHBr_3$ the rate of respiration was increased and both the feeding rate and the size of the gonads were reduced. Rapid uptake of the compound occurred, but the depuration in clean water was complete within 96 h. Although the feeding rate then returned to normal, damage to the gonads appears to be irreversible.

Bioaccumulation potential of the THMs appears to be low, compared to many other chlorinated organic compounds. Gibson *et al* (1979) conducted 28 day uptake and depuration tests on three species of Penaeid, shrimp and fish. The authors found that both uptake and depuration were rapid, with an equilibrium reached after 24 hours. Bioaccumulation factors were relatively low (between 1 to 10 times the water concentration). For instance, exposure to 90 microgram/l bromoform for 24 hours resulted in a bioaccumulation factor of 7.6. Uptake and depuration of bromoform were both rapid and completed within 24-48 hours. However, it was concluded that the rate of uptake and depuration was dependent on the species and the concentration of bromoform in the water.

8.8 Fate and Environmental Impacts of Chlorinated VLHS in the Near- Shore Marine Environment

Chloro-benzene: Dichlorobenzenes are volatile and prone to removal from the water column by volatilisation and also by sorption to particulates which settle out into sediments. According to Hedgecott *et al* (1998), models for environmental volatilization, and real monitoring data, suggest 50% or more may volatilize from waters in 8 hours to 3 days, whilst this may increase from 3 to 100 days (but mostly less than 30 days) for seawater mesocosms. Biodegradation of dichlorobenzenes in aerobic aqueous and soils systems has been widely reported. However, its environmental significance is probably limited, except where volatilization is impeded.

In a reproduction study by Crane and Fawell (1989), adverse effects of chloro-benzenes were observed at 0.15 mg/l. However, the ecological implications of the observed pattern of effects were unclear and, therefore, a possible safe concentration could not be determined.

Crane and Fawell (1989) reviewed both fresh and saltwater studies and concluded that bioaccumulation of dichlorobenzenes resulted in tentative Bio-Concentration factor (BCF) values ranging between 36 and 280 in seawater species.

Chloro-phenols: Grimwood and Mascarenhas (1997) reviewed the data on the aquatic toxicity of chlorophenols and concluded that the majority of reported LC_{50} data ranging from 0.6-19.5, 2.55-29.7 and 5-7 mg/l for algae, crustaceans and fish, respectively, indicating moderate to high acute toxicity. Long-term exposure data available for saltwater organisms in a study in which a 4-CP and 2,4-DCP concentration of 1.0 mg/l was found to cause severe inhibition of growth and biomass of mixed species of natural phytoplankton communities (Kuiper and Hanstevit 1984). The toxicity of chlorophenols to aquatic organisms rises with increasing degree of chlorination and substitution away from the ortho- (2-) position. The higher toxicity of the more highly chlorinated congeners can be ascribed to an increase in lipophilicity which leads to a greater potential for uptake into the organism.

Grimwood and Mascarenhas (1997) concluded that the vast majority of aquatic organisms did not readily accumulate monochlorophenols or 2,4-Dichloro-phenol to high levels, with Bio-Concentration Factors (BCFs) in fish ranging from 3.8-34.0 at neutral pH, and depuration half-lives in the order of hours to days. Since toxicity is directly linked to bioaccumulation, Grimwood and Mascarenhas (1997) also concluded that all the issues concerning the effects of degree of chlorination and dissociation on the toxicity of chlorophenols, also related to the uptake and bioaccumulation of these compounds.

8.9 Fate and Environmental Impacts of Anti-Foaming Agents

Antifoaming additives are considered non-toxic. Polyglycols, particularly when they have molecular masses of less than 4000, they exhibit high degree of biodegradability. They can transform into a polymerised state which is more persistent in the environment, but due to the low concentrations used in desalination plants, polyglycols are of little concern for the marine environment (Lattemann and Höpner, 2003).

