Desalination: Brine and Residual Management

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Global Water Research Coalition

In 2002 twelve leading research organisations have established an international water research alliance: the Global Water Research Coalition (GWRC). GWRC is a non-profit organisation that serves as a focal point for the global collaboration for research planning and execution on water and wastewater related issues.

The Coalition focuses on water supply and wastewater issues and renewable water resources: the urban water cycle. The function of the GWRC is to leverage funding and expertise among the participating research organisations, coordinate research strategies, secure additional funding not available to single country research foundations, and actively manage a centralised approach to global issues. GWRC offers its members the opportunity to leverage resources through cooperative planning and implementation of research.

The present members of the GWRC are:
KWR – Watercycle Research Institute (Netherlands), PUB – Public Utilities Board (Singapore), Stowa – Foundation for Applied Water Research (Netherlands), SUEZ Environnement – CIRSEE (France), TZW – German Water Center (Germany), UK Water Industry Research (UK), Veolia Environnement VERI (France), Water Environment Research Foundation (US), Water Quality Research Australia (Australia), Water Research Commission (South Africa), Water Research Foundation (USA), and the Water Services Association of Australia.

The US Environmental Protection Agency has been a formal partner of the GWRC since 2003. The Global Water Research Coalition is affiliated with the International Water Association (IWA).

GWRC members represents the interests and needs of 500 million consumers and has access to research programs with a cumulative annual budget of more than €150 million. The research portfolio of the GWRC members spans the entire urban water cycle and covers all aspects of resource management.

Project Summary

Shortage of freshwater supply is a major global challenge. To meet this challenge and overcome the issue of depleting freshwater resources, desalination of seawater and brackish water has become a principle alternative. Desalination is already used extensively in the water-scarce regions worldwide and the market is still rapidly expanding.

Despite the crucial benefits offered by desalination, there a number of concerns related to the potential environmental impacts of the desalination plants. The main issues of desalination plants are intensive energy use, its footprint, and most significantly the adverse impacts of brine discharge. The concerns are growing with the increase in number of desalination plants operating worldwide. Thus it becomes critical to understand and address these issues of desalination to make it economical and environmentally sound process.

This report is focused on evaluating the issues related to brine and residual management associated to seawater and brackish desalination. The physical and chemical characteristics of brine and process residuals are identified. An overview of the brine disposal methods is given. It provides analysis and assessment of existing methods of brine disposal, brine minimization and treatment. Furthermore focus is given to the potential impacts of the brine discharge and the relevant regulations for controlling concentration limits of brine discharge to the sea.

Project Conclusion

In the report brine disposal methods being applied around the world are highlighted for both seawater and brackish water. The benefits and possible issues related with each method are discussed. The main brine management approach regarding its disposal is to minimize the volume of brine discharged by desalination plants. Using brine treatment and minimization techniques and zero liquid discharge systems the production of brine discharge can be reduced and as a result potential adverse impacts of brine are mitigated. There are some well-proven technologies like brine concentrators and crystallizers. Many technologies such as Dewvaporation and Wind-Aided Intensified Evaporation are in process of adoption by the industry. Further improvements are expected to provide a wider range of brine management techniques. However brine management options for volume minimization and ZLD are still associated with relatively high costs. There is still need for research of feasible solutions that can fulfill the technical, environmental and cost requirements.

There is also potential for beneficial reuse of brine discharge. Techniques like SAL-PROC are used to recover marketable chemicals. And through energy recovery devices, the accumulated energy in the brine discharge is reused in the desalination plant reducing the energy requirement of the plant.

Regarding the potential impacts of brine there have been some studies showing varied impact on marine ecosystem. But most of studies are based on short-term toxicity and there is no information about the long-term effects of brine salinity and residual chemicals. There are only few field monitoring studies on the impacts of brine discharges on marine life in the discharge area. So there is uncertainty about the exact environmental impacts of brine discharge. For a complete assessment of brine impact on marine life pre- and post-operational monitoring and baseline information is necessary.

The adverse impact of brine discharge can minimize by ensuring proper dilution of the brine. The design of brine outfall structure is critical in this context. Best available technology and optimal design configuration of outfall should be considered. This analysis is done with the help of mixing zone models especially designed for environmental impact assessment. The optimal solution for brine management of each project should be identified individually based on the given conditions regarding technical, environmental and economical aspects of the specific project. For sound impact assessment specific factors like project site location, applied desalination technology and plant configuration and local environmental conditions of receiving water body, including existing plants and their discharges in the proximity must be considered individually for each desalination project.

Environmental guidelines at both European and International level lack desalination specific regulations, however there are certain wastewater legislations applicable to brine discharge. Also there is no consistency in discharge designs, monitoring, assessments and regulations worldwide.

Legislations are expected to be more stringent in future in context of approval of environmentally-sensitive disposal options to preserve groundwater and seawater quality and the ambient ecosystem.
The development of environmentally viable and cost effective brine disposal systems, which conform to regional and federal environmental constraints, still remains an imperative issue.

Since each desalination project is unique and depends on project-specific conditions and considerations, permit granting for each project should be evaluated on a case-by-case basis.

Key words

Desalination, brine, process chemicals, brine disposal, brine minimization, zero liquid discharge, selective salt recovery, energy recovery, discharge design, environmental impact, marine toxicology.

LIST OF ABBREVIATIONS

AS	Ambient Standards
°C	Degrees Celsius
µg/L	Microgram per liter
BOD	Biochemical oxygen demand
BWRO	River water reverse osmosis
CDI	Capacitive Deionization
ED	Electrodialysis
EDR	Electrodialysis reversal
EPA	Environmental Protection Agency
ES	Effluent Standards
FO	Forward osmosis
g/L	Gram per liter
gpd	Gallons per day
gpm	Gallons per minute
HERO	High-Efficiency Reverse Osmosis
IX	Ion exchange
kWh	Kilowatt-hour
MED	Multi-effect distillation
MF	Microfiltration
mg/L	Milligram per liter
mgd	Million gallons per day
m/s	Meter per second
MSF	Multi-stage Flash
NF	Nanofiltration
O&M	Operations and maintenance
ppm	Parts per million
RO	Reverse osmosis
SWRO	Seawater reverse osmosis
TDS	Total dissolved solids
TSS	Total suspended solids
VSEP	Vibratory Shear-Enhanced Processing
WAIV	Wind-Aided Intensified Evaporation
WFD	Water Framework Directive
WWTP	wastewater treatment plant
ZLD	zero liquid discharge

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1. General Introduction

1.1. BACKGROUND

Global water shortage is a major risk faced by the world today. The earth's limited freshwater resources (which constitute only 2.5 % of earth's water) are unable to meet increased water demands of the burgeoning global population. Also pollution of available water supplies, economic growth, urbanization, climate change all are adding to pressure on freshwater resources. The widening gap between the freshwater supplies and demand of water for industrial, agricultural, and domestic use is disquieting. There is need to develop new additional water sources to make up for the exhausting natural freshwater resources. This necessity has led to development of desalination technology as a key alternative freshwater resource.

Desalination involves removal of salts and other dissolved minerals from seawater or brackish water or treated wastewater. Desalination plants use a variety of technological processes for production of potable water, the main categories being thermal and membrane processes. The reverse osmosis membrane technology and multi-stage flash (MSF) thermal technology are predominant among the different range of available options. During the last decade reverse osmosis technology has grown tremendously as compared to thermal processes, in which salt water is forced through a membrane that allows water molecules to pass but blocks the molecules of salt and other minerals. The Reverse Osmosis process requires lower energy and space as compared to the thermal processes consequently reducing the cost of the potable water obtained. (Einav, Harussi and Perry, 2002; Purnama, Al-Barwani and Al-Lawatia, 2003).

Though desalination offers many benefits, there are several concerns over its possible detrimental effects on the environment. Discharge of brine, which is the waste stream, generated by desalination plants pose a major problem. The brine is highly saline (having >36,000mg/L of total dissolved solids), and depending on the desalination process employed, contains a range of different chemicals, heavy metals and higher temperature. These brine characteristics have varied potential impacts on the marine ecosystem. The choice and siting of brine disposal method determines the extent of its effect.

Disposal methods of the brine vary widely, subjected to type and location of the desalination plant. The most common approach for the desalination plants situated near the sea is surface discharge either directly to the sea or after mixing with other streams (i.e. waste water effluent, outlet of power station's cooling water). Some other brine disposal options include deep well injection, land application, evaporation ponds, brine concentrators, and zero liquid discharge (ZLD) technologies (Hoepner and Lattemann 2002).

Besides the adverse impacts of brine other environmental concerns of desalination plants include impingement and entrainment of organisms when seawater is taken in, intensive energy consumption, emission of pollutants into the atmosphere, noise pollution and its footprint. Although overall energy consumption of desalination plants has been significantly reduced using innovative designs but still they remain energy-intensive processes. Their heavy reliance on fossil fuel energy results in CO_2 emissions. There are recent developments to use green energy e.g. wind and solar energy for the desalination processes with the aim to reduce emissions of pollutants.

Most of the desalination plants are sited near seashores, which are particularly sensitive environmental habitats with many social, economic, ecological and recreational functions. Selection of an appropriate site taking into account these differing interests can help in minimize the affect of land usage.

Desalination market is rapidly growing with the technical advancements in desalination technology. Today desalination is extensively used by many water stressed countries around the world. It is a major source of public water supply for several countries in the Middle East, North Africa, Central Asia, America and Southern Europe (El-Dessouky and Ettouney 2002, Schiffler 2004, Mickley 2002). Taking into account the extensive use of desalination technology it is important to assess the extent of environmental impact of the desalination plants and devise methods to alleviate this impact.

Desalination: Brine and Residual Management is an important topic for the members of the Global Water Research Coalition (GWRC) and their stakeholders. The topic is recently added as new priority area to the joint research agenda of the GWRC. Suez Environment – CIRSEE assumed the role as lead agent to develop the research area in conjunction with the participating GWRC members and to survey the possibilities and needs of joint activities. The report at hand is the first product of this collaborative effort.

1.2. OBJECTIVE & FOCUS

The main aim of this study is to understand the different aspects of brine and residual management. Extensive studies have been done over the years with regards to the environmental and ecological effects of desalination plants. The main focus of these studies has been the possible affect of the brine discharges on marine ecosystems. Still the data concerning the dispersion of these brine effluents and their effects on marine ecosystem are very scarce. There is a need to critically review the available data in order to better understand the brine management practices and their impact. Besides it is imperative to evaluate other non- conventional brine disposal options, which could be employed on commercial scale to minimize potential environmental impact of desalination plants.

Thus the key objective of this report is to analyse and synthesize the knowledge so far and document current practices in terms of brine and residual management. Then based on this current knowledge identify any knowledge gaps for future R&D proposals.

The main scope of the study is to evaluate and review:

- Characteristics of brine discharge and process chemicals
- Existing brine disposal methods
- Brine minimization and treatment techniques
- Zero discharge methods
- Energy recovery from brine using advance technology
- Potential environmental impacts of brine and residuals
- Brine discharge design
- Determination of marine sensitivity
- Relevant environmental regulations

1.3. METHODOLGY

In order to prepare this state of science report information is collected from extensive literature review and the survey conducted among the participating organisations of Global Water Research Coalition (GWRC).

Literature Review:

The aim was to obtain, evaluate and conclude available scientific literature on environmental impact of desalination and brine disposal methods

Survey of GWRC participating members

The survey was conducted to collect information on ongoing and finished activities from members regarding brine & residual management.

The desalination data from survey questionnaire could not be processed because of non-uniformity. However the information from available reports, ongoing projects and issues identified in the survey are incorporated in the report. The questionnaires are provided in the annexes.

Next steps

This report will be used as input to the GWRC workshop ‘Desalination: Brine and Residual Management’ to facilitate the discussion of the present State-of-the-Science in this area. Based on the discussion the resulting knowledge gaps and research needs will be identified and the involved GWRC members will formulate a set of proposals for joint activities to address these ‘gaps and needs’.

2. Desalination Market

Desalination market has witnessed a significant boom during the last decade. According to Global Water Intelligence report of 2006 approximately 12,300 desalination plants were located in 155 countries with a total capacity of over than 47 million cubic meters per day. By 2011 the total cumulative desalination capacity has increased up to 65.2 million cubic meters per day (Figure 1 & 3).

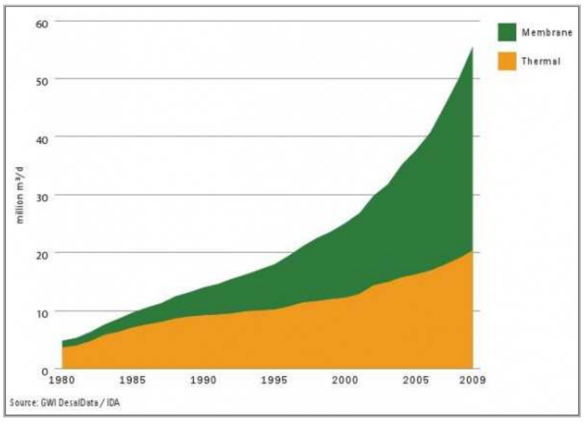

Figure 1: Installed membrane and thermal capacity, cumulative from 1980-2009

Middle East has the largest share in desalination market with over 50 % of the global desalination production. Within Middle East the Gulf States like Saudi Arabia, United Arab Emirates, Kuwait, Bahrain, Qatar, and Oman have the majority of desalination facilities. Nineteen percent of the desalinated water is produced in the Americas and 6% in Africa. Asia pacific region and Europe share about 10% of the global desalinated water respectively.

The Figure 2 presents the existing desalination facilities worldwide per region. The Arabian Gulf has been "hot spot" of intense desalination activity always but other regional centres of activity are emerging such as the Mediterranean Sea and the Red Sea, or the coastal waters of California, China and Australia (Lattemann 2010).

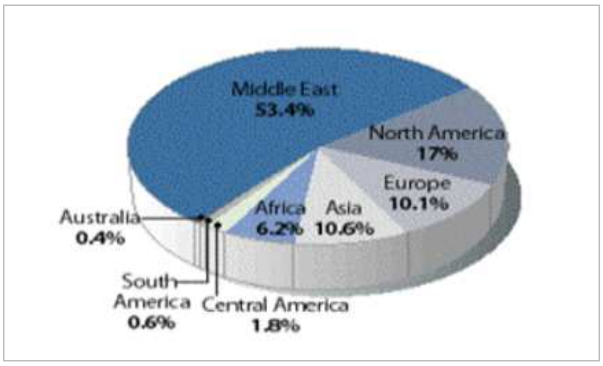

Figure 2: Existing desalination facilities worldwide by region

(Danoun, 2007)

Reverse Osmosis (RO) is the most common desalination technology worldwide, accounting for 60% of the total installed desalination capacity or approximately 39 million cubic meters per day (Figure 3). Improvements in membrane technology and cost advantage over thermal process have boosted RO desalination plants. Multi-stage Flash (MSF) technology is the second-most common desalination technology, with approximately 17.5 million m^3/day installed capacity or 26.8 %. The Multi-effect distillation (MED) thermal process contributes 8% followed by Electro-dialysis (ED) process with 3.6%. Other minor technologies like EDI, Hybrid, and NF are used in less than 2 % of the installed desalination plants.

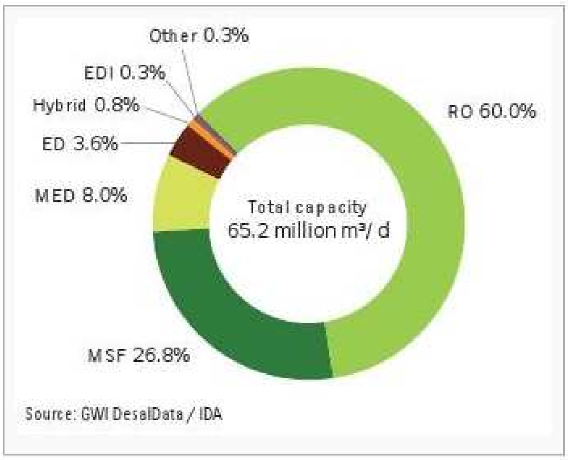

Figure 3: Total worldwide installed capacity by technology

(IDA 2010)

If we look into the global desalination capacity in terms of source water type, seawater as raw water source dominates the market. As of 2008, only 5% of the total volume of came from wastewater sources, 19% is produced from brackish water sources, and 63% from seawater sources (Lattemann 2010).
The data shows that seawater reverse osmosis (SWRO) plants are predominant among the available desalination processes.

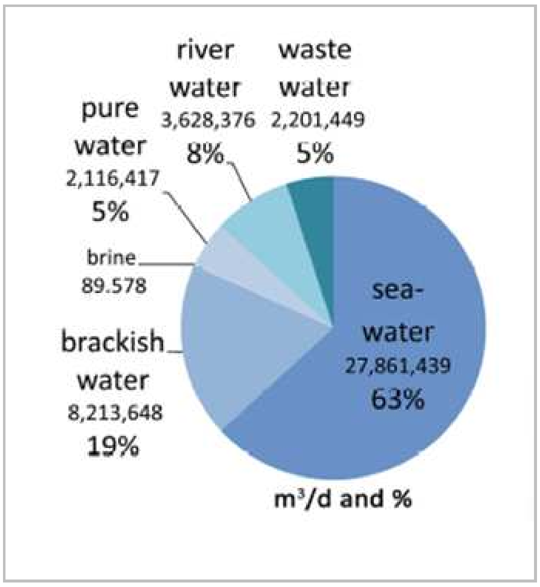

Figure 4: Total worldwide installed capacity by source type(Lattemann et al. 2010)

This review of global desalination situation shows that desalination is a huge market and the cumulative installed capacity of desalination plants is increasing at a record rate. This increase in desalination capacity also means an enormous increase in the amount of brine discharge and thus an increased risk of adverse environmental impact. Handling of brine discharge in an economical and environmentally feasible way is becoming more and more challenging. The growing of size of plants and "hot-spot" areas with accumulated desalination plants limit the disposal options. An additional constraint is the increased number of regulations on discharges that makes disposal more difficult (Mickley 2004). Hence the need for addressing brine management in order to preserve environment becomes inevitable.

3. Physico-Chemical Characteristics of Brine

Brine discharge (also termed as concentrate) is the main by-product of the desalination processes that produce potable water by separating dissolved salts from saline water. The brine discharge contains saline water in highly concentrated form and also residual chemicals used during pre-treatment and post-treatment cleaning processes.

Brine discharge characteristics vary generally, depending on the feed water salinity and type of desalination technology applied in the plant, either membrane based reverse osmosis or thermal distillation process. The amount of brine discharged from desalination plants typically range between 15 to 85% of the feed flow, however volume of the residual chemicals is usually much smaller than the brine concentrate.

3.1. Salinity, Temperature and Density

The concentration of dissolved salts in the brine discharge depends on the feed water salinity and the recovery, which is represented by concentration factor (CF). The concentration factor is the relation of the concentration of a given constituent, here total dissolved salts (TDS) in the concentrate, to the feed concentration depending on the water recovery as follows:

$$CF = \frac{C_C}{C_f} = \frac{1}{1-R}$$

Where, CF is the concentration factor
C_c, the concentrate concentration
C_f, the feed concentration
R, the water recovery

The Figure 5 demonstrates that the brine discharge becomes more concentrated as either the feed concentration increases or the recovery increases. Higher concentration leads to solubility and recovery limitations (Howe 2004).

The water recovery rates for the membrane processes are normally higher than for the thermal processes as given in Table 1. The discharged brine from seawater reverse osmosis plants may contain up to 2.5 times more salt concentration than the feed water. Whilst the brine discharges from thermal distillation process such as Multiple Effect Distillation (MED) or Multi-stage flash (MSF) may have only a 10% higher salt concentration than the feed water (Younos 2004).

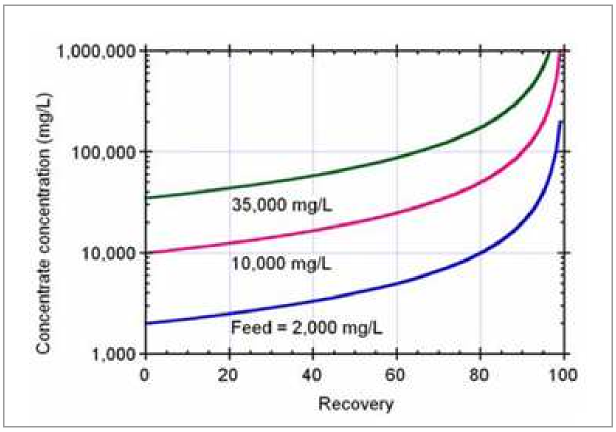

Figure 5: Brine concentration depending on recovery and feed water salinity (Howe 2004)

During the desalination process, the brine discharge by the RO membrane is typically concentrated to salinity up to 65,000–85,000 mg/, and the discharge from a MSF thermal plant has about 50,000 mg/L of salt concentration (Lattemann and Höpner 2008)

Table 1: Brine discharge characteristics for various desalination processes

(Cath et. al 2009, Younos 2004)

Process	BWRO	SWRO	MED/MSF
Feed water	Brackish	Seawater	Seawater
Recovery	50-85 %	30 -60%	15-50%
Temperature	Ambient	Ambient	5℃ to 15℃ above ambient
Concentration factor (CF)	2.5-6.7	1.4-2.5	<1.15

Table 1 also shows that brine discharge from thermal processes is typically 5℃ to 15℃ above ambient water temperature. In contrast temperature of brine discharge from the reverse osmosis process remains at the ambient water temperature.

The density of the brine discharge is higher than freshwater due to higher salinity. When the brine is discharged to water (sea) of lower salinity (thus lower density) it tends to sink down to the bottom layers (Einav et al., 2002). The density difference between brine discharge and ambient seawater, as a function of salinity and temperature, primarily determines spreading and mixing of the brine discharge plume in the receiving water body (Younos 2004). This may lead to brine accumulation at the sea-bottom and pose risk to marine ecosystem. To avoid the risks some desalination plants dilute the brine discharge before disposal to the sea.

The details of different brine disposal methods are discussed in the section 4.

3.2. Process Residuals

A number of process chemicals are applied in the pre-treatment and post treatment phase of the desalination process in order to maintain plant efficiency and the plant equipment over a long operation period. The waste stream from process chemicals and other cleaning wastes are either discharged directly without treatment or separately treated before final disposal.

The type of chemicals used throughout the desalination process may be different for different type of desalination processes. Table 2 shows the pre- and post treatment chemical processes for thermal and RO desalination. Chemicals used to prevent bio-fouling and scaling are common for both RO and thermal plants (MED/MSF). Foaming agents and corrosion inhibitors are applied only in thermal desalination plants whereas chemical additives against suspended solids and scale deposits are particularly subject to reverse osmosis plants (indicated in Table 2).

The subsequent figures 6 and 7 show the conventional pre-treatment and chemical dosage steps for SWRO system and a MSF distillation plant respectively (UNEP 2008).

There is minimal post treatment of brine discharge usually. Post-treatment may consist of aeration for oxygen, degasification to get rid of CO_2 and H_2S and pH adjustment in case of BWRO plants and only pH control in SWRO.

Table 2: Chemicals affecting brine discharge characteristics for MSF/MED and RO

MED/MSF	SWRO
• Antifouling agents • Antiscalants • Corrosion inhibitors • Antifoaming agents	• Antifouling agents • Antiscalants • Filter backwash wastewater • Coagulants • Flocculants

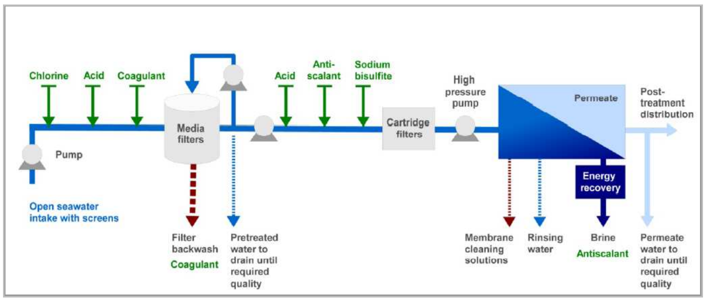

Figure 6: SWRO system showing the conventional pre-treatment and chemical dosage steps (green) and the different waste and side streams (UNEP2008)

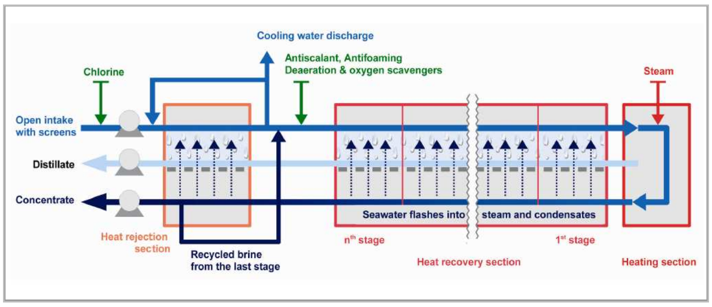

Figure 7: MSF distillation plant showing the conventional pre-treatment and chemical dosage steps and the different waste and side streams (UNEP208)

As a result of the pre- and post treatment of saline water in the desalination plant, the brine discharge may contain some small concentrations of the following major process chemicals, besides the concentrated dissolved solids of saline water.

3.2.1. Antifouling/Biocides

To control biological growth in the desalination plant equipment biocide treatment is done regularly. Usually free chlorine or chlorine in the form of sodium hypochlorite solution (NaOCl) is applied for chlorination. Chlorination is typically done at the plant's intake before the feed water enters the desalination unit (as shown in Figure 6 and 7). Chlorine is a strong oxidant and highly effective biocide and residual levels in the discharge may be toxic to marine life close to the discharge site (Younos 2004).

Most modern RO plants operate on polyamide membranes, which are sensitive to oxidizing chemicals. That's why a dose of sodium bisulphite (SBS) is then added for dechlorination.

3.2.2. Antiscalants

Antiscalants are used to prevent scale formation in both thermal and RO desalination plants. The main types of antiscalants are organic polymers (mainly polyacrylic acid and polymaleic acid), phosphonates and polyphosphates like SHMP (sodium hexa meta phosphate) (UNEP 2008).

3.2.3. Coagulants

When a RO desalination plant has an open intake for feed water the suspended solids need to be removed prior to treatment. This may be done by flocculation, filtration, floatation, sedimentation or alternatively by pre-treatment using Micro/Ultra Filtration. In a conventional pre-treatment mostly coagulants (such as ferric-III-chloride) and coagulant aids (such as high molecular organics like polyacrylamide) are added to feed water for flocculation and coagulation and media filtration of suspended material (UNEP 2008). Media filter units are backwashed intermittently, and the backwash water containing the suspended material and coagulants is typically discharged to the sea if not treated before discharge.

3.2.4. Antifoaming Agents

Chemicals like polyethylene and polypropylene glycol are added to intake seawater of thermal desalination plants to disperse foam causing organics and to reduce surface tension in the water/air interface.

3.2.5. Heavy Metals

Brine discharge may contain traces of heavy metals due to corrosion of desalination equipment. Copper concentrations may be present in trace concentrations in thermal desalination plant discharges as copper-nickel alloys are commonly used as heat exchanger materials in distillation plants.

The RO- discharge may contain traces of iron, nickel, chromium and molybdenum, but contamination with metals is generally below a critical level, as non-metal equipment and stainless steels predominate in RO desalination plants (Younos 2004).

3.2.6. Cleaning Chemicals

To restore the plant performance desalination plants are cleaned using a variety of chemicals. Cleaning chemicals used in SWRO plants differ from thermal desalination plants.

The frequency of chemical cleaning of membranes depends on the feed water quality and degree of fouling. Chemically enhanced backwash (CEB) is typically applied using chlorine, acid and base conditioning on a daily basis and cleaning in place (CIP) using the same chemicals is done on monthly basis, typically from 3 to 6 months. There are a variety of chemicals that may be used for membrane cleaning, for example, *citric acid* is commonly used to dissolve inorganic scaling, and other acids (of pH 2-3) may be used for this purpose as well. Strong bases (of pH 11-12) such as *caustic* are typically employed to dissolve organic material. Detergents (e.g. dodecylsulfate) and surfactants may also be used to remove organic and particulate foulants, particularly those that are difficult to dissolve. Chemical cleaning may also utilize concentrated disinfectants such as a strong chlorine solution to control bio-fouling. Due to the variety of foulants that are present in many source waters, it is often necessary to use a combination of different chemicals in series to address multiple types of fouling (Lattemann and Höpner, 2008).

In the case of thermal plants acid cleaning is required mainly for heat exchanger surfaces, which need to be cleaned at certain intervals in order to maintain the process efficiency. Acidic solution (of pH 2) containing corrosion inhibitors such as benzotriazole derivates is usually used for acid cleaning (Lattemann and Höpner, 2008).

Cleaning solutions from acid cleaning are normally neutralized (around pH 7) before final discharge.

4. Disposal of Brine Discharge

Since desalination processes generate considerable amounts of brine discharge, several methods for disposal and volume reduction of the brine reject have been developed. Adoption of a particular brine disposal option usually depends on the location of the desalination plant and the type of process used. The conventional brine disposal options employed in the industry include discharge to surface water or wastewater treatment plants, deep well injection, land application, evaporation ponds, and zero liquid discharge. A number of brine volume minimization techniques are also in use and some new techniques are under development.

The critical factors that influence selection of a disposal method among the different available 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 (Mickley 2006).

Detailed discussion on salient features of each brine disposal method is as follows:

4.1. Surface Water Disposal

In this method brine is discharged into a nearby surface water body. The surface water bodies used for brine disposal include tidal rivers, streams, lakes, ponds and coastal waters such as oceans, estuaries, and bays (Younos 2004).

In order to ensure proper dispersion of the brine discharge and minimize the risk of its adverse impact a number of techniques are used for brine disposal to sea. Brine disposal is accomplished by directly dumping brine into water body, installing engineering controls such as outfall diffusion devices, or mixing brine with other less saline waste streams before ultimate discharge to receiving water body (Younos 2004).

4.1.1. Direct discharge

The most common method of brine disposal is via new outfall structure specifically designed for that purpose. Over 90% of large desalination plants use this method of brine disposal for discharge into the sea (WHO).

When brine discharge enters the water body it creates a plume because of its higher density compared to the receiving water. This plume if not well mixed sinks to the bottom and may impact the marine ecosystem. Therefore a suitable outfall structure that can minimize the zone of high salinity around the point of discharge is the key challenge. The options available to speed up brine mixing process are to either rely on the naturally occurring mixing capacity of the tidal (near shore) zone, or to discharge the brine beyond the tidal zone and to use diffusers at the end of the discharge outfall in order to improve mixing (WHO 2007).

Discharge at the shoreline may be appropriate, depending on the surroundings and the properties of the receiving water. If the salinity of brine discharge is lower than the tidal zone threshold mixing capacity then brine disposal to this tidal zone is significantly more environmentally compatible and cost effective than the use of long, open outfalls equipped with diffuser systems. An example of such case is Ashkelon Desalination Plant (85 MGD) in Israel, which uses the natural intensive tidal mixing (Shown in Figure 8) for brine dilution.

Figure 8: Shoreline brine discharge

(Pankratz 2009)

Although the tidal zone carries a significant amount of turbulent energy and usually provides much better mixing than the diffuser outfall system, this zone has a limited capacity to transport and dissipate the brine discharge. Also, in case of SWRO plant in a highly populated area, shoreline disposal may be a problem because of the interference of the mixing zone with the recreation on the beach.

This is especially noticeable on days when the sea is calm and little to no natural dilution occurs. Though disposal to freshwater water bodies such as rivers and lakes is not regarded as an environmentally viable option, however, it is mainly applied to smaller plants (Younos 2004).

If the tidal zone doesn't have natural mixing capability diffusers are used and in the case of large desalination plants ocean outfall with diffusers are extended beyond the tidal zone. The outfalls are equipped with diffusers in order to provide the mixing necessary to prevent the heavy brine discharge plume from accumulating at the ocean bottom in the immediate vicinity of the discharge. The length, size and configuration of the outfall and diffuser are typically determined based on hydrodynamic modelling for the site specific conditions of the discharge location (WHO 2007). Many large desalination plants in Spain, Middle East, Africa, South America, Australia and the Caribbean are using brine diffuser systems for brine disposal. Examples are Gold coast, Sydney and Perth 1 desalination plant in Australia (discharging over 140 MGD of brine) and Llobregat desalination Plant (47.5 MGD) in Spain (Figure 9). One of the examples of brine disposal into freshwater is Taunton River desalination Plant in US (Voutchkov 2011).

Figure 9: Installation of outfall for Llobregat desalination Plant (47.5 MGD) Spain

(Pankratz 2009)

The factors which determine the extent of dilution and mixing in the receiving water body and the design of outfall system are discussed in depth under section 8. This method provides benefit of accommodating practically any size desalination plant although it can prove to be costly if sophisticated diffuser systems are required. The advantages and constraints related to direct surface disposal are given in Table 3.

Table 3: Advantages and Constraints of Direct Surface Disposal

Advantages	Constraints
• An established, well accepted disposal practice • Low capital and operating costs if outfall structure is simple • Low energy requirement • Can accommodate large volumes • Water body promotes dilution	• Requirement of sophisticated outfall structures to create mixing zones • Pre-treatment such as dechlorination and aeration is required prior to discharge, which increases cost. • The presence of dissolved gases, and/or low dissolved oxygen limit the viability of freshwater surface disposal • Good knowledge and monitoring of receiving waters are required • Limited natural assimilation capacities may cause adverse impacts on marine environment. • Whole effluent toxicity tests may be required for permitting

4.1.2. Discharge to outlet of the power plant

If a desalination plant is co-located with a power plant, the discharge (cooling water) of power plant is used as blending water to dilute brine prior to discharge to the ocean. A common discharge outfall is used for final brine disposal (Einav et al., 2002).

The capital costs are reduced significantly in co-located plants, in addition to the benefit of high dilution rates. Blending of the brine discharge with the lower salinity power plant cooling water often allows reducing the overall salinity of the ocean discharge within the range of natural variability of the seawater at the end of the discharge pipe, thereby alleviating the need for complex and costly discharge diffuser structures. The advantages and constraints related to this method are summarized in the following Table 4.

Table 4: Advantages and Constraints of discharge to power plant outlet

Advantages	Constraints
• Combined outfall reduces the cost and environmental impacts of building two outfalls • Low energy requirement	• Dependent on the presence of a nearby thermal power plant

Tampa Bay Seawater Desalination plant in US was the first project to use co-location with a power station on a large scale. Since then numerous co-located plants in the United States and worldwide have been used. Figure 10 shows the schematic of Tampa Bay SWRO desalination plant. The intake and discharge of the plant are connected directly to the cooling water discharge outfalls of the Tampa Electric (TECO) Big Bend Power Station (Voutchkov 2005).

Figure 10: Schematic of Tampa Bay SWRO Plant Co-location

Voutchkov 2005)

4.1.3. Discharge to sewage system

Another option of brine disposal is to discharge the brine into nearby wastewater collection system. It is widely used for disposal of brine from brackish water desalination plants. This brine discharge method however, is only suitable for disposal of brine from very small brackish water and seawater desalination plants into large-capacity wastewater treatment facilities (WHO 2007).

The factors to be considered in brine disposal to a sewage system include the volume and composition of the brine in relation to the treatment capacity of the wastewater treatment plant, the convey processes and the possible impacts of high TDS on the wastewater treatment plant equipment (Younos 2004).

The feasibility of this disposal method is limited by the hydraulic capacity of the wastewater collection system and by the treatment capacity of the wastewater treatment plant receiving the discharge. Typically, wastewater treatment plant's biological treatment process is inhibited by high salinity when the plant influent TDS concentration exceeds 3000 mg/L. Also, if the effluent from the wastewater treatment plant is designated for water reuse, the amount of brine that can be accepted by the wastewater treatment plant is limited not only by the concentrate salinity, but by the content of sodium, chlorides, boron and bromides in the blend as well. All of these compounds could have a profound adverse effect on the reclaimed water quality, especially if the effluent is used for irrigation (Younos 2004).

Following Table 5 gives summary of advantages and constraints of brine disposal to sewage system

Table 5: Advantages and constraints of disposal to sewage system

Advantages	Constraints
• Established, well accepted disposal practice • Lowers the BOD of the resulting effluent • Dilutes the brine discharge • Low cost alternative • Low energy requirements	• Feasible only if WWTP is available • Can inhibit bacterial growth • Can hamper the use of the treated sewage for irrigation due to the increase in TDS and salinity of the effluent • May overload the existing capacity of the WWTP while diminish its usable hydraulic capacity • Whole effluent toxicity tests may be required

4.1.4. Discharge via wastewater treatment plant outfall

A large number of desalination plants worldwide discharge the brine through existing wastewater treatment plant (WWTP) outfalls. The key benefit of this combined discharge method is dual dilution, of wastewater and brine discharge both. When the heavier (high salinity) brine concentrate is blended with the lighter (low salinity) wastewater discharge accelerated mixing happens. As a result size of discharge plume is reduced. Also higher levels of metals, organics and pathogens present in wastewater discharge as compared to brine discharge are diluted (WHO 2007).

Main considerations related to the use of WWTP outfalls for brine discharge are availability and cost of wastewater outfall capacity and the potential for whole effluent toxicity that may result from ion imbalance of the blended discharge (Mickley 2006). This method is feasible only if there is an existing wastewater treatment plant in the vicinity of the desalination plant with extra outfall discharge capacity (WHO 2007).

Some examples of the desalination plants that use this combined discharge method for brine disposal are Boca Raton plant in US (40 MGD), Bekton desalination plant in UK (40 MGD), Fukuoka SWRO plant (13 MGD) in Japan and the largest one is Barcelona SWRO plant (50 MGD) in Spain (shown in Figure 11). (Voutchkov 2011)

Figure 11: An aerial photograph (left) and WWTP Equilibrium Tower (right) of the Barcelona Desalination Plant

The advantages and constraints of discharge via WWTP are listed in Table 6 below.

Table 6: Advantages and Constraints of discharge via WWTP outfall

Advantages	Constraints
• Established, well accepted disposal practice • Very simple technology • Low cost requirement • Low energy requirement	• High TDS concentrations may limit the options for the reuse of treated water (irrigation of crops with a high TDS tolerance) • The actual bio-toxicity caused by the brine would need to be determined

4.2. Deep Well Injection

Deep well injection is a proven liquid waste disposal technology. This method is widely used for brine disposal from inland desalination plants and considered as a viable option (Glater and Cohen 2003). In this method a system of disposal wells are used to inject brine from desalination plants into an acceptable, confined, deep underground aquifers that are not used for drinking water. They are designed to isolate the brine from potential potable water aquifers in order to prevent migration of contaminants to the potable water.

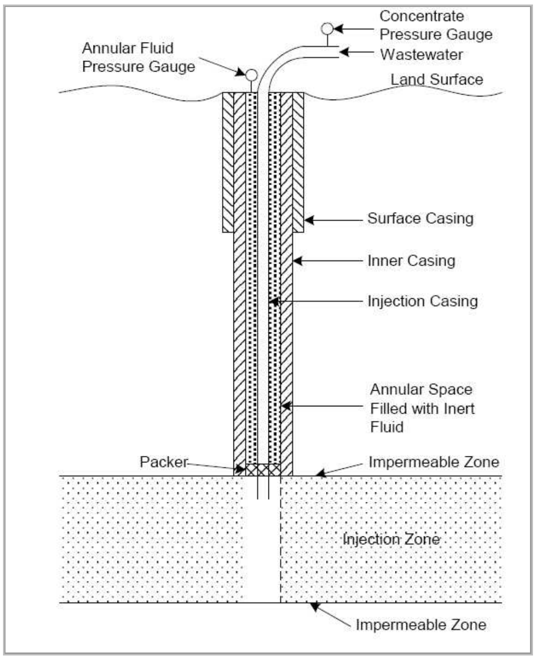

Figure 12: Schematic of a Deep Injection Well (USBR 2009)

A typical deep well comprises of concentric pipes as shown in Figure 12. The pipes extend down into a saline, porous injection zone, usually sandstone or limestone, which are confined vertically by impermeable strata. The depth of the well normally ranges from 300 to 2400 m below the earth's surface. The well's outer casing extends well below any underground drinking water sources. Typically the wells are cased with concrete from the surface down to the underground injection zone to further prevent any seepage from the injection zone into areas above it. Inside the surface casing there is string casing containing tubing. The waste is injected under pressure into the injection tubing through perforations in the string casing, or a hole in the bottom of this casing. An inert, pressurized fluid, called the annulus, is put in the space between the injection tube and the casing. This is sealed in to prevent injected waste backing up into the fluid (USBR 2009).

The feasibility of deep well injection depends highly on site conditions especially on geological and hydro- geological conditions. For the deep well injection method to be an effective option, the receiving aquifer must have a relatively high transmissivity to accept the injected waste at economical pressures and must be hydraulically isolated from other aquifers (Muniz and Skehan 1990). Due to potential risk of contamination, deep injection wells should not be located in areas vulnerable to earthquakes or regions with mineral resources, or where groundwater supplies for domestic or agricultural use is significant.

A thorough geological investigation of the selected site needs to be conducted prior to design and drilling of the deep wells. In addition, potential need for filtration of total suspended solids (TSS) and conditioning of the concentrate should be assessed prior to injection in order to ensure stable injectivity. Suitable locations for deep wells can be potentially in areas with aquifers that can accept larger amounts of brine over the full life of desalination plant. To ensure overall performance of this method, monitoring wells must be drilled along with injection wells and operators should check monitoring wells regularly to detect any changes to groundwater quality. Deep injection wells also should be subjected to tests for strength under pressure and checked for leaks that could contaminate adjacent aquifers periodically (Glater and Cohen 2003, USBR 2009, Mackey and Seacord 2008). All these constraints add substantially to the overall cost of deep well injection.

Several studies have been done on various aspects of deep well injection method. Mickley (2009) has developed models for estimation of capital and operating costs, and for conditions of stable well performance. Mickley states that deep well injection is a reasonable method for brine disposal, provided that long-term operation can be maintained, in order to dispose of large volumes of process fluid (Mickley 2009). Saripalli et al. (2000) have developed a mathematical model that has been used successfully to simulate injection well performance. Outcomes of this model indicate that high TSS in process fluids, low injection rate, low injection pressure, and low porosity and permeability of the well strata all contribute to rapid well plugging and diminished injectivity. Skehan and Kwiatkowski (2000) have investigated design criteria for deep injection wells. According their report this method of brine disposal is the most cost effective as compared with other systems in practice for inland desalination plants.

4.3. Land Application/ Spray irrigation

Land application is a beneficial reuse method in which brine from the desalination plants is used for landscape and irrigation purposes. This method of brine disposal includes spray irrigation, rapid infiltration, percolation ponds and overland flow application. Spray irrigation is widely used for irrigation of salt tolerant grasses and vegetation in places such as lawns, parks, golf courses, or crop land. The leftover irrigation water from plants may be percolated into the subsurface (Sethi et al. 2006). Figure 13 shows a typical unlined spray irrigation system using membrane concentrate as the water source.

Table 7: Advantages and Constraints of Deep Well Injection (USBR 2009, Drewes 2009)

Advantages	Constraints
• An established disposal practice for desalination and hazardous wastes • Relatively low energy requirements • Cost-effective for moderate to large plant capacities • Suitable for Inland desalination plants • Eliminates impact on surface water and shallow groundwater • Reduces or eliminates costly long-distance pipelines and ocean outfalls • Reduced surface imprint and land use impairment • Provides a sustainable local management option for urban areas and facilities • No marine impact expected	• Only feasible in regions with deep confined saline aquifers • Not viable in seismic zones or in regions containing recoverable mineral resources • Risk of groundwater contamination in case of injection well failure • Monitoring wells are required to verify that vertical fluid movement doesn't occur • A backup disposal or storage method must be available during maintenance periods • Possibility of corrosion and subsequent leakage in the well casing • Injected wastes must be compatible with the mechanical components of the injection well system and the natural formation water. Pre-treatment of injectate could be required • Organic carbon could serve as an energy source for indigenous or injected bacteria, which could result in rapid population growth and subsequent fouling • High concentrations of suspended solids (typically >2 mg/L) can lead to plugging of the injection interval.

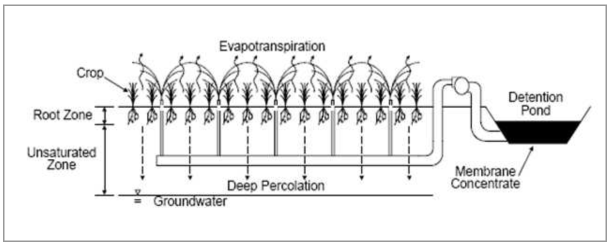

Figure 13: A typical unlined spray irrigation system using membrane concentrate as the water source

(CASS 2006)

Land application is used only for smaller volumes of concentrates. Usually brine needs to be diluted before discharge to meet groundwater regulations. As the diluted brine is much higher in volume compared to volume of brine, large land area is required (Mickley 2009). The land application is suited to places with favorable climate only.

Factors associated with feasibility of land application include tolerance of target vegetation to salinity, the ability to meet ground water quality standards, the availability and cost of land, percolation rates, and irrigation needs (Mickley 2009). Another feature to be considered is that there must be an alternative disposal method available for periods of heavy rainfall (CASS 2006).

Contamination of the aquifer may become an issue if liners and drainage systems are not incorporated. Case studies conducted in India (Rao et al. 1990) and United Arab Emirates (Mohamed et al. 2005) indicated that discharged brine has caused groundwater contamination and resulted in an increase in hardness of groundwater.

Table 8: Advantages and Constraints of Land Application

Advantages	Constraints
• Can be used to irrigate salt tolerant species • Viable for inland plants with small volumes of brine • No marine impact expected • Economical option for small plants • Used with smaller concentrate volumes • Low energy requirements	• Requires large areas of land • Can affect the existing vegetation • Can increase the salinity of groundwater and underlying soil • Storage and distribution system needed • May require dilution water • Relatively level land required • Climate dependent • Suitable for smaller discharge flows

4.4. Landfill Disposal

Another potential brine disposal option is to convert the brine from a liquid to a solid (or dense slurry) and then dispose of the waste material in a suitable landfill. This is used as the end disposal mechanism for majority of brine disposal alternatives e.g. brine concentrators. Hence, the type and efficiency of alternative used determines the amount of material disposed of to the landfill site (USBR 2009). Before the final transport of the wastes to a landfill, liquids are recovered and removed from the brine. The whole process requires a great deal of energy.

There are potential future environmental impacts to groundwater near the landfill, because most landfills eventually leak. Thus appropriate site selection for landfill disposal needs careful consideration. Some of the constraints for landfill disposal option mentioned by Kepke et al. (2008) are:

- Disposal of liquid waste may not be permitted at every facility and can be significantly more expensive if disposal of liquid waste is required to be done in drums.
- Many landfills have a requirement that at least 50 percent of the material to be put in the landfill must be in solid form.
- There are high transport and permit costs associated with disposing industrial material in landfills, and disposal fees can vary dramatically with landfill facility.

4.5. Brine Minimization Techniques

Brine minimization is an approach aiming at decreasing the production of brine discharge by membrane process recovery and enhancement techniques or reducing its concentration prior to disposal. After the volume of brine is reduced using one of these technologies, an additional process is required to completely dispose of the concentrate, either in the form of a solid brine product or liquid concentrate (USBR 2009).

4.5.1. Brine Concentrators

Brine concentrators use thermal energy to evaporate water, which is subsequently condensed and discharged as clean distilled water. Brine concentrator systems have been widely used in desalination plants to concentrate the brine reject and recover additional treated water.

Figure 14 below shows a schematic diagram of a typical single-effect vertical tube brine concentrator.

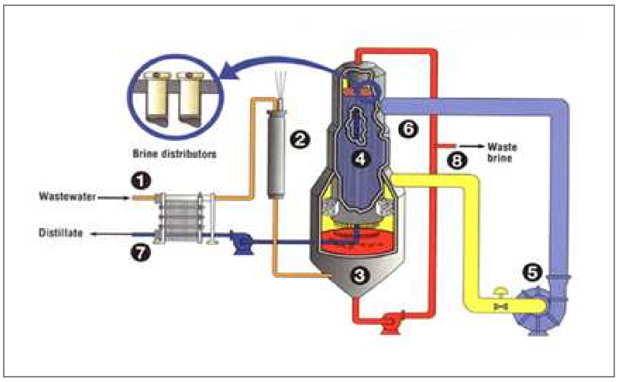

Figure 14: Schematic Diagram of Brine Concentrator Processor Flow (Pumps Not Shown)

(Source: GE Company)

The process as shown in the figure starts with wastewater feed. The wastewater, such as RO concentrate, enters a feed tank (not shown) where the pH is adjusted between 5 and 6 for deaeration, decarbonation, and residual H_2S removal (shown as (1) in the figure above). The acidified wastewater then passes through a heat exchanger and enters a deaerator (2), where non-condensable gases such as oxygen, carbon dioxide, and volatile organics are removed. From the deaerator, the wastewater enters the evaporator sump (3), where it mixes with the brine slurry. The brine slurry is constantly circulated from the sump to a floodbox at the top of a bundle of heat transfer tubes. Water from the floodbox flows through brine distributors and moves as a thin film down the interior walls of the evaporator tubes (4). Some of the brine evaporates as it flows in a falling film down the heat transfer tubes and back into the sump. The evaporated brine in form of vapor passes through mist eliminators and enters the vapor compressor (5), where additional heat is added. Compressed vapor then flows to the outside of the evaporator tubes, where its heat is transferred to the cooler brine falling inside the tubes (6). As the compressed vapor gives up heat, it condenses as distillate. The distillate is collected and pumped back through the heat exchanger, where it transfers its heat to the incoming wastewater (7). During the process a small amount of waste brine is blown down from sump if needed, to control the brine density (8) (Mickley 2006)

Energy input to the brine concentrator is provided by an electric-driven vapor compressor or by process steam from a host industrial facility. The estimated energy consumption approximately varies from 60 to 90 kilowatts per hour per 1,000 gallons (kWh / 1,000 gal) of feed water.

According to Mickley (2006), majority of the operating brine concentrators are single-effect, vertical tube, falling film evaporators that use a calcium sulphate-seeded slurry process. Calcium sulphate and silica precipitates build up on calcium sulphate seed crystals in the recirculated brine instead of scaling on the heat transfer surfaces. Thus seeded slurry process helps to prevent scaling of heat transfer tubes within the brine concentrator. With the seeded slurry process, concentration of up to 30 percent can be reached without scaling (CASS 2006).

It has been observed that brine concentrators reduce the brine flow to about 2 % of the feed water flow thus minimizing the volume of brine discharged from a plant (Tsiourtis. 2001). The recovery rate of concentrators usually ranges within 90 to 98 %, giving high quality water distillate with TDS concentration of less than 10 mg/L normally. The remaining slurry is high in TDS concentration and may equal 250,000 mg/L. There are number of ways to dispose of the slurry. The concentrated slurry is pumped to either an evaporation pond or disposal pond. In other cases it is solidified using crystallisers or spray dryers. In this way zero liquid discharge can be achieved.

Commercially available brine concentrators range from smallest 10 gpm (0.014 mgd) capacity concentrators to the largest concentrators with 1200 gpm (1.65 mgd) capacity. However, the small ones are more common, typically treating around 300 gpm (0.4 mgd) of wastewater (CASS 2006). Brine concentrators are built with high quality expensive materials such as titanium, molybdenium, and stainless steel to resist the corrosive wastewater brines for 30-year evaporator life. This increases the capital cost of the system (Mackey and Seacord 2008).

The brine concentrator technology is seen as a viable solution. The system is reliable and doesn't depend on weather conditions. But the limiting factor for this process is its high operation and maintenance costs besides the cost of power to operate them.

A brine concentrator system (BCS) operating in California is shown in Figure 15 as an example. In this particular case the resulting concentrated reject from the RO system is sent to the BCS where up to 250 gallons per minute of concentrate is processed in a single-stage, falling film evaporator. The BCS reduces the volume of this wastewater effluent stream by ~98% and returns high-quality distillate to post treatment where it is blended with the RO permeate. The brine concentrator uses seeded-slurry, falling film evaporation technology. It is driven by mechanical vapor recompression (MVR), which optimises energy efficiency.

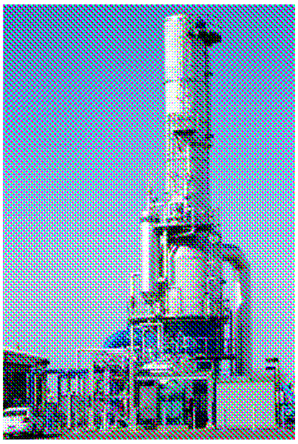

Figure 15: ZLD Water Treatment Facility at D.V.I. in California

(Source: HPD Company)

Advantages and Constraints related to brine concentrators are given in Table 9.

Table 9: Advantages and Constraints of Brine Concentrators

(CASS 2006, Mackey and Seacord 2008, Younos 2004)

Advantages	Constraints
• Can produce zero liquid discharge • Recovery of salt and minerals • Feasible in area where other, lower cost options are not • Product recoveries can range from 90-98 % • Small footprint	• Expensive • High energy consumption (~60-90 kWh/ 1000 gal) • Production of dry solid waste– precipitates • Not feasible for large concentrate flows

4.5.2. Forward Osmosis

Forward osmosis is a membrane desalination method, which uses osmotic pressure gradient for separation of salts from water, instead of hydraulic pressure as in reverse osmosis method (Figure 16).

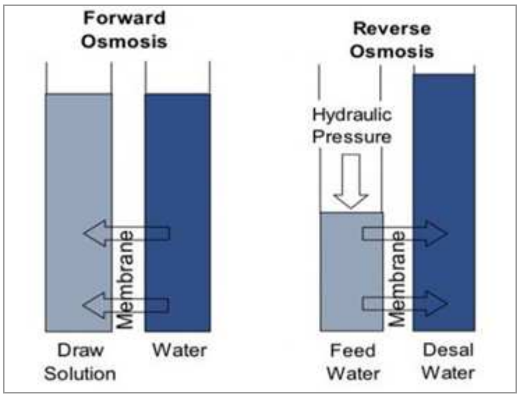

Figure 16: Forward and Reverse Osmosis

(Source: greentechmedia)

In the forward osmosis process a draw solution of higher concentration is used at the permeate side to create substantial osmotic force causing natural osmotic flow of clean water across a semi-permeable membrane into the draw solution. Ammonia and carbon dioxide mixture of draw solution is commonly used (Mickley 2009). The diluted draw solution is then separated in a distillation column or membrane gas separation unit and recycled back to the forward osmosis unit. High osmotic pressure gradients can lead to a high recovery given appropriate staging of the process (Sethi et al. 2006). Figure 17 illustrates the FO process in a typical unit.

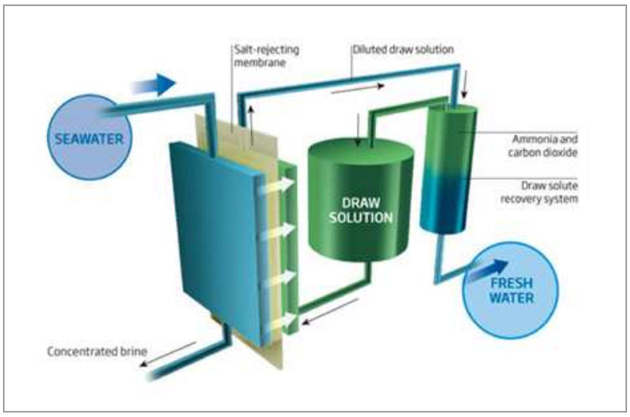

Figure 17: Forward Osmosis process

(Source: greentechmedia)

The membranes used for this process are dense, non-porous barriers composed of a hydrophilic, cellulose acetate active layer cast onto either a woven polyester mesh or a micro-porous support structure (Drewes 2009).

The main source of driving force in the forward osmosis process is draw solution. So the feasibility of the forward osmosis method mostly depends on appropriate selection of draw solution. A solution is considered suitable if it has high osmotic efficiency, its presence in the product water is acceptable and which can be easily and economically removed and recycled. Example draw solutions include magnesium chloride, calcium chloride, sodium chloride, potassium chloride, ammonium carbonate and sucrose. (USBR 2009). With the use of a suitable draw solution, very high osmotic pressure driving forces can be generated to achieve high recoveries.

The forward osmosis process is characterized by relatively high recovery efficiency, lower energy costs and low fouling potential. However, FO permeation rates are much lower than for RO and, at present, there are no commercially available processes.

The forward osmosis process is still at developmental stage. A number of lab scale experiments of FO process for seawater, brackish water and wastewater have been conducted. The study conducted by Mccutcheon et al. (2005) on use of seawater feed for FO revealed that reverse osmosis (RO) membranes are not suitable for the FO process because of relatively low product water fluxes attributed to severe internal concentration polarization in the porous support and fabric layers of the RO membrane. Holloway et al. (2007) have studied feasibility of forward osmosis to concentrate sludge from traditional water treatment processes using a sodium chloride draw solution. In addition, a bench-scale FO unit was built and has been operated at Yale University laboratory since 2005 (USBR 2009). The different research groups are investigating a variety of draw solutions and different membranes.

Table 10: Advantages and Constraints of FO

Advantages	Constraints
• Low energy cost • High recovery • Low fouling potential	• No full scale application yet

4.5.3. Precipitative Softening/RO

The precipitative softening process is used to control the precipitation of sparingly soluble inorganic salts, which are a major hurdle in operation of RO processes at higher recoveries. The process involves chemical addition and clarification for softening (i.e., alkalinity and hardness removal) and pH adjustment for silica removal. This process is integrated with the RO system to increase recovery of brine and thus acts as a volume-reduction process.

In an RO process generally inorganic salt precipitation can be controlled at lower recoveries by using appropriate antiscalant and by lowering the pH of feed water. However, at higher recoveries, antiscalants are not effective and pH control does not prevent precipitation of some problematic minerals such as barium sulphate and calcium sulphate, which cannot be removed by chemical cleaning. In addition, silica scaling is problematic at lower pH (Kepke et al 2008).

The precipitative softening process is effective at removing calcium, barium, and strontium (primary scale-forming ions). Silica removal also can be performed if the pH is elevated by adding magnesium and/or sodium hydroxide to increase the pH to 10.3 or higher (USBR 2009).

A process flow diagram for a precipitative softening process is presented in Figure 18.

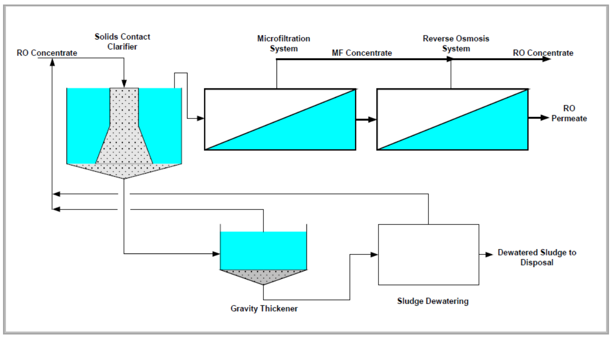

Figure 18: Precipitative Softening /RO Process Flow Diagram

4.5.4. High-Efficiency Reverse Osmosis (HERO™)

The High-Efficiency Reverse Osmosis (HERO™) system is used for increased recovery of brine and thus reduces the amount of brine discharge. The HERO™ process consists of standard two phases of RO treatment and chemical processes. The schematic of a typical HERO™ is shown in Figure 19 (the first phase RO treatment is not shown).

The brine discharge from the first-phase RO system is initially treated for hardness to reduce the scaling potential of the brine fed to HERO system. The conventional hardness removal process consists of lime soda softening, followed by filtration and weak acid cation (WAC) exchange. During the WAC process, alkalinity is converted to carbon dioxide and the pH of the water is reduced. The water is then decarbonated through a forced-draft air stripper or membrane degassifier to remove carbon dioxide and alkalinity. After degasification, pH of the concentrate is raised by adding a small amount of caustic soda to retard silica scaling and biofouling. In the final step the concentrate is fed to secondary RO system to recover water for reuse. The secondary RO step operates at high efficiency due to lime softening pre-treatment and operation at a high pH. This process results in a higher recovery than standard RO systems. (CASS 2006, Kepke et al. 2008)

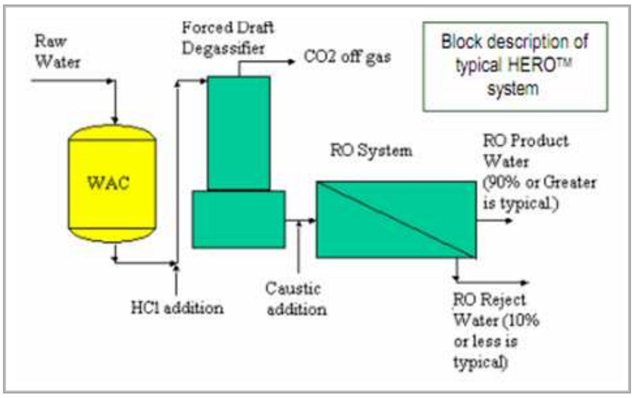

Figure 19: HERO™ Process Flow Diagram SAMCO Technologies Inc.)

This type of RO treatment is relatively new and will need detailed pilot testing prior to implementation. It has not been used for water reuse applications but has been applied in the power station and mining industries in the US. The advantages and constraints (USBR 2009) related to the HERO TM are given in Table 11.

Table 11: Advantages and Constraints of HERO™ process

Advantages	Constraints
• Applicable to concentrate flows with high silica content • Relatively small foot-print • Small aesthetic profile (no tall stacks) • Reduction in scaling • Elimination/reduction of biological and organic fouling due to high pH • Higher recoveries (up to 95 %.)	• Inefficiency due to TDS limitations • High capital and O&M costs • Highly skilled operations staff required • Complex process control system runs the IX, pH adjustment, and RO systems • high chemical usage (due to lime softening process and ion exchange), • The disposal of two concentrated waste streams generated from the lime softening process (solids) and ion exchange (waste brine).

4.5.5. Electrodialysis & Electrodialysis Reversal Process

Electrodialysis (ED)/electrodialysis reversal (EDR) is used to remove dissolved salts from a solution. It is an electrochemical driven separation process in which ions are transported through ion permeable membranes from one solution to another under the influence of a potential gradient. The electrical charges on the ions allow them to be driven through the membranes fabricated from ion exchange polymers. Applying a voltage between two end electrodes generates the potential field required for this. Since the membranes used in electrodialysis have the ability to selectively transport ions having positive or negative charge and reject ions of the opposite charge, a concentrated stream and a demineralized product stream is generated by electrodialysis process (Kepke et al 2008, Drewes 2009).

An ED stack consists of a series of anion exchange membranes (AEM) and cation-exchange membranes (CEM) arranged in an alternating mode between anode and cathode (Figure 20). The positively charged cations (e.g., sodium [Na^+]) migrate toward the cathode, pass the cation-exchange membrane, and rejected by the anion-exchange membrane. The opposite occurs when the negatively charged anions (for example, chloride [Cl^-])) migrate to the anode. This results in an alternating increasing ion concentration in one compartment (concentrate) and decreasing concentration in the other (diluate). The EDR process is similar to the ED process, except that it also uses periodic reversal of polarity to effectively reduce and minimize membrane scaling and fouling, thus allowing the system to operate at relatively higher recoveries (Kepke et al 2008, Drewes 2009).

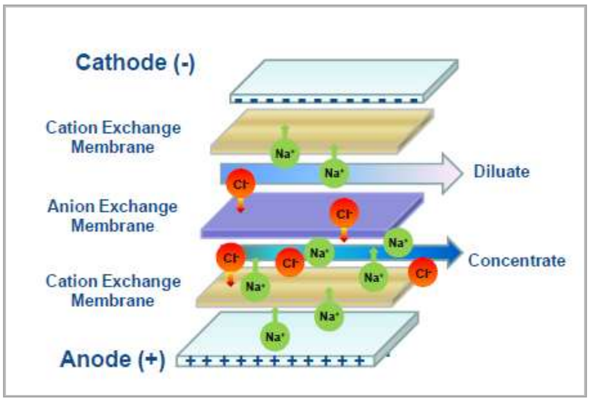

Figure 20: Schematic of an ED/EDR stack

The efficiency of ion transfer is determined by the current density and the residence time of the solutions within the membrane cells. The membrane selectivity decreases with increasing ion concentrations. Depending on feed water chemistry, water recovery in ED and EDR can be between 70 and 90%. EDR and ED processes are typically used in desalination of brackish water. These processes are not feasible for seawater because their cost increases substantially with increasing salinity (USBR 2009).

This technology has been widely used for potable water and for wastewater applications. Advantages and constraints associated with this method are given in Table 12. (USBR 2009)

4.5.6. Electrodialysis Metathesis (EDM)

Electrodialysis Metathesisand (EDM) differs from conventional Electrodialysis by an innovative arrangement of ion excange membranes and use of NaCl solution. The Electrodialysis Metathesisand (EDM) is composed of four solution compartments and four membranes, rather than two of each in the repeating unit. Typical metathesis applications are conversions of Calcium salts of organic acids into their acidic form by metathesis with hydrochloric acid.

Table 12: Advantages and constraints of ED/EDR method

Advantages	Constraints
• Higher water recovery than RO • Can treat water with a higher level of suspended solids than RO • Unaffected by non-ionic substances • Reduced or no impact from thermal discharges • Intermittent flushing of the system minimizes need for pre-treatment chemicals and membrane fouling (EDR only) • Less prone to fouling than RO (EDR only) • Potential for higher recovery than other membrane processes.	• Prone to fouling and scaling (ED only) • Can result in product water with a higher concentration of bacteria than the feed water • Most membranes cannot tolerate strong oxidants, such as chlorine • Effectiveness is achieved only when TDS concentration in the feed water is less than 8,000 mg/L. • Multiple stages are required for treatment of high-TDS feed water, such as concentrate, which increases capital and O&M costs • Inability to remove all constituents (like boron, silica, and uncharged micro- pollutants)

The EDM membrane configuration is shown in Figure 21. The repeating unit comprises one diluate compartment; two concentrate compartments, one NaCl solution compartment, one ordinary anion exchange (A), one ordinary cation exchange (C), one monovalent selective anion exchange (SA), and one monovalent selective cation (SA). This unique configuration is designed to separate EDM concentrate into two streams of highly soluble salts: one containing sodium with anions and the other containing chloride with cations.

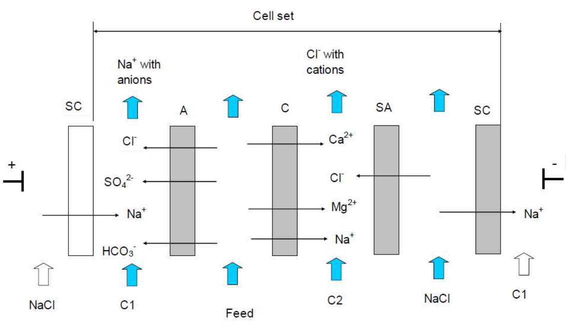

Figure 21. Electrodialysis Metathesis.

Table 13: Advantages and constraints of CDI technology

Advantages	Constraints
• High product water recovery. • Potential to develop reusable salts and brines. • Reduces concentrations of all ions without chemical addition or production of solid waste. • Membrane fouling potential of uncharged species such as silica does not increase through the process.	• EDM still under development. • Above 10 g/L, energy requirements begin to shift the economics in favor of thermal processes..

4.5.7. Capacitive Deionization (CDI)

Capacitive deionization is an electrostatic process operating at low voltages and pressures. The process is used for removal of dissolved ions from solution. In CDI process, solution is passed through a porous electrode assembly (Figure 21).

Due to the voltage electric field (having a potential difference of 1.2 Volts) the ions in the solution are attracted to the oppositely charged electrodes and adsorbed, leaving deionized water behind. Eventually, the electrodes become saturated with ions and must be regenerated, by eliminating the electric field. Once the applied potential is removed, the ions attached to the electrodes are released and flushed from the system. This flushing produces a more concentrated brine stream, as illustrated in Figure 21b.

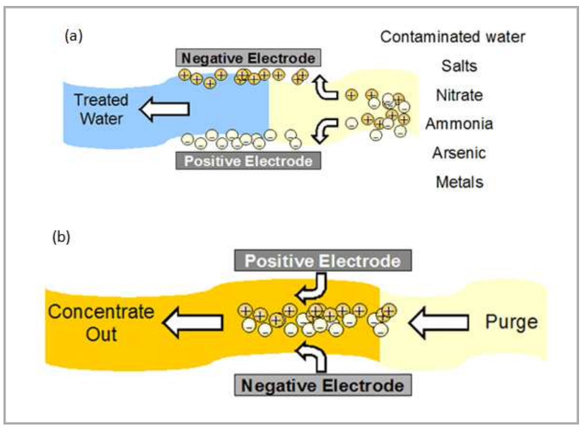

Figure 22: CDI operation (a) and regeneration (b) (USBR 2009)

The efficiency of CDI strongly depends on the surface property of electrodes such as their surface area and adsorption properties (Drewes 2009). CDI has higher energy efficiency than other types of salt removal technology (such as RO). But it has low recovery rate, e.g. the water recovery achieved with brackish water desalination is 70%. Other considerations related to CDI are, requirement of large number of gel electrodes, which are expensive. However, a variety of electrode materials and configurations have been developed to enhance the CDI performance (USBR 2009). Table 13 gives some of advantages and constraints of CDI technology.

Table 14: Advantages and constraints of CDI technology

Advantages	Constraints
• CDI has low consumption of energy. • No chemicals are used for regeneration of electrodes. • Silica does not limit the recovery.	• CDI is still under development. • The process cannot remove all constituents (boron, silica, and neutral micropollutants). • Multiple stages might be required for treatment of high-TDS feed water, such as brine discharge, which increases capital and O&M costs. • CDI recovers lower amounts of water than conventional membrane processes.

4.5.8. Vibratory Shear-Enhanced Processing

Vibratory Shear-Enhanced Processing (VSEP) is a patented process of New Logic Research, Inc. The conventional membranes are subject to colloidal fouling because suspended material can become polarized at the membrane surface and obstruct filtration. The VSEP was developed as an alternative method for producing intense shear waves on the face of a membrane instead of producing high cross flow. Shear waves produced on the membrane surface keep the colloidal material in suspension, thereby minimizing fouling.

In a VSEP System, the feed slurry remains nearly stationary, moving in a leisurely, meandering flow between parallel membrane leaf elements (Figure 22). Shear cleaning action is created by vigorously vibrating the leaf elements in a direction tangent to the faces of the membranes. This high shear processing exposes the membrane pores for maximum throughput that is typically between 3 and 10 times the throughput of conventional cross-flow systems. The VSEP gives higher throughput and recovery than conventional membrane system. Water recoveries of up to 90% can be achieved by VSEP. Also, due to high flux and minimized membrane scaling and fouling, the VSEP technology is very energy efficient (0.27 kWh/kgal filtrate). (Drewes 2009, USBR 2009)

The VSEP technology is currently being used in agricultural industrial applications, but it has not been demonstrated at a full-scale for treatment of brine discharge.

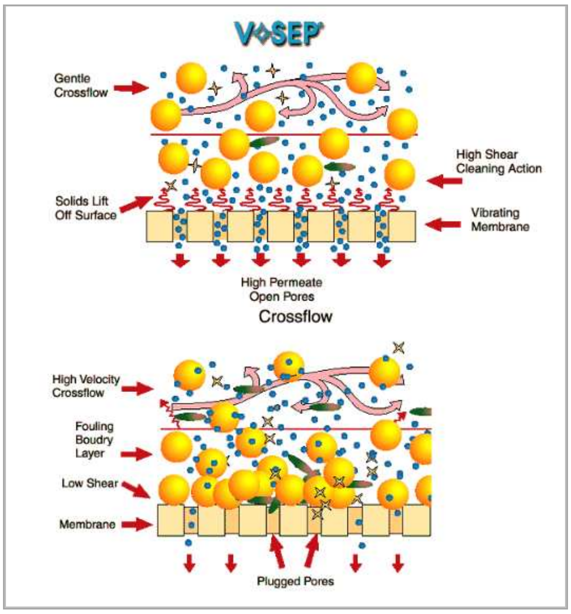

Figure 23: Gentle (top) and high velocity (bottom) cross flow mechanism of VSEP (USBR 2009)

Advantages and constraints related to VSEP are summarized in the Table 14.

Table 15: Potential advantages and constraints of VSEP technology

Advantages	Constraints
• Potentially no requirement for pre-treatment chemicals • Small footprint • Low energy consumption • Low fouling and scaling potential • Potentially high recovery rates • Production of high-quality water (similar to conventional RO) • Minimal environmental issues associated with use	• Potentially susceptible to fouling with aluminium, iron and manganese oxide deposits • Much higher clean-in-place (CIP) frequencies than conventional RO due to operating with much higher fluxes • Changing all membrane elements in a stack is required if one membrane plate needs replacement • Higher capital and O&M costs than traditional RO • Proprietary technology from a single vendor

4.5.9. Other Brine Minimization Options

Besides the aforementioned brine minimization techniques that are used to reduce size and cost of ultimate brine discharge facilities, there are many other options available. Some of them, which are not discussed in this report, are Natural Treatment Systems, Two Pass Nanofiltration, Membrane Distillation, Slurry Precipitation and Reverse Osmosis and Advanced Reject Recovery of Water (USBR 2009).

4.6. Zero Liquid Discharge

The zero liquid discharge consists of high recovery processes used to dry out the brine discharge, such that no brine discharge leaves the plant. The main stage of a zero liquid discharge system is thermal or mechanical evaporation, which produces solid end product. This end product is in the form of precipitated salts and/or mineral slurries that is either disposed of in landfill or can be sold if there are any market possibilities. Zero Liquid Discharge system is normally a combination of several different disposal techniques. Volume minimization by brine concentrator followed by crystallizers is one the typical approach of ZLD system.

The ZLD system varies from natural evaporation systems to more complex mechanical evaporations. Some of the ZLD methods are described in the following topics.

4.6.1. Evaporation ponds

Evaporation ponds have been used for salt generation over many centuries. Evaporation ponds are used extensively for final disposal of brine where brine is evaporated using solar energy. When water evaporates from brine it results in accumulation of precipitated salts, which are collected and disposed of in landfills from time to time. Evaporation ponds are especially suitable for disposing of brine from inland RO plants in arid and semi-arid areas due to the abundance of solar energy (Ahmed et al. 2000).

The process of evaporation pond method is simple and straightforward. The brine delivered to the evaporation ponds is spread out over a large lined area and allowed to evaporate naturally. A series of ponds are constructed to ensure uninterrupted brine disposal. Periodic maintenance includes allowing the evaporation pond to be idle to desiccate 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 (USBR 2009).

The evaporation ponds need to be appropriately lined with an impermeable barrier to prevent percolation of brine into the groundwater table. The material and thickness of the liner needs careful consideration and must be selected appropriately because increased salt content could cause the liners to deteriorate (Mickley 2006). In addition, a biological system favorable to salt production has to be established and maintained in the ponds for a successful operation of evaporation ponds (Davis1999).

The size of an evaporation pond mainly depends on the evaporation rates in the region, flow rate of the brine, surge capacity, freeboard, and storage capacity. The evaporation and brine flow rates determine the surface area required, while the other factors determine the depth of the pond (Younos 2004). The required pond area in arid climates with high net evaporation rates will be comparatively lower than the humid climates that have low net evaporation rates. Likewise, greater the flow rate of brine, larger the area required for evaporation ponds (USBR 2009).

The feasibility of implementing evaporation pond method is determined by factors like the flow rate of the brine, the geographical location and specific site location of a prospective evaporation pond. Evaporation ponds are only viable in relatively warm, dry climates with high evaporation rates. Besides, they are land intensive and need a level terrain. As net evaporation rates are lower than soil-uptake rates in general, the evaporation ponds require more land than spray irrigation for a given volume flow (Mickley 2001). The capital costs for this method are very high, mainly due to land acquisition cost and cost of expensive impermeable liners. Thus the evaporation ponds are typically economical and are employed only for smaller brine flows and coupled with high-recovery desalination processes (Sethi et al. 2006). Also, the evaporation pond method has the potential for commercial exploitation of valuable elements and compounds found in brine.

The main potential environmental impact related to use of evaporation pond method is pond leakage, which may result in contamination of under lying aquifer systems or adjacent freshwater resources (Glater and Cohen 2003). Ahmed et al. (2000) have reported several leakage issues in their detailed survey report of evaporation ponds in Oman and the United Arab Emirates. Another environmental concern is that elevated salinity and trace constituents in evaporation ponds and potential bioaccumulation of toxic substances may be problematic for breeding and migrating birds. A case study conducted by Tanner et al (1999) showed that brine shrimp, the main attractant for water birds, had higher selenium levels than recommended. This may pose a long-term hazard through the accumulation of selenium in the food chain (Tanner et al 1999).

Evaporation pond technology is practiced primarily in the Middle East and also in Australia, Israel and US. This technology is probably the most widespread method of brine disposal from inland desalination plants (Glater and Cohen 2003).

Figure 24: Two Evaporation ponds in Texas, US

Advantages and constraints of evaporation pond are summarized in Table 15.

Table 16: Advantages and Constraints of Evaporation Pond Method

Advantages	Constraints
• A viable and proven option for inland plants in highly arid regions • Possible commercial salt exploitation • No marine impact expected • Simple method hence low technological and managing efforts required • Inexpensive option for small plants in warm arid region	• Expensive option • Can increase salinity of underlying soil and groundwater • Needs dry climates with high evaporation rates • Requires large level areas of land • Potential regulatory and environmental/habitat issues exist due to accumulation and concentration of micro pollutants • Unusable salts have to be disposed off in landfills during periodic maintenance

Evaporation rates of the ponds can be enhanced by providing a larger evaporative surface for increased exposure of brine into the air. Some of approaches utilized to boost evaporation rates include spraying or misting the water into the air, letting the water fall through the air, or saturating a cloth material and exposing it to air flow. The possible concerns related these methods are drifting of mist and scattering of dry salt particles. However, they have potential to reduce required land area and capital costs (Mickley, 2009).

Figure 24 shows a picture of mechanical misters at work, along an evaporation pond. They are spraying the brine into the atmosphere in tiny droplets, thereby increasing the liquid surface area. This way the rate of evaporation of the pond is increased substantially.

Figure 25: Mechanical misters

(Source: DriBoss®)

4.6.1.1. Salinity Gradient Solar Ponds

Salinity gradient solar pond is a special form of evaporation pond. A salinity-gradient solar pond (SGSP) is a body of water that collects and stores solar energy.

A typical salinity-gradient solar pond consists of three regions. The top region is called the surface zone, or upper convective zone (UCZ) that has ambient temperature and low salt content. The middle region is called the main gradient zone (MGZ), or non-convective zone (NCZ), which constitutes thermal insulating layer and salinity gradient. The bottom region is called the storage zone, or lower convective zone (LCZ).
The lower zone is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified.

If the salinity gradient is large enough, there is no convection in the gradient zone even when heat is absorbed in the lower zone because the hotter, saltier water at the bottom of the gradient remains denser than the colder, less salty water above it. The gradient zone acts as a transparent insulator, permitting sunlight to be trapped in the hot bottom layer. The useful thermal energy is then withdrawn from the solar pond in the form of hot brine. A common method to speed heat removal is to extract heat with a heat transfer fluid, which is pumped through a heat exchanger placed on the bottom of the pond (Lu et al. 2002).

Desalination by salinity-gradient solar ponds has been studied in the US, Israel, and several other countries. According to a research (Lu et. al 2002) conducted on thermal desalination powered by salinity-gradient solar ponds in University of Texas El Paso, salinity-gradient solar pond can be a reliable and environmentally friendly heat and cooling source for thermal desalination and brine concentration processes (Lu et al. 2002). Figure 25 shows the pond used for the research.

But these salinity gradient solar ponds are not considered economically viable for desalination waste management in US, according to the report of Mackey and Seacord. (2008).

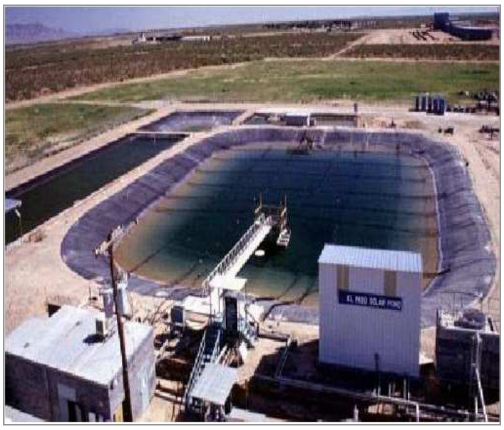

Figure 26: Salinity Gradient Solar Pond at El-Paso, Texas

4.6.2. *Crystallizers*

Brine crystallizer method is primarily used as the last stage of brine disposal in zero liquid discharge systems. The crystallizer by using mechanical evaporation reduces brine to a transportable and manageable solid form that can be disposed of in landfill. High quality product water is also recovered during the process.

Brine typically undergoes volume reduction before it is fed to a crystallizer and has TDS concentration of about 200,000 to 300,000 mg/L (USBR 2009). Normally in most of the RO plants, brine crystallizers are operated in conjunction with brine concentrators for volume reduction in order to achieve zero liquid discharge. Capacity of most brine crystallizers ranges between 2 to 50 gpm. Smaller systems (in the range of 2 to 6 gpm) are steam-driven while larger systems use electrically driven vapor compressors (Mickley 2006).

Figure 26 below gives the process flow diagram for a typical forced circulation, vapor compression crystallizer.

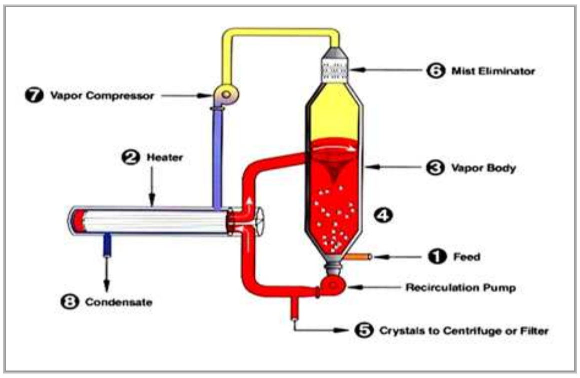

Figure 27: Forces-Circulation, Vapor Compression Crystallizer Process Flow

As the figure above displays, the crystallization process starts with wastewater feed pumped to the crystallizer (1). Wastewater joins the re-circulating brine and pumped to a heat exchanger (2). Here compressed and de-superheated steam heats the brine above its boiling point at atmospheric pressure, by condensing on the outsides of the heat exchanger tubes. This way brine doesn't boil and thus prevents scaling. The heated brine then enters the crystallizer vapor body (3), which operates at slightly lower pressure causing flash evaporation. As water is evaporated from the brine, crystals form (4). Most of the brine is re-circulated back to the heater and a small stream (1-5 % of the brine) from the re-circulating loop is sent to a centrifuge or filter to separate remaining water from the salt crystals (5). Salt can be disposed of in a landfill, and filtrate can be returned to the feed tank. The vapor from evaporation passes through a mist eliminator (6) and enters the vapor compressor. The vapor compressor (7) heats the vapor. Compressed vapor is de-superheated with hot distillate and feed to heat exchanger, where it heats the re-circulating brine flowing inside the heat –transfer tubes. Condensate is collected and may be delivered as distillate water or blended with RO product water. Total recovery of product water across the crystallizer is between 95 and 99 percent (USBR 2009).

The energy requirements of brine concentrators are very high around 200-250 kWh/1000 gal (Mackey and Seacord 2008). In addition crystallizers are mechanically complex and need relatively high maintenance due to corrosivity of very high levels of the brine. However it has a small site footprint.

Crystallizer is the most expensive alternative in comparison to the evaporation pond, salinity solar pond and deep well injection method (Swift et al. 2002). Thus according to Mickley (2006) crystallizer method is the most viable option in areas where the construction cost of evaporation ponds is high, solar evaporation rates are low and the deep well injection treatment is costly or unfeasible.

Table 17: Advantages and Constraints of Crystallizers

(Mackey and Seacord 2008)

Advantages	Constraints
• Proven technology use in industrial applications • High-quality product water which can be used elsewhere • Feasible in area where other, lower-cost options are not • Small site footprint	• High capital and O&M costs • Very energy intensive (~ 200-250 kWh/1000 gal) • May require frequent cleaning when used for complex salt waste streams. • Mechanically complex

4.6.3. Spray Dryers

Spray drying is a continuous single stage process, extensively used to convert slurries into dry powder within a few seconds without any intermediate handling. Spray dryers provide an alternative to crystallizers for concentration of brine to solids. They are usually operated in conjunction with brine concentrator evaporators in desalination plants.

Spray dryers consist of a large cylindrical drying chamber and a dried brine separator (bag filter) to collect dried solids as shown in Figure 27.

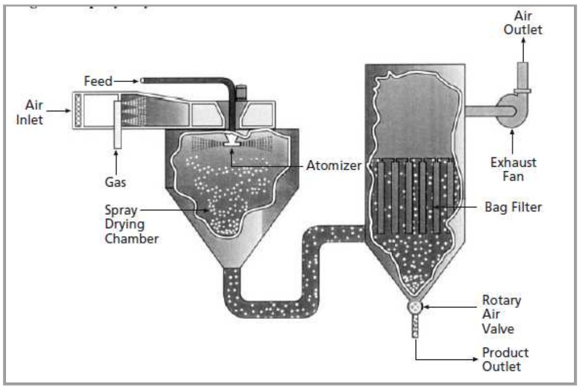

Figure 28: Schematic of Spray dryer

(Source: Bostjancic and Ludlum 1996)

The brine is fed to the drying chamber in the form of droplets through brine atomizer. The atomizer consists of a shaft and rotating disc that protrudes into the hot, gas stream. Air, heated by a gas, oil, or electric-powered heater, is introduced to the drying chamber. When the brine droplets contact with the hot air, they dry to a powder. To separate the dry powder from the hot air stream, air is passed through bag filter with the help of an exhaust fan. The dry powder is collected then for transfer to a disposal site and the air exits to the atmosphere. Figure 28 shows picture of a spray dryer facility.

The spray dryer method is considered as an expensive and energy intensive method. The cost of spray dryer is significantly affected by the characteristics of brine feed, which determines the type of construction materials required. The spray dryers are generally more cost effective for small brine volumes in the range of 1 to 10 gpm (Mickley 2006).

Figure 29: A Spray dryer facility

(Source: Swenson Technology, Inc.)

Table 18: Advantages and constraints of spray dryer

Advantages	Constraints
• Concentration of slurries to solid waste • Recovered product water can be used elsewhere • Feasible in area where other, lower-cost options are not • Small footprint	• Very high capital costs • Very energy-intensive (> 200 kWh/1000 gal)

4.6.4. Wind-Aided Intensified Evaporation

Wind Aided Intensified Evaporation (WAIV) is one of the emerging technologies for brine treatment. It uses wind energy to enhance evaporation thus reducing the surface area required for brine treatment. The basic concept is exploiting wind energy to evaporate wetted surfaces that are packed in high-density footprint (Gilron et al. 2003).

Figure 29 shows layout of a WAIV pilot unit. The WAIV unit is operated by the wetting of vertically mounted evaporation surfaces, which are placed in arrays to optimize the process. The hydrophilized evaporation surfaces can consist of woven nettings, or nonwoven geo-textiles, or tuff (volcanic rock). Water is pumped from a small holding pond or a storage tank to a distribution network on the top of these vertical surfaces. From there it is allowed to trickle down the vertical surfaces by gravity. As dry air passes over the vertical surfaces, evaporation takes place and the salts are deposited on the surfaces. Any excess liquid is drained back to the pond, while the salts deposited are knocked off by the wind action and caught in a trough below the fabric for disposal in a landfill (Drewes 2009, USBR 2009).

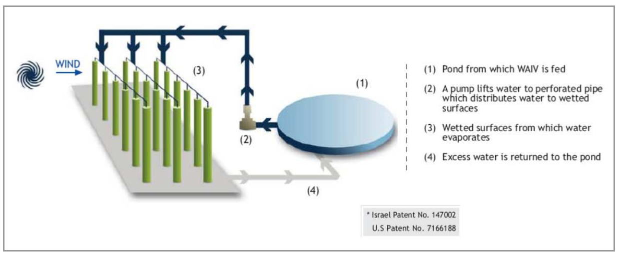

Figure 30: Schematic of a WAIV Unit

(Source: Lesico 2011)

The pilot studies have shown that the WAIV method intensifies the evaporation process up to 20 times more than a conventional evaporation pond (Gilron et al. 2003). The system employs a floating surface that has 33 times the wetted surface area as that of the footprint. It covers part of the pond on strips and can result in a land requirement of only one-tenth of the conventional ponds (Drewes 2009) .The WAIV technology can serve as cost effective alternative to brine disposal methods with relatively low energy costs and reduced land area requirement, compared to traditional evaporation ponds and brine concentrators.
The WAIV technology is best suited for a climate with high evaporation rates. Also selection of an appropriate material for evaporation surfaces needs careful consideration. Therefore a site specific detailed pilot testing is important before adopting this method (USBR 2009).

Lesico CleanTech commercially manufactures the WAIV technology. The company has developed several commercial pilot units mainly in Israel, and recently in Australia and Mexico (Lesico 2011). Also the US Bureau of Reclamation (2009) has tested this technology and identified that the dripping nozzles would salt up and clog. This required cleaning of the nozzles on a regular basis.

The advantages and constraints of the WAIV are summarized in Table 18.

Table 19: Advantages and Constraints of the WAIV method

(Mackey and Seacord 2008, USBR 2009)

Potential Advantages	Constraints
• Reduces the footprint of evaporation ponds • Very low energy requirements • Natural energy sources (solar and wind) are used resulting in lower O&M costs. • Operation is less complex compared to thermal and RO based brine management options • Reduction of up to 50% in treatment costs of RO rejected waste • Modular and scalable designs facilitating highly cost effective solutions for any production capacity	• The technology is only suitable for climates with high evaporation rates • Technology is still under development. Surface material and packing density need to be optimized. • No full-scale performance and capital and O&M data exist. • Precipitative fouling of feed lines • Scattering of brine flow due to wind • Periodic rinsing and acid wash are required for cleaning of woven surfaces. • Residuals need to be disposed of in landfills.

4.6.5. Salt Recovery

Retrieval of beneficial chemical components of brine discharge offers an attractive solution to avert disposal issues. The recovery of specific chemicals that can be used as feed-stock for various industries (e.g. pulp and paper industry) gives an additional economic benefit.

If a salt production plant is in proximity to the desalination plant, the brine discharge could be used to recover table salt. For example a dual purpose SWRO plant (2.64 MGD) in Eilat, Israel uses its brine discharge for production of table salt. The brine discharge from the SWRO plant is blended with seawater, and this stream is fed to a series of evaporation ponds, and thereafter to a salt processing factory (Xu et al. 2009).

Several methods have been investigated for recovery of chemical components in the brine discharge for additional applications. Such as experiments to use electrodialysis and elctrochlorination technologies (Davis 2006, Kumar et al. 2006 cited in Xu et al. 2009) to recover useful products from RO brine discharge.
The SAL-PROC is a full-scale application to recover beneficial salts from RO brine discharge and has been successfully tested in pilot studies as well as in the field.

4.6.5.1. SAL-PROC

SAL-PROC™ is a patented process of Geo-Processors USA, Inc. (Glendale, California). The process was designed to facilitate the sequential or selective precipitation and extraction of specific dissolved chemical compounds and salts from saline waters. The process involves multiple chemical processing with evapo-cooling and crystallization steps for recovery of valuable by-products. No hazardous chemical is used in the process. The final product of the Sal-Proc system is a refined chemical salt that may have commercial value. Depending on feed water quality these salts may include gypsum-magnesium hydroxide, magnesium hydroxide, sodium chlorite, calcium carbonate, sodium sulphate, and calcium chloride (USBR 2009).

Geo-Processor has developed a model that consists of two subsystems, including one or more selective salt recovery steps that are linked with RO desalination, thermo-mechanical brine concentration, and crystallization steps. A desktop modelling exercise enables the selection of an appropriate ZLD process scheme. The selected ZLD systems utilize multiple reaction steps using lime and soda ash to produce carbonated magnesium, calcium carbonate, and a mixed salt. The overall system recovers the entire flow and can generate high-quality water. However, SAL-PROC is not a stand-alone brine discharge treatment technology and requires incorporation of one or more desalination technologies to reduce volume significantly. It acts as a product recovery process. The suitability of using SAL-PROC depends upon the water quality and type of application (Drewes 2009, USBR 2009). A simplified schematic of SAL-PROC is shown in Figure 30 below.

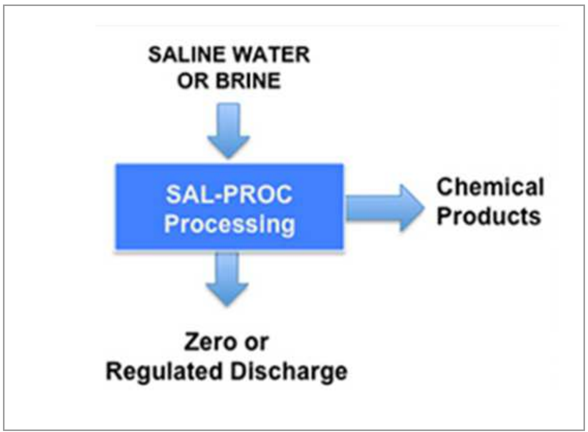

Figure 31: A simplified schematic of SAL-PROC™

Large scale-pilot trials and public demonstrations of SAL-PROC have confirmed that this technology has the capacity to convert a number of brine waste streams into marketable products (precipitated salts) while achieving zero liquid discharge.

The major advantage of implementing this process is that it can recover marketable products. Also it is designed to be highly modular and readily integrated into other unit processes. Whereas main consideration of SAL-PROC systems is that infrastructure requirements may be relatively high, and will likely require significant footprint to accommodate chemical reagent storage and product salt storage. (Drewes 2009)

4.6.6. Dewvaporation

Dewvaporation is a thermal distillation method of desalination that involves evaporation process followed by dew formation. The main goal of this technology is to provide a less expensive desalination method for small-scale applications. Also the Dewvaporation technology could be potentially applied for volume reduction of brine in Zero Liquid Discharge plants.

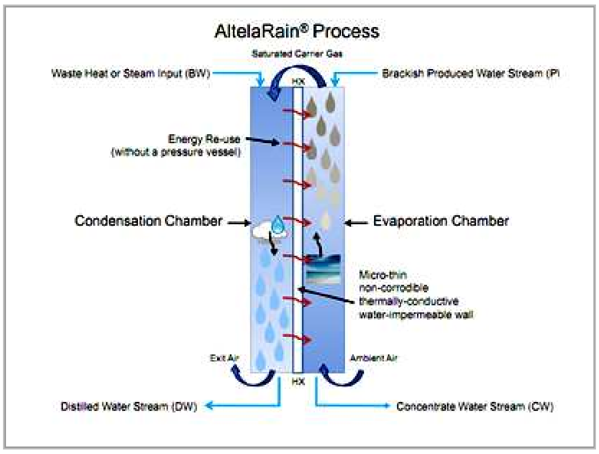

Figure 32: Schematic of AltelaRain™ process (Godshall 2006)

The DewVaporation system consists of a tower with two compartments separated by a heat transfer wall, one for evaporation and one for dew formation (Figure 31). The system using air as carrier-gas evaporates water from brine feeds and condenses respectively, to form a relatively pure condensate at atmospheric pressure. In Dewvaporation process air is introduced into the bottom of the evaporation chamber at an ambient temperature. Simultaneously the heat transfer wall is wetted with brine by feeding it to the top of the evaporation chamber. As the air flows upwards its temperature rises because of heat transfer walls and evaporate water from the brine. The remaining water, now concentrated salts, exits from the bottom of the tower and warm saturated air rises to the top of the tower. Energy in the form of steam is added to the tower at this point, saturating the air. This hotter saturated air is then sent to the condensation side of the heat transfer. As the air travels down the condensation chamber it cools and begins to condense. The condensation releases heat through the heat transfer surface to the evaporation side. Pure distilled water condensate leaves the condensation side of the tower at the bottom of the tower. The concentrate is collected from evaporation chamber and sent for further treatment.

Heat sources for dewvaporation can be combustible fuel, solar, or waste heat. Since the evaporation occurs at the liquid-air interface and not at the heat transfer wall no scaling problems are encountered.

The Dewvaporation concept was developed at Arizona State University. Dewvaporation has been pilot tested extensively. However, no full-scale application of this process for desalination and RO concentrate treatment exists (USBR 2009). DewVaporation has only been demonstrated for small applications of 100 gpd to 5,000 gpd. Research is being done to prove the technology can maintain 95 percent recovery of the saline feed water. The technology is still being tested and there have been improvements on the tower design and operation of heat sources (CASS 2006).

Currently Altela Inc. is manufacturing this technology under the trade name of AltelaRain^{SM} (schematic shown in Figure 31) .The process designed by AltelaRain^{SM} can treat approximately 4,000 gallons per day of produced water with TDS in excess of 60,000 mg/L. The AltelaRain^{SM} system can reduce brine discharge volume by as much as 90% (Godshall 2006).

The Dewvaporation works at ambient pressures and low temperatures thus drastically reducing energy costs. Also the unit is built of thin plastic films to avoid corrosion and to minimize equipment costs. Other potential benefits are low operating capital costs and small footprint. On the other hand, potential considerations in the use of this process include the requirement of large heat transfer areas, the impact of ambient weather, and the need for a low-temperature sink to permit condensation.

Table 20: Advantages and Constraints of DewVaporation

Advantages	Constraints
• The DewVaporation towers were reliable and ran constantly for extended periods of time • The towers could process high TDS feed • Dewvaporation produces high-quality (distilled) water. • Solar or waste heat can be used to power the unit. • Operation is less complex than thermal and RO based concentrate management options. • Operation cost is low due to moderate operating temperature and atmospheric pressure. • Plastics heat transfer walls reduce capital cost and eliminate corrosion concerns.	• No full-scale units are in service, • No data exist on full-scale performance or on capital and O&M costs. • Dewvaporation results in lower water recovery (30 to 40 percent) (USBR 2009) • Small amounts of distillate were produced from each tower (5-8 gallons/hour), and • The energy multiplication factor was approximately 2.5 (while theory predicted an energy multiplication factor of 5).

4.7. Treatment of Process Residuals

The RO filters in reverse osmosis plants need to be backwashed intermittently to maintain their efficiency. Filters are backwashed with either filtrate or brine and the frequency depends on the quality of the raw water. This backwash water is a major process residual. The residuals from backwash contain natural suspended solids and sludge together with coagulants and residual disinfectants. These residuals are either discharged into the sea or are dewatered and the sludge is disposed of in a landfill.

Many smaller RO plants and all of the UF plants discharge the backwash waters without treatment. But a growing number of RO plants, with conventional pre-treatment, treat the backwash stream onsite before disposal. The stages of a conventional treatment process for process residual are (Mauguin and Corsin 2005, Lattemann 2010, Mickley 2009).

i- Neutralization:

First, waste water streams (e.g. chemical storage, chemical cleaning and preservation of RO membranes) containing chemicals are collected separately in a retention basin for neutralization and detoxification by dosing acid (e.g. *HCl*) and caustic (e.g. *NaOH*) and flocculated by means of adding coagulant (e.g. *FeCl3*) prior to further treatment.

Backwash water streams from pre-treatment and post-treatment sections with high suspended solid content are collected in a backwash wastewater basin. Already neutralized chemical wastewater from neutralization is added to backwash wastewater basin

ii- Sedimentation:

Collected wastewater streams are then transferred to sedimentation section of the wastewater treatment system on a continuous basis. To aid sedimentation and settling, flocculants can be added into the feed of the sedimentation stage. To separate sludge flakes from clear water, a special kind of clarifier called lamella clarifier is used. The flakes get accumulated on the lamellas and slide down to the bottom of the clarifier.

iii- Sludge thickening:

Sludge generated in lamella clarifier of sedimentation part is transferred to sludge thickener tank to further concentrate sludge content before dewatering. The overflow of the sedimentation system is water with low turbidity (clear water), which may be discharged to sea given the condition that turbidity is within allowed limits. If not, treated backwash water is returned to pre-treatment section of RO plant. The clarified water from sludge thickener tank is transferred back into backwash wastewater basin upstream the sedimentation system.

iv- Sludge dewatering:

For sludge dewatering, centrifuge and filter press technologies are generally applied where drier solids are produced. For the improvement of filtration efficiency of sludge dewatering system, appropriate type of flocculants can be dosed into dewatering system feed lines before entering the centrifuge or filter press. Thickened solids discharged from sludge dewatering unit should be in the form of a cake with a dry solid (DS) content of around 20%. The cake is discharged to be disposed to landfill according to local solid disposal regulations. If dissolved air flotation (DAF) is applied in the pre-treatment of RO, floating sludge layer from DAF units is directly fed into sludge dewatering unit. A schematic view of filter backwash wastewater treatment plant is shown in Figure 31.

The presented treatment approach of conventional treatment is a cost effective solution in general. It has been applied in Australian SWRO desalination plants in Gold Coast, Perth I and Sydney for treatment of pre-treatment backwash wastewater before discharge (Lattemann 2010).

The specific wastewater treatment plant scheme for a selected site is however subject to individual assessment, considering project and local site data.

4.8. Evaluation of Brine Disposal Methods

The environmental risks related to brine discharge can be minimized by selecting an 'optimal' disposal method. There are several brine disposal techniques in practice worldwide, as discussed in the previous section. But there is no single best practice for brine disposal. A site-specific approach is required when determining the appropriate method of brine disposal and often one single method of disposal is not adequate.

Surface discharge of brine is the most commonly used and least expensive disposal method in practice today (Mickley 2009, USBR 2009). Minimal adverse impacts are expected if rapid mixing and dilution are ensured in the discharge zone (Lattemann and Höpner 2008, Ahmed et al., 2001).

Evaporative ponds are an ideal method of disposal but can be cost prohibitive because of the large amount of land needed and the undesirable aesthetic component of the ponds. However, evaporative ponds allow minimize impacts to marine environments and allow for the remaining solids to be reused or disposed of appropriately in a landfill.

Deep well injection disposes of brine underground to be diluted within an existing aquifer system. Although, it requires a comprehensive hydro-geological investigation to ensure that existing or adjacent groundwater resources will not be contaminated and that the aquifer system has the capacity to sustain injection indefinitely.

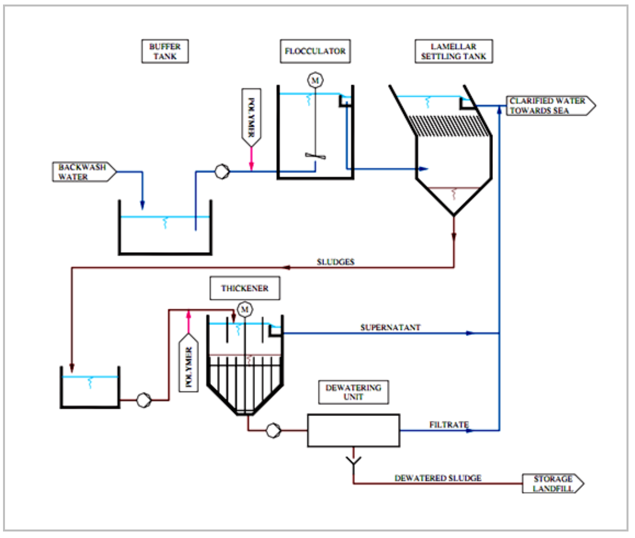

Figure 33: Schematic diagram of filter backwash waste water treatment process from pre-treatment of SWRO

(Mauguin and Corsin 2005)

The brine minimization techniques used to increase membrane system recovery are mostly based on extensive pre-treatment of feed water or a two-stage membrane system or inter-stage treatment prior to the second membrane stage. Such additional recovery processes increase the costs and if feed water has high hardness levels the treatment may require additional chemicals.

In a zero liquid discharge (ZLD) system, by using evaporators brine volume can be reduced to about 5% of the feed volume. The brine evaporator slurry is then sent to the crystallizer, where about 95% of this feed can be reclaimed as distillate. Another ZLD approach can be using deep well injection in conjunction with evaporation ponds.

Conventional zero liquid discharge technologies are very energy and cost intensive. There are particular considerations in order to reduce these costs e.g. by coupling membrane systems prior to the thermal evaporative systems of ZLD. Cost-effective zero liquid discharge (ZLD) techniques can potentially enable the desalination of especially brackish water resources in water-scarce regions.

Thus there have been many developments in terms of brine minimization and ZLD in recent years but still there is need for further research to produce cost effective techniques.

5. Energy Recovery from Brine Discharge

The reverse osmosis desalination process uses high amount of hydraulic pressure to force purified water through a semi-permeable membrane filter. A significant part of this energy is accumulated within brine discharge that leaves the system. Hence energy recovery devices are used in order to recover pressure from the brine discharge and return it to the process. Two types of energy recovery concepts are currently employed in specific situations to reduce the energy demand.

5.1. Energy Recovery Turbine (ERT)

The turbine based centrifugal energy recovery devices (ERD) are especially used in RO systems that employ a second pass RO unit to further purify permeate from the primary RO system while treating high TDS feed water. In such cases, with the help of a Pelton turbine or a hydraulic turbocharger energy is recovered from the primary RO high pressure reject stream to help drive the second RO system.

Figure 33 shows a schematic diagram of RO process with a turbine energy recovery device. The brine discharge is ejected at high velocity through one or more nozzles onto a turbine wheel. The turbine, coupled to the high-pressure pump shaft, assists the motor in driving the pump that pressurizes the RO system. Because energy is converted twice, once by the turbine and once by the pump impeller, a great deal of energy is lost. The overall efficiency of the ERD is typically 60 to 75% (Stove 2008).

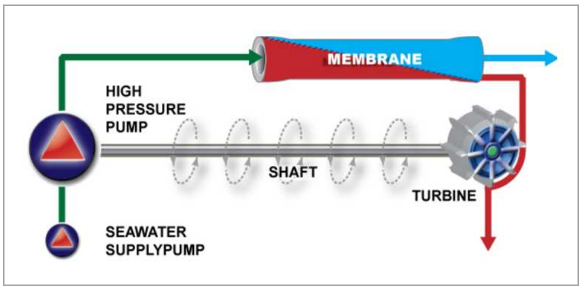

Figure 34: RO Process with a Turbine Energy Recovery Device (Stove 2008)

This method works best when the brine discharge has a TDS between 10,000 and 40,000 mg/L, where recovery is relatively low and the pressurized reject stream has a significant amount of recoverable potential energy (USBR 2009)

5.2. Pressure Exchanger (PX)

Isobaric energy recovery devices or pressure exchangers (PX) transfer pressure from the high-pressure reject stream to a low-pressure feed water stream with an efficiency of nearly 98%. A typical process configuration for an RO system equipped with isobaric ERDs is illustrated in Figure 34. Because the PX device itself consumes no electrical power, the overall energy consumption of an SWRO process is cut in half or less (Stove 2008).

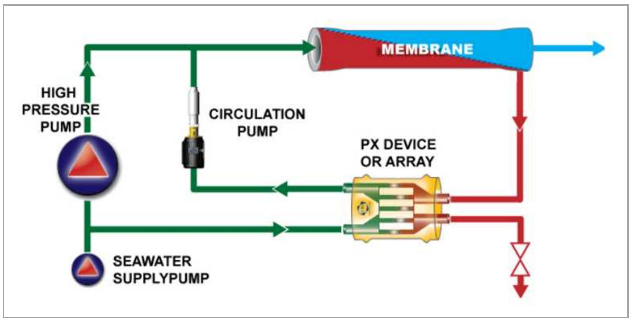

Figure 35: RO Process with an Isobaric Energy Recovery Device (Stove 2008)

The Perth desalination plant in Australia is one of the SWRO plants that utilize pressure exchangers to reduce energy consumption. The plant uses arrays of ERI PX-220 energy recovery devices for this purpose. One PX device array is shown in Figure 35.

Figure 36: PX device array serving one SWRO train in Perth Desalination Plant (Stove 2008)

6. Environmental Impacts of Brine Discharge

The brine discharge contains concentrated salts, pre-treatment chemicals and heavy metals. It may be discharged directly into the surface waters (like oceans, seas and estuaries), or combined with other discharges (e.g., power plant cooling water or wastewater treatment plant effluent) before surface discharge, or discharged into a sewer for treatment in wastewater treatment plant, or dried out. The environmental impacts of the brine discharge may vary depending on factors including the location of a desalination plant and method of brine disposal used.

The brine discharge changes water quality of the receiving water and as a result adversely affects the marine ecology. The brine discharge may also impact the groundwater. Extensive research has been conducted on the impact of brine discharge on salinity and temperature of the outfall area, and introduction of residuals. Also there are several studies on potential impacts on marine ecology. Based on literature review of these research studies potential impacts of brine discharge are presented in the following topics.

6.1. Impact on the seawater

The large volumes of brine discharge from desalination plants may lead to an increase in salinity in the discharge zone. When the concentrate is pre diluted with other waste streams such as cooling water, dissipated by a multiport diffuser system, or discharged into a mixing zone that can effectively dissipate the salinity load due to strong wave action and currents, the salinity increase can be minimized. The brine discharge has a different density (or salinity) than the receiving water. This may affect mixing processes and density stratification of the sea, especially in areas that are characterized by weak natural currents and waves.

In addition, it may increase dissolved metal concentrations in the mixing zone of the discharge plume and may thereby affect water quality. According to an estimate by Lattemann (2010) the daily chemical discharges of desalination plants into the Gulf can amount to 23.7 metric tons (t) of chlorine, 64.9 t of antiscalants and 296 kg of copper.

Also brine discharge and cooling water from thermal distillation plants cause thermal pollution in the discharge site and may change the ambient temperature profiles.

6.2. Impact on Marine Ecology

The brine disposal into the ocean affects the marine ecology in the vicinity of the outlet due to the higher salinity and potential presence of additional chemicals introduced in the desalination processes (Einav et al. 2002). The level and extent of impact may vary depending on both, the physico-chemical properties (discussed in detail under topic 3) of the brine discharge and the hydrographical and biological features of the receiving water (UNEP 2008).
The hydrographical features of seas like bathymetry, waves, currents, depth of the water column etc. determine the extent of the mixing of the brine discharge and therefore the geographical range of the impact. Enclosed and shallow sites with abundant marine life are generally considered to be more sensitive to desalination plant discharges compared to expose, high energy, open-sea locations, which are more capable to dilute and disperse the discharges (Lattemann and Höpner 2008). The environmental effects related to each physico-chemical characteristic of brine discharge are as the follows.

6.2.1. Salinity

Salinity is one of the vital parameters for marine life. Many marine organisms are naturally adapted to changes in seawater salinity (typically, natural salinity fluctuation is at least ± 10 % of the average annual ambient seawater salinity) (Danoun 2007). But local salinity levels around the brine discharge location mostly exceed natural salinity levels and pose threat for a variety of marine species. Most marine organisms can adapt to minor deviations in salinity and might tolerate extreme situations temporarily. However, only few species will be tolerant of high salt concentrations over extended periods of time

Benthic communities, such as sea grass beds, may be more affected by RO plant discharge, which has higher salinity and tends to form salt layer at bottom. In contrast, brine discharge of distillation plants will affect open water organisms (Lattemann and Höpner 2008). The speed of dilution of the discharged brine decreases with growing density differences between brine and the receiving water. Thus particularly RO brines can keep critical salinity levels over a larger area of the water body

The impact of concentrate salinity on a receiving water body is highly site specific. Toxicity depends on the sensitivity of the species to increased salinity, the natural salinity variations of their habitat and life cycle stage (UNEP 2008). Studies indicate that mortality of many marine flora and fauna species can occur at salinity concentrations exceeding 40g/L. The sea grass species are particularly sensitive to increases above this limit. Most organisms can cope with short salinity peaks of up to 50 mg/L and can adapt to long-term variations of 1-2 mg/L. Some organisms have very low levels of tolerance such as corals, the salinity of 43 mg/L can already be lethal for them (Lattemann, et al., 2010). However, physiological functions (e.g. reproduction, growth etc.) of many species can be impaired at far lower salinity concentrations than this. Salinity concentrations of approximately 2.5g/L above background maximum salinity concentrations (average of 35 g/L) could result in chronic and possible adverse effects on more sensitive species.

One such study investigated the impact of salinity on *Posidonia oceanica*, a Mediterranean seagrass. The investigations showed significant effects on seagrass structure and vitality at salinities of 39.1 mg/L and 38.4 mg/L, respectively. A salinity of about 45 mg/L caused about 50% mortality in 15 days and growth rates were reduced by 50 % at a salinity of 43 mg/L. However, *P. oceanica* plants that survived in a salinity of 43 mg/L over 15 days were able to recover when returned to normal condition, hence showing high temporary tolerance levels (UNEP 2008).

Some macrofauna taxa such as echinoderms (e.g. sea urchins, starfish), which are strictly marine, seem to be more sensitive to salinity variations (UNEP 2008). For example, the higher salinity levels near the outfall of the Dhekelia SWRO plant (10.5 MGD) in Cyprus were reported to be responsible for a decline of macro-algal population. Some echinoderm species completely vanished within 100 m from discharge point after 3 years of plant operation (Fritzmann et al. 2007)

In contrast, two seagrass species common to Western Australian waters, *Posidonia australis* and *P. amphibolis*, seem to be more adapted to higher salinities. Densest covers of meadows are being observed at salinities between 40 and 50 (cf. Box 2, Perth). The available studies suggest that some sea grasses are more tolerant to hyper saline conditions than others, at least some Atlantic and Pacific species. Furthermore, young life cycle stages, such as sea urchin embryos, are considered to be more sensitive than adults (UNEP2008).

For many other ecosystems, the exact effects of increased salinity on marine organisms are still not entirely investigated. Detailed analysis is lacking and further research is needed.

6.2.2. Temperature

Temperature is another vital parameter for marine life. Increased temperature of brine discharge is an issue only in the case of thermal desalination plants. Thermal desalination plants generate high thermal emissions and discharge the brine at 5-15 °C above ambient. In case of RO plants the brine is discharged at only slightly higher than ambient values and can be neglected.

Marine species need favourable temperature conditions to grow. Significant long-term alterations in temperature can be harmful for most of the species. The temperature of seawater rises in the vicinity of thermal discharges. This may provide favourable temperature conditions and boost biological activities in winter. But in summer it can be lethal to marine life when critical values are exceeded. Marine organisms could be attracted or repelled by the warm water, and species more adapted to the higher temperatures and seasonal pattern may eventually predominate in the discharge site of the distillation plant (UNEP 2008).

The distribution and extent of thermal impacts is influenced by the location of the plant discharge, with brine discharges to enclosed water bodies more likely to result in measurable thermal effects than discharges to well-flushed environments.

Also, the oxygen solubility in water reduces with the increased temperatures, which can lead to significant decrease in oxygen levels in the brine discharge area. The lower oxygen content may be harmful to marine life (Lattemann and Höpner 2008).

6.2.3. Process Residuals

The studies show that concentrations of residuals cause acute impacts within a local mixing zone unless they are decreased to harmless or ambient levels. The acute impact zone depends on the dilution rate of the brine in the receiving water. These process residuals can cause chronic impacts and long-term effects if the accumulation rate surpasses the natural decomposition rate. Chronic impacts are not necessarily restricted to a zone around the outfall but can occur in the whole water body.

Possible ecological impacts of brine discharges on marine environment are as follows.

6.2.3.1. Biocides

Antifouling chemicals like chlorine are highly toxic, but are mainly an acute problem within the mixing zone of thermal plants. In case of RO plants the pre-treated water is de-chlorinated before it enters the RO unit to protect the membranes. Therefore residual chlorine levels found are very low to non-detectable.
Potential impacts may result in formation of halogenated by-products that may harm the marine organisms.

6.2.3.2. Antiscalants

The toxicity of antisacaling chemicals to marine life is generally low. They contain polymeric chemicals like polycarbonic acids and phophonates, which are poorly degradable and might cause chronic impacts due to load accumulation.

Also, problems of eutrophication have been observed near the outlets of desalination plants in the Gulf where polyphosphates were used, as these are easily hydrolyzed to orthophosphate, which is a major nutrient for primary producers (UNEP, 2008).

6.2.3.3. Coagulants

Coagulants have a very low toxic potential, but may disturb the photosynthesis process as they increase water turbidity. If ferric salts are used, their discharge causes an intense coloration (reddish colour) of the brine discharge. The turbidity of the brine discharge increases as a result and may cause aesthetic impacts and algae bloom at the discharge point location (Lattemann and Höpner 2008).

6.2.3.4. Antifoaming agents

Antifoaming additives are non-toxic but can be highly polymerized, which reduces their biodegradability. Potential adverse effects are not likely, as dosage levels are low (in ppm ranges) and discharge concentrations are further decreased by dilution in the seawater environment (Lattemann and Höpner, 2008, UNEP 2008).

6.2.3.5. Heavy metals

Copper is transported and accumulated in sediments like most metals, which is a major concern for point discharges, and may potentially lead to increased sediment concentration in the discharge vicinity. Metals in sediments can be assimilated by benthic organisms, which often form the basis of the marine food chain (Lattemann and Höpner, 2008).

6.2.3.6. Cleaning Chemicals

The cleaning solutions, especially their additives, may be harmful to aquatic life if discharged to surface water without treatment.

6.3. Impact on soil and groundwater

In the surface discharge method of brine disposal, if a desalination plant is located far from discharge location, brine is transported to the outfall via long pipes. In case of any leakage of pipes laid over the aquifers, the brine may penetrate underground and contaminate the groundwater (Einav et al. 2002)

The deep well injection method also poses a potential threat for groundwater. In addition to injection well failure, prolonged well injection also pose threat of contaminating water aquifers used for drinking water supply. In case of prolonged well injection a salty plume may develop around the recharge well, which migrates downward due to the high density of the plume and thus affect deeper drinking water production wells (Mohamed et al. cited in UNEP 2008).

Impact of land disposal of brine discharge from desalination plants on soil and groundwater was reported by Mohamed et al. (2005). In this study, 25 inland brackish water reverse osmosis (BWRO) desalination plants in the eastern region of Abu Dhabi (namely Al Wagan, Al Quaa, and Um Al Zumool) were evaluated. The brine is disposed directly into surface impoundment (unlined pits) in a permeable soil with low clay content, cation exchange capacity, and organic matter content. The overall study indicated that effluents discharge to the desert can have an adverse effect on the feed water and (or) underground aquifers. Most of the water samples (feed, product, reject, and pond water) showed the presence of major, minor, and trace constituents. Some of these constituents were above the allowable standards.

7. Determining Marine Impact of Brine Discharge

7.1. Marine Sensitivity

The marine ecosystems vary in their sensitivities to brine discharge, as discussed in the previous topic. Hopner and Windelberg (1996 cited in Einav et al. 2002) have subdivided the global marine habitats into 15 categories. They ranked the habitats in terms of their perceived sensitivity towards brine discharge, the water exchange capacity and the natural recovery potential. This ranked from the least sensitive high-energy oceanic coast and exposed rocky coasts to the most sensitive—coral reef, salt marsh, and mangrove. They are according to their ranking as follows (Einav et al. 2002):

1. *High-energy oceanic coasts, rocky or sandy, with coast-parallel current*
    - Energy input prevents local accumulations and oxygen and nutrient levels favour biodegradation.
    - Rapid water exchange prevents damages by high salinity and elevated temperature.
2. *Exposed rocky coast*
    - Good water exchange, even in small niches.
3. *Mature shoreline*
    - Sediments mobility prevents local accumulation of particle-adsorbed matter.
    - This type of coast does not include bays and lagoons of long water and sediment residence times.
4. *Coastal upwelling*
    - The danger of stagnant beach near water is greater than in case 1.
    - Conditions change seasonally, sometimes containing nutrients and suspended solids.
    - The sensitivity of the sub ecosystem, however, is lower than in the forthcoming classes.
5. *High energy soft tidal coast*
    - There are large inter tidal areas and large sediment surfaces susceptible to adsorption and accumulation.
    - The water exchange and the sediment mobility, however, are high.
6. *Estuaries and similar systems*
    - Similar to 5, above, with high nutrient input.
    - Turbidity and seasonal water quality changes not suitable for desalination plants
7. *Low energy, sand-, mud- and beach rock-flats*
    - Sensitive because of high individual numbers at low species numbers.
    - Loads may accumulate because of adsorption to large surfaces and because of evaporation.
    - Limited water exchange
8. *Coastal sandbanks* (salt flats)
    - Sandbanks mostly continue into the inter-tidal zone and change into area types like 7, exposed to wind and dust.
    - The sandbanks themselves are flooded occasionally.
    - Degradation is only during the rare inundation periods.
9. *Fiords*
    - Enclosed deep water bodies of limited exchange.
    - Danger of thermo-clines and oxygen deficits in the depth.
    - They are shelter and breeding areas of sea animals.
10. *Shallow low-energy bays and semi-enclosed lagoon*
    - Similar to 7, but exchange is still lower.
    - Brine discharge load add to natural stress factors like high and changing salinities, changing water level, solar irradiation.
11. *Algal mats*
    - Wide intertidal areas at very low beach slopes.
    - At one hand algal mats are very sensitive to salt, irradiation, dryness and even oil. But the sensitivity to other stress factors is unknown.
12. *Seaweed bays and shallows*
    - The category shares the sensitivity of 10 and bears additionally the sensitivity of the seaweed and the animals, which feed from plants, look for shelter and use seaweed for breeding (e.g. dugongs and turtles).
13. *Coral reefs*
    - Coastal coral reefs receive coastal discharges.

- Coral reefs are the basis of a species rich community of which the species have different sensitivity.

14. Salt marsh

- Sensitivity similar to 7, with the additional sensitivity of macrophytes (aquatic plants) and animals that inhabit salt marshes.

15. *Mangal* (mangrove flats)

- Sensitivity is assumed to be close to category 14.
- The rapid decline of mangrove areas in the past argues for a high sensitivity to many impacts.

These categories can be used to select the least sensitive location for a desalination plant, and/or are indicative of the degree of mitigation that is required.

However, according to NRC report (NRC 2008) the sensitivity scale used by Hopner and Windelberg (1996) was based on the sensitivity of different environments to oil spills and thus might not be applicable for every situation. For example, the ranking considered high-energy rocky coasts to be relatively insensitive (as they are to oil spills), but rocky habitats with kelp beds along the California coast are considered critical sensitive ecosystems (Cooley et al., 2006 cited in NRC 2008). And though salt marshes and mangroves are very sensitive to the effects of oil spills because oil will persist in the sediments for a very long time, these estuarine sites will probably have a higher tolerance to increased salinity, because estuaries normally experience fluctuations in salinity (NRC 2008).

Thus, furthers study is needed to determine the relative sensitivity of different types of marine environments to brine discharges. And toxicity tests specific for each desalination plant needs to be conducted.

7.2. Determination of Marine Eco-toxicity

The brine discharge has potential of adverse impacts on marine ecology due to its high salinity. These impacts are usually very site - specific and depend to a great extent on the salinity tolerance of the specific marine organisms inhabiting the water column and benthic environment influenced by the discharge. It also depends on the period of time these organisms are exposed to the elevated salinity (Mickley, 2006). Hence, for environmentally safe disposal of brine it is important to determine and set site-specific salinity thresholds for desalination plants discharges.

A number of methods have been developed for the assessment of the impacts of brine discharge on the marine ecosystem in the discharge area. Whole Effluent Toxicity (WET) tests are the most common.
Whole effluent toxicity refers to the aggregate toxic effect to aquatic organisms from all pollutants contained in a facility's wastewater effluent. WET tests measure wastewater's effects on specific test organisms' ability to survive, grow and reproduce (US EPA). The basic concept of this approach is to derive a single threshold or trigger value from a suite of bioassays that use the whole effluent of a given discharger to measure the acute and chronic toxicity to different local marine species representing different taxonomic and trophic levels.

Bioassays and bio monitoring are carried out using species that occur in the receiving waters or closely related species. Fish, invertebrates, and plants may all be considered for bio monitoring. The test species are selected based on ecological relevance and the salinity of the test samples (brine discharge). The toxicity endpoints or measurements may be acute, chronic, or both. The acute toxicity test is a measure of the organism’s survival rate. Chronic toxicity occurs when the survival, growth, or reproduction rates of the test species exposed to the effluent are significantly less than those of the control specimens. Whole effluent toxicity testing may include acute tests of 96 hours’ duration using larval or juvenile fish and invertebrates, with survival as the end point, and chronic tests of 7 days in duration using early life stages of a fish and an invertebrate, considering metrics such as growth. Local species may also be used instead of “standard” bioassay organisms if a bioassay has been developed for them and is approved by EPA.

Whole effluent toxicity (WET) tests have been used in a number of desalination plants across Australia. They include Perth, Sydney, Gold Coast and Olympic Dam SWRO desalination projects (see Appendix 1). Using the WET tests the safe dilution ratio which protects a given percentage of the local species from adverse impacts is calculated. The WET tests for Olympic Dam SWRO project showed that a dilution of 45:1 will protect 99% of the marine species in the area, corresponding to salinity increase of 0.7 units above ambient. In Gold Coast desalination plant, it was anticipated that the brine discharge will be diluted 40:1 using diffusers to avoid negative effects on marine life (Latteman 2010).

Salinity Tolerance Evaluation (STE) is another methodology for testing the long-term salinity tolerance of marine species. This procedure has been successfully applied to identify the salinity tolerance of the aquatic life inhabiting the vicinity of brine discharge for two large seawater desalination projects located in Carlsbad and Huntington Beach in Southern California (Voutchkov 2007).

In the Carlsbad desalination project, the salinity level in the middle of the zone of initial dilution in 95% of the time was predicted using hydrodynamic models. Zone of initial dilution (ZID) is defined as the area within 330 m from the point of discharge. In the next step, a long-term biometric test with 18 species in a single aquarium over a period of 5 months was carried out. In addition, salinity tolerance tests were carried out over a range of salinities to investigate if marine organisms will be able to survive periodic extreme (worst case) salinity conditions. Three local species which are known to have the highest susceptibility to salinity stress were used (purple sea urchin *Strongylocentrotus purpuratus*, sand dollar *Dendraster excentricus*, and the red abalone *Haliotis rufescens*). The tests produced no indication of potential negative effects of the proposed discharge. Also, it was found that these marine organisms can tolerate the maximum salinity of 40 mg/L that could occur in this discharge area under extreme conditions (Voutchkov 2007).

8. Brine Discharge Design

The environmental impact of surface disposal of brine discharge can be mitigated by optimizing the design and operation of brine discharge outfall. The design of the outfall structure determines the degree of brine dilution in the vicinity of the discharge. The higher the dilution rates lower the impact area of brine discharge. Hence the main objective of outfall design is to achieve maximum possible dilution.

The discharge outfall can be on shore or offshore depending on the site conditions. The outfall is oriented into the open water body with a velocity high enough to prevent deposition of solids. The discharge configuration is particularly important for low energetic water bodies where the natural dilution rates are low. In such cases submerged outfall structures fitted with single or multi-port diffusers are designed. Submerged discharges allow for improved mixing before interacting with boundaries and multi-port diffusers guarantee enhanced mixing (Bleninger and Jirka 2008).

The mixing of brine discharge in the receiving water body and subsequent dilution process are discussed in the following topics. Also some important considerations regarding the design of diffusers are mentioned.

8.1. Mixing processes and their characteristics

The hydrodynamic mixing behavior of brine discharges depends on discharge characteristics and on ambient environment conditions. The RO desalination plant generates brine with a higher salinity and a higher density in contrast to a thermal process such as MSF. The various density differences between the brine and the receiving water represented by the buoyancy flux causes different flow characteristics of the discharge.

The RO plants (because of high recovery) increase the concentration of brine discharge about two times the concentration of feed water. As a result the density of brine discharge is also high. This dense RO brine discharge has the tendency to fall as negatively buoyant plume (Figure 36).

On the other hand, the brine discharge from thermal plant (MSF/MED) is usually mixed with cooling water from the power plant before disposal. As a result the brine discharge is lighter than the receiving water (Lattemann & Höpner 2008). This brine discharge has a neutral to positive buoyant flux causing the plume to rise (Figure 37).

The mixing process is generally separated into two regions near-field and far-field in which different physical mechanisms dominate (Figure 38). Figure 38 illustrates the typical behavior of positively or negatively buoyant jets discharging into the receiving water through a submerged single port.

8.1.1. Near-field region

The near field region is characterized by initial mixing, which mainly depends on the brine discharge configuration, the discharge velocity and momentum, the discharge angle and the density difference between brine and seawater. It extends from tens of meters up to a few hundred meters from the outfall location.

In the initial mixing process a plume rises from the diffuser or an open ended pipeline to the surface of the sea. When the plume rises, seawater is entrained into the plume and thus the dilution is achieved. Normally, the brine discharge system is designed to maximize dilution in the near field region. The ambient conditions also influence the mixing process in the near-field. Ambient currents deflect the jet trajectory into the current direction inducing higher dilution.

Density stratification has a negative effect on dilution since it inhibits vertical acceleration leading the plume to be trapped at a terminal level.

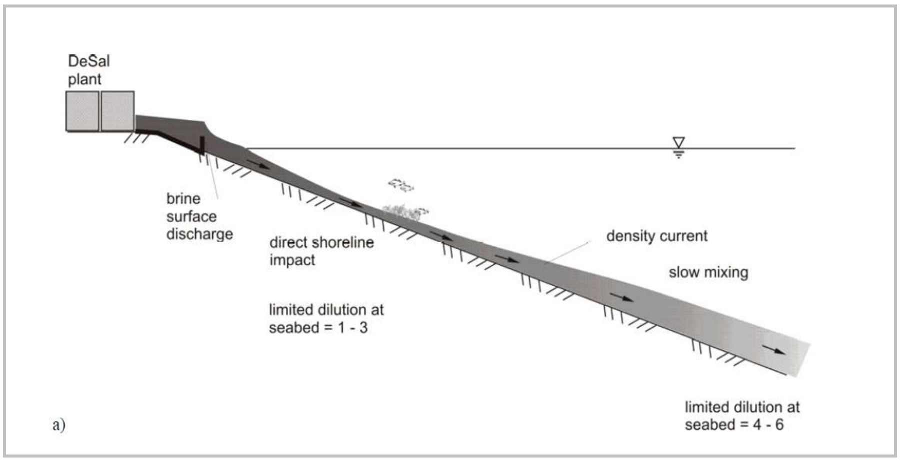

Figure 37: Mixing characteristics and substance distribution for shoreline brine discharge configurations via channel or weir from RO plant (dense effluent)

(Bleninger and Jirka 2008)

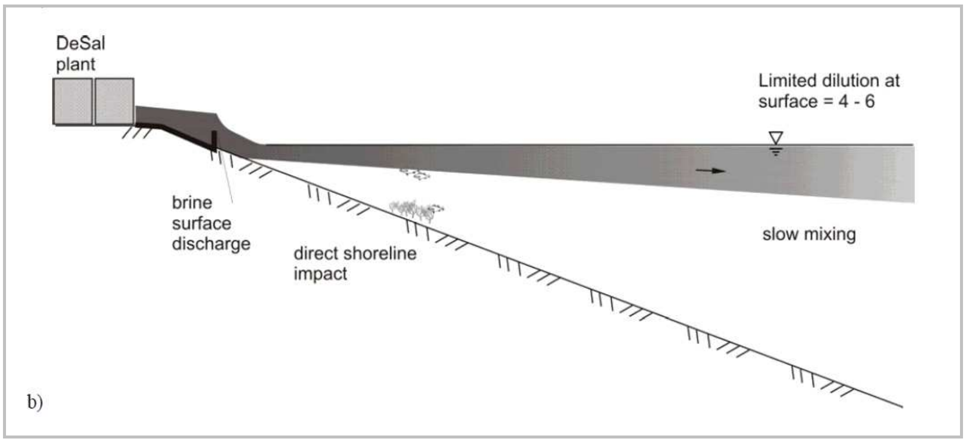

Figure 38: Mixing characteristics and substance distribution for shoreline brine discharge configurations via channel or weir from thermal plant

(Bleninger and Jirka 2008)

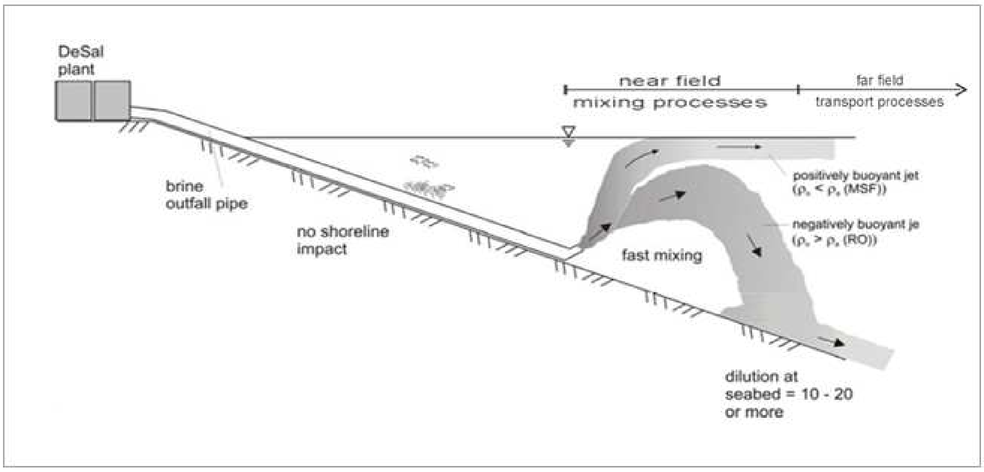

Figure 39: Submerged discharge via pipeline and nozzle or diffuser for two effluent types: positively (thermal plant) and negatively buoyant (RO) plant.

(Bleninger and Jirka 2008)

8.1.2. Far-field region

The far field region is located further away from the discharge point, where the brine turns into a gravity current that flows down the seabed. Mixing depends on the ambient conditions (bathymetry, currents, waves, etc.) and the differences in density between the hyper saline plume and receiving waters. Buoyant forces caused by density differences spread the mixed effluent flow over large distances in lateral direction. A plume of substantial thickness is thereby decreased to a thin but wide layer.

The brine dilution ratio is very small in this region and tends to take an almost constant value. This region extends from hundreds of meters to tens of kilometers.

8.2. General Design Approach for Diffusers

In the case of submerged discharge diffusers are used to enhance the mixing behavior of brine. The diffusers are designed to ensure that the required dilutions are achieved in the near-filed region where strong initial mixing occurs. The diffusers may be either single port diffusers or multi-port diffusers.

A single port outfall is a submerged pipe with a single efflux opening typically applied in situations where ambient conditions favor rapid dilution, or dilution requirement is low, and where bathymetry or bottom stability precludes a diffuser.

A multi-port diffuser consists of a submerged header pipe containing several ports, which inject a series of turbulent jets of brine discharge at high velocity into the ambient receiving water body (Figure 39). They can be installed in unidirectional or alternating direction, Multi-port diffusers are typically used for facilities with larger flows (> 1 MGD), or where maximum dispersion is imperative. Multiport diffusers improve the dilution by increasing the pressure and velocity of the discharged brine as well as by increasing the contact area with the surrounding seawater. The efficiency depends on the number of ports and the space between each other. The lower the interaction between the different port plumes and the smaller the port diameter, the higher are the dilution rates (Einav, et al., 2002).

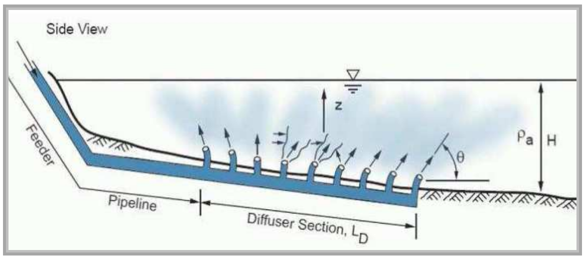

Figure 40: Layout of an outfall pipeline with multiport diffuser

(Bleninger, 2008)

The diffusers may be installed in a number of ways. One alternative is to lay the diffuser pipe on bottom surface with holes drilled in the side. In the other the ports or nozzles may be connected to vertical risers attached to an underground pipe or tunnel (Figure 40). Dilution modeling is generally done to develop conceptual designs of diffusers by exploring the various design variables within the constraints of the ambient conditions and the dilution requirements. Sometimes, several different designs can meet the dilution requirement, in which case, usually a design with a shorter diffuser and smaller ports will offer the less expensive option.

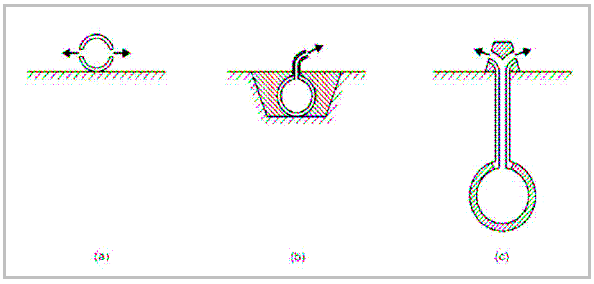

Figure 41: Typical construction details for multiport diffusers in water bodies: (a) Diffuser pipe on bottom with port holes, (b) diffuser pipe buried in trench with short risers, (c) deep tunnel construction with long risers

(Bleninger and Jirka 2008)

8.3. Dilution Modeling

The mixing and dilution process of brine discharge varies according to local conditions (i.e. bottom topography, current velocity, and wave action), discharge characteristics (i.e., concentration, quantity, and temperature) and configuration. Dilution modeling is vital to determine the achievable initial dilutions for a particular plant.

As per the mixing zone regulations of the area where desalination plant is sited, the surface brine disposal requires to meet certain dilution rate in a given radius around the outfall (compliance with Ambient Standards, AS). With the help of dilution modeling different design configurations can be evaluated to find the optimal and cost effective solution.

There are various prediction theories and techniques (models) available for determining the level and extend of mixing and dilution of brine discharge. The choice of the methodology depends on requirements and specifications of the project and also on the level of expertise of the professional implementing it. Some of the predictive as well as diagnostic techniques are as follows (Bleninger and Jirka 2008):

Field measure measurements or tracer tests: used for existing discharges in order to verify whether they comply with the AS values or not

Hydraulics model studies: replicate the mixing process at small scale in the lab. The hydraulics model studies and field measurements are costly to perform and in efficient for examining a range of possible ambient/discharge interaction conditions.

Simple analytical equations or nomograms: (e.g. Rutherford 1994; Holley and Jirja, 1986) are often satisfactory to predict reliably the mixing behavior of a pollutant plume. They give very fast as first estimate about the discharge conditions and very easy to handle, there especially useful for the design purpose of design structure.

Mixing Models: are simple versions of more general water quality models. General water quality models may be required in more complex situations. They describe with good resolution the details of physical mixing processes (mass advection and diffusion). But the calculations are time sensitive and expert knowledge is mandatory. Such studies are done once the plant draft has been developed and detailed environmental impact assessments considered.
Bleninger and Jirka (2010) have provided a detailed analysis and application of the design nomograms and predictive models in their report "Environmental planning, prediction and management of brine discharges from desalination plants".

8.3.1. Near-Field Mixing Models

CORMIX (Cornell Mixing Zone Expert System) is a well proven near-field model consisting of software systems for the analysis, prediction and design of discharges into diverse water bodies. The methodology contains systems to model submerged single-port (CORMIX1) and multiport diffusers (CORMIX2) as well as surface discharge sources (CORMIX3) and negatively buoyant discharges (D-CORMIX). The main emphasis is on the geometry and dilution characteristics of the initial mixing zone. Boundary interaction, buoyant spreading and passive ambient diffusion are also considered for far-field predictions. Although it is in principle a steady-state model, unsteady mixing in tidal environments can also be analyzed. The mixing zone model CORMIX (Doneker and Jirka, 1991; Jirka et al., 1996 cited in Bleninger and Jirka 2010) is applicable to many water body types (rivers, lakes, estuaries, coastal waters).

Another model VisJet can also be used for near-filed modeling. Visjet is a general predictive, flow visualization tool to portray the evolution and interaction of multiple buoyant jets discharged at different angles to the ambient tidal current. VisJet can be used to study the impact of either a single or a group of inclined buoyant jets in three-dimensional space. The model has been validated for discharges with relatively small flow rates, such as wastewater discharges and brine discharges, and does not include a physical, dynamic interaction with boundaries. It is therefore limited to strictly near-field applications and jet regimes (Bleninger and Jirka 2010).

8.3.2. Far-Field Models

In the case of complex boundary conditions (e.g. multiple current regimes etc) far-field models are also required in addition to near-filed models. Far field models provide the required physical background flow situation, such as current and density profiles in the whole domain. Transport models are then applied to mix and transport the substances through that flow domain using proper turbulent mixing coefficients.

Delft3D (from Deltares) is a common software package for the far-field modeling of flow, waves, water quality, ecology, sediment transport and bottom morphology and the interactions between those processes. It consists of several modules, which are capable to interact with each other. Delft3D-FLOW is the hydrodynamic module to simulate twodimensional or three-dimensional unsteady flow and transport phenomena resulting from tidal and meteorological forcing. It also includes the effect of density differences due to a non-uniform temperature and salinity distribution.

Other widely used models are MIKE3 (from the Danish Hydraulics Institute), POM (Princeton Ocean Model - Princeton University), ECOM-si (modified version of POM used at Hydroqual), Telemac 3D (from EDF, Electricité de France, and Wallingford) and SisBAHIA (Bleninger and Jirka 2010).

The EIA study for the SWRO plant in Sydney, which is projected to have a maximum capacity of 500,000 m³/d, investigated possible discharge designs for the plant. Simulations incorporating local coastal data were carried out in order to determine the design with the best near-field dilution performance. Finally, a multiport diffuser system, situated 250-300 m offshore in water depths of 20-30 m, was recommended. The diffuser ports are installed at 25 m distance from each other and are positioned at angles of 60° from horizontal (shown in Figure 41). The brine exits the diffuser ports at a velocity of 7 m/s and at a salinity of 65 g/l. Within a mixing zone of 50-75 m, the salinity of the plume is decreased to values that do not deviate more than 1 g/l from ambient values (≈ 36 g/l) (Bleninger and Jirka 2010). This equals a dilution rate of 28. Hence, the outfall design enables to limit the critical brine concentrations within an area 75m. This example highlights the mitigation potential of multiport diffusers.

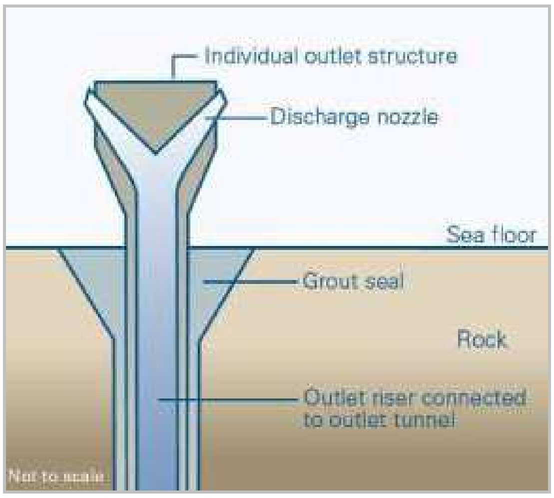

Figure 42: Schematic design of multiport diffuser for SWRO plant Sydney

Alameddine et al. (2007) developed Brine discharge from desalination plants: a modeling approach to an optimized outfall design of thermal effluents, based on simulation results of the CORMIX modeling tool. For open surface discharges, the width of the channel is recommended to be increased and the height of the discharge point should be reduced in order to enhance the horizontal spreading of the plume. However, the open surface discharge proved inadequate to achieve acceptable dilution rates in most cases.

The mixing performance of submerged single port outfalls is improved by splitting the concentrate up into several outfall pipes with adequate space among each other. However, simulations showed that the best dilution rate was reached by multi port diffusers. A tenfold dilution rate was achieved within a 300 m mixing zone. Bleninger et al. (2008) found that the submerged discharge at offshore locations and at high velocities provides a high mixing efficiency for negatively buoyant jets. After examination of recent data and simulations with the CORMIX jet integral model, discharge angles of 30° to 45° above horizontal were recommended. These provided better offshore transport of the effluent during low current activities and reached better dilution rates at the point of impingement with the seabed.

However, more experimental data and more accurate modeling, particularly of the far-field mixing process, are needed to confirm these results. The recommendations about the best outfall design for brine discharges vary according to the overall project conditions. The reliability and accuracy of the applied simulation models has to be improved in order to give more secure recommendations about an optimal discharge design under specified conditions.

9. Environmental Policy and Guidelines

Management of brine discharge and other residuals of the desalination plant in order to minimize its potential impact is one of the major issues in design and implementation of desalination plants. In order to control the adverse impacts of the brine and residual discharge, regulatory legislations are necessary. The legislations may regulate the brine discharge management by setting up discharge limits or imposing environmental standards and conditions mandatory for receiving operating permits.

From a regulatory viewpoint, aquatic pollutants are typically regulated at the point of discharge (emission standards, ES) or as water quality objectives within the receiving water body (ambient standards, AS) or both (combined approach). While ES encourage source control principles, such as effluent treatment, AS can be associated with the concept of a mixing zone, where gradual mixing in the water body reduces the pollutant concentration to the AS, which must be met at the edge of a defined mixing zone. 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).

The regulatory situation of desalination is not uniform worldwide as many countries have their own water regulations. Moreover there is limited amount of country-specific legislations addressing desalination in particular. But there a number of regulations related to industrial effluents in general, which are applicable to brine discharges. A general overview of relevant regional and some national regulations is as follows:

World Bank Guidelines represent an International Standard that can be used as a reference. The World Bank recommends applying more stringent regulations when national regulations differ from international guidelines.

The European Water Framework Directive (WFD) lists desalination as one of many supplementary measures to achieve the objectives of improved water management and protection (European Parliament and Council 2000, Article 11 (4), Annex VI). The Water Framework Directive is implemented in 2000 by European Commission with aim to attain a good qualitative and quantitative status of all water bodies including near-shore marine waters by 2015. The WFD follows a 'combined approach' in regulation, by limiting the direct emissions from point sources (or Ambient Standard) as well as by setting environmental quality standards (or Emission Standards). All point sources in member states have to meet both Ambient Standards and Emission Standards. Thus, the direct emissions of a plant as well as possible accumulation of pollutants and long-term effects on the water body are sought to be limited. Although, the lack of a proper mixing zone definition impedes the practical use of the directive. Further regulation is delegated to the member states.

In case of groundwater protection, the WFD prohibits any direct discharge of contaminants to an aquifer. This means that contaminants, including brine, may not be 'injected' back into an aquifer (Article 11, section 3(j)). 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. The treatment chemicals found in the brine discharge are not mentioned in Annex II of the proposed directive. This means that currently the WFD and its Daughter Directive would not prohibit the inland disposal of brine as long as it did not upset any other parameters of 'good' water quality. This shows that regarding the discharge of the brine, salt or residual chemicals from desalination processes are not explicitly listed in the Water Framework Directive. However, in view of the River basin Management Plan new standards are expected to include salt concentration and activities, such as indirect discharge by percolation through ground or subsoil, which could cause saline intrusion into aquifers (Gibbons and Papapetrou 2006).

In United States, the U.S. Environmental Protection Agency (EPA) is the federal environmental institution. The agency has not established any specific regulations concerning the disposal of desalination wastes, but there are various acts that are applicable to brine discharges. In some cases the federal regulations are only guidelines for the states, whereas in others the federal regulations are mandatory. US EPA has delegated responsibility of legislations to states. Therefore, states are primarily responsible for regulation of brine discharges (Mickley, 2001). At present there are no federal or state salinity surface discharge limits in the US. The salinity of desalination plant brine discharges is regulated by establishing project-specific acute and chronic Whole Effluent Toxicity (WET) objective. The US EPA 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 plants. These guidelines are likely to also apply to small plants and they will include concentrates from desalination processes as well as other residuals (US EPA 2010).

A very few countries in the Middle East have adopted environmental regulations. Oman is one of them. The Omani legislation “Promulgating the bylaws to discharge liquid waste in the marine environment” is the main legislation for liquid waste discharges into the sea. The liquid waste is defined as “any liquid containing environmental pollutants discharged into the marine environment from land or sea sources”. It includes discharge limits for salinity, temperature and other residuals, and a distinct mixing zone definition (300 m in diameter around the outfall) and constructional standards for plants (Bleninger and Jirka 2010).

Similarly, Israel, has added environmental regulations for discharging brine from desalination into the sea to their Environmental Quality Standards for the Mediterranean Sea, including BAT (Best Available Technique) guidance for outfall design, however, not setting general discharge quality standards (Safrai and Zask 2006). On the other hand Australia has not issued any detailed regulation and defines environmental standards depending on the respective project and the affected ecosystem. However in South Africa, the department of water affairs (DWA) has formulated an operational policy for the disposal of land-derived water containing waste to the marine environment. Some of the groundrules set by DWA are applicable to brine discharge as well.

Few of aforementioned countries have regulations dealing with desalination plants in particular. Most of them define discharge standards for temperature, chlorine, copper and pH, but regulations for other important factors like salinity, antiscalants and the chemicals used in cleaning solutions are lacking.

The following table illustrates brine discharge standards in the mixing zone (Bleninger and Jirka 2010).

The environmental policies, regulations, and guidelines for desalination projects are still underdeveloped.
The UNEP (2008) published resource and guidance manual for Environmental Impact Assessments of desalination projects, represents an important step towards the establishment of environmental regulations.

9.1. Environment Requirements

Some of the requirements for brine discharge management based on environmental regulations are:

- Brine disposal to surface water must be acceptable (in terms of pH, total suspended and dissolved solids, and different individual chemicals for example)
- Pre-treatment and post-treatment waste waters must be treated before discharge
- Limits based upon characteristics of the receiving water body and human and aquatic toxicity studies are defined, also whole effluent toxicity test (WET test) are required
- Limits for brine discharge mixing zone need to be defined.
- For concentrate disposal to groundwater aquifers e.g. deep well injection option, the well integrity and water quality must be monitored
- For permits to use evaporation ponds, monitoring of pond integrity must be done
- For disposal to sewage systems, concentrate is classified as industrial waste and must follow the stipulated discharge standards
- For zero liquid discharge there are requirements for disposal of the solids to approved, impervious areas posing no threat to surface and groundwater
- Land application disposal is considered to be a groundwater discharge. Therefore, a zone of discharge is established only if adequate

Table 21: Brine discharge standards in mixing zone

Pollutant	Effluent Standard (ES)	Ambient Standard (AS)	ES / AS
Copper	500 µg/l (World bank)	4.8 µg/l (US EPA)	104
Chlorine	200 µg/l (World bank)	7.5 µg/l (US EPA)	27
Temperature	10 °C above ambient (Omani regulation)	3°C above ambient (World bank)	3
Salinity	Not existing yet (RO causes up to 35ppt above ambient)		10

10. Summary and Conclusions

Desalination market has seen a rapid growth in recent years and is considered as a key alternative freshwater resource. The Middle East region is predominant in desalination market followed by America and other European and Asian countries. Seawater reverse osmosis is the most common method employed for desalination. Then MSF and MED desalination based on seawater. Brackish water desalination plants or inland desalination plants have a smaller proportion compared to that. With the increase in number of desalination plants apprehension regarding its environmental impacts on the surrounding environment is increasing. The major environmental concern is linked with impacts of the brine discharge. The brine discharge is characterized by high salinity, high temperature in case of thermal plants and residual chemicals. Due to these physico-chemical characteristics the discharge brine can potentially affect the receiving environment.

In the report brine disposal methods being applied around the world are highlighted for both seawater and brackish water. The benefits and possible issues related with each method are discussed. The main brine management approach regarding its disposal is to minimize the volume of brine discharged by desalination plants. Using brine treatment and minimization techniques and zero liquid discharge systems the production of brine discharge can be reduced and as a result potential adverse impacts of brine are mitigated. There are some well-proven technologies like brine concentrators and crystallizers. Many technologies such as Dewvaporation and Wind-Aided Intensified Evaporation are in process of adoption by the industry. Further improvements are expected to provide a wider range of brine management techniques. However brine management options for volume minimization and ZLD are still associated with relatively high costs. There is still need for research of feasible solutions that can fulfill the technical, environmental and cost requirements.

There is also potential for beneficial reuse of brine discharge. Techniques like SAL-PROC are used to recover marketable chemicals. And through energy recovery devices, the accumulated energy in the brine discharge is reused in the desalination plant reducing the energy requirement of the plant.

Regarding the potential impacts of brine there have been some studies showing varied impact on marine ecosystem. But most of studies are based on short-term toxicity and there is no information about the long-term effects of brine salinity and residual chemicals. There are only few field monitoring studies on the impacts of brine discharges on marine life in the discharge area. So there is uncertainty about the exact environmental impacts of brine discharge. For a complete assessment of brine impact on marine life pre- and post-operational monitoring and baseline information is necessary.

The adverse impact of brine discharge can minimize by ensuring proper dilution of the brine. The design of brine outfall structure is critical in this context. Best available technology and optimal design configuration of outfall should be considered. This analysis is done with the help of mixing zone models especially designed for environmental impact assessment. The optimal solution for brine management of each project should be identified individually based on the given conditions regarding technical, environmental and economical aspects of the specific project. For sound impact assessment specific factors like project site location, applied desalination technology and plant configuration and local environmental conditions of receiving water body, including existing plants and their discharges in the proximity must be considered individually for each desalination project.

Environmental guidelines at both European and International level lack desalination specific regulations, however there are certain wastewater legislations applicable to brine discharge. Also there is no consistency in discharge designs, monitoring, assessments and regulations worldwide. Legislations are expected to be more stringent in future in context of approval of environmentally-sensitive disposal options to preserve groundwater and seawater quality and the ambient ecosystem.

The development of environmentally viable and cost effective brine disposal systems, which conform to regional and federal environmental constraints, still remains an imperative issue. Since each desalination project is unique and depends on project-specific conditions and considerations, permit granting for each project should be evaluated on a case-by-case basis.

11. Recommendations

The analysis of the current situation of brine and residual management draws our attention to lack of comprehensive information and tools for assessing the environmental impact of brine discharge on marine life. Salinity tolerances have not been examined for all concerned marine species.

There is a wide range of approaches and methods used for environmental impact investigation and hence no consistency is there. Also existing policy and legislation generally do not address the unique issues resulting from desalination.

Although there have been many general studies but the complete scale of impacts provoked by brine and residual discharges is still not entirely known. Hence there is a need to further improve the environment impact assessment methodology of desalination plants.

Some main recommendations related to overall brine discharge management are:

- Develop cost-effective approaches for brine and residual management that minimizes environmental impacts
- Explore beneficial reuse of the desalination by-products and develop technologies that reduce the volume of this discharge.
- Develop monitoring and assessment protocols for evaluating the potential ecological impacts of surface discharge of brine.
- Long-term, laboratory-based assays are needed and cumulative effects of other stressors (e.g. nutrients, sediments, etc. need to be investigated
- Regional eco-toxicological studies to analyse the local species characteristics and their vulnerability on local effluent characteristics must be conducted.
- The hydrodynamic models for the near field region require more validation studies in the laboratory, to improve the formulations after boundary impingement and further density spreading with the effect of ambient currents.
- More comprehensive studies are needed to adequately identify all contaminants in desalination brines and to mitigate the impacts of brine discharge.

A summary of identified research areas and also the ongoing research conducted by GWRC participating organizations is proposed in Table 22. This report will be used as input to the GWRC workshop ‘Desalination: Brine and Residual Management’ to facilitate the discussion of the present State-of-the-Science in this area. Based on the discussion the resulting knowledge gaps and research needs will be validated and the involved GWRC members will formulate a set of proposals for joint activities to address these ‘gaps and needs’.

Table 22: Summary of ongoing research and identified future research areas

Topic	Ongoing Research	Research Need Identified	
		From GWRC	*From literature review*
1. Environmental Impact Assessment	• Assessment of environmental impacts from seawater desalination discharge on coastal areas		• Monitoring and assessment protocols for evaluating the potential ecological impacts of surface discharge of brine
2. Toxicology studies		• Assessment of toxicology of brine discharge.	• A 'best practice' guideline for long term toxicology monitoring.
3. Brine volume Minimization	• Recovery of water and salts from multi-component hyper saline Brines using Eutectic Freeze Crystallization • Development of process solutions for brine volume reduction and high water recovery for brackish water desalination • Evaluation of Forward Osmosis Technology for the treatment of concentrated brines • Industrial Brine Minimization: Determining the Physical Chemical Parameters that Affect Evaporation Rates on Multi Component Hyper Saline Effluents • Enhanced Reverse Osmosis Systems: Intermediate Treatment to Improve Recovery • Treatment and recovery of RO brine from NEWater factories with CDI –RO process		• Cost-effective approaches that minimize environmental impacts
4. Zero liquid discharge	• Pilot demonstration of membrane Zero Liquid Discharge Process for Drinking Water Systems	• Process solutions to reach cost and energy effective ZLD (or near ZLD) schemes	
5. Beneficial Uses of Brine		• Beneficial in-plant use of brine discharge	
6. Selective Salt recovery		• To produce marketable products	
7. Hydrodynamic Models			• Validation of hydrodynamic models within and outside the mixing zone.
8. Evaporation Ponds	• Field testing methods to determine the evaporation rates on brine solutions produced from mine water treatment		

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APPENDIXES

Appendix 1: Whole Effluent Toxicity Test Data

Whole effluent toxicity test data: The species protection trigger value (SPTV) is calculated from a range of test species and gives the minimum dilution ratio that should be achieved at the edge of the mixing zone for a given species protecting level (SPL). The SPTV is compared to the actual dilution ratio that has been predicted for or is actually achieved by the diffuser. (Lattemann 2010)

Plant	SPL	SPTV	Diffuser dilution ratio	WET test species
Perth [176]	95% 99%	12.3:1 15.1:1	45:1	Tests at commissioning and after 12 months of operation 72-h macroalgae germination (*Ecklonia radiata*) 72-h macroalgae growth test (*Isochrysis galbana*) 48-h mussel larval development (*Mytilis edulis*) 28-d copepod reproduction test (*Gladioferens imparipes*) 7-d larval fish growth test (*Pagrus auratus*)
Sydney [177]	95%	30:1	30:1 dilution ratio at the edge of the near field (50-75 m) equal to salinity variations of 1 unit above ambient as determined by modeling	five target organisms: algae, crustaceans (prawn), molluscs (oysters) echinoderms (sea urchin fertilization and larval development), chordates (fish)
Gold Coast [178]	95%	9:1	47:1 minimum dilution in 60 m distance from the diffuser (edge of mixing zone) determined by modeling; validation during start-up confirmed a dilution in excess of 9:1 at the edge of the mixing zone	6 species from more than 3 trophic levels representative of the local ecosystem, targeting sensitive early life cycle stages (fertilization, germination, larval development and growth): Acute microtox (bacterium *Vibrio fischeri*) 72-h microalgae growth inhibition (*Nitzschia closterium*) 72-h macroalgae germination (*Ecklonia radiata*) 48-h rock oyster larval development (*Saccostrea commercialis*) 72-h sea urchin larval development (*Heliocidaris tuberculata*) 7-d larval fish imbalance (*Pagrus auratus*)
Olympic Dam [179]	99% 100%	45:1 85:1	45:1 dilution within: 0.3 km (90% of time) 1.1 km (99% of time) 2.2 km (100% of time) 85:1 dilution within: 1.1 km (90% of time) 2.8 km (99% of time) 3.9 km (100% of time) 45:1 dilution would be achieved in 30% of the time at the edge of the near field mixing zone (100 m); the salinity increases for the dilution ratios of 45:1 and 85:1 would be 0.7 and 0.4 units above ambient, respectively	15 species from more than 4 trophic levels representative of the local ecosystem, including acute and chronic tests with early life cycle stages, juveniles and adults: 72-h microalgae chronic growth rate inhibition test (*Nitzschia closterium* and *Isochrysis galbana*) 72-h macroalgae chronic germination success (*Ecklonia radiata* and *Hormosira banksii*) 48-h chronic copepod reproduction (*Gladioferens imparipes*) 96-h acute prawn post-larval toxicity test (*Penaeus monodon*) 21/28-d juvenile/adult prawn growth (*Melicertus latisulcatus*) 7-d sub-chronic crab larval growth test (*Portunus pelagicus*) 48-h sub-chronic oyster larval development (*Crassostrea gigas* and *Saccostrea commercialis*) 72-h sea urchin sub-chronic fertilization success (*Heliocidaris tuberculata*) 96-h acute fish larval imbalance and mortality (*Seriola lalandi*) 7-d sub-chronic fish larval growth test (*Seriola lalandi, Pagrus auratus, Argyrosomus japonicus*) chronic developmental and hatching tests (*Sepia apama*)

Appendix 2: GWRC Brine Survey Questionnaire

GWRC research area
Brine & Residual Management Member survey

Organisation:
Contact person:
Email addresses:

1. Data on Desalination

Please fill in the table below for the country (region) you represent.

Volume of water treated	Capacity (m^3/year)	Application (1)	Technology (2)	Brine vol. (m^3/year)	Contaminants (3)
Drinking Water					
Agriculture/irrigation					
Industrial use					
Other use :_______					

[1] SW: softening BW: brackish water SW: seawater Other : Please specify
[2] RO/Thermal/IX
[3] NaCl, Ca, Mg, metals, heat, solids….(and level on concentration)

2. Available reports

Please provide a list of available reports on brine & residual management (title and summary) from both internal and external sources

3. Ongoing projects

Please provide a list of ongoing projects on brine & residual management you may have (title and brief description)

4. Current practises for brine disposal/treatment

Please provide examples of projects/case studies on brine & residual management

5. Identified main issues for brine disposal/treatment

Please provide main issues on Brine you have identified (and brief description)

Appendix 3: Brine Survey of GWRC Members (VEOLIA)

Organisation: Veolia Environnement
Contact person: Jerome LEPARC
Email address: jerome.leparc@veolia.com

1. Data on Desalination

Information for large desalination plants designed, built and operated by Veolia Water (capacity > 80 MLD – 28 million m3/year)

Volume of water treated	Capacity (million m^3/year)	Application (1)	Technology(2) (RO/Thermal/IX/ ..)	Brine vol. (million m^3/year)	contaminants(3)
Drinking Water	Ashkelon -120	SW	RO	175	Filter backwash waters combined to brine salinity: 75-80 g/L
Drinking Water	Sydney – 90	SW	RO	135	salinity: 75-80 g/L
Drinking Water	Gold Coast – 45	SW	RO	67	salinity: 75-80 g/L
Drinking Water	Sur, Oman – 29	SW	RO	43	salinity: 75-80 g/L
Drinking Water	Fujairah 2 MED: 165 RO : 47	SW	Hybrid – MED/RO	From MED: 935 From RO: 71	From MED: - salinity: 47 g/L - □T: + 8°C From RO - salinity: 80 g/L But both brine streams combined with cooling water from power plant (1.8 million m^3/d)
Drinking Water	Al Hidd, Bahrain 100	SW	MED only	930	- salinity: 53 g/L - □T: + 7°C
Agriculture/irrigation					
Industrial use					
Other use :________					

1 SW: softening BW: brackish water SW: seawater Other : Please specify
2 RO/Thermal/IX
3 NaCl, Ca, Mg, metals, heat, solids….(and level on concentration)

2. Available reports

"Discharge effluents from desalination plants into the marine environment: physical and chemical characterization, potential environmental impacts and assessment tools" by Stellio Casas – Veolia Environnement – internal report.

Note: A presentation of the main outcomes of this comprehensive literature review could be done at the upcoming project workshop

List of publications see below section

3. Ongoing projects

- **Assessment of environmental impacts from seawater desalination discharge on coastal areas**

This project already led to several communications:

– "Environmental Impact Assessment of concentrate discharge from desalination plants" by Stellio CASAS, Emmanuelle AOUSTIN, Jérôme LEPARC, Emmanuel SOYEUX, Nicolas RAMPNOUX Presented at the 2009 SETAC Conference – see below poster

Environmental Impact Assessment of concentrate discharge from desalination plants

Stellio CASAS[1], Emmanuelle AOUSTIN[1], Jérôme LEPARC[2], Emmanuel SOYEUX[1], Nicolas RAMPNOUX[1]

[1]Veolia Environnement, Recherche et Innovation, 10 rue Jacques Daguerre, 92500 Rueil-Malmaison, France.
Email contact : stellio.casa@veolia.com

[2]Veolia Environnement, Water Research Center, 78603 Maisons-Lafitte, France.

Keywords: Desalination, environmental impact assessment, dispersion model, bioindicators.

I. Desalination and the marine environment

- Several studies have been undertaken on the socio-economic and environmental impacts of desalination plants (1,2 & 3). However, there have been very few studies dealing with the impact of hypersaline brine effluents on the marine environment.
- According to the authors, the main impact on marine communities of desalination plants is caused by the discharge of an effluent of very high salinity (70-90psu). The magnitude of the impact will depend on the size of the plant, the sensitivity of the ecosystem that receives the effluent and the general hydrodynamic field (4 & 5).
- In addition, a number of other substances (such as anti-scalants, cleaning solutions) may continuously or sporadically be present in the concentrate discharge, which may also have an environmental impact.

II. Identify, Evaluate and Mitigate potential impacts

- Our R&D project aims to develop a **sound and complete methodology** to quantify and monitor the potential environmental impacts that may occur in the marine environment related to the discharge of desalination concentrates.

2.1. Effluent Characterisation

To evaluate the potential of the seawater concentrate to cause an environmental impact, two steps are distinguished:

- **Characterise the physical and chemical composition** of the water effluents: S°, T°; pH, TOC, DOC, BOD, TSS, TDS, anions, cations, nutrients, bacteria and algae, organic pollutants, metals, etc.
- **Undertake toxicity testing** of water effluents to detect, qualify and quantify their potential ecological effects on different target organisms designed to encompass a wide taxonomic range and organism complexity.

2.2. Discharge Dispersion Models

- Modelling the dispersion of the hypersaline discharge aims **to define the area potentially impacted**, and to **understand the influence of discharge work geometry** (near field) and discharge localization (far field).
- This component involves **numerical modelling** of the seawater concentrate plume as it disperses into the water column from the discharge work, often equiped with diffusers. In general, the subtidal zone where the discharge work is located is a high energy, wave dominated environment.
- The results of the discharge dispersion model will be combined with the results of toxicity testing to **delineate the extent of the mixing zone** in representative conditions (wind, current, tide), which may be defined as the zone within which ecological effects could occur.

2.3. Environmental Impact Assesment

- The Environmental Impact Assessment Program aims to **identify relevant environmental indicators** at different levels: exposure, effect and biodiversity indicators and to **evaluate potential impacts on aquatic fauna and flora.**
- Environmental chemicals could affect biological systems at **different levels of organisation**, from individual enzyme systems through cells, organs, single organisms and populations to entire ecosystems (cf. Fig.2).
- Information on the **sensitivity and specificty** of those environmental indicators provides a basis for planning the use and evaluating the potential environmental impacts.

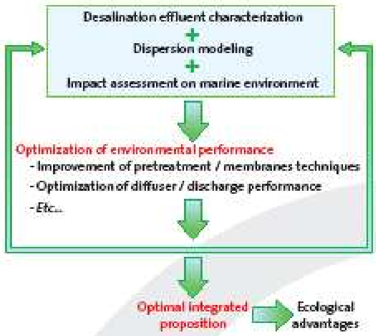

Figure 1: An optimal integrated EIA: "environmental impact assessment".

III. Results and future development

The selection and combination of those different environmental tools aims to manage the discharges, to optimize and minimize impacts and to improve the desalination process. On-site testing on several different desalination plants, covering different desalination processes and diverse receiving environment, will allow for a validation of the proposed methodology.

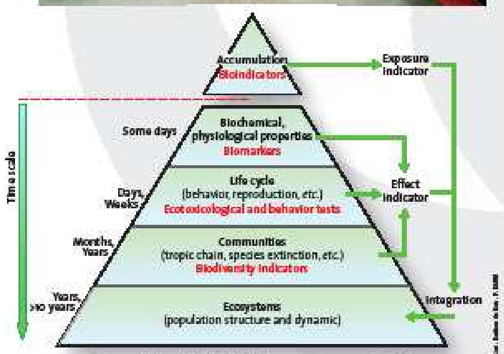

Figure 2: Integrative bioindicators: exposure and effect.

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- “Environmental Impact Assessment of concentrate discharge from desalination plants: chemical and toxicity characterisation, dispersion model and biomonitoring tools” by Stellio CASAS, Emmanuelle AOUSTIN, Jérôme LEPARC, Emmanuel SOYEUX, Nicolas RAMPNOUX – presented at the 2009 EDS Conference, Baden Baden , Germany

- “ENVIRONMENTAL IMPACT OF DESALINATION EFFLUENTS: ECOTOXICITY TESTING AND SAFE DILUTION FACTORS EVALUATION” – by Stellio Casas, Jérôme Leparc
IDA World Congress 2011 – full manuscript available in Sept. 2011

A section of this project dedicated to the evaluation of the impact of desalination brine on specific marine species and to the identification/development of bio-indicators was carried out in collaboration with the Paul Ricard Institute.

- Development of process solutions for brine volume reduction and high water recovery for brackish water desalination

4. Current practices for brine disposal/treatment

- Environmental studies performed as part of full-scale desalination projects

Sydney desalination plant
The overall programme related to the environmental studies were developed by the client (Sydney Water) – see manuscript presented at the 2009 IDA Wolrd Congress – “Sydney’s Desalination Plant: Addressing Environmental Issues Using Innovative Design, Planning and Monitoring” by Susan Trousdale et al.
The detailed engineering studies required to meet environmental regulations and performance objectives (e.g. seawater intake, sizing of the brine dispersion system) were conducted by the EPC (JV between Veolia Water Solutions & Technologies, John Holland, and SKM). The environmental monitoring programme is mainly being carried out by Sydney Water, with some specific activities on the characterisation of the plant’s discharge being performed by Veolia Water Australia in charge of the plant operation.

Gold Coast desalination plant
The details of the environment programme developed as part of the design and operation of the Gold Coast desalination plant can be found in the manuscript presented at the 2009 IDA Wolrd Congress – “Community, Environmental and Marine Impact Minimisation at the Gold Coast” by Nelly Cannesson et al.
With respect to the brine discharge, design studies were carried out to meet the brine dispersion objectives and conductivity monitoring campaigns are performed on regular basis to ascertain the dispersion system the meet the performance criteria.

5. Identified main issues for brine disposal/treatment

Current and future regulations on brine disposal into sea coastal areas

Today, regulations related to the discharge of saline effluents from desalination plants is very project specific, depending on local regulations – based on country regulations, sometimes based on regional/local regulations, and even sometimes facing the absence of regulations adapted for the application, the specifics of the effluent to be discharged off, and the receiving environment. Therefore, there is a need for the development of a more universal approach towards the regulation of discharge practices for the desalination industry, notably for stand-alone desalination plants. In the case of power/water cogeneration plants, blending of seawater used for cooling purposes and desalination discharge significantly change the content and volume of the effluents to be discharged into the coastal environment. It is therefore preferable to differentiate best practices for discharge at power/water cogeneration plants separately from the practices for discharge of highly saline effluent generated by stand-alone SWRO plants.

Regulations and best practices for the management of desalination discharge for stand-alone desalination plants should notably take into consideration:

- choice of the performance criteria: target dilution ratio or target conductivity at a given distance from the discharge location ?
- how to set this target dilution ratio or target conductivity ? For example, two different "standard" approaches exist today (European guidelines and the Australian and New Zealand guidelines), and the application of these guidelines leads to significant difference in discharge objectives.
- how to account for change in operating mode of the desalination plants ?
- how to account for the presence of local marine species very sensitive to water quality change (salinity, temperature)

Process solutions to reach zero-liquid discharge (or near zero-liquid discharge) desalination schemes without compromising the cost- and energy-efficiency.
Process-oriented development. In the "chase" to zero-liquid discharge, cost-effectiveness of the process solutions should remain important selection criteria, and the "best available technology" approach should be used as long as environment-compatible and sustainable process solutions can be found.

Appendix 4: Brine Survey of GWRC Members (PUB)

Organization: Public Utility Board (PUB), Singapore
Contact person: Kiran Kekre
Email address: Kiran_Kekre@pub.gov.sg

1. Data on Desalination

(SINGAPORE)

Volume of water treated	Capacity (million m^3/year)	Application [(1)]	Technology [(2)] (RO/ Thermal/IX/ ..)	Brine vol. (million m^3/year)	Contaminants [(3)]
12.1. Drinking Water	49 million m^3/year	SW	RO	59 million m^3/year	
Agriculture/irrigation	-				
Industrial use (NEWater)	191 million m^3/year	Effluent from used water treatment plant	UF-RO-UV	63 million m^3/year	Please see attached annex.
Other use :_______					

[1] SW: softening BW: brackish water SW: seawater Other: Please specify
[2] RO/Thermal/IX
[3] NaCl, Ca, Mg, metals, heat, solids….(and level on concentration)

2. Available reports

-

3. Ongoing projects

Treatment and recovery of RO brine from NEWater factories with Capacitive deionization (CDI) – RO process

To increase the water recovery and treat the RO brine, a Capacitive Deionization (CDI) process with biological activated carbon (BAC) as pre-treatment was developed and tested. The results show that ion concentrations in CDI product were quite low except SiO2 comparing with RO feed water. RO permeate (CDI product as feed) was of good quality including low SiO2 comparing with NEWater. It could be beneficial to use a dedicated RO operated at optimum conditions with better performance to recover the water. It was observed that the type of pre-treatment, the feed water chemistry and the cleaning technique and chemicals played important role in the sustainable operation. Enhanced pre-treatment and lowering pH could minimize the fouling. CDI had a water recovery of at least 80%, so CDI based RO brine treatment could improve overall water recovery of NEWater production over 90%. Work is still in progress towards process optimization.

4. Current practises for brine disposal/treatment

Please provide examples of projects/case studies on brine & residual management

Brine from SWRO plant is discharged to sea via submerged out fall.
RO reject from NEWater factories is mixed with treated effluent and discharged to sea.

5. Identified main issues for brine disposal/treatment

Please provide main issues on Brine you have identified (and brief description)

Singapore being a small island, there are no issues on brine disposal.

Appendix

Water quality of RO brine from NEWater Plant

Conductivity (µS/cm)	2060
TDS (mg/L)	1275
TOC (mg/L)	31.1
Cl (mg/l)	389
F (mg/l)	1.52
NO3 (mg/L)	69
PO4 (mg/L)	19
SO4 (mg/l)	197
Na (mg/l)	305
K (mg/l)	54
Ca (mg/l)	83
Mg (mg/l)	14
SiO2 (mg/l)	41.1

Appendix 5: Brine Survey of GWRC Members (WRC)

Organization: Water Research Commission (WRC), South Africa
Contact person: Jo Burgess
Email address: job@wrc.org.za

1. Data on Desalination

-

2. Available reports

An investigation of innovative approaches to brine handling
Authors: van der Merwe IW; Lourens A; Waygood C; 2010/11/09; Research Report No.1669-1-09

Managing the sludges and brines produced during desalination is expensive and can exceed the cost of desalination itself. This project found that 530 000 kL/d of effluent, containing 1060 t/d of salt, is currently being discharged within inland systems. Volumes are expected to grow significantly over the next 20 years with salt loads projected to reach 15 000 t/d. Lined evaporation ponds are the most frequently used brine disposal option, with a trend to develop technologies that achieve fractional precipitation of constituents. However, the by-products produced in this way offer only limited potential for import replacement. Reducing the volume of brine as much as possible through brine softening and treatment is the most cost effective strategy to manage brine disposal. The proof of concept of three promising technologies was evaluated at laboratory scale. Two utilized enhanced evaporation, viz. Wind Aided Intensified eVaporation (WAIV) and Dewvaporation; the third being freeze desalination. On a cost basis all three technologies compares favorably with traditional brine disposal options (evaporation ponds and mechanical evaporation and crystallization).

Novel technology for recovery of water and solid salts from hypersaline brines: eutectic freeze crystallization
Authors: Lewis A; Nathoo J; Randall D; Zibi L; Jivanji R; 2010/08/01; Research Report No.1727/1/10

Two major problems currently facing South African water users are the declining availability of sufficient quantities of water and the deterioration of the quality of the available water. However, with the increasing use of water recycling, the result has been an increased generation of inorganic brines and concentrates. Eutectic freeze crystallization (EFC) offers a novel, sustainable method for treating brines and concentrates that were previously regarded as recalcitrant due their complex nature and were consequently discharged to evaporation ponds. With EFC, pure water and pure individual salts can be recovered, thereby making a significant leap towards achieving zero effluent discharge. Eutectic freeze crystallization has been shown to be effective in separating a single salt and water, but has yet to be applied to complex hypersaline brines that are typical of reverse osmosis retentates in South Africa. Thus, the aim of this research was to investigate the applicability of EFC to the hypersaline brines and inorganic effluents produced by industries. The experimental work aimed at investigating the effect of complex aqueous chemistry and impurities on the EFC process. The presence of impurities, even in small concentrations, had a significant depressing impact on the eutectic temperature of the binary system. Maintaining a critical solid mass content i.e. the amount of ice and salt crystals in the reactor was found to be of significant importance as it directly affected the purity and yield of the crystalline products. Thermodynamic modelling of the effects of salts on eutectic temperatures was carried out and demonstrated that, at these relatively low concentrations, the ice always crystallizes first, followed by the higher hydrated salts. No significant shifts in salt freezing points were observed due to the relatively low concentration of salts in the retentate. Experimental studies were carried out on synthetic brines to establish the eutectic temperatures and compositions. A preliminary economic evaluation was conducted to provide an approximation of the expected concentrations, had a significant depressing impact on the eutectic temperature of the binary system. Maintaining a critical solid mass content i.e. the amount of ice and salt crystals in the reactor was found to be of significant importance as it directly affected the purity and yield of the crystalline products. Thermodynamic modelling of the effects of salts on eutectic temperatures was carried out using a reverse osmosis retentate as the stream of interest. It was found that, at these relatively low concentrations, the ice always crystallizes first, followed by the higher hydrated salts. No significant shifts in salt freezing points were observed due to the relatively low concentration of salts in the retentate. Experimental studies were carried out on various types of synthetic brines to establish the eutectic temperatures and compositions. The metastable zone (MSZ) width, an important parameter for EFC process operation, was also established for a number of different cases. The study showed that the MSZ for ice was generally wider than that for salt, regardless of the cooling rate used. For the sodium sulphate system, a faster cooling rate resulted in a wider MSZ. The difference in the nucleation temperatures for repeat experiments was attributed to the stochastic nature of nucleation. The findings from the experimental work have emphasised the importance of identifying the appropriate EFC operating conditions (operating temperatures and the operating region within the phase diagram) in order to promote good product characteristics and maximise yields. A preliminary economic evaluation was conducted to provide an approximation of the expected operating and capital costs associated with using EFC. These were compared to triple-effect evaporative crystallization (EC). The costs of electricity to the compressor in the EFC refrigeration unit and the steam requirement for the evaporative crystallization process were identified as the major contributors to the operating costs for the two processes. Hence, these were used as the basis for calculating the operating costs. Two brines broadly representative of typical South African industrial brines i.e. consisting of Na_2SO_4 and NaCl were investigated. The concentration factor difference between the two brines was approximately 10 with Brine 2 being more concentrated than Brine 1. A basis of $100m^3$/day of brine was used. The operating cost calculated for using EFC to treat Brine 1, without heat integration, with a cooling requirement of 534kW was R28/m^3. In contrast, the operating cost for a triple-effect EC process to treat Brine 1 was R132/m^3. The operating cost calculated for using EFC to treat Brine 2, without heat integration, with a cooling requirement of 556kW was R29/m^3. In contrast, the operating cost for a triple-effect EC process to treat Brine 2 was R126/m3. Hence, the operating cost savings of using EFC over EC are 79% and 76% for Brine 1 and Brine 2 respectively. The cost savings of using EFC could potentially be further enhanced by incorporating the income generated from the sale of the pure salts produced by the EFC process, as well as taking into consideration the additional mixed salt disposal costs for EC. Eutectic freeze crystallization offers an innovative solution for the treatment of hypersaline brines. It is a technology that can be used either in isolation or in conjunction with other water treatment processes such as reverse osmosis, towards achieving zero effluent discharge sustainably. Future studies in EFC will need to focus on further refining the understanding of the scientific fundamentals together with investigating key operating parameters that will enable the process to be tested at pilot scale before full-scale implementation. operating and capital costs associated with using EFC. These were compared to triple-effect evaporative crystallization (EC) using two brines broadly representative of typical South African industrial brines i.e. consisting of Na_2SO_4 and NaCl. A basis of $100m^3$/day of brine was used. The operating cost calculated for using EFC to treat Brine 1, without heat integration, with a cooling requirement of 534kW was R28/m^3. In contrast, the operating cost for a triple-effect EC process to treat Brine 1 was R132/m^3. The operating cost calculated for using EFC to treat Brine 2, without heat integration, with a cooling requirement of 556kW was R29/m^3. In contrast, the operating cost for a triple-effect EC process to treat Brine 2 was R126/m^3. Hence, the operating cost savings of using EFC over EC are 79% and 76% for Brine 1 and Brine 2 respectively. Eutectic freeze crystallization offers an innovative solution for the treatment of hypersaline brines. It is a technology that can be used either in isolation or in conjunction with other water treatment processes such as reverse osmosis, towards achieving zero effluent discharge sustainably. Future studies will focus on further refining the understanding of the scientific fundamentals together with investigating key operating parameters that will enable the process to be tested at pilot scale.

3. Ongoing projects

Field testing methods to determine the evaporation rates on brine solutions produced from mine water treatment (2009 - 2011, Golder Associates): Several coal mining groups in Mpumalanga have found that they either currently or will in the near future have excess water which needs to be treated. Strict water quality targets must be met for either potable use or discharge to the environment. The most cost-effective technology currently available to achieve the targets is usually reverse osmosis, which produces aconcentrated brine requiring an environmentally sound and stable disposal method. In Mpumalanga, evaporation ponds are the preferred brine disposal method. A good estimate of the evaporation rate is required to size a brine disposal pond. The salinity of the water results in a reduction in the evaporation rate. It is suggested that the evaporation rate for water at the disposal area is multiplied by a factor of 0.7 to determine the evaporation rate of brine. However, the evaporation rate varies from location to location and depends on the composition of the solution being evaporated. Very little literature is available on the evaporation rate of brine solutions, and this study will benefit the water engineering community of South Africa and result in more reliable information for use in the design of the brine disposal facilities by filling this knowledge gap.

Extended Investigations into Recovery of Water and Salts from Multi-component Hypersaline Brines using Eutectic Freeze Crystallization (2010 - 2012, University of Cape Town, Prof Alison Lewis): South African water users are facing challenges in terms of the declining availability of sufficient quantities of water and the deterioration of the quality of the available water. In addition, with the increasing use of water treatment, the result has been an increased generation of inorganic brines and concentrates. Treating these brines, either for the recovery of the salt, or for the reduction of waste streams via a concentration process, is energy intensive and thus costly. The standard design approach for inland desalination plants is one of bulk softening and subsequent concentration of mono-valent salts. This results in mixed brines and sludges of low (or even negative) value, often containing hazardous substances. As a result, brine and sludge disposal occur mainly through forced evaporation and crystallisation of mixed (and often hazardous) salts. The extremely large energy requirements to evaporate the water can be prohibitive and the salt product is still a waste that must be disposed of. Eutectic freeze crystallisation (EFC) is an alternative technology for the separation of highly concentrated aqueous streams. EFC is a technique that is capable of separating aqueous solutions into pure water and pure, solidified solutes and that is highly energy efficient, without the introduction of any solvents. A modelling and experimental programme focussing on the use of EFC has already been undertaken (WRC project K5/1727, which has shown proof of concept for EFC as a feasible treatment for hypersaline brines. However, as for any novel technology, there are still many aspects that need to be investigated and these are the focus of this proposal.

Industrial Brine Minimization: Determining the Physical Chemical Parameters that Affect Evaporation Rates on Multi Component Hyper Saline Effluents (2011 - 2014, University of the Western Cape, Dr Leslie Petrik): Brines are a major waste byproduct from industrial activities. This study aims to understand and provide solutions for the efficient minimization of industrial brines. The study will evaluate evaporation rates and design and assemble climate controlled enclosures for the study of evaporation processes of brines. The data will result in the development of protocols for the measurement of evaporation rates from brines which will lead to the development of empirical models for determining evaporation processes of industrial brines under controlled laboratory conditions and the development of theoretical models for determining evaporation rates of brines. Finally, it is envisaged that this understanding will result in the development of novel textured surfaces and absorbents for enhanced evaporation of industrial brines.

Evaluation of Forward Osmosis Technology for the treatment of concentrated brines (2011 - 2014, University of KwaZulu Natal): Forward osmosis is a new technology for industry in South Africa and this scoping project is to assess the applicability for further application for concentrated inorganic brines. The study will aim to evaluate whether forward osmosis can be used as a lower energy consuming technology compared to reverse osmosis. It will evaluate the advantages, limitations and feasibility of using forward osmosis technology to concentrate various high ionic strength wastewaters and to assess the fouling characteristics of forward osmosis on various high ionic strength industrial streams which are known to be badly fouling.

4. Current practices for brine disposal/treatment

None

5. Identified main issues for brine disposal/treatment

- Inland disposal of simple (e.g. NaCl) brines is an issue and coastal sites cannot continue to dispose of brines from e.g. seawater desalination in the surf zone die to localised hypersalination of the marine environment.
- Inability to utilise mixed solids residues.
- Solar evaporation is too slow or totally ineffective.
- Increasing application of membrane technology is causing increasing production of brines without an equivalent development in treatment and/or disposal practices.

Appendix 6: Brine Survey of GWRC Members (WRF)

Organization: Water Research Foundation
Contact persons: Jennifer Warner
Email address: jwarner@waterresearchfoundation.org

1. Data on Desalination

Sources:

Treatment of Concentrate (Mickley, 2009). U.S. Bureau of Reclamation. Desalination and Water Purification Research and Development Program Report No. 155 (http://www.usbr.gov/pmts/water/media/pdfs/report155.pdf).

As of 2003, there were **234** municipal desalination plants operating in the U.S. Most of these plants are located in California, Texas, and Florida.

GWI (Global Water Intelligence), 2006. *IDA Worldwide Desalting Plants Inventory*. Report No. 19. Gnarrenburg, German: Wangnick Consulting GMBH.

Desalting in North America accounts for 15.1% of the world's total desalination capacity. More than 2,100 desalination plants operate in the U.S.

2a. Available published reports (from Water Research Foundation)

Beneficial and Nontraditional Uses of Concentrate
WateReuse Research Foundation, 2006
Order No. 2971 http://www.waterrf.org/Search/Detail.aspx?Type=2&PID=2971&OID=2971

Prepared by CH2M Hill and co-sponsored by Water Research Foundation, WERF, and the U.S. Bureau of Reclamation, the report provides a comprehensive review and comparison of the full range of alternate uses of concentrate and assesses the feasibility of implementation, economic considerations, and environmental safety. Also evaluates both direct uses of concentrate and the potential for recovery and marketing of individual salts separated from concentrate.

Comparing Conventional and Pelletized Lime Softening Concentrate Chemical Stabilization
Water Research Foundation, 2011, *in press*

Prepared by Carollo Engineers, Inc. and co-sponsored by the City of Phoenix, Arizona, the report describes the pilot scale demonstration of the economic and associated energy efficiencies of pelletized softening to improve reverse osmosis (RO) recovery from 85 to 95 percent. The treatment train also reduces concentrate volume by two thirds. The report provides information that should benefit utilities that are planning and/or implementing inland desalination facilities to access brackish water resources, especially waters with problematic silica and/or barium concentrations.

Critical Assessment of Implementing Desalination Technologies
Water Research Foundation, 2009
Order No. 91253 http://www.waterrf.org/search/detail.aspx?Type=2&PID=4006&OID=91253

Prepared by Colorado School of Mines, Resource Trends, Inc., and the University of Wollongong, the report examines the full range of water quality, economic, and social considerations regarding the implementation of desalination technology. There is a chapter in the report focused on brine management. U.K. Drinking Water Inspectorate co-sponsored the study which surveyed 16 utilities employing brackish water desalination and ten utilities applying seawater desalination in the U.S., the U.K., Israel, and Australia.

Desalination Product Water Recovery and Concentrate Volume Minimization
Water Research Foundation, 2008
Order No. 91240 http://www.waterrf.org/Search/Detail.aspx?Type=2&PID=3030&OID=91240

Prepared by Carollo Engineers, Inc., the report presents a state of science review and technical assessment of promising and emerging treatment configurations and technologies for improving the recovery of desalination plants and minimizing concentrate. The report also presents an innovative configuration selected based upon the state of science review that includes reverse osmosis filtration followed by concentrate treatment process which includes chemical precipitation, possible filtration, and secondary electrodialysis and/or electrodialysis reversal.

Evaluation of VSEP to Enhance Water Recovery During Treatment of Brackish Water and RO Concentrate
Water Research Foundation, 2010
Order No. 4148 http://www.waterrf.org/search/detail.aspx?Type=2&PID=4148&OID=4148

Prepared by the University of Washington and co-sponsored by the U.S. Department of Energy, the report explores the performance of a vibratory RO membrane system in treating simulated and real brackish raw waters and brines from first-stage RO systems, with the goal of achieving >99 percent overall recovery combined with excellent solute rejection.

Guidelines for Implementing Seawater and Brackish Water Desalination Facilities
Water Research Foundation, 2010
Order No. 4078 http://www.waterrf.org/search/detail.aspx?Type=2&PID=4078&OID=4078

Prepared by Stratus Consulting Inc., Colorado School of Mines, Oxenford Consulting, Resource Trends, Reiss Environmental, and co-sponsored by the U.S. Department of Energy, the WateReuse Research Foundation, the U.S. Bureau of Reclamation, the California Department of Water Resources, California-American Water, and Tampa Bay Water, the report presents detailed, practical, and comprehensive guidance using information gathered in *Critical Assessment of Implementing Desalination Technologies*. An electronic decision support tool called Planning Issues Matrix was also developed in the project. Fourteen case studies support the guidance development. Brine management is covered in the report.

Inland Membrane Concentrate Treatment Strategies for Water Reclamation Systems
Water Research Foundation, 2009
Order No. 91233 http://www.waterrf.org/search/detail.aspx?Type=2&PID=3096&OID=91233

Prepared by Arizona State University and co-sponsored by the Cities of Phoenix, Goodyear, and Scottsdale, Arizona, the report identifies and develops methods to manage brine streams from water reclamation systems (including agricultural drainage) so that the water may be recovered for potable or industrial purposes while the salts are converted into solid by-products. Also determines the optimum combination of membrane, thermal, and solid-liquid separation processes for different brine solutions, and presents a computer model for optimizing unit processes for different water qualities. The report also provides a bench-scale testing protocol for simulating different brine concentration strategies.

The Impacts of Membrane Process Residuals on Wastewater Treatment: Guidance Manual
WateReuse Research Foundation, 2008
Order No. 4071 http://www.waterrf.org/search/detail.aspx?Type=2&PID=4071&OID=4071

Prepared by Black & Veatch and co-sponsored by Water Research Foundation, WERF, and the U.S. Bureau of Reclamation, the report provides practical guidance to utilities concerning the effects of membrane process residuals on wastewater treatment, including treatment processes, effluent quality, and water reuse and residuals management options.

Regional Solutions to Concentrate Management
WateReuse Research Foundation, 2008
Order No. 4072 http://www.waterrf.org/search/detail.aspx?Type=2&PID=4072&OID=4072

Prepared by Carollo Engineers, Inc. and co-sponsored by Water Research Foundation, WERF, and the U.S. Bureau of Reclamation, the report surveys concentrate disposal and management practices and develop a decision methodology for manager, regulators and stakeholders to use in assessing the viability of concentrate disposal options on a regional and local basis.

Survey of High Recovery and Zero Liquid Discharge Technologies for Water Utilities
WateReuse Research Foundation, 2008
Order No. http://www.waterrf.org/search/detail.aspx?Type=2&PID=4073&OID=4073

Prepared by Mickley & Associates and co-sponsored by Water Research Foundation, WERF, and the U.S. Bureau of Reclamation, the report gathers, analyzes, and synthesizes information concerning technologies appropriate for volume reduction, zero liquid discharge, and zero discharge of membrane concentrate.

Water Treatment Residuals Engineering
Water Research Foundation, 2006'
Order No. 91093 http://www.waterrf.org/search/detail.aspx?Type=2&PID=2934&OID=91093

Prepared by Environmental Engineering & Technology, Inc., the report provides a comprehensive update to the 1987 manual *Water Treatment Plant Waste Management* (Water Research Foundation Project #112). The report includes information on the impacts of new U.S. regulations (e.g., new Filter Backwash Rule) and treatment goals on residuals processes, the advent of treatment technologies (e.g., enhanced coagulation, desalination), as well as information on beneficial applications of residuals. The report also highlights the critical findings of all Foundation residuals research projects completed since publication of the original manual.

Zero Liquid Discharge Desalination
Water Research Foundation, 2011, *in press*

Prepared by Black & Veatch and co-sponsored by Orlando Utilities Commission, Tampa Bay Water, South Florida Water Management District, Southwest Florida Water Management District, St Johns River Water Management District, and City of Ormond Beach, Florida, the report evaluated ZLD desalination of brackish waters with high concentrations of natural organic matter. The report provides guidance for communities where evaporation ponds are not feasible due to climate, cost, or space constraints. The report includes protocols that allow utilities to evaluate ZLD processes in their own source waters.

Zero Liquid Discharge for Inland Desalination
Water Research Foundation, 2007
Order No. 91190 http://www.waterrf.org/search/detail.aspx?Type=2&PID=3010&OID=91190

Prepared by Black & Veatch, the report describes a process train for zero liquid discharge including primary RO, concentrate treatment process, secondary RO, brine concentrator (thermal desalination), and evaporation pond. The process was studied using five brackish water sources representing a broad range of water quality characteristics. California Energy Commission co-sponsored the study which included the participation of five U.S. drinking water utilities.

2b. Available white papers and state-of-the-science reports

Advancing the Science of Water: AwwaRF and Water Treatment Residuals
http://www.waterrf.org/Research/ResearchTopics/StateOfTheScienceReports/ResearchonResidualsfromWaterTreatment.pdf

3. Ongoing projects

Water Research Foundation Project 4061
"Enhanced Reverse Osmosis Systems: Intermediate Treatment to Improve Recovery"
http://www.waterrf.org/Search/Detail.aspx?Type=1&PID=4061&OID=0

> Will design and develop two inter-stage treatment systems to increase recovery in reverse osmosis preparation of drinking water and thus reduce disposal costs in particular for inland facilities. Will compare recovery using advanced oxidation of anti-scaling compounds and subsequent solid precipitation with that of electrodialysis. Project is led by the University of Texas at Austin.

Also, several proposals are being considered related to institutional issues of permitting a desalination facility, forward osmosis demonstration for an inland desalination system, and reducing the energy consumption of a seawater plant.

4. Current practises for brine disposal/treatment

Chapter 9 of *Guidelines for Implementing Seawater and Brackish Water Desalination Facilities* (2010, Order No. 4078) contains eleven U.S. case studies including seawater plants and inland, brackish water plants. Each of the case studies include concentrate management practices.

Mickley reported (*Treatment of* Concentrate, 2009) the frequency (in percent) of use of conventional disposal options in the U.S.:

- 45% disposal to surface water
- 27% disposal to sewer
- 13% disposal via deep well injection
- 8% disposal via land application
- 4% disposal to evaporation pond

5. Identified main issues for brine disposal/treatment

The main issues identified in the research we have funded deal mainly with reducing the volume of concentrate requiring treatment and/or disposal. Disposal options are limited in the U.S. by source water type and geographic location. Inland systems have greater challenges for concentrate disposal.

Volume Minimization – Research is needed to improve the recovery of product water and minimize the volume of concentrate waste streams. Many treatment technologies could be further advanced and improved to minimize waste streams, for example electrodialysis/electrodialysis reversal, forward osmosis, membranes, etc.

Beneficial Uses of Concentrate – Research is needed to investigate beneficial in-plant use of concentrate. Possible uses could include pretreatment filter backwash, generation of sodium hypochlorite, addition of minerals to RO permeate, generation of electricity via pressure RO, or sequestration of CO_2.

Selective Salt/Mineral Recovery – Research is needed to produce marketable products from concentrate.

Appendix 7: Brine Survey of GWRC Members (WERF)

Organization: Water Environment Research Foundation (WERF) , US
Contact person: Jeff Moeller
Email address: jmoeller@werf.org

1. Data on Desalination

The report “Membrane Concentrate Disposal: Practices and Regulations” (Mickley, 2006) contains one of the most extensive surveys conducted of desalination and membrane facilities in the US. Through the project, an effort was made to identify all municipal membrane plants that have been built in the 50 United States through 2002 (of size 25,000 gpd and greater) and to produce a list of these plants. Based on the survey results, a total of 422 plants were identified consisting of 234 desalting plants (reverse osmosis, nanofiltration, and electrodialysis) and 188 low-pressure (microfiltration and ultrafiltration) plants. Of these, about 30 plants operate at wastewater facilities in water reuse situations. Most of the plants produce drinking water.

The identification of utility plants and the survey provide statistics to characterize the water and wastewater utility’s use of membrane processes by startup date, size, location, type of process, and several other parameters. The dramatic growth of membrane use in the utility industry is documented, along with the equally dramatic increase in size of the membrane plants and the increased number of States that now have membrane plants. Statistics are provided about concentrate, backwash, and cleaning waste disposal practices, and results of the survey are compared with the results of a 1992 survey (Mickey et al., 1993). A stand-alone executable database was developed to permit viewing, manipulation, and printing of the survey information.

The brine concentrate data developed in the Mickley 2006 report, and other concentrate reports that I am aware of for the US, is not in a form or format that can be easily transferred or readily derived for input into the table below.

2. Available reports

Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities (03-CTS-17aCO).
This is an essential reference for utilities considering high recovery processing for desalination projects. Consideration of high recovery and zero liquid discharge processing of municipal concentrate has been limited to site-specific paper studies as there are no high recovery municipal desalination plants due to high costs. The research conducted provides a systematic characterization of high recovery performance and costs over a range of size, salinity, and composition. Published by WERF, AwwaRF, and WateReuse Foundation (WRF-02-006a-01).

Beneficial and Non-Traditional Uses of Concentrate (03-CTS-17bCO)
Production of low-salinity water from desalination of brackish and seawater results in a byproduct known as "concentrate" which has significantly increased total dissolved solids (TDS) relative to the source water. Disposal of this concentrate is becoming increasingly problematic. The goals of this project were to provide a comprehensive review and evaluation of the full range of potential beneficial and nontraditional uses of concentrate and to assess the feasibility of implementation, economic considerations, and environmental safety. Published by WERF, WateReuse Foundation, and AwwaRF.

Impacts of Membrane Process Residuals on Wastewater Treatment (03-CTS-17cCO)
An essential guidance manual for any utility that handles membrane process residuals. The report and accompanying CD-ROM provide utilities with two types of models for predicting the impacts of membrane concentrate loadings on the collection system and the wastewater treatment plant. Interactive Microsoft® Excel models allow users to predict point source impacts of the discharge of concentrates from a variety

of sources such as reverse osmosis and the mass balance model examines the impacts of system-wide concentrate discharges. Published by WERF, AwwaRF, and WateReuse Foundation (WRF-02-006c-01).

Regional Solutions for Concentrate Management (03-CTS-17dCO)
Provides an overview of concentrate disposal and management practices and includes a decision methodology that can be used to assess not only what concentrate disposal options are technically feasible but also what options are viable. The decision methodology is provided in the form of interactive software included on a CD-ROM that allows users to enter site-specific data and assess options. Published by WERF, AwwaRF, and WateReuse Foundation (WRF-02-006d-01).

3. Ongoing projects

Demonstration of Membrane Zero Liquid Discharge Process for Drinking Water Systems

In April 2011, WERF initiated a new brine concentrate disposal pilot demonstration project in the state of Colorado valued at approximately $1 million.

Increasing demands for potable water have forced drinking water utilities to consider water supply from lower quality sources. These lower quality sources require the use of advanced treatment technologies such as reverse osmosis (RO) or nanofiltration (NF) membranes to treat the water to a level suitable for human consumption. At present, drinking water utilities have been reluctant to undertake RO or NF membrane projects due to the uncertainty surrounding the availability of feasible disposal options for the concentrate which may be of concern to wastewater treatment plants. Zero liquid discharge (ZLD) is a potentially sustainable disposal option that may represent a long-term solution to concentrate disposal for utilities that need membrane treatment to produce safe drinking water. The primary barrier to implementing ZLD is the lack of cost and performance data developed for drinking water systems. A pilot test demonstrating ZLD will help address the technical and financial uncertainties which currently hinder its implementation. With this knowledge, utilities will be more likely to undertake membrane projects that depend on lower quality water sources.

Objectives of the pilot study include:

- Comparing the performance of two ZLD technologies at two drinking water facilities in the state of Colorado;
- Developing capital, operating and maintenance costs for ZLD technologies;
- Determining the quantity and quality of the water recovered from the ZLD process;
- Characterizing the quantity and composition of brine/concentrate created by the process;
- Determining the handling, transportation and disposal requirements for brine/concentrate created by the process;
- Identifying potential marketable residuals from the ZLD process and summarizing applicable case studies;
- Disseminate information and results to the water quality community

4. Current practises for brine disposal/treatment

Five conventional concentrate disposal methods account for disposal at over 98% of the municipal membrane desalination sites built in the United States (Mickley, 2007). These options are:

- Surface water discharge
- Discharge to wastewater treatment plant
- Subsurface injection
- Evaporation ponds
- Land application

Another option is further treatment for concentrate to facilitate disposal, use, or reuse. This includes reducing the volume of concentrate by high-recovery and zero-liquid discharge (ZLD) processes (Mickley, 2008).

5. Identified main issues for brine disposal/treatment

- **Surface water discharge** is the most common and typically the cheapest concentrate disposal option, if available. Characteristics of the receiving water body and the concentrate are critical considerations. Potential impacts to aquatic organisms are a primary consideration. Adverse human health impacts may occur if the surface water is used downstream as a source of potable water or if the water body is used for recreational purposes or for fishing. Surface water disposal is generally not feasible in the rapidly growing, water-short, and landlocked areas of the U.S. desert southwest, which lack perennial riverine supplies. Ecological risk factors are likely to be the major issues for oceanic discharge, and permitting of new ocean discharges is likely to be increasingly difficult. [Jordahl, 2008]

- **Sewer discharge** is the simplest means of concentrate discharge, if available. Sewer discharge may be limited, especially for larger membrane plants and their associated larger concentrate flows. The major economic issue is the fee charged by the wastewater treatment plant (WWTP) for the discharge. [Jordahl, 2008]

  The ultimate fates of the constituents in the concentrate depend on their reactivity in the wastewater stream and partitioning onto biomass within the WWTP. Inorganic constituents neither react nor partition. The additional mass loading can have an adverse impact on the performance of a WWTP. An increase in the total dissolved solids (TDS) concentration can affect settling by changing the wastewater density, inhibit the biological treatment process, and increase the aquatic toxicity, which may limit the options for surface discharge or reuse. In addition, the treatment plant's discharge permits (National Pollutant Discharge Elimination System permits in the United States) may include limits for TDS or specific ions, most commonly sodium and/or chloride. Chloride above a certain level can adversely impact the whole effluent toxicity testing results for a WWTP, resulting in exceptions to the permit. Concentrates containing high TDS levels can also aggravate corrosion of the collection system piping and treatment plant process equipment. In these cases, concentrate disposal via ocean or estuarine discharge might not be an option because of the distance from production to disposal (e.g., inland desalination facilities), high cost, or regulatory limits. [Rimer, 2008]

- **Deep well injection** is widely used in Florida, where geologic conditions are especially favorable. It is very expensive, but there are significant economies of scale for larger plants. The entire volume injected represents water that is essentially unrecoverable or "lost" for other potential uses, but salts in the concentrate are permanently removed from the basin. [Jordahl, 2008]
- **Evaporation ponds** are a simple, widely used technology, applicable to all concentrates unless there are unacceptable ecological exposures from certain constituents in the concentrate (e.g., selenium). Use of evaporation ponds is largely limited to areas with a warm, dry climate having high pan evaporation rates. Limited availability of adequate areas of low-cost land further restricts evaporation pond use, especially for desalination facilities with high concentrate volumes that are located in or near urban areas. There is no significant economy of scale for evaporation ponds. [Jordahl, 2008]
- **Rapid infiltration** is a potential low-cost method of disposal, but regulatory and technical constraints are significant. This disposal method is not likely to be a viable alternative for most membrane facilities. [Jordahl, 2008]
- **High recovery and ZLD systems** used for various industrial applications are not currently used at any municipal sites in the United States due to their high cost. WERF recently initiated a demonstration project of ZLD technologies to develop realistic performance and cost analyses for several ZLD technologies to assist municipalities with the increasing challenges associated with concentrate disposal.

  Detailed water quality analyses need to be done at the concentrate level to determine whether contaminants present at low levels in feedwater (or perhaps undetectable there) will result in brine or solids being hazardous or containing problematic levels of radionuclides. (Mickley, 2008).

Appendix 8: Brine Survey of GWRC Members (WSAA)

Organisation: Water Services Association of Australia
Contact person: Greg Ryan
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Water Corporation Western Australia

Organisation: Water Corporation Western Australia
Contact person: Gabrielle O'Dwyer
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1. Data on Desalination

Please note this table was readily available

Site #	Location	M3 24hrs	OEM	Application & Process	Feed TDS mg/l	Reject Disposal	Brine vol. (m^3/year) (24hrsx 365days)
1	Leonora, WA	1500	WTA	Potable BWRO	1500	Mine Shaft	245,280
2	Denmark, WA	1000	CRS	Potable BWRO	1200	River/Cart	109,500
3	Hopetoun, WA	300	WTA	Potable BWRO	1400	Infiltration Pond	48,180
4	Ravensthorpe, WA	180	Veolia	Potable BWRO	9000	Disused Mine Shaft	35,916
5	Coral Bay, WA	200	Osmoflo	Potable BWRO	4500	Infiltration Pond	32,412
6	Denham, WA	250	Veolia	Potable BWRO	5500	Infiltration Pond	53,436
7	Denham, WA	250	Veolia	Potable BWRO	5500	Infiltration Pond	53,436
8	Gascoyne Junct, WA	120	Veolia	Potable BWRO	1500	Infiltration Pond	19,272
9	Wiluna, WA	150	GE	Potable EDR	800	Brine Evap Ponds	6132
10	Yalgoo (HERO), WA	180	Osmoflo	Potable BWRO	800	Brine Evap Ponds	35,040
11	Burrup/Karratha, WA	1150	Veolia	Industrial BWRO	1100	Ocean Outfall	157,680
12	Burrup?Karratha, WA	3000	VaTech	Industrial MVC	39000	Ocean Outfall	735,840
13	Cocos Island, WA	40	Veolia	Potable BWRO	1250	Ocean Outfall	22,776
14	Beenyup Pilot, WA	5000	Koch	WW Reuse BWRO	1000	Ocean Outfall	608,820
15	Brewery, WA	2000	Osmoflo	Potable BWRO	400	Sewer	157,680
16	KWRP, WA	16700	Veolia	WW Reuse BWRO	900	Ocean Outfall	1,533,000
17	Desal 1 Kwinana, WA	144000	Degremont	Potable SWRO	38000	Ocean Outfall	60,000,000
18	Desal 2 Binningup, WA	153000	Tecnicas Reunidas & Valoriza Agua	Potable SWRO	35000	Ocean Outfall	76,650,000

2. Available reports

- Review of literature on the effects of desalination plant brine discharge on cetaceans, URS 2008
- Membrