Development of an advanced, innovative, energy autonomous system for the treatment of brine from seawater desalination plants

SOL-BRINE

Deliverable 1.1 Report on the evaluation of existing methods on brine treatment and disposal practices

Action 1 Preparatory Actions

Action 1(a) Literature review on brine treatment methods, brine minimization techniques and common disposal practices in EU and Internationally. Evaluation of existing methods on brine treatment and disposal practices.

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Disclaimer

The information included herein is legal and true to the best possible knowledge of the authors, as it is the product of the utilization and synthesis of the referenced sources, for which the authors cannot be held accountable.

Keywords

● Reject brine ● Brine treatment ● Brine disposal ● Brine minimization practices ● Brine discharge ● Brine disposal in inland locations ● Brine disposal in coastal locations ● Deep well injection ● Deep aquifer injection ● Natural Treatment Systems ● Solar gradient ponds ● Evaporation ponds
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Executive Summary

This report provides a thorough analysis and assessment of existing methods on brine treatment, minimization and disposal practices. In the framework of SOL-BRINE project, it is critical to investigate the existing and common practices being applied worldwide, in order to underline and the most viable and efficient technologies to recruit an innovative brine treatment autonomous system.

Taking into consideration the tremendous population growth and the increasing pressure on available water resources, unconventional water resources such as desalination represent inevitable sources to mitigate water scarcity worldwide. Desalination water treatment is one solution to provide sufficient fresh water to populations in arid areas. The introduction of desalination technology has been associated with several potential environmental impacts, the most important of which is the discharge of the concentrate brine into the marine environment. However, limited efforts have been made to characterize and assess the impacts of the brine discharge on the ambient environment.

The aim of the present deliverable is to highlight common brine disposal methods in inland and coastal locations as well as brine treatment and minimization techniques based on the newest and most updated technologies. The advantages and disadvantages, from an environmental perspective, of the most common disposal methods are outlined. The study is also intended to identify potential concentrate treatment and minimization options, focusing on the potential adverse environmental impacts and analyzing implementation issues, cost considerations and the state of current technology. The structure of the sector in this deliverable referring to the applicable legal framework has been divided into relevant subsectors so as to distinguish and render more convenient for the reader the categorization of applicable laws on national and international level. In light of the fact that no specific legislation exists in respect of brine disposal and/or treatment and/or minimization neither in a European nor in a unified international level the deliverable contains an elaborated description of the most vital EU water management directives, which
after all, are applicable, each to a lesser or a greater extent on brine disposal. Furthermore, various national, including non European jurisdictions have put forward local laws in respect of brine disposal per se. These national laws, even though not many in numbers have been duly analysed and contemplated in detail.
1 Introduction

Water has always been considered as one of the most valuable and precious natural resources for humans and ecosystems. Over the past decades, the tremendous population growth, the increased urbanization and the boom in industrial and commercial development have resulted in a significant high demand for fresh and clean water. Additionally, this development around the world has leaded to the pollution of available water resources, the degradation of natural sources, the deforestation and the climate change owing to global warming, all of which play a vital role in the reduction of average rainfall and runoff (North et al., 1995), (World water assessment program, 2003).

During the last century, the world population increased from 1.65 billion to 6 billion, while it is expected to increase further in this century. The rapid growth in population and industrialization place pressure on the remaining water resources and the need for discovering new resources of potable water is getting an imperative-urgent issue. Nowadays, about 20% of the world’s population is lacking of access to safe drinking water.

According to the latest figures from the United Nation’s “World Water Development Report”, by 2025 more than 50% of the world’s nations will confront water crises, nevertheless by 2050 the possibility for the 75% of the total population of facing serious water shortage will be significant (United Nations, 2003).

Considering the fact that water covers the 75% of the earth surface and the saline water (seawater, saline groundwater and saline seas) constitutes about the 98% of this, just only 2% is fresh and potable suitable for domestic, industrial and agriculture purposes-applications-uses. Additionally, on a global basis the average baseline consumption of fresh water is 300 liters per day per person which equals to around one hundred thousand liters of fresh water per person annually. To meet and accomplish water challenges, it is imperative to find or create new alternative ways of water resources provided that-as long as- the natural ones (the water resources) are not inexhaustible and have nearly vanished. Dams and artesian wells have been
traditionally used as fresh water resources, even though the produced amount of water is insufficient or unpredictable.

Consequently, there is an imperative need for the introduction of a new technology for the production of potable water (Svensson, 2005).

For over half a century, thermal technologies have been available for the production of potable water from existing water sources. Desalination, despite the high cost, a parameter that highly limits its applicability, is one of the most valuable alternative water resources applied to many countries around the world. Desalination techniques date back to the early stages of life, based on the principle of removing the salt from the seawater to use as drinkable water (Einav et al., 2002).

Despite the high cost of desalinated water, a significant quantity can be produced to meet the need for fresh water worldwide. In 1961, John F. Kennedy stated that: “If we could ever competitively, at a cheap rate, get fresh water from saltwater, that would be in the long-range interests of humanity and would dwarf any other scientific accomplishments”.

The last 10-15 years, due to the introduction of membrane desalination, the major technological advancements and innovations within the field, desalination has become a predominant technology in a wide spectrum of suitable applications. The emerging arguments have been raised against the building and operation of desalination plants are related to the environmental impacts on the surrounding area and specifically to marine life due to the high concentrated brine effluent being disposed to the sea. The impacts of the brine discharge are primarily due to the high level of salinity, the total alkalinity and the variation in temperature level. These impacts have effects on the marine organisms in regard to the development of species, survival of lavra, reproductive traits and breeding (Svensson, 2005).

Consequently, in order to accomplish the basic human right for available clean and fresh water, desalination processes have to be embraced while further technological innovations regarding energy consumption, the cost of desalinized water in combination with environmental strategies must be made.
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Universally, approximately 12,300 desalination plants are located in 155 countries with a total capacity of over than 47 million cubic meters per day (Global Water Intelligence, 2006). About two thirds of plants are located in the Middle East, representing the 60% of the capacity worldwide (Pantell, 1993), in some of the most arid parts especially Gulf States where natural clean water is limited. The second largest producer of desalinated water after Saudi Arabia is the United States of America, where there are nearly 800 desalination plants with a combined capacity of about one million cubic meters production representing the 12% of the world’s desalinated water capacity (Danoun, 2007). The following figure presents the existing desalination facilities worldwide.

![Figure 1-1: Existing desalination facilities worldwide by region](image-url)
Figure 1-2: Demonstration of global water distribution and percentage of fresh and salty water
(Encyclopedia of desalination and water resources)
2 Environmental and chemical aspects of brine discharge

Brine discharge is the fluid waste from a desalination plant, which contains a high percentage of salts and dissolved minerals. It is disposed back to the sea and being diffused according to different aspects. There are two different types of the brine discharge applied in a desalination plant, through a water channel and a pipeline.

2.1 Brine discharge plume current

The brine might be rejected directly either into the ocean and sea or combined with other discharge. There are particular factors that play significant role in the discharge plume and the diffusion into the seawater. These influencing parameters are the following (Jenkins and Wasyl, 2005):

1. Direction of the wind and speed. These factors have a large impact on the diffusion of the discharge brine into the ocean and can affect the dilution of the highly concentrated plume into seawater in a short distance.
2. Wave height and speed. Another factor playing major role in the variation of seawater properties and may have significant effects on the ambient environment (Gill, 1982).
3. Bathymetry and the tidal mean and average. The brine discharge could potentially have a minimum impact on the variation to the physical properties, according to scientific researches. Great changes on salinity and alkalinity will occur during the high tide in a shallow depression (Swanson et al, 2006).

The dilution process is a function of two constituents: the primary and the natural dilutions. The parameters that affect the primary dilution are the following: the difference in the density between the brine and the receiving water body, the flow rate of the brine, the velocity and the flow rate at the effluent pipe, the diameter of the pipe and the depth at the outlet to the seafloor.
The natural dilution follows the primary one and is influenced by diffusion and mixing which are caused by waves and currents. Natural dilution is enhanced by the use of diffusers at the effluent pipe by increasing the pressure of the brine entering the seawater and therefore allows the brine to be diluted to a larger volume of seawater. The efficiency of dilution depends on the angle that the diffuser is installed to the seafloor and as a result the brine flow is directed upwards.

Breaking waves cause turbulence and larger waves incur better mixing, tidal currents generate turbulence by fiction of the seafloor, and wind drives surface current which is also turbulent. The turbulence level influences the rate of diffusion in the ocean current fluctuation (Jones and Kenny, 1971).

Whether any of these features exists, then rapid diffusion will be occurred and as a result better diffusion and dilution of brine discharge into the ocean water will take place. Knowledge about the topography and the prevailing currents in the area are two very important considerations for selection of brine outlet point as they affect the dilution rate a lot (Kimes, 1995). The faster dilution of brine discharge entails less potential impacts on the seawater quality. Therefore, the zone of risk will be reduced nevertheless the particular low risk area will be increased. All the above mentioned parameters have a serious effect on the current and the rate of diffusion of brine discharge into the sea or the ocean.

The plume of brine discharge comprises of the following constituents:

- High salt concentration and chemicals used in the pretreatment stage
- High total alkalinity content as a result of the double content of seawater in calcium sulfate, calcium carbonate and other elements
- High temperature range of the discharge brine due to the elevated temperature rate in the desalination facility
- Toxic heavy metals due to the metallic materials used in the desalination plants’ components.

Worldwide, the salinity of sea and ocean water varies between 30-37 ppt (parts per thousand), while the total alkalinity is estimated to $2.32 \times 10^{-3}$ mol/Kg. The average
value of sea and ocean water differs from the two polar areas to the equator between 15-27 °C (Danoun, 2007).

The major environmental impact of brine disposal into the ocean is the marine disturbance in the vicinity of the outlet due to the higher salinity and often chemical constituents in the brine waste (Svensson, 2005). Brine, because of its high specific weight, creates a plume at the outlet preventing a well mixing and making the brine plume sink to the bottom. As a consequence, a salty dessert in the closest area of the outlet is formed which affects negatively the benthic environment. According to surveys, benthic environments are tolerant to salinity increases of 1 ppt while the actual impact of brine is a function of the particular ecosystem in the area being disposed (Mickley, 1995). Especially vulnerable are areas such as salt marshes, coral reefs, mangrove forests and low energy intertidal areas and shallow coasts. Exposed rocky coasts with high energy wave action may be less susceptible (Höpner and Windelberg, 1996). More sensitive to effluent discharges are enclosed seas, such as Red Sea and Arabian Gulf, which have limited water exchange capacities and are generally shallow and less energetic.

Another potential environmental impact of brine disposal is eutrophication, due to the high levels of phosphates in the brine effluent. Discoloration in receiving water is attributed to the high concentration of ferric constituents of brine, also to high level of suspended solids of the untreated backwash water.

Common conflict points arising from desalination plants’ planning concern the impact on local fisheries or tourism resources with considerable economic consequences. The increased plant capacities have resulted in high impact concentrations of effluent constituents that are harmful to the marine environment.

Another significant aspect concerns the presence of chemicals that are used both in inland brackish water desalination and in a grater extend in seawater desalination (Svensson, 2005). There have been formed several opponent opinions on the environmental impact of brine chemical substances. According to the one side, the use of chemicals does have an impact, while the second one is stating that due to
the minor amount of chemicals present in the brine waste, it is not expected to have adverse environmental impacts (Tsiourtis, 2001).

Due to the presence of several sorts of substances (blots) in seawater which can plug the membrane, seawater has to be treated with chemicals in the pretreatment, post-treatment and membrane cleaning processes. The basic chemicals used are chlorine, antiscalants and acids. Chloride, as a biocide, is considered as the most harmful substance and has detrimental effects on the aquatic life. Chlorine reacts with organic compounds in seawater forming a large number of chlorinated and halogenated organic byproducts. Studies show that many of these compounds are carcinogenic or otherwise harmful to aquatic life (California coastal commission, 2003). The use of chemicals has to be evaluated in terms of the environmental effects and the possibility of their substitution by alternative approaches. Some of these materials are the following (Danoun, 2007):

- Sodium hypochlorite NaOCl or free chlorine is used for chlorination to prevent biological growth in the membrane facility.
- Ferric and aluminum chlorides FeCl₃, AlCl₃ can be utilized as disinfectants for flocculation and removal of suspended matter contained in the water.
- The adjustment of the pH of seawater is done with the use of hydrochloric acid HCl or sulfuric acid H₂SO₄.
- Sodium hexameta phosphate (NaPO₃)₆ (SHMP) is used to prevent scale formation on the pipes and on the membrane.
- Any remains of chloride in the feed water can be neutralized with membrane preservative sodium bisulphate NaHSO₃.
- Crystalline acid EDTA C₁₀H₁₆N₂O₈ is used for the removal of carbonate deposits also in combination with weak acid detergents such as citric acid C₆H₈O₇ and sodium polyphosphate NaPO₃ can be used to clean the membrane.

The major environmental issues for a desalination plant include the location of the plant operation, brine disposal and energy considerations (Tsiourtis, 2001). In the
point of plant location, the site should be determined considering parameters such as the available energy supply also the distance in relation to the feed water intake, the disposal site and the end-user. The most important environmental consideration in deciding the location of the plant is avoiding sensitive ecosystems.

Provided that energy consumption represents approximately 25-40% of the total cost of desalination technology, the selection of energy source is a vital aspect. The use of renewable energy such as geothermal, wind, solar and hydropower must be considered as alternative sources especially in remote regions. In areas where there is lack of water and thus not allowing the implementation of hydropower energy, it is often the case that one encounters the ample use of wind and solar energy sources. Despite the remarkable seasonal variations, wind energy is widely used in small desalination units on islands. Solar energy is considered as a more reliable source despite the fact that involves large areas of costly solar acceptors.

The selection of brine disposal method is a crucial issue. In practice, there exist two entirely different scenarios regarding brine disposal being determined by the location of the plant. These include brine disposal in inland areas and in coastal areas, with the primary difference being the possibility for discharge to a large saltwater recipient such as the sea or the ocean. Brine disposal into the ocean is a widely implemented method, as such the most simple and least costly among others. Nevertheless, in inland locations far from the sea, alternative methods have to be applied taking into consideration the related economical and environmental impacts (Svensson, 2005). The cost of brine disposal ranges from 5% to 33% of the total cost of desalination, while the disposal cost of inland desalination plant is higher than that of plants disposing brine into the sea (Glueckstern, 1996), (ESCWA, 1993). The critical factors that have an influence on the selection of a disposal method among other options are: the quantity or volume of concentrate, the level of treatment before disposal, the quality or constituents of concentrate, physical and geographical location of the discharge point, public acceptance, and permissibility of the option.

The analysis of common brine disposal options is presented below.
3 Disposal of Brine in Inland Locations

In recent years there is an increasing utilization of inland brackish groundwater for desalination. Nevertheless, the limiting factor for a desalination plant is brine disposal. There is a considerable number of disposal alternative practices which are widely acceptable today. Most of them are being utilized or under investigation, but the availability of the disposal alternatives is a site-specific issue. Therefore, all the disposal methods from an environmental and economical point of view have to be evaluated site-specifically.

3.1 Deep aquifer injection

This disposal method includes the injection of the rejected water through drilled wells to deep and consolidated aquifers that contain non-drinkable water. This is only possible where these deep aquifers exist whereas the ability to monitor the discharges is limited resulting in an uncertainty of environmental impacts. Furthermore, this method is a costly procedure (Reimold et al., 1996). It is extensively applied in Florida due to the good hydrogeological conditions of the region (Mickley, 2001).

3.2 Deep well injection (DWI)

Deep well injection is currently applied worldwide for disposal of industrial, municipal and liquid hazardous and non-hazardous wastes. The particular technology is considered as a viable option for brine disposal from land desalination plants (Glater et al., 2003). This alternative method ultimately stores the liquid waste in subsurface geologic formations. A well is used to transfer the liquid waste a short distance below the ground surface where it is released into a geologic formation. The well’s depth depends on various factors such as the existing geologic strata, the
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depth to groundwater aquifers and the class of well that is used. The depth of the well is typically less than 2500 meters. The Deep Well Injection method is affected by various factors such as site availability, well classification, concentrate compatibility, and public perception. The site must have favorable underground geology conducive to deep-well injection, with a porous injection zone capable of sustaining adequate injection rates over the life of the membrane facility. Additionally, a water-resistant layer is required to prevent the migration of the injected concentrate into drinking water sources. Another issue that is taken into consideration is that by injecting concentrate, an increase in water pressure on fault lines could occur resulting in earth movement (Kepke et al.).

According to Mickley (Mickley, 2001), the deep well injection is a practical method for brine disposal provided that long-term operation can be maintained, in order to dispose of large volumes of process fluid. The disadvantages of this technology are: the cost of conditioning the waste brine, the possibility of corrosion and subsequent leakage in the well sheath, the seismic activity which could damage the well and subsequently result in ground water contamination. Another drawback of this method is the uncertainty of the well half-life which can only be estimated using mathematical simulation techniques (Saripalli et al., 2000). Models for estimation of capital and operating costs, for conditions of stable well performance, have been developed by Mickley. However, the deep well injection method of brine disposal is considered as the most cost effective system for land based desalination plants (Skehan et al., 2000).
3.3 Aquifer reinjection

This method is mainly applied to smaller plants and involves the reinjection of the brine into the same aquifer used as feed in order to gradually increase the salt concentration in the feed water to be achieved. The full reinjection results in the salinity increase and by diverting part of the brine volume for various other disposal alternatives, the full reinjection effects can be reduced. There are also some significant factors that should be taken into consideration. These include the size of the aquifer, total salt load that is returned and the salt concentration in the aquifer. Moreover, the distance between the intake well and the reinjection well should be adequate in order the feed water quality deterioration to be limited (Mickley, 2001).

3.4 Discharge to wastewater treatment plants

This method is usually applied in cases where the desalination plant is located near a wastewater treatment plant. However, there are some factors to be considered such as the volume and composition of the brine in relation to the treatment capacity of the wastewater treatment plant, the convey processes and any possible charges might be imposed and finally the possible impacts of brine on the wastewater.
treatment plant equipment like the calcium carbonate precipitation on filters. In the U.K., the permission for the brine disposal must be granted by the local water company when disposal is carried out via a wastewater system and permission for this must be approved by the local water company. An adverse effect that brine discharge can have on a wastewater treatment plant is the precipitation of calcium carbonate on filters (Squire, 2000).

3.5 Discharge to sewage system

Small membrane desalination plants discharge the brine concentrate to the sewage system. The benefit of the particular disposal method is the dual purpose dilution being achieved. This disposal method is simple and usually cost effective, while it does not require a permit from the water treatment plant.

However, if the wastewater is mixed with the brine, the level of TDS in treated wastewater is increased having effects on the microorganisms of the system and the water may be rendered unsuitable for irrigation use. Additionally, this practice lowers the biological oxygen demand (BOD) in treated wastewater that can be beneficial under some circumstances.

Thus, considerations have to be made concerning the capacity of the sewage system (Ahmed et al., 2000). In general, the wastewater disposal method (including membrane wastes) by dilution in large bodies of water is mainly used in the United States.

3.6 Discharge to open land

This method is applied in two RO desalination plants located to Saudi Arabia. The reject water is simply discharged to a “natural pond”, the desert (Alabdula'aly et al., 1995). Through this method the salinity level of groundwater might be increased.
The Gulf countries, have become the world leader in desalination of sea and brackish water, and currently have more than 65% of the world's total capacity. The strategy of Saudi Arabia to meet present and future demands for water resources has shifted attention to the role of desalination technology in alleviating water shortages using sea and brackish water as feed (Al-Faifi et al., 2009). The reject brine from the seawater desalination is generally discharged to the sea, while in the inland desalination plants of brackish water and reject brine is disposed to evaporation ponds. Considering the fact that the environmental implications associated with the brine discharge from desalination plants have not received adequate considerations by concerned authorities, the uncontrollable discharge of brine to land has led to deterioration of soil structure and groundwater quality. Consequently, the infiltration rate of water and the soil aeration are reduced.

Consequently, disposal of reject brine from Salbukh water desalination plant at Riyadh (Saudi Arabia) to the pond has a significant environmental consideration. Results pertaining soil properties indicated that the soil pH, electrical conductivity values and the concentrations of soluble ions were higher in soils closed to the pond (Al-Faifi et al., 2009).

### 3.7 Reuse for agriculture or landscaping

Water reuse for landscape, ornamental and agricultural applications is an alternative method. In Florida for example, this method is applied to the high salt-tolerant turf grass (Reimold et al., 1996). It should be mentioned that salt and chemical concentrations in the water are appropriate for the avoidance of soil and groundwater pollution. These concentration levels should be dictated by underlying groundwater salinity and vegetation tolerance (Mickley, 1995). An important factor regarding irrigation of plants tolerant to high salinity with brine is that there must be an alternative disposal method available for periods of heavy rainfall (Squire, 2000). In San Diego County, the disposal of brine to a brackish water wetland area can
contribute to a beneficial wetland habitat development (Everest, 1995). The main criteria for using brine water as feed for irrigation purposes include site selection, hydraulic loading rates, land requirements, selection of vegetation and surface runoff control (Ahmed et al., 2000).

### 3.8 Discharge to inland surface water

The disposal of the membrane wastes may be done to surface waters either directly or following passage over the soil. Ultimate disposal is by dilution in receiving water (Mickley et al., 1993).

Disposal to surrounding inland surface waters that are not saltwater bodies such as rivers and lakes is not regarded as an environmentally viable option. However, it is mainly applied to smaller plants. There are significant differences in the composition of groundwater and the composition of seawater. Raw groundwater may contain toxic contaminants at certain concentration levels that may affect the aquatic organisms (Mickley, 1995). In natural streams there is a balance between animal life and plant. In waters characterized by good quality, there is a multiplicity of species with no dominance. Organic matter entering the stream is decomposed by bacteria to nitrates, sulfates, carbon dioxide and ammonia that are utilized by plants and algae to produce oxygen and carbohydrates. Consequently, the natural cycle can be disturbed by the introduction of excessive quantities of waste material.

Water pollution control is related to the protection of the aquatic environment and the maintenance of water quality in lakes, streams, rivers, ocean, estuaries and reservoirs. Water quality criteria that should be maintained depend on the potential final uses of the water.

In UK, considering this environmental consideration for brackish groundwater plants the disposal of the brine to surface waters requires permission by the Environment Agency (Squire, 2000).
3.9 Solar gradient ponds

Salt gradient solar ponds (also known as salinity gradient solar ponds) constitute a form of renewable energy source starting from Israel the last thirty years. Successful power generation by this technology has been demonstrated primarily in arid and semiarid parts of the world. According to recent experimental studies, in Italy and Switzerland solar ponds are coupled with thermal desalination systems while studies at the University of Texas involve power generation and thermal desalination in combination with brine disposal for recharge of the bottom layer of the pond.

Salinity gradient solar ponds can be utilized as heat collectors also as a means of heat storage. A solar pond has the potential to produce low cost thermal energy from a renewable source at large scale for industrial applications, including desalination. Pond surface areas range from 100 to 1,000,000 m$^2$ and depths range from two to four meters. The hot brine from a solar pond can be used as a heat source in industrial processes e.g. for vaporizing feedwater in small multistage flash evaporator units or multi-effect distillation desalination, for water/space heating and in electricity generation.

The heat storage in solar ponds can be attributed to their unique chemically stratified nature. In a solar pond there are three layers: 1. The upper or surface layer called the upper convection zone (UCZ), 2. The middle layer, the salinity gradient zone that is non-convection zone (NCZ) and 3. The lower layer, called the storage zone or lower convection zone (LCZ) (Foldager, 2003). The studies have shown that for sites where conditions are favorable for salinity gradient solar ponds, the particular method is less costly than other solar options. Moreover, a solar pond provides the most feasible and less expensive option for heat storage and seasonal and daily cycles.
3.9.1 The Case Study of El Paso Solar Pond Project

The El Paso Solar Pond (Figure 3-2) is a research, development, and demonstration project operated by the University of Texas at El Paso and funded by the Bureau of Reclamation and the State of Texas. The solar pond has been operated since 1993. Studies in countries such as United States, Israel, have shown that where the conditions are favorable for salinity gradient ponds, this technology for brine disposal is less costly than other solar options. In the particular project, the salinity gradient pond technology is combined with a multi-effect, multi-stage flash (MEMS) desalination (distillation) unit and has been tested under various operating conditions at the El Paso Solar Pond site. The whole system can possibly lead to a “zero discharge” desalination process.

The concentrate effluent from the primary desalination process (e.g. reverse osmosis, electrodialysis or multi-stage flash) provides feed brine to the salinity gradient solar pond, which in turn provides feed brine to a MEMS system. The highly saline brine from the MEMS will feed a brine concentrator and recovery system. The system of brine concentrator is driven by thermal energy from the solar pond and leads to a near-slurry salt discharge which in turn is used either to recharge the solar pond or for sale. The two vital environmental issues being addressed through this technological approach, concern the reuse of brine reject by negating the need for disposal (zero discharge) and the use of pollution – free renewable energy for desalting process (Lu et al., 2002).
Figure 3-2: A solar pond in El Paso (University of Texas, 2002)

Figure 3-3 illustrates how a typical MSF unit operates using solar pond brine as a heat source. The hot concentrate (shown in yellow) is pumped from the active zone of the pond and into the brine heater. Feedwater (shown in gray) enters at the end of a series of \( n \) stages (effects). The feedwater serves as coolant fluid for the water vapor held in each effect. Water vapor in the effect condenses outside the feedwater carrying pipe. By the time the feedwater reaches the brine heater, it is pre-warmed due to its contact with the condensing vapor. In the brine heater, the feedwater is warmed to the top brine temperature (the same temperature of the solar pond brine in the brine heater). Next, the feedwater flows into the first effect where the pressure is lowered to cause the evaporation of a fraction of the feedwater. This vapor rises up the effect, where it encounters the colder feedwater carrying pipe and condenses. The condensate is the final product (shown in blue), which is pumped into storage or distributed (Foldager, 2003).
As the feedwater passes into the second effect, the pressure is again lowered to cause evaporation, and so on throughout the n effects. Excess vapor that does not condense in the final effect is run through a condenser in order to remove the maximum amount of product.

Reject brine is pumped out of the final stage and into the solar pond, or into a secondary evaporation pond. Computer models developed and verified by Lu et al. at the El Paso Solar Pond Project show that, for a solar pond powered MSF unit, the only variables significantly affecting production rate are the flash range (the difference in temperature between the first stage and the last stage), the reject brine concentration level, and the rate of circulation in the first effect (Foldager, 2003) (Lu et al., 2002).

Lu et al. have stated that solar ponds are not suited for electricity generation because of the relatively low temperature of storage zone brine.

### 3.10 Evaporation ponds / Solar saltworks

One of the most traditional methods over the centuries for salt generation is the evaporation pond. Evaporation ponds consist of a series of connected ponds through
which seawater flows, evaporates by the power of the sun and wind, and deposits sodium chloride (salt) in crystallizing ponds.

The evaporation pond is merely an excavated depression in the ground which serves as a reservoir for desalination wastewater. The brine reject is concentrated causing precipitation of salt crystals as the solubility limit is reached. Through evaporation ponds, solar energy evaporates water from the concentrate, leaving behind precipitated salts that are ultimately disposed in landfills.

Arid climates facilitate evaporation ponds because of their high net evaporation rates, which decreases the pond area that is required in comparison to humid climates that have low net evaporation rates. In the most common case, concentrate is conveyed to the evaporation ponds where it is spread out over a large area and allowed to evaporate. The use of multiple ponds allows a continual receipt of concentrate while some ponds are taken offline for periodic maintenance. Through periodic maintenance the evaporation pond remains offline to firm the consistency of the precipitated salts. Once the precipitated salts have reached a satisfactory consistency, the ponds are cleaned by removing and transporting the precipitated salts to a landfill for ultimate disposal.

The evaporation ponds must be appropriately lined to prevent percolation of reject water down to the groundwater table. Liner material and thickness must also be selected appropriately, since increased salt content may cause deterioration of the liners. Mechanical misting equipment (Slimline Evaporators, also known as Turbo-Mist evaporators) is used to decrease the pond spraying the concentrate into the atmosphere in tiny droplets significantly increasing evaporation. The increased exposed surface area corresponds to a very high evaporation rate. Depending on the atmospheric conditions, large amounts of water can be evaporated leaving only precipitated salts. In this case, the ponds should be located to minimize the potential for aerosols being ingested especially when the ROC is from secondary effluent treatment process (Kepke et al.).
The major determinants of the cost of an evaporation pond include land costs, earthwork, lining, miscellaneous cost (like seepage monitoring) and operation and maintenance cost (Mickley, 2001).

Crystallization of sodium chloride (table salt) begins to happen at a concentration of 25.8% leaving a mineral solution as different salts crystallize at different concentrations (Salt Institute). Crystallization beds are used for the crystallization with even bottoms as this is where the salt crystals form when they grow heavy enough to overcome the surface tension of the water. The process can be described as follows: when salt is accumulated forming a layer of 10 to 15 cm, the sodium chloride is harvested, washed, and stockpiled. The purity of produced salt is 99.7% on a dry basis. The capacity of evaporation ponds ranges from 500 tons to 600 million tons of salt annually, corresponding to one third of the salt production worldwide. The annual production is estimated to be around 70 million tons. The seaside location of most ponds facilitates a ready access to seawater whilst the use of relatively inexpensive transport of the salt also the brine concentrate from desalination plants has to be explored.

Unlike other brine treatment and disposal methods, evaporation ponds produce only small amounts of effluents. The only waste product is the bittern (supernatant liquid above the deposited salt in the crystallizers), that is less than five percent of the volume of the intake seawater. The effluents are gradually released from small saltworks cause little damage to the environment. The remaining bitterns are placed in crystallizers to extract the remaining salt instead of being discharged into the sea. Alternatively, they remain permanently in deep lagoons, or be processed on the site or sold to obtain MgSO₄, MgCl₂, and K₂SO₄.

The pond area that is required to sustainably take care of all the brine would be approximately 1.6 hectares or about 2 soccer fields of international size. Furthermore, the effect of salinity on evaporation is always taken into consideration. If a recovery rate of 70 % is used, the total amount of brine produced would be increased by approximately. 90 m³/day and the additional required pond area would
increase with approximately 11500 m$^2$ or almost 1.5 soccer fields of international size.

The liners are a major component in the construction cost of evaporations ponds. These can be made from PVC, polyethylene, butyl rubber, hypalon etc. Prices from 1992 for PVC were approximately $ 5.7/m$^2$ (Ahmed et al., 2002). This means that the cost of lining would be $ 2850 for a 500 m$^2$ pond. Clay liners can be used extensively for agricultural ponds. The cost of the lining is heavily reduced by using clay liners, however there will most likely be some leaching to the groundwater. For that reason, reasonable limits of the leaching combined with groundwater that is brackish, can make clay lining to be a viable choice. The only limitation will be the availability of clay. The principal environmental concern associated with evaporation pond disposal is pond leakage, which may result in subsequent aquifer contamination.

The main precondition for an efficient pond is the establishment and maintenance of a biological system favorable to salt production. The environment provides physical requirements for the biological-water system with essential nutrients (e.g. combined nitrogen and phosphate) energy from sunlight and wind, and microorganisms in each community at various salinity levels (Davis, 1999).

In the southern part of Israel and specifically in the Negev region, there is an inland brackish well water desalination plant producing approximately 5000 m$^3$/day of permeate and 384 m$^3$/day of brine with a recovery rate of 92%. The disposal method that is used is evaporation ponds and the total area amounts to 65000 m$^2$. The cost of this amounts to $ 8.5 cent/m$^3$, included the land costs (Glueckstern, 1996). Evaporation ponds are regarded to be more competitive for relatively small plants in remote, inland locations with high evaporation rates (Mickley, 2001).
3.10.1 The Case Study of Middle East

In the Middle East, evaporation pond technology is widely practiced and to a lesser extent in Australia where the regions are arid. This technology is probably the most widespread method of brine disposal from inland-based desalination facilities. In regions with low rainfall and where climatic conditions are favorable for steady and relatively rapid evaporation rates, evaporation pond technology becomes more effective. Moreover, in locations where the cost of adjacent level land is relatively low the use of desalination plants is facilitated.

The common practices of brine disposal in Oman and the United Arab Emirates (UAE) range from of evaporation ponds to the disposal in shoreline, wadi beds and ocean. The paper study of Ahmed et al., provide information and quantitative data being gathered through field visits to 10 desalination plants in the Sultanate of Oman and 8 plants in UAE also through questionnaire surveys being conducted. The studied reverse osmosis plants in Oman utilize brackish groundwater as feedwater and the applied disposal methods are mainly land based. On the other hand, in the plants located in UAE the brine is disposed into the sea. The remarks arising from site visits to evaporation ponds concern leakage issues from the ponds and holes in the liners.

According to construction cost data of brine disposal into evaporation ponds, the unit cost of construction is reduced as the pond size increases. There are several influencing factors being involved in the total cost of an evaporation pond. These factors include the remoteness of the plant location, the availability of local construction materials and labor. Table 3-1 presents construction cost data for five recently built evaporation ponds, provided from the Ministry of Electricity and Water in Oman (Ahmed et al., 2000).
Table 3-1: Cost of disposal (evaporation pond construction in Oman)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Capacity (m³/d)</th>
<th>Recovery rate (%)</th>
<th>Design reject brine production (m³/d)</th>
<th>Cost of construction ($US)</th>
<th>Pond size (m²)</th>
<th>Unit cost ($US/m²)</th>
<th>Unit cost per m³/d of reject brine ($US/m³/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adam</td>
<td>1000</td>
<td>75</td>
<td>333</td>
<td>384,157</td>
<td>57,600</td>
<td>6.7</td>
<td>1154</td>
</tr>
<tr>
<td>Haima</td>
<td>100</td>
<td>38</td>
<td>163</td>
<td>121,360</td>
<td>15,040</td>
<td>8.1</td>
<td>745</td>
</tr>
<tr>
<td>Esherjah</td>
<td>100</td>
<td>42</td>
<td>138</td>
<td>184,766</td>
<td>13,200</td>
<td>15.0</td>
<td>339</td>
</tr>
<tr>
<td>Al-Haj</td>
<td>100</td>
<td>40</td>
<td>150</td>
<td>153,423</td>
<td>13,200</td>
<td>11.6</td>
<td>1023</td>
</tr>
<tr>
<td>Khumkham</td>
<td>100</td>
<td>45</td>
<td>122</td>
<td>65,629</td>
<td>1,200</td>
<td>54.7</td>
<td>538</td>
</tr>
</tbody>
</table>

3.10.2 The Case Study of Greece

Evaporation ponds, commonly known as solar saltworks, natural and artificial have existed in Greece for a long time and are considered important wetland ecosystems. According to a recent study conducted in Greece, it was investigated the option of directing the desalination effluent to evaporation ponds for salt production aiming at achieving the principle of zero liquid discharge. Also, with desalination plants becoming zero effluent, there is no need for the construction of a metallic non-corrosive pipe and diffuser that discharges the effluent brine deep in the sea. A survey was carried out evaluating the potential of transferring brine to ponds, in
order to avoid the disposal into the sea. Considering the fact that the construction of desalination infrastructure projects is restricted due to social reactions surrounding the potential environmental impacts of desalination plants, also the fact that water continues to be transported by ships, the cost of potable water is very high and burdens the State. It is estimated that the 25.5 million € that the Greek government has spent in three years for transporting water could be used for the construction of 15 seawater desalination units with a capacity of 30,000 m$^3$ per day in total, with an indicative water production cost of 0.4 €/m$^3$ (Karanikas, 2007). Additionally, local communities suffer from the consequences of the unreliability of water transport. The most important factor in assessing the feasibility of operating a zero discharge seawater desalination plant system is cost. In this case, the largest cost is incurred in transporting the brine from desalination plants to evaporation ponds. The analysis concluded that that brine transfer by trucks is prohibitively expensive and that efforts should be directed into developing a more efficient technology that will result in the production of only a fraction of the brine that is produced from the systems today, in order to make the zero discharge plant an economically feasible option (Laspidou et al., 2010). The following figures illustrate two different types of solar saltworks, one in Greece and another in Oman.

Figure 3-4: Solar saltwork in Mesologhi (Greece)
3.10.3 The Case Study of Autonomous Desalination Systems (ADS) in Morocco

Four autonomous reverse osmosis desalination systems powered by photovoltaic energy were installed in the sites located in Azla, Tazekra (province of Essaouira), and in the rural communities of Tnine Amellou and Tangarfa (Province of Tiznit). Among the aforementioned places, the case of the village of Azla required an additional activity according to which the pond at the well area will be covered up in order to avoid possible presence of biologic pollution in the feed water. Each system comprise of three hydraulic connections: feed water pipe from the well to the building, fresh water outlet to the reservoir, and rejected brine to the evaporation pond. Piping connections are divided into the low pressure circuit (feed and fresh water) and high pressure circuit (feed water inlet and brine outlet to the pressure vessels). A high quality plastic material (polypropylene) has been selected for the high pressure pipes in order to reduce the corrosion. The rejected flows end to an evaporation pond, wherein brine is stored and then evaporated. Evaporation is accelerated by the use of nozzles in the disposal point. Nozzles convert the flow in a rain of small drops, this important increment in the contact surface reduce the evaporation time (Subiela et al., 2008). The total cost of brine treatment systems comes to 19,000.00 € and the average unitary cost is estimated at 4,750.00 €.
The main critical environmental impact of an inland desalination system is the brine disposal, provided that there is no large sink to connect the rejected water flow. For the four studied cases, evaporation pond is the selected brine disposal option. In the case of Alza, there are close saline ponds, used to produce salt. This local experience and know-how will be used to design and built the evaporation ponds for the villages of the Essaouira province. Water evaporation mainly depends on the water temperature, humidity of surrounding air and local wind speed. Taking into consideration the above variable factors, a system to increase the water air contact surface has been proposed. It is based on the use of nozzles that convert the water flow into a set of small drops of water (Subiela et al., 2008). The design of the system and images of the nozzles are show in the following figure.

![Figure 3-6: From bottom to top: trench for the feed water pipe, well, fountain and brine evaporation ponds (Amellou)](image)

3.10.4 The Case Study of Central Arizona (Valley of the Sun)

In the Phoenix metropolitan area advanced water treatment, reverse osmosis (RO) is being currently used and anticipated to be increased in the future to supplement potable water supplies. Large amounts of potable water will be produced but also large...
amounts of waste in the form of brine will be created. If there is not a sustainable method to manage the brine then possibly those future RO facilities will not be constructed.

In the particular area the two most common methods of brine management are evaporation ponds and sewer disposal. Neither method is sustainable provided that larger quantities of brine are generated. Large evaporation ponds are extremely expensive and brine disposal into sewers diminishes the usable hydraulic capacity at the receiving waste water treatment plant and is detrimental to the valuable effluent being produced there (Poulson, 2010). Therefore, there is a planning process seeking for a regional solution aiming to move the brine out of the urban environment considering the low cost of land. Regional solutions for brine management must be cost effective, energy efficient, environmentally friendly and implementable.

At a planning level, there are six possible alternatives for a regional brine management solution. Alternatives such as brine concentrators are energy intensive, while regional evaporation ponds are too expensive and deep well injection needs special geology not found in central Arizona. According to the Central Arizona Salinity Study (CASS) six regional brine management alternatives were developed during CASS meetings. These alternatives were examined for cost, energy consumption, environmental acceptability and intangibles. The main tool used to compare the alternatives was cost, both capital and operational. Some of the design/cost analysis tools (models) developed in the CASS Phase II report being used to calculate the costs.

The alternative scenarios studied are: **Alternative 1**: Pipe line to Yuma, **Alternative 2**: Pipe line to Evaporative Ponds in Desert, **Alternative 3**: Brine Concentrator/Evaporation Ponds, **Alternative 4**: Softening/2\textsuperscript{nd} RO/ Vibratory Shear Enhanced Processes (VSEP)/Evaporation pond, **Alternative 5**: Wetlands with Surface Discharge to Gila River, **Alternative 6**: Pipeline to Deep Well Injection Site.

Table 3-2 shows the capital costs, operation and maintenance costs (O&M) and annualized costs for the 10 mgd sized alternatives. Evaporation ponds have by far the most expensive upfront capital costs, while the brine concentrator option consumes
tremendous energy and thus has high O&M costs. On an annualized basis, these two alternatives would be the most expensive to implement.

Table 3-2: Alternative Comparison 10 mgd (millions of dollars)

<table>
<thead>
<tr>
<th>10 MGD</th>
<th>Pipeline to Yuma</th>
<th>Evaporation Pond</th>
<th>Brine Concentrator</th>
<th>Soften/RO/VSEP</th>
<th>Wetlands Surface Discharge</th>
<th>Injection Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$266.11</td>
<td>$651.69</td>
<td>$272.71</td>
<td>$286.56</td>
<td>$150.22</td>
<td>$114.46</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>$0.62</td>
<td>$3.50</td>
<td>$29.75</td>
<td>$6.90</td>
<td>$1.75</td>
<td>$11.31</td>
</tr>
<tr>
<td>Annualized</td>
<td>$14.92</td>
<td>$40.26</td>
<td>$44.40</td>
<td>$22.30</td>
<td>$10.37</td>
<td>$17.46</td>
</tr>
</tbody>
</table>

Table 3-3 presents the annual energy consumed, the cost of that energy and the amount of water recovered by the 10 mgd alternatives. Water recovered from the brine is an attractive feature of the Softening/RO/VSEP and the brine concentrator alternatives despite the fact that the brine concentrator energy costs are prohibitive.

Table 3-3: Alternative Comparison - Annual Energy & Water Recovered

<table>
<thead>
<tr>
<th>10 MGD</th>
<th>Pipeline to Yuma ****</th>
<th>Evaporation Pond</th>
<th>Brine Concentrator</th>
<th>Soften/RO/VSEP</th>
<th>Wetlands Surface Discharge</th>
<th>Injection Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy* (kilowatt-hours)</td>
<td>minimal</td>
<td>1,146,000</td>
<td>310,250,000</td>
<td>68,135,000</td>
<td>minimal</td>
<td>143,769,000</td>
</tr>
<tr>
<td>Energy Cost**</td>
<td>minimal</td>
<td>$88,000</td>
<td>$23,889,000</td>
<td>$662,000</td>
<td>minimal</td>
<td>$11,070,000</td>
</tr>
<tr>
<td>Water Recovered*** (af)</td>
<td>0</td>
<td>0</td>
<td>10,528</td>
<td>9,238</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Kilowatt-hours of energy required (annual)
** $.077 per kilowatt-hour
*** Acre-feet of water recovered from the brine by this alternative (annual)
**** Does not include the pipeline to Salton Sea Option which would require energy for pumping

The two alternatives that seem to have the most advantages are the Softening/2nd RO/VSEP/Evaporation pond and the Wetland with Surface Discharge on a local scale but it is difficult to implement on the regional scale.

The first optimum alternative, Softening/2nd RO/VSEP/Evaporation pond, is relatively cost effective recovering much of the water from the brine which otherwise would be rejected. The particular alternative can be examined at many different magnitudes. It could be implemented as a zero liquid discharge (ZLD) brine management technique at a
Deliverable 1.1: Report on the evaluation of existing methods on brine treatment and disposal practices

single RO facility which had sufficient space. It could be implemented by one or two cities working together which had two or three RO facilities located relatively close together.

The second alternative, Wetlands with Surface Discharge, is attractive as it has the lowest annualized costs of all the alternatives examined and the energy requirements are minimal. It supports habitat along the Gila River when other forces are acting on the River to dry it up. Nevertheless, the Net Ecological Benefits rule would have to be successfully argued and accepted by Arizona Department of Environmental Quality (ADEQ). Moreover, as the regulated ions are sequestered from the environment, the majority of the salts are just moved further downstream (Poulson, 2010).

3.11 Landfill

For a majority of the concentrate reduction alternatives, the end disposal mechanism is to landfill as either liquid/slurry or solid concentrate. The efficiency of the treatment alternative has a significant effect on the amount of material disposed into a landfill. In most landfills, at least 50 percent of the material is required to be put in the landfill in solid form. Additionally, the disposal of liquid waste may not be permitted at every facility while the disposal of liquid waste may have a higher cost where it is required to be done in drums.

Furthermore, there are high transport and permit costs associated with disposing industrial material in landfills whilst disposal fees can vary dramatically with landfill facility (Kepke et al.).
4 Disposal of Brine in Coastal Locations

Brine discharge into the sea or an open ocean is considered as the most conventional method applied mainly to desalination plants located to coastal places. The disposal methods of brine in coastal locations comprise of the surface water disposal and submerged disposal. The most common way to dispose brine effluents is to reject them into surface waters such as ponds, freshwater lakes, tidal streams, oceans, bays and estuaries.

The submerged disposal is defined as the rejection of brine concentrate underwater, rather than its disposal on the surface of water. Likewise surface disposal, submerged disposal takes place in tidal or estuarine environments. Disposal is conducted using pipes far into the ocean in contrast with surface disposal that usually occurs closer to the coastline. Country regulations usually define certain zones in open oceans known as “allocated impact zones” and the water quality limits can be exceeded in such zones for non-toxic pollutants (Kimes, 1995).

At present, approximately 48% of desalination facilities in the U.S. and most plants in the Middle East dispose brine effluents to surface waters. On the contrary, this disposal method does not represent a viable option for desalination plants located to inland regions whereas the transport of concentrate to the final recipient is not associated with cost-effectiveness. Specifically, considering that brine is corrosive, pipelines and tanker trucks have to be fitted with special protective liners for its transportation.

Because of the mentioned requirements and the cost of transportation, ocean disposal is getting more and more expensive by the increase of the distance between the source of the waste and its final destination at the ocean (Foldager, 2003).

4.1 Ocean disposal

There are primarily four different ocean disposal alternative options:
4.1.1 Discharge by pipe far into the sea

A critical factor of this method is the distance between the intake and the outlet of the water that has to be considerable enough avoiding or minimizing the risk of feed water deterioration. The brine should be disposed by pipe sufficiently far out into the sea. If the brine concentrate is discharged directly into the sea, a plume of elevated density is formed that will descend to the sea floor and extend horizontally following the sea bottom bathymetry.

For instance, the Dhekelia plant in Cyprus the distance between the inlet and the outlet is more than 2 km. Mitigation measures should be taken so as to reduce the potential impacts on the marine environment (Einav et al., 2002).

4.1.2 Direct discharge at the coastline

The particular disposal method is not a viable option. Considering the low cost, it is implemented by smaller desalination plants that dispose the brine concentrate at insensitive shores. The associated impact on the shore environment might be high, in case of seasonal calm conditions that the rate of dilution is low (Einav et al., 2002). The direct brine disposal on the shoreline can lead to salinity increase along the coastline and the intensity of saline intrusion effect (Purnama et al., 2003). Another impact is the deterioration of feed water quality. Coastal saline intrusion is the phenomenon where seawater displaces or mixes with fresh water in an aquifer owing to hydrogeological changes. It is caused by the excessive drainage of low lying regions close to the coast or the overpumping of groundwater that is connected hydraulically with seawater. As a result, the hydraulic equilibrium is disrupted due to the decrease in groundwater level also the freshwater is displaced by seawater and the interface of the mixed saline/fresh water interface is moved inland (SIWIN, 2004).
4.1.3 Discharge at a power stations outlet

The main advantage of this method is the high brine dilution rate resulting in low density of brine and therefore reducing the sink of the plume in the seawater. This is practiced extensively in thermal desalination plants operated as hybrid installations combining water and energy production (Einav et al., 2002).

4.1.4 Discharge to a plant for salt production

The particular method is an environmental and economical option. However, a considerable limitation for this method could be the presence of salt production plants in the close region near the desalination plant (Einav et al., 2002). This is applied in Eilat, the southern point of Israel.

4.2 Natural Treatment Systems

Wetlands (NTSs) constitute an alternative approach both for disposal and treatment of brine reject. Wetland systems are based on natural processes for water quality improvement through physical, chemical and assimilative processes. The capability of wetlands and aquatic ecological systems to improve the quality of water treatment has been recognized for over than 25 years. Nowadays, it is considered as an acceptable control technology rather than a research concept. Wetland treatment systems have been developed and engineered to treat wastewater from municipal, industrial and agricultural sources. A wetland system represents a cost effective and energy efficient alternative among energy-intensive conventional brine treatment methods. Another benefit arising from the treatment systems is the wildlife habitat creation. The discharge is ecologically safe to wetland biota. Data from pilot tests in wetlands have indicated that brine concentrate may sustain viable native plant communities. Non-conservative elements can be removed through natural biological and chemical transformation processes, while conservative
elements are eliminated through physical and chemical processes. The removal rate relies on the type of wetland system.

5 Brine Treatment Options

Introduction of RO concentrate

During the last years, Reverse Osmosis (RO) membranes have been utilized to a greater extent in water supply applications for industrial and municipal uses. The treated water ranges from brine surface or ground waters, to secondary treated effluent or sea water. In spite of the expansion in recycled water systems being introduced by this technology, the associated brine treatment represents an important limitation to water reuse also an economic hurdle for various applications. The cost of concentrate treatment has to be determined in the evaluation of economic feasibility of utilizing RO technology. Additionally, the effectiveness and desirability of RO treatment have to be determined considering the availability and feasibility of concentrate treatment options. Recently there have been developed new treatment technologies of RO concentrate (Kepke et al.). An analysis of potential concentrate treatment options, the state of current technology, implementation issues and cost considerations is presented below.

5.1 Advanced Solar Dryer

5.1.1 The Case Study of “AQUASOL” Project

Among low capacity production systems, solar ponds represent the best alternative in case of both low fresh water demand and land price. For higher desalting capacities, it is necessary to choose conventional distillation plants coupled to a solar thermal system, which is known as indirect solar desalination (Garc’ia–Rodríguez and G’omez–Camacho, 2001).
The AQUASOL project named “Enhanced Zero Discharge Seawater Desalination using Hybrid Solar Technology” is one attempt at putting solar energy as the energy input to the desalination plant. The project was approved by the European Commission and the activities have been initiated in 2002.

The AQUASOL aims at the development of a lower cost multi-effect distillation technology MED with improved energy and environmental performance, promoting the use of solar energy both in the desalination and in the effluent treatment processes. Combining the reduction of energy consumption in the MED process, with the utilization of NaCl as a sub-product resulting from the effluent treatment process through brine concentration in a solar passive dryer, the project represents a likely means to accomplish a lower water cost objective. An advanced solar dryer reduces to zero any discharge allowing brine concentration and/or ultimate salt recovery, from the MED brine effluent by increasing the concentration in the brine until it has reached the saturation point of calcium carbonate (Figure 5-2).

Figure 5-1: Solar chimney dryer (Aquasol Project)
Zero discharge will enhance the overall process not only from the environmental point of view, but also from the economical as the salt obtained from each cubic meter of brine could even be more valuable than the distilled water itself. It is expected to at least, double the present normal production rate at conventional salt pits (Blanco et al., 2002). Taking into consideration the specificities of salt production in a classical saltworks, in the context of AQUASOL an optimized design based on a passive approach was studied, aiming at developing an improved system to deal with a constant brine flow.

The concept of the project includes a MED plant being located close to a conventional Saltworks and feed into it the produced effluent, while adding means to promote a more efficient concentration of the brine, as compared with the conventional production technique. Its design involves the following parameters and constraints (Collares-Pereira et al., 2003):

- The elimination of brine dilution by the action of rain fall in the ponds
- The promotion of air circulation being achieved by natural convection preventing the increase in moisture content near the brine surface which would imply the need for evaporation.
A prototype with a 20 m² evaporation area was constructed for testing under real brine evaporation conditions and a data acquisition system was installed for continuous monitoring of prototype performance (Collares et al., 2003). Common greenhouse materials were used in the prototype construction, resting over a concrete base with its entrance aperture due south. The evaporation pond has been set with a liner having 1.5 mm thickness: High Density Polyethylene film. The greenhouse structure constructed in galvanized steel tubes and covered with 0.2 mm thickness 3 layer thermal polyethylene films. Additionally, the solar chimney constructed with 0.8 m diameter galvanized tube, painted black. The variables and measuring points are indicated in the following Fig.5-3.

After monitoring, it was identified that there was a loss of performance due to low airflow velocities around the interface region brine/air, underlined the necessity to introduce modifications of the prototype. These modifications were meant to increase air velocity as close to the water/air interface as possible. Consequently, a lowered evaporation channel was adopted, inducing higher airflow velocities around the interface brine/air. Furthermore, non-imaging optics were adopted enhancing the performance of chimney increasing also the solar collection area and producing the heating of the whole chimney surface (Collares et al.2003).
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The final full-scale Advanced Solar Dryer prototype (ADS) at Lesvos (Greece) consists of a group of three parallel evaporation channels with individual solar chimneys and smooth convergent pre-heater modules positioned towards the dominating local wind direction (North, at final Lesvos location). The final dimensions of each of the ASD modules correspond to an evaporation pond area of 65 m$^2$, a solar chimney length of 3 m, an evaporation channel width of 4 m and a total length of about 22 m.

Each evaporation channel has a plastic cover, a preheating section at the inlet, and a solar chimney located at the outlet to promote air stream inside the channels. According to simulation models, a 2.5 increase in efficiency compared to traditional open-air salt evaporation ponds is foreseen.

![Simulated view of the three advanced solar dryer modules proposed in the AQUASOL Project](courtesy of INETI)

**Figure 5-4**: Simulated view of the three advanced solar dryer modules proposed in the AQUASOL Project (courtesy of INETI)

### 5.2 Electrodialysis – Electrodialysis Reversal (EDR)

Throughout this process, the solutions are desalted or concentrated electrically. The method can be utilized as a secondary desalting process by substituting the stage of brine evaporation.

Dissolved salts are dissociated into positively and negatively charged ions. A semipermeable barrier allows the passage of either positively (cations) or negatively charged ions while excluding the ions of opposite charge. The semipermeable barriers are normally known as ion exchange, ion-selective and electrodialysis membranes. Membrane barriers are used mainly for desalting and demineralization
processes, while the product water does not pass through the barrier. This process is subject to high capital and operating cost, while methods such as landfill and crystallization are required for the final brine disposal. This technique can be competitive due to the lower pretreatment requirements (http://www.electrosynthesis.com/ess/weid.html).

5.3 VSEP Membrane System

This minimization technique is aiming at reducing scaling potential and increasing recovery. Like EDR method, this system can efficiently decrease the amount of brine concentrate need to be disposed. The particular method can be applied such as an intermediate treatment stage of brine by substituting the single effect evaporation.

A vibratory shear-enhanced processing membrane system is used to treat directly either brackish raw water or brine produced by conventional Reverse Osmosis treatment of this water.

New Logic Research Incorporation located in California (Emeryville) has developed a system known as Vibratory Shear Enhanced Processing VSEP, an alternative method that produces intense shear waves on the surface of membrane. During system’s operation a shear cleaning action is created by vigorously vibrating the leaf elements in a direction tangent to the membranes’ faces. The vibration contributes to the reduction of brine concentration level at the surface of membrane, a phenomenon known as concentration polarization (CP). The CP layer except for cutting down on the flux performance of the membrane it also acts as a secondary membrane reducing the selectivity of membrane. The shear waves produced by the vibration might cause potential foulants which are lifted off the membrane surface and remixed with the bulk material flowing through the membrane stack. Through this process, the membrane pores are exposed to maximum throughput that is normally between 3 to 10 times the throughputs of conventional cross-flow systems (Kepke et
Nevertheless, methods such as landfill and crystallization would still be required for the ultimate brine disposal.

At present, VSEP technology is used in various industrial applications for treatment of surface water to make ultrapure water, also for treatment of wastewater reject from other membrane systems to reinforce the principle of Zero Discharge. Nevertheless, it has not been demonstrated in full scale for the treatment of municipal water reuse concentrate (http://www.vsep.com/technology/index.html).

5.4 Chemical Softening and Secondary Desalting

This approach combines chemical and physical procedures to enhance recovery from brine produced by a primary RO plant. Primary brine is treated with conventional softening chemicals (lime, sodium hydroxide and soda ash) causing hardness and minerals precipitation. According to recent pilot studies, at appropriate pH values silica is removed through co-precipitation as being absorbed into magnesium precipitates. Thereafter, the supernatant layer is filtered to remove remaining solids from the precipitation step. Some slightly soluble salts can be removed almost by 90%, depending on operational conditions, often returning the hardness and silica concentration to those of the initial feed to the primary RO plant. After softening, water is fed to a secondary desalting process such as EDR or RO. Provided that the total dissolved solids (TDS) of the produced softened water is higher than that of the primary RO feed, the secondary membrane process is forced to operate at higher feed pressure in a RO, or higher electrical potential in EDR.

Despite the increase in the feed water TDS concentration, higher recovery is sometimes possible in the secondary desalting step because the upstream softening may result in lower concentrations of scaling precursors than the primary feed. The main disadvantages of this treatment approach are the production and disposal of large volumes of solids from chemical softening, the need for high dosages of chemicals, and the presence of fine solids from the softening step that can impact
downstream process performance (Eastern Municipal Water District Carollo Engineers, 2008).

5.5 Precipitative Softening/Reverse Osmosis

The main constraint on RO operation at higher recoveries is the precipitation of barely soluble inorganic salts. At lower recoveries, the precipitation of inorganic salts can be controlled by using antiscalants and adjusting feedwater pH value. At higher recoveries however, antiscalants are not effective and pH control does not prevent precipitation of minerals such as barium sulphate and calcium sulphate which cannot be removed by chemical cleaning. Another obstacle that can be generated by low pH is the scaling of silica (Kepke et al.).

5.6 High Efficiency Reverse Osmosis (HERO™)

The HERO process comprises of several pre-treatment steps combined with reverse osmosis method operating at high pH. The primary process consists of three steps: hardness, suspended solids and carbon dioxide removal and RO treatment at elevated pH values. Pre-treatment stages, except for RO treatment, can be adjusted to water chemistry and properties also site-specific design criteria.

Total hardness and other cationic species that would form scaling on the membrane surfaces must be removed and suspended solids have to be reduced to near zero to minimize plugging. Additionally, carbon dioxide is removed to minimize buffering. RO recovery does not limited by silica, provided that it is highly soluble at elevated pH. In the hardness removal process, it is used conventional lime soda softening followed by filtration in dual media or pressure filters and weak acid cation ion exchange.

This type of RO treatment is relatively new. It has not been utilized in water reuse applications but has been applied to power stations and mining industries. The main
advantages of this process over conventional RO include reduction in scaling, elimination of biological and organic fouling due to high pH and recoveries of up to 95%. The disadvantages of the HERO process are the high chemical usage (due to lime softening process and ion exchange), higher capital cost than conventional RO and the disposal of waste streams generated from the lime softening process (solids) and ion exchange (waste brine). HERO has been installed by U.S. supplier AquaTech in six industrial applications (Kepke et al.).

5.7 Mechanical Evaporation

The treatment of brine reject by mechanical evaporation is a costly process. In plants where the principle of zero-liquid discharge is practiced, mechanical evaporators are in use. The overall cost is high due to the high energy consumption and cost required for brine or final salt disposal.

The mechanical evaporation process is driven by the heat transfer from condensing steam to the lower temperature membrane reject across a metallic heat transfer surface. As a result, the water is evaporated and the reject salt concentration is increased. The vapor is then condensed to a liquid distillate for reuse. Evaporators are classified according to the arrangement of heat transfer surface and the method used to transfer heat to the feed solution. The common types of evaporators include Single effect, multiple effect, vapor compression, vertical tube falling film, horizontal tube spray film, forced circulation. The most frequent combination of evaporators aiming to achieve full evaporation of brine reject streams is the vertical tube falling film for vapour compression evaporation followed by a crystallization or landfill step.

5.7.1 Residual Recovery (SAL-PROC)

SAL-PROC represents one of the newest entry treatment options into the drinking water industry. It is a proprietary technology developed by Geo-Processors USA, Inc. (Glendale, California) which comprises of several processing steps. Through the
process, dissolved constituents of the saline feed can be sequentially extracted in the form of valuable chemical byproducts in crystalline, slurry and liquid forms. The main steps include multiple evaporation and/or cooling supplemented by conventional chemical and mineral processing steps like desulphation and reaction.

The technology is based on simple closed-loop processing and fluid-flow circuits, through which inorganic saline streams can be utilized for the recovery of precious mineral and chemical products (Eastern Municipal Water District Carollo Engineers, 2008).

Large-scale pilot systems have already demonstrated the technical feasibility of the process to produce a number of valuable chemicals from one or more waste streams while achieving the principle of zero liquid discharge ZLD. The chemicals typically isolated from saline streams are gypsum-magnesium hydroxide, magnesium hydroxide, sodium chloride, calcium carbonate, sodium sulfate, and calcium chloride. These can be sold to a number of industries, generating an income stream. Therefore, the waste product is transformed into a resource, and the revenue generated may be used to offset operational costs of the facility. The cost of this processing type of technology can be improved with access to a cheap energy source (Svensson, 2005).

![Diagram of the SAL-PROC technology](image-url)

*Figure 5-5: The SAL-PROC technology*
This process selectively or sequentially removes dissolved salts from a saline stream such as RO brine as useful products and returns a large percentage of the flow stream for potable water use. It is a proprietary process that is generally applied in conjunction with RO membrane and other volume reduction technologies to minimize or eliminate the brine disposal needs.

6 Description of Unit Processes for Brine Minimization

Desalting technologies are categorized into two basic types: thermal desalting processes and membrane processes. The second type involves brine concentration and crystallization methods that are characterized by high-energy demand and low efficiency to meet the criteria of drinking water industries such as the high-volume and the low-cost products. Most commercially available technologies are driven by thermal processes entailing great capital, operations and maintenance costs than RO plants.

The domain membrane desalting technologies have been restricted to RO and EDR. They are used widely in water industrial applications despite the large volumes of produced undesirable saline waste during operation at standard recoveries of 50 to 85%. This fact has shift the interest in new competitive membrane technologies such as forward osmosis FO and membrane distillation MD that are capable of operating at higher recoveries and achieving ZLD (Zero Liquid Discharge) opportunities. These nonthermal processes that show promising results, for now, they are not available for commercial applications.

Waste minimization is an approach aiming at decreasing the production of brine concentrate by membrane process recovery and enhancement techniques or reducing its concentration prior to disposal. The particular approach is not usually considered a very economic viable option given the need for an extensive pretreatment and the increased membrane area.
The brine minimization techniques are: brine concentrators (BC), crystallizers (XLZR) and Zero Liquid Discharge systems (ZLD). The brine minimization processes are described in detail below.

6.1 Brine Concentrators

Brine concentrators are mechanical evaporators being used in the power industry to promote concentration of cooling tower before the final disposal. The majority of concentrators operate on single-effect evaporators, which use steam to heat brine solutions thus promoting water evaporation during the operation of an electrically powered vapor compressor. The released heat from condensing steam is transferred via a heat exchanger to the brine solution which is boiled. The overall efficiency of the process can be enhanced by multiple stages throughout brine concentrators’ operation. The major advantage of brine concentrators includes the production of high-purity distilled water with a monetary value, also the reduction of brine solutions to highly concentrated levels. At recoveries of 90 to 98%, the level of TDS may be as high as 250,000 mg/l.

The reject brine tends to be very corrosive and therefore the evaporators have to be constructed of durable and high quality materials such as stainless steel and titanium. These materials are characterized by high cost, increasing the capital expenditure of concentrators (Eastern Municipal Water District Carollo Engineers, 2008). Capacities of commercially available brine concentrators range from 10 to 700 gallons per minute (gpm) with estimated energy consumption of approximately 90 kilowatt hours per 1,000 gallons (kWh / 1,000 gal). The brine stream may be discharged to an evaporation pond. Figure 6-1 presents an overview of a brine concentrator.
6.2 Crystallizers

The latest years, the need to concentrate wastewater so as to be reduced to a transportable and manageable solid form has been increased. For many years crystallizer (XLZR) technology has been used to concentrate feed streams especially brine reject from desalination plants. Crystallizer technology is the most viable option in areas where the construction cost of solar evaporation ponds is high, solar evaporation rates are low and the deep well injection treatment is costly or unfeasible. The crystallizer converts the waste reject to clean water that is proper for reuse in the plant and the solids to a suitable form to be disposed in landfills. The capacity of a typical crystallizer for brine disposal ranges from about 2 to 50 gpm. These units consist of vertical cylindrical vessels with heat input from vapor compressors or an available steam supply. For small systems in the range of 2 to 6 gpm, the steam-driven crystallizers are more economical. For larger systems, the heat of evaporation is supplied from electrically driven vapor compressors.

In the case of RO concentrate disposal, crystallizers are normally operated in conjunction with a brine concentrator evaporator so as to reduce the blowdown of brine concentrator to a transportable solid resulting in a Zero Liquid Discharge.
system (Eastern Municipal Water District Carollo Engineers, 2008). Crystallizers can be used to concentrate RO reject directly, while the corresponding capital cost and energy usage are quite higher than those of a brine concentrator of equivalent capacity (Mickley, 2001). Figure 6-2 presents an overview of a crystallizer.

![Fig. 6-2: Schematic of brine crystallizer](image)

### 6.3 Zero Liquid Discharge

The basic principle of the method is based on the production of a dry end product with no reject water being discharged in the environment. This enables the possibility for a resource recovery system, resulting to less volumes of brine with higher concentrations.

The main stage of a zero liquid discharge system is thermal evaporation that it ends to a solid end product. This end product is in the form of precipitated salts and/or mineral slurries that can be sold if there are any market possibilities. ZLD is normally a combination of several different disposal techniques. Evaporation ponds followed by enhanced evaporation techniques using additional energy sources to further concentrate the brine is a typical ZLD approach.

A ZLD system is mostly used in certain situations where waste brine streams are relatively small and the available land is limited. This technology has been applied
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to wastewater rejects from power plants, mining operations and oil refineries. The energy requirements characterizing the system are large and the overall capital cost unfavorable for handling large volumes of brine (Glater et al., 2003).
7 Evaluation of Brine Treatment and Disposal Methods

The mitigation of environmental implications of concentrate disposal is most closely related to the means through which it is managed.

Several disposal techniques of the brine concentrate are practiced worldwide including: direct surface water discharge, discharge to a sewage treatment plant, deep well disposal, land application, evaporation ponds, brine concentrators as well as mixing with the cooling water or sewage treatment effluents prior to surface discharge.

Brine discharge into surface water bodies is the most commonly used and least expensive disposal method in practice today (Mickley, 1995), (Del Bene et al., 1994) (Squire, 2000). Minimal adverse impacts are expected if rapid mixing and dilution are ensured in the discharge zone (Höpner, 1999) (Ahmed et al., 2000). These optimal mixing conditions can be attained by the careful design and construction of outfalls that account currents, and the hydrodynamic characteristics of the discharge area. Outfalls should avoid lagoons, shallow water and inter-tidal areas with limited circulations and look for rather exposed coastal stretches with strong flushing capabilities (Höpner, 1999), (Khordagui, 1997), (Bushnak, 1997), (California Coastal Commission, 1993). In fact, the USEPA prohibits the discharge of any effluent in shallow near-shore water bodies and requires the construction of offshore outfalls. In Cyprus, the new Larnaca RO plant (capacity 54,000 m$^3$/day) was required to be equipped with an outfall exceeding 1 km in length and discharging at least 10 m below sea surface to limit brine impact on existing biota (Einav, 2002). Submerged discharge outfalls however are more costly, particularly in the Gulf region since the distance required for laying down the pipes is relatively long due to the shallowness of the Arabian Gulf. The adoption of submerged multi-port diffusers is expected to be cheaper than single-port submerged outfalls in the case of the Arabian Gulf since multi-ports are capable of ensuring rapid mixing even in shallow water bodies thus
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reducing the costs associated with placing pipes over long distances. This is attributed to the presence of a multitude of nozzles in the diffuser that increase the plume’s contact area with the ambient water, increase initial mixing rates, and reduce the downstream distance traveled by the plume before meeting the environmental regulatory requirements (Davis, 1999), (Fischer et al., 1979).

The following table summarizes the advantages and disadvantages of the most common brine disposal methods in the wider context of environmental protection focussed on the associated impacts and cost (Ahmed et al., 2000), (Khordagui, 1997), (Mickley, 1995), (Jirka, 1996), (Del Bene et al., 1994), (Truesdall et al., 1995).
Table 7-1: Advantages and disadvantages of common brine treatment and disposal methods

<table>
<thead>
<tr>
<th>Disposal method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct surface water discharge</td>
<td>• Natural processes promote degradation&lt;br&gt;• Can accommodate large volumes&lt;br&gt;• Water body promotes dilution&lt;br&gt;• Low cost&lt;br&gt;• High dilution rates in the water body, possible dilution and blending with power plant discharge</td>
<td>• Dilution depends on local hydrodynamic conditions&lt;br&gt;• Good knowledge, monitoring and planning programs of receiving waters are required&lt;br&gt;• Limited natural assimilation capacities cause adverse impacts on marine environment if exceeded&lt;br&gt;• Thermal pollution, reduction of dissolved oxygen in receiving waters, eutrophication, toxicity, pH increase, damage of biota</td>
</tr>
<tr>
<td>Discharge to a sewage treatment plant</td>
<td>• Lowers the BOD of the resulting effluent&lt;br&gt;• Dilutes the brine concentrate&lt;br&gt;• Uses existing infrastructure</td>
<td>• Can inhibit bacterial growth&lt;br&gt;• Can hamper the use of the treated sewage for irrigation due to the increase in TDS and salinity of the effluent&lt;br&gt;• Overload the existing capacity of the sewage treatment plant while diminish its usable hydraulic capacity</td>
</tr>
<tr>
<td>Deep well injection</td>
<td>• Viable for inland plants with small volumes of brine&lt;br&gt;• No marine impact expected</td>
<td>• Cost efficient only for larger volumes&lt;br&gt;• Needs a structurally isolated aquifer&lt;br&gt;• Increases the salinity of groundwater</td>
</tr>
<tr>
<td>Land applications</td>
<td>• Can be used to irrigate salt tolerant species&lt;br&gt;• Viable for inland plants</td>
<td>• Requires large areas of land&lt;br&gt;• Suitable for smaller discharge flows&lt;br&gt;• Can affect the existing marine environment</td>
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## Deliverable 1.1: Report on the evaluation of existing methods on brine treatment and disposal practices

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix with small volumes of brine</td>
<td>- No marine impact expected</td>
<td>- Can increase the salinity of groundwater and underlying soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Storage and distribution system needed</td>
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<tr>
<td>Evaporation ponds</td>
<td>- A viable option for inland plants in highly arid regions</td>
<td>- Expensive option</td>
</tr>
<tr>
<td></td>
<td>- Possible commercial salt exploitation</td>
<td>- Risk of underlying soil and groundwater pollution</td>
</tr>
<tr>
<td></td>
<td>- No marine impact expected</td>
<td>- Needs dry climates with high evaporation rates</td>
</tr>
<tr>
<td></td>
<td>- Low technological and managing efforts</td>
<td>- Requires large areas of land with a level terrain</td>
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<td></td>
<td></td>
<td>- Needs regular monitoring</td>
</tr>
<tr>
<td>Brine concentrators/Zero liquid Discharge</td>
<td>- Can produce zero liquid discharge</td>
<td>- Expensive</td>
</tr>
<tr>
<td></td>
<td>- Can commercially exploit concentrate</td>
<td>- High energy consumption</td>
</tr>
<tr>
<td></td>
<td>- Recovery of salt and minerals</td>
<td>- Production of dry solid waste – precipitates</td>
</tr>
<tr>
<td></td>
<td>- No marine impact expected</td>
<td></td>
</tr>
<tr>
<td>Mixing with the cooling water discharge</td>
<td>- Achieve dilution of both effluents prior to discharge</td>
<td>- Dependent on the presence of a nearby thermal power plant</td>
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<tr>
<td></td>
<td>- Combined outfall reduces the cost and environmental impacts of building two outfalls</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Necessary to reduce salinity if disposing in fresh water bodies</td>
<td></td>
</tr>
<tr>
<td>Mixing with the sewage treatment</td>
<td>- Achieve dilution of brine effluent prior to discharge</td>
<td>- The brine could enhance the aggregation and sedimentation</td>
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| effluent | Does not overload the operational capacity of sewage treatment plant | Use of existing infrastructure | Necessary to reduce salinity if disposing in fresh water bodies | of sewage particulates that can impact benthic organisms and interfere with the passage of light in the receiving water body |
8 Legal Framework on European and National Level

8.1 European Legal Framework Applicable

Initially, let it be noted that on a European Level, there is no specific piece of legislation dealing with desalination per se. There is a number of EU Directives which each apply partially, directly or indirectly, to the wider regulatory framework of water management generically and by analogy, these Directives affect and set the standards for the operation of desalination plants and respective water waste management.

During the past 30 years, EU law has firmly encroached upon national member state legislation in a firm attempt to create a unified legal framework within which all individual states may operate towards adopting an environment-friendly approach with respect to water waste management and treatment of water in general. In short there has been a slow transition period from the local/municipal feature of the applicable laws towards a wider introduction of a set of unified rules.

Since EU legal framework on the element of water is rather far too expanded and complex sometimes, we have focused on those EU pieces of legislation, which in their vast majority have been introduced in way of a Directive (which are not directly applicable to national laws of the Member States but require that the latter to pass respective national law encompassing the content of the Directive), involving a direct or potential effect on water and waste water services. Having said that, we will concentrate our analysis to the Water Framework Directive (EC 2000/60) which created a new and dynamic model of water resources management while evidencing the law-maker strong will to protect adequately the status of aquatic ecosystems.

Directives passed from early 1970s to mid 1980s have been characterized as significantly unsuccessful due to their failure to achieve the objective goals for which they were initially introduced. The reluctance of several European Member States to
introduce respective laws so as to enforce on a national level the provisions of the EC Directives has been a significant drawback. It has to be noted that the below brief description of each piece of EU legislation is primarily ranked basis chronological order and not order of significance. Subsequent to the setting out the main points of each legislation, this report will mainly focus on the Water Framework Directive, which constitutes the culmination of water policy legislation within the EU. In particular:

- **The Surface Water Directive (75/440/EEC)**
  
  This has been the first EU attempt to tackle the issue of setting standards for the quality of surface water intended for the consumption of drinking water in the various Member States. This directive has in essence paved the way for the later enactment of the Drinking Water Directive (see below).

- **The Dangerous Substances Directive (76/464/EEC)**
  
  We will only refer to this piece of legislation very briefly, as we have done with the Surface Water Directive, since it is of not direct relation to the desalination methods examined in this paper. However, it must be noted that the Dangerous Substances Directive set high goals for the prevention and minimization of water pollution from potentially dangerous elements. It attempts to place rigid standards of protection of the aquatic system from being contaminated with the so called “black list” candidate substances, however, the different interpretations as well as the strong reluctance of Member Stated to efficiently enforce its provisions, led to a great degree of inequitable results amongst the EU countries. This Directive is scheduled to be repealed by the Water Framework Directive in 2013.

  
  It mainly aims to safeguard groundwater, which since then was still regarded as unaffected by water contaminants. It refers to two main pillars of substances which a) is prohibited to be discharged into groundwater and b) their respective discharge in the groundwater is limited. As above, this Directive shall be repealed and replaced by the Water Framework Directive in 2013 with, however, ambiguous results since
groundwater protection proved to be a highly contentious matter amongst Member States to reach a middle ground on.

➢ **The Bathing Water Directive (76/160/EEC)**

This Directive engages in the number of bacteriological indicator parameters allowed in the assessment of beach waters. Constant revision of the allowable parameters takes place hardening the standards. As in most cases, various interpretations “techniques” by the Member States have led to disputes over implementation of the provisions of the Directive. The wide scope of the activities enhanced by the said Directive has raised concerns over the potential costly upgrading of waste-water treatment plants which will be left with no other option but to meet these higher standards set. It has been argued, as the Directive is currently under reform, that the scope of the legislation applied only to swimming (and no other water activities) since an extension of the scope to other recreational activities is almost certain that will result in affecting agriculture and discourage the construction of new (or upgrade existing) waste water units.

➢ **The Integrated Pollution Prevention and Control Directive (96/61/EC)**

This Directive constitutes one of the most fundamental pieces of legislation when it comes to industrial activity and its impact on the environment. A large number of industrial sectors, such as waste treatment industries, are obliged to obtain specific permits, to apply preventive measures so as to avoid potential contamination and waste production while they are requested to recycle or deposit unavoidable waste.

The said Directive, however, has a significant drawback, namely its lack of defining straightforward and clear standards across the EU Member States. Emission Limit Values (ELV), specific preventive measures to be adopted by the industries and monitoring requirement in general are all decided on an ad hoc basis without any notion of uniformity. The concept of “Best Available Technique”(BAT) is introduced according to which each case shall be dealt with. It is clear that this creates room for flexible maneuvers, thus creating great degree of both confusion and uncertainty. Individual BAT per industry have had a severe impact on the enforceability of the
Directive, as BAT concept across EU has been diluted. Lack of uniform enforceability and determination amongst Member States has, as of now, been nominated as the main reason why the aspired goals of this Directive have not yet been fulfilled.

➢ The Urban Waste Water Directive (91/271/EEC)

One could argue that this Directive has had the most considerable impact on urban water management since it imposed rather heavy financial burdens as well as technical requirements to be fulfilled within a rather short period of time. In several cases, the operators had to seek the assistance of private investment sector in order to comply. Its core aim is to protect the environment from the adverse effects of discharges of urban waste water and waste water coming from the industry. This harsh and determined way of enforcing the provision of this Directive has shown remarkable results (e.g. in Germany the level of rivers pollution has significantly decreased within less than a decade).

The Directive has established ambitious requirements for the collection and treatment of wastewater in areas of even 2,000 inhabitants. “Sensitive Areas” are also defined in the Directive and Member States have the obligation to nominate them respectively in line with the set criteria as specified therein (eutrophic water bodies and nitrates concentration exceeding 50mg/l on surface waters). As is the commonplace in all above mentioned pieces of legislation, their implementation determination by the national parliaments has not been uniform, thus leading to severe inequitably differences with regards to the costs generated. Financing to bring about the changes required has also been a differentiating factor amongst the Member States. It is noteworthy that France, which let local municipalities to entirely seek financing out of their own means, has met most of the targets set while other Member States imposed taxes and levies so as to pass on the extra cost to ultimate water users. In a few words, the implementation of this Directive has provided a boost for the involvement of private sector in the water waste management field.
The Urban Waste Water Directive has also led to the unexpected increase of sludge produced. Major companies of the private sector have also been involved in providing solutions for waste water and sludge treatment. In short, the need for financing and implementation of harsh measures within limited amount of time squeezed municipal budgets and assisted in the creation of large multinational water conglomerates.

➢ The Drinking Water Directive (98/93/EEC)

This Directive sets the standards to ensure safe consumption of the drinking water supplied to end consumers. No explicit reference is made to drinking water by desalination, thus the values apply to the same extend to re-desalinated water as to conventional fresh water supply. As per Gibbons & Papapetrou (2006), most parameters listed in the directive are microbial contaminants which will be automatically removed during the desalination process. Aspects such as the very low mineral contents are not addressed in the Directive at all. Small scale water supplies providing an average of less than 10m3 per day or to fewer than 50 people are exempted from the water quality regulation of the Directive if the water is not intended for public or commercial use. *(Intelligent Energy, Guidelines for the Regulation of desalination, Promotion of Renewable Energies for Water Production through Desalination)*


This Directive is the result of the aggregate failures of the previous legislation as well as an attempt to consolidate and upgrade EU water legislation mainly aiming at the creation and maintenance of a pragmatic, sustainable and fair water use. Newly introduced concepts such as pronounced public information, administrative planning units have formed core aspects of the Directive. All water users have been integrated in one with common target to improve the environmental performance of water. Let it be noted that despite the fact that the WFD does not specifically lists the discharge of concentrates, salts or other pollutants from desalination processes, it is expected that the newly introduced concept of the Riverbasin Management Plan
will refer to salt concentration and activities, such as indirect discharge by percolation through ground or subsoil, which would cause saline intrusion into aquifers (Gibbons & Papapetrou, 2006).

Groundwater and Surface waters are of key playing role in this Directive while straightforward ecological objectives are imposed and shall be achieved with specific timetables (good ecological status up to 2015). Having said that, one has to point out that along with the establishment of the concept of “good ecological status”, there are several respective exceptions provided which, after all, compromise the ultimate end of the Directive. Such exceptions include indicatively and not exclusively, time periods extension to comply up to 18 years, waters strongly affected by human activity are designated as heavily modify waters and thus their good ecological status is automatically waived.

The WFD is so designed to apply to solely to river basins thus rendering rivers basin in a sole hydrological and ecological entity. This had as a direct result the cease of the inefficient various fragmentations of sectors of a river basin while uniform plans shall be prepared on the basis of detailed analysis of activities and ecological status.

Another vital fresh element introduced by the WFD is the assessment of the recovery of the costs of the water services. Having taken into consideration the present water service costs, the party who shoulders this financial burden and the current cost – recovery level, water water service operators will undertake the obligation to publish the requested data in time.

The WFD also touches upon the operation of the waste water treatment plants. In case the so called “good ecological status” is not achieved for a particular river basin, then the waste – water operators need to engage in further treatment steps. The European Association of waste – water operators (EUREAU) has complained that in some cases it is almost inevitable to avoid or to minimize the presence of non degradable substances. In such a case, they will be encountering with a stalemate. It is indeed true that especially in cases where the persistent “forbidden” substances appear in rather low concentrates, it is difficult for waste – water operators to deal
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with such eventuality. EUREAU has put forward the proposition to shift such burden to the private/commercial user and the manufacturers. Waste Water operators should only be burdened with the obligation to remove and eliminate chemicals and substances in general which they were responsible for.

The WFD introduced the so called “combined approach” as a new strategy against water pollution. The “combined approach” consists of both limitations on pollutant releases at the source due to promulgation of emission limit values as well as the establishment of concrete environmental quality standards.

As aforesaid, the WFD does not deal directly with the desalination methods; however, there is a great concern for the disposal of the waste brine from autonomous desalination plants. The Directive lists desalination as one of many supplementary measures to attain the goals of water quality protection and efficient management. From a regulatory point of view, several countries, including USA or European Union countries set restrictions on aquatic pollutants levels both at the discharge point (effluent standards - ES) and within the receiving environment (ambient standards - AS). The control on discharge point (ES) encourages effluent treatment and recycling technologies. AS require the consideration of the ambient response often associated with the concept of the “mixing zone”, an allocated impact zone, in which the numerical water quality standards can be exceeded (Jirka et al., 2004).

Concentration or load limits for ES and AS can be found in state, national and international legislations for different chemical substances, effluents and receiving water characteristics. The most relevant parameters for seawater desalination plant effluents are temperature, salinity, pH, dissolved oxygen, dissolved organic matter and residual chemical pollutants such as copper, nickel, free chlorine and chlorinated byproducts (Bleninger and Jirka, 2010).

More specifically, direct injection of brine into an aquifer is prohibited under the Water Framework Directive (WFD) and would be counterproductive for desalination plants. Indirect discharge that is those which have first percolated through the
ground before reaching the aquifer is covered in a proposed ‘Groundwater Daughter Directive’ (European Commission, 2003).

The WFD sets out a specific prohibition in relation to groundwater. Article 11, section 3(j) prohibits any direct discharge of contaminants to an aquifer. This means that contaminants, including brine, may not be ‘injected’ back into an aquifer. Indirect discharges are not affected by this prohibition. The proposed Groundwater Daughter Directive allows discharge of contaminants to groundwater as long as it is filtered through the ground or subsoil first (indirect discharge), and as long as they are not contaminants which are prohibited or controlled. Although some treatment chemicals may be found within the brine discharge at low levels, none of these are contained in Annex II of the proposed directive (WIP, 2006).

Up until now, salt or other chemicals likely to be found in the brine discharge are not on the list of substances that are controlled or prohibited from indirect discharge to groundwater. However, there is the possibility to reassess list if EU member states believe that additional substances are causing a pollution risk to an aquifer and in the future this could potentially include brine if it was thought to cause contamination of aquifers. The risk of saline intrusion into an aquifer must be considered as part of each mandatory river basin management plan, and conductivity must be monitored to detect changes. Brine disposal into coastal or transitional water is not specifically covered in the WFD. Ambient salinity levels in coastal or transitional water do not by themselves affect water quality status; and any changes in salinity levels will not affect the official ‘good’ status of such waters, unless that change is enough to affect other elements such as phytoplankton or macro-algae. Because the environmental effects of small-scale desalination plants are relatively localized, brine disposal (or even water abstraction) are highly unlikely to render a body of coastal or transitional water as ‘at risk’ unless the water body was extremely small and lacking good mixing (Gibbons et al., 2007).
8.2 World Bank recommendations

The World Bank recommends that the temperature of the discharge water should be reduced prior to discharge, to ensure that the effluent water temperature will not result in ambient temperature increase of 3 °C at the edge of allocated mixing zone. According to regulations in Oman on the liquid waste discharge into the marine environment, the temperature of liquid waste at the discharge point should not exceed 10°C over the temperature of the water surrounding. The discharge should not result in a temperature increase of more than 1 °C (weekly average) in a circular area of 300 m diameter around the discharge point (Sultanate of Oman, 2005).

The way to control and restrict the adverse environmental impacts of seawater desalination plants is to establish national laws or transnational agreements. These may involve regulation of brine discharge management, discharge limits or mandatory environmental standards and conditions for receiving operating permits. Worldwide, the regulation with respect to desalination units is very diverse and uncertain. There are no common standards, as each country obeys to its water regulations which are more or less publicly accessible, this being the case to some extend also in the European Union. The main criticism lies with the fact that the majority of national regulations is ambiguous and is not specialized in desalination plants, but to industrial effluents. World Bank Guidelines represent an International Standard that can be used as a reference. The World Bank can recommend more stringent regulations in case of national regulations differ from international guidelines.

The following table illustrates brine discharge standards in the mixing zone (Bleninger and Jirka, 2010).
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Table 8-1: Emission and ambient standards (Sultanate of Oman)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Effluent standard (ES)</th>
<th>Ambient standard (AS)</th>
<th>ES / AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>500 μg/l (Worldbank)</td>
<td>4.8 μg/l (Worldbank)</td>
<td>104</td>
</tr>
<tr>
<td>Chlorine</td>
<td>200 μg/l (Worldbank)</td>
<td>7.5 μg/l (Worldbank)</td>
<td>27</td>
</tr>
<tr>
<td>Temperature</td>
<td>10 °C above ambient (Worldbank)</td>
<td>3°C above ambient (Worldbank)</td>
<td>3</td>
</tr>
<tr>
<td>Salinity</td>
<td>Not existing yet (RO causes up to 35ppt above ambient)</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

In the Sultanate of Oman, the maximum values described in Table 8-2 apply for effluents discharged into the marine environment.

Table 8-2: Maximum values for selected parameters for effluent discharges into the marine environment (Sultanate of Oman, 2005)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum value in mg/l (unless otherwise stipulated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total chlorine</td>
<td>0.4</td>
</tr>
<tr>
<td>Copper</td>
<td>0.2</td>
</tr>
<tr>
<td>Iron</td>
<td>1.5</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.0</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.05</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.05</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.100</td>
</tr>
<tr>
<td>Aluminum</td>
<td>5.0</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.01</td>
</tr>
<tr>
<td>Lead</td>
<td>0.08</td>
</tr>
<tr>
<td>Oil</td>
<td>15.0</td>
</tr>
<tr>
<td>Oxygen biological deficiency</td>
<td>20.0</td>
</tr>
<tr>
<td>Oxygen chemical deficiency</td>
<td>200.0</td>
</tr>
<tr>
<td>Total suspended solids (TSS)</td>
<td>30.0</td>
</tr>
<tr>
<td>Organic halogen</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
8.3 United States Regulatory Approach

The United States Environmental Protecting Agencies (US EPA) has not established any regulations that are specifically directed at disposal of water treatment plant residuals (which include membrane wastes). Federal regulations have been established for acts that are applicable to membrane wastes. These regulations can be in some cases guidelines for the states, while in other cases they can be obligatory. Most states have been delegated by US EPA to take responsibility for establishing and administering regulations that will meet the requirements of the federal acts. Consequently, the regulation of membrane wastes is mainly subjected to the responsibility of the states (Mickley, 2001).

The U.S. state of California has introduced six different laws relating to desalination, only one of which sets concrete requirements, namely that desalination projects are entitled to the same extend of state aid as other water supply projects. The USEPA is currently developing new rules regarding the direct discharge of residual products from drinking water production to surface water as well as the indirect discharge through wastewater treatment plans. These guidelines are likely to also apply to small plants and they will include concentrates from desalination processes as well as other residuals (USEPA 2010).

Barcelona Convention – Dumping & Land Based Sources Protocols

Barcelona convention aim is from Land-Based Sources to reduce pollution in the Mediterranean Sea from land base sources, protect and improve the marine environment in the area, while contributing to its sustainable development. Seawater desalination is not included in the sectors of activity which should be primarily considered when setting priorities for the preparation of action plants, programs and measures for the elimination of the pollution from land-based sources and activities (UNEP, 2001).
8.4 Individual States - National Laws

➢ Greece

The WFD has been incorporated in Greek Law by introduction of Law 3199/2003 which represents a fundamental restructuring of the competencies in water management in Greece. Greece, though, due to its peculiar landscape, has encountered several practical problems when tries to implement the provisions of the WFD. In particular: the numerous small river basins, the extensive coastline, the capacity shortage in management water resources, the transboundary river basis at the northern part of the country.

Still as of now, Greece is in the process of nationalizing the contents of the WFD facing, though, serious challenges. Greece is currently updating the national Qualitative and Quantitative water data bases, trying to put in place a long term national water policy, develop and publicize the River Basin Management Plans while categorizing/determining the Reference Conditions of water bodies. It still remains to be seen whether and to what extend shall Greece be able and successful to adopt this very ambitious project plan.

➢ Israel

The Israeli government has recently introduced respective framework dealing with the environmental regulations and guidelines with regard to the construction and mainly the operation of desalination plants lying along the Israeli coastline. In light of these developments, Israel has set the establishment of desalination plants as a national goal encouraging three main types of desalination discharges, namely seawater (SW), brackish water (BW) and effluent (EW).

The following policy and environmental requirements which relate to planning and operational phases of desalination plants are primarily based on related legislation of four major national laws (Safrai, 2007), (State of Israel-Ministry of the Environment, 2002).

Planning phase
According to Planning and Building Legislation (1965) and The Law for the Protection of the Coastal Environment (Amendment) (5764-2004), any plan for installation of seawater or brackish water desalination plant, will be constructed taking into consideration a solution for concentrated brine disposal. The protected coastal zone is defined as 300 m inland and 30 m depth or one nautical mile offshore (the distant).

**Operational phase**

Mediterranean countries, which use desalination to cover their freshwater needs, should apply appropriate guidelines or procedures for the disposal of brine according to the LBS and Dumping Protocol. Discharge of brine to the sea is referring to Prevention of Sea Pollution (LBS) Law (1988), its regulations (1990) and its amendments (2005). Existing legal instruments such as the Dumping and LBS protocols are based on Barcelona Convention for protecting the Mediterranean Sea from land base sources and its protocols (1976), amended in 1995.

Discharging brine to the sea can take place, as LBS law sets, according to a valid permit and after applying the best available technology (BAT). BAT is related mainly to the design of brine outfall (dilution and dispersion effects, sediment transport etc.), applied additives and pretreatment method (organics, nutrients removal).

Permit is also set as a comprehensive part of license of the plant (Licensing of Businesses Law, 1968). Interministerial permits committee for discharge of waste to sea issues the permit under stipulated conditions. It is given for limited time and its conditions may vary with time, as necessary. Seven different ministries and a representative from public environmental organizations form the eight member inter-ministerial committee. The Marine and Coastal Environment Division in the Ministry of Environmental Protection serve as a professional advisory body to the committee, also coordinates its activities and is responsible for enforcement and inspection of permit holders (Safrai, 2007), (State of Israel-Ministry of the Environment, 2002).
The Israeli Ministry of the Environment has established the Policy for the Protection of the Mediterranean Marine and Coastal Environment from Desalination Facilities” (2002) which serve as a base for sea water reverse osmosis and brackish water reverse osmosis desalination plants. The main issues being addressed with regard to the marine environmental aspects are:

- Discharge composition
- Marine outfall
- Marine monitoring program

**Discharge composition**

Discharge characteristics are mainly a result of:

1. Raw water source and composition — SWRO or BWRO and its raw constituents’ concentrations.
2. Pretreatment method and its rejects — whether pretreatment rejects are discharged to the sea, whether it is treated and how (sand filter, UF etc.).
3. Additives — including types, such as phosphate antiscalants (polyphosphonates) or phosphate free concentrations and loads.
4. The rate of recovery has an effect on the concentration of constituents but does not affect the rate of loading
5. Operational regime — such as intermittently or continuously disposal of untreated backwash water. It might be reflected in peaks of high concentrations for TSS and turbidity or homogenous concentrations of the brine.
6. Flow rate — affect mainly on the pollutants loads.

**Marine outfall — policy and guidelines for protection of the marine and coastal environment**

According to the Law for the Protection of the Coastal Environment came into effect in 2004 and includes instructions and guidelines for damage prevention to the coastal environment. The Ministry of Environmental Protection in Israel has
established the following criteria for a marine outfall (Ministry of Environmental Protection, 2006):

- A prerequisite for discharge to sea is the installation and operation of best available technologies (BAT).
- Discharge will be via an outfall deep into the sea. Discharge to the coast will be prohibited, with the exception of cooling water outfalls of power plants.
- The outfall will be terminated by a diffuser for a better dispersion and dilution. In case of desalination where the reject brine is heavier than seawater, the outfall diffuser will be at least 2m above the seabed achieving a more efficient dilution.
- The outfall pipeline will be monitored background in order to be approved. Once discharge is initiated an annual monitoring program is required to examine and estimate the impact on the marine environment.
- The following criteria, among others, will determine the length of the pipeline and its specific location: 1. Minimum outfall length will be 300m offshore (bathing site according to the arrangement order — Ministry of Health). 2. Damage to the coastal area will be avoided, as much as possible, by an outfall extending to a water depth of 30 m or to a distance of one nautical mile (the distant one as defined by the law for the Protection of the Coastal Environment, 2004). The outlet pipes may contain discharge sludge that is usually highly concentrated brine but may also contain low concentrations of chemicals sometimes at elevated temperatures. Therefore, careful monitoring of the piping as well as flow processes is needed. Appropriate monitoring devices should be attached to fixed structures to ensure failsafe subsurface flow processes and thus should be considered before construction is completed. 3. Sufficient distance will be maintained from declared and proposed marine nature reserves. 4. Oceanographic characterization (water exchange, bathymetry, currents etc.). 5. Discharge composition in relation to local environmental standards. 6. Composition of the proposed discharge.
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- Integrated Infrastructures
- The entire length of the marine pipeline will be buried using BAT to minimize damage to the coastal area while take into account, inter alia, sand movement, fishing activities, safety of bathers and protection of the ecosystem in general.

It has to be noted that the Israeli central government has also put in place an extended monitoring program of all the above so as to keep a close eye on monitoring implantation of the goals set. (Environmental Regulations for discharging Desalination Brine to the Sea and its Possible Impacts, Iris Safrai & Alon Zask, Ministry of Environmental Protection)

As mentioned above there is no specific discharge quality standards set by law for all different methods of desalination and so the operators have to comply with bits and pieces of national and international legislation imposing, each at its own extend, specific parameters. In essence, the discharge composition quality is to be examined on a case by case basis, however, for solely indicative purposes. For instance, the respective table below represents an evidence of the discharge quality standards of Askelon seawater desalination plant in Israel.

**Table 8-3: Askelon Seawater Desalination Plant Discharge Quality Standards (DQS)**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Max Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended Solids 105 C</td>
<td>mg/l</td>
<td>20</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>10</td>
</tr>
<tr>
<td>BOD</td>
<td>mg/l</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>9.0&gt;pH&gt;6.5</td>
</tr>
<tr>
<td>Ferric (temporary)</td>
<td>mg/l</td>
<td>2.0</td>
</tr>
<tr>
<td>Temperature – After conducting</td>
<td>C</td>
<td>4 above ambient seawater</td>
</tr>
<tr>
<td>power station</td>
<td>mg/l</td>
<td>Not exceeding 1.7 times ambient seawater concentration</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>Nitrogen Species</td>
<td>mg/l</td>
<td>Not exceeding 1.7 times ambient seawater concentration</td>
</tr>
<tr>
<td>Phosphorous Species</td>
<td>mg/l</td>
<td>Not exceeding 1.7 times ambient seawater concentration</td>
</tr>
<tr>
<td>Heavy metals (Ag, Cd, Cu, Cr, Hg, Ni, Pb, Zn)</td>
<td>mg/l</td>
<td>Not exceeding 1.7 times ambient seawater concentration</td>
</tr>
</tbody>
</table>

(Environmental Regulations for discharging Desalination Brine to the Sea and its Possible Impacts, Iris Safrai & Alon Zask, Ministry of Environmental Protection)

9 Concluding Remarks & Assessment

As extensively discussed above, there is no legislation dealing per se with the desalination methods and the respective waste water / brine management. On a global scale there are only few countries such as Israel to have enacted specific legislation in connection to brine waste management and these countries are mainly located in the Middle East where one encounters prolonged use of desalination methods. However, the complete lack of concrete legal framework on international level regulating the quality control of fluid-effluents from desalination plants creates a significant degree of incompatibility amongst different methods of evaluation control. In addition, this considerable lack of established regulatory framework and guidance results in one hand in insecurity for investors and developers while on the other, the local authorities burdened with the task of issuing permits appear hesitant to approve further licenses.

In light of the above, despite the lack of existing, comprehensive and specific legislation regard the elimination and/or the minimization of brine, operators need to be very careful so as always to comply with the respective - to desalination - provisions, as contained in several other pieces of legislation that may be touching
upon the subject matter. In essence, by not introducing specific laws for the waste treatment/removal of brine, then the operator is forced to comply with bits and pieces of other Directives such as the WFD and the UWWD which, even though they do not deal with desalination plants per se, they do state in a wider context particular parameters that have to be satisfied so as to fall within the applicable law. In any case and given the current legal scheme, current operators and potential investors in desalination plants have no leeway but to comply in general with all the laws and regulations effected on water management.

Finally and bearing in mind the importance of saving energy, the industry should promote small scale autonomous desalination schemes powered by renewable energy. Such plants are ideal for implementation of arid or semi arid regions like the Mediterranean Sea. Assessing the above mentioned European legislation, it has been found that the operators need to satisfy unnecessary strict regulations that apply to the entirety of drinking water supplies. The careful review of the relevant Directives and standards had to be undertaken and adapt documentation so as to prepare for rapid growth of autonomous desalination plants. Contrary to that, these autonomous plants have gained significant ground in form of support of for non conventional water resources, as well as sustainable and rural development. What is now needed is the introduction of a technology platform that will push and convince the law – maker to improve policy and institutional framework conditions so as to raise general awareness.
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