According to Falbe and Regitz (1995), 80% of the polyglycols have low molecular masses and are readily decomposed in the marine environment. The physico-chemical properties of the antifoaming agencies are controlling their fate, transformation and transport in the near-shore marine environment. At high temperature and in the presence of oxidizing agent such as chlorine added to control biofouling, polyglycols is likely to decompose, reducing further its concentration in the discharged brine. Given their non-toxic properties, the very low doses used in desalination and dilution with massive cooling water, antifoaming agents should be of minimum concern for the near-shore marine environment of the Mediterranean Sea. Their only potential environmental impacts is manifested in the very slight increase in the natural background concentrations of dissolved organic carbon in the mixing zone surrounding the outfalls.

8.10 Fate and Environmental Impacts of RO Membrane Cleaning Agents

Formaldehyde: In case formaldehyde is used as a RO membrane cleaning chemical, it might cause toxicity in the immediate vicinity of desalination plants outfalls following the discharge event. According to Toxicology Data Network (TOXNET-a), formaldehyde is not expected to adsorb to suspended solids and sediment. Volatilization from water surfaces is also not expected. The potential for bio-concentration in aquatic organisms is low. Formaldehyde readily biodegrades under both aerobic and anaerobic conditions in the environment. In a die-away test, degradation was complete in 30 and 40 hrs under aerobic and anaerobic conditions, respectively, Kitchens et al. (1976).

Ethylene Diamine Tetraacitic Acid (EDTA): EDTA is recommended as a membrane cleaner by most membrane manufacturers. According to TOXNET-b, EDTA is expected to adsorb to suspended solids and sediment. It will exist almost entirely in the anion form at pH values of 5 to 9 and therefore volatilization from water surfaces is not expected to be an important fate process. Potential for EDTA bio-concentration in aquatic organisms is low. It is poorly biodegraded and is not expected to undergo hydrolysis in the environment due to lack of functional groups that hydrolyze under normal environmental conditions (Layman, et al., 1990). The persistence of EDTA in the marine environment and its capacity to chelate with trace metals will lead to the mobility and transport of trace metals deep into the water masses of the Mediterranean. However, on the positive side, the EDTA chelated toxic trace metals are not bioavailable for uptake by the marine biota.

Sodium Perborate: Sodium Perborate is recommended by some membrane manufacturers as a cleaner to oxidize organic colloids deposited on the RO membranes. In water, it readily decomposes into hydrogen peroxide and sodium borate. The hydrogen peroxide will be consumed in oxidizing the organic deposits while releasing oxygen. Using the appropriate doses recommended by membrane manufacturers, the toxic peroxide will be totally consumed without residuals for discharge to the marine environment. According to Lattemann and Hopner (2003), toxicity of sodium perborate to most sensitive aquatic organisms is discernable only at unlikely doses higher than 14 ppm.

Sodium dodecylbenzenesulfonate: Sodium do decylbenzenesulfonate is used as an anionic detergent to clean RO membranes. In water, it is expected to be essentially non-volatile. Bio-accumulation, adsorption to sediment, and hydrolysis are not expected to be important in aquatic systems. Biodegradation of sodium dodecylbenzenesulfonate is expected to be an important fate process in water (TOXNET-c). Experimental results suggest that bio-concentration of sodium dodecylbenzenesulfonate in aquatic organisms will not be an important fate process. According to Lattemann and Hopner (2003), by comparison of toxicity data and estimated environmental concentrations, dilution as it always the case, will determine the near-share marine impacts.

This section could be amended by mitigation recommendations for each chemical, unless these are provided later in the report. For instance, the cleaning solutions could be diverted to the sewer system or stored and treated on site in tanks prior to discharge due to their comparatively small volumes and intermittent use.

9 Cumulative Impacts of Brine Discharges to the Marine Eco-system

According to the USA Code of Federal Registrar (2012), cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. The cumulative environmental impacts of brine discharge should not be addressed in separation from factors such as the synergistic and antagonistic effects, different chemical constituents and its physical characteristics such as temperature and density, biodiversity of the near-shore marine environment, sensitivity of marine biota within the vicinity of the brine outfalls and the degree of vulnerability of various species.

It is important to note that the most devastating environmental effects often result not from the direct effects of a particular action such as a single desalination plant, but from the combination of individually minor effects such as a large number of desalination plants and industrial installations constructed and operated over time in addition to harbors, oil and gas installations, rigs and terminals in addition to urban development on the coast lines. Due to the concentration of urban centers on the shorelines of the Mediterranean Sea, a number of existing water quality concerns are largely resulting from non-point source pollution such as urban and agricultural runoff that must also be taken into consideration when addressing cumulative impacts. Cumulative effects of a desalination plants around the Mediterranean Sea in combination with other existing and future desalination plants were never assessed or foreseen. Currently, there is a lack of integrated information systems and networks to assess the potential cumulative impacts of desalination plants in the Mediterranean Region. Figure 24 schematically illustrates the cumulative impacts of two close-by desalination projects.

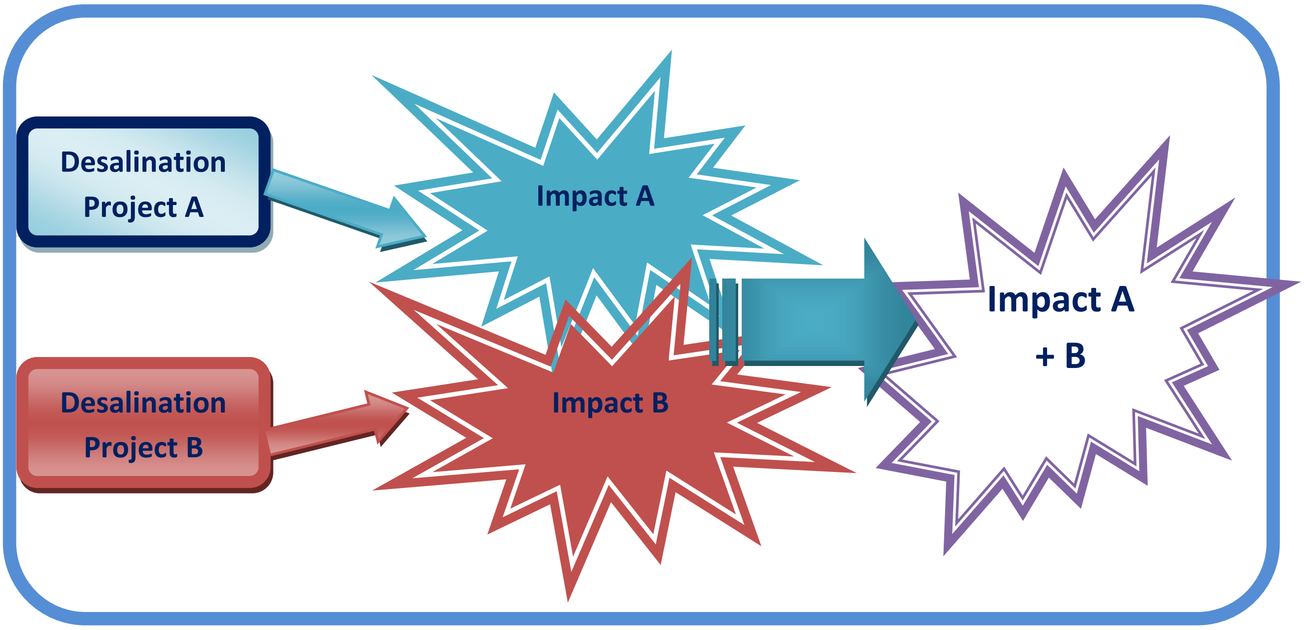


Figure 25: Cumulative Impacts: Impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project.

Many environmental experts contend that the majority of significant environmental impacts can be seen as cumulative and possibly synergistic or antagonistic in nature. With progressing development, most environmental systems have already been altered, degraded and often debilitated by a series of single, fragmented and unrelated human actions. According to William Odum (1982) environmental degradation from cumulative effects is the tyranny of small unrelated decisions.

The cumulative impacts of a particular desalination plant on the coast lines of the Mediterranean are often determined by its location, the technology utilized, characteristics of its brine, feed water quality, the service area and site specific aspects of the design and operation of the plant. The cumulative environmental impacts of desalination plants affecting the near-shores of the Mediterranean water quality and ecology will require more complex comprehensive and integrated analysis. The cumulative impacts of desalination in the Mediterranean region can be defined as the impact on the environment which results from the incremental impact of a planned desalination plant when added to other past, present, and reasonably foreseeable future human activities affecting the same environment.

For a planned desalination plant, there is no single formula available for determining the appropriate scope and extent of a cumulative impact analysis. Ultimately, the water and environment officials must determine the methods and extent of the analysis based on the scale, technology and design of the proposed plant, its location and potential to affect different environmental resources.

The cumulative impact analysis for a new desalination plant builds upon information derived from the predicted direct and indirect impacts analyses. The potential cumulative impacts should be considered as early as possible, preferably during scoping phase of any desalination project. Such early consideration of cumulative impacts may also facilitate the design of alternatives so as to avoid or minimize the cumulative impacts within the affected geographic boundaries. Therefore, the consideration of cumulative impacts should not be differed. It is recommended that the team conducting the conventional EIA of a specific desalination project to widen their scope to provide their inputs on potential cumulative impacts as well. It is important to note that the process is iterative and as more information about direct and indirect impacts becomes available during the EIA investigations, it should be further refined to fine-tune the cumulative impact analysis.

How to Conduct a Cumulative Impact Analysis?

In addition to the conventional EIA for desalination projects as developed by (UNEP-ROWA and WHO-EMRO, 2008), cumulative impacts of planned desalination plants can be assessed using the following 9 steps as adapted from the US-EPA (2005) guidance.

Step 1: Identify Resources to Consider in the Cumulative Impact Analysis

The first step in performing the cumulative impact analysis of a new seawater desalination plant is to identify which coastal and marine resources to consider in the analysis. Near-shore and coastal resources such as marine water quality, coral reefs, mangroves, endangered and threatened species, sea grass (Posidonia oceanica), archeological sites etc. should be listed in consultation with relevant experts. The cumulative impact analysis should focus only on: 1) those resources significantly impacted by the project; or 2) resources currently in *poor or declining health* or *at risk* even if proposed desalination project impacts are less than significant.

Step 2: Define the Study Area for Each Identified Resource

In step 2 the geographic boundaries for each resource to be included in the cumulative impact analysis should be identified involving specialists with knowledge of the resources and regulatory mandates. Each resource would have a unique study area rather than a single, consolidated study area, for instance a water quality resource might have a much wider study area compared to an archeological site. Public agency representatives and interested citizens should also be encouraged to offer input during the scoping process.

Step 3: Describe the Current status of Each Identified Resource

The purpose of Step 3 is to provide and account of each identified resource by: i- portraying the present status within its geographic boundaries in terms of its stability, vitality, sustainability, continuity to provide services, etc. and ii- drafting a summary on how the resources got to the current state. The output of step 3 will provide the platform and background necessary to assess the potential added impacts of the planned desalination project on these resources and it will also provide a chronological account, within an appropriate timeframe, on how the status of the resource evolved to reach the current status.

To portray the current status of the identified resources, the experts will rely on their professional knowledge, consult the technical specialists of the desalination project proponents, check with other resource specialists, access data sources, review other environmental documents characterizing the vicinity of the proposed plant, or use any combination of methods to gather information.

Step 4: Identify Direct and Indirect Impacts of the Proposed Desalination plan that Might Contribute to a Cumulative Impact.

A cumulative impact analysis must look at the impacts of a proposed desalination project in combination with the impacts of other past, present, and reasonably foreseeable projects (desalination and others) identified within the defined geographic boundaries. In this step, the potential direct and indirect impacts from each of the proposed desalination project alternatives on the affected resources are identified. If the environmental impacts of the project vary substantially between alternatives and options such as RO, MSF, MED, beach-wells, conventional intakes, diffusers, etc., it is important to differentiate each alternative's potential to contribute to cumulative impacts.

Step 5: Identify Other Reasonably Foreseeable Projects that Affect Each Resource

The purpose of Step 5 is to identify other current and reasonably foreseeable projects to be considered in the cumulative impact analysis. First, the current and reasonably foreseeable desalination and non-desalination projects need to be identified that are likely to be executed, with potential impacts onthe resources identified under step 1. When identifying reasonably foreseeable projects, it will be necessary to evaluate each listed project to determine whether it is probable enough to be evaluated or too speculative to be considered. Once a list of projects has been developed, it has to be determined for each project whether it would have a direct or indirect impact on the resource. The use of quantitative data is especially valuable for analysis when biological resources are affected. This data will be critical in identifying avoidance and mitigation measures.

Step 6: Assess Potential Cumulative Impacts of Planned Desalination Plants.

In this step, the information collected in steps one to five is reviewed and analyzed for potential cumulative impacts. Developing a list of projects to include in the cumulative impact analysis will also provide insight into the prospective changes within the geographic boundaries, and how those changes will affect the identified resources. The methodologies that can be used for analysis would range from simple methods such as matrices or mapping overlays, to data-intensive methods such as modeling or trends analysis. The selection of the method will be a function of the resource considered, the type of available information, and the scale of the proposed desalination project.

Step 7: Draw Conclusions

Based on the analysis in step 6, conclusions can be drawn about the cumulative impacts to the identified resources by applying professional judgment to the results, and by coordinating with technical experts as deemed necessary.

First, the expert need to conclude if the planned desalination project in combination with other activities will affect the identified resources within the selected geographic boundaries resulting into cumulative effects (either negative or positive).

Second, the expert need to conclude if the cumulative impacts of the project is significant, severe and of what magnitude. For most resources, the cumulative impact analysis conclusion will not require a description of the severity of impact (e.g., substantial, moderate, minor, significant) unless the method specifically reports results in such terms. However, water quality impacts must be categorized using specific criteria.

Once the cumulative impact analysis is complete, it is advisable to compare its results with the results of the conventional EIA analyses of the proposed desalination project. This comparison can test the soundness of the conclusions about each resource. For example, if the planned desalination project impacts would result into a 200 meter radius loss out of a 2000 meter radius mixing zone of similar habitat, this might not be considered a significant impact. However, if another 200 meter radius impact is caused by another project, the cumulative impact may be significant.

Step 8: Report the Results

The purpose of this step is to document the results of the step-wise cumulative impact analysis. The product will typically include a summary of the analysis approach and the conclusions. This summary should include the identification of resources considered in the analysis, the geographic boundaries for each resource, and the conclusions concerning the status and the chronological evolution of each specific resource. Step 8 shall also present the desalination project impacts that might contribute to the overall cumulative impact including other reasonably-foreseeable projects considered in the cumulative impact analysis, and obviously the conclusions of the analysis as outlined in Step 7.

The report should also include a brief description of the methodology and analytical procedures used in assessing and interpreting of the cumulative impacts. Any assumptions or limitations should also be explained in the report.

Step 9: Assess the Need for Mitigation and Recommend Solutions

Determining techno-economically feasible mitigation measures and alternatives for a cumulative impact can be very difficult. A cumulative impact often results from the combined actions of numerous public and private sectors. Cumulative assessment of a planned desalination project might also provide good opportunities for the project proponent to propose and consider innovative cumulative impacts solutions. Furthermore, the recommended solutions might be used to influence future decisions and/or help identify opportunities for avoidance and minimization when other projects are proposed.

As a tenth step, setting up a monitoring program for resources of high ecological and preservation value (coral reefs, seagrass beds) that are under pressure from different development activities could be considered. Predicting the impacts of a single project is difficult and even more so is the prediction of cumulative impacts. Monitoring could provide an opportunity for reevaluating the predictions made as part of the conventional and cumulative EIAs. As stated above, "environmental degradation from cumulative effects is the tyranny of small unrelated decisions." I would add: as well as the lack of post-project monitoring and the willingness to learn from past mistakes and correct them where necessary.

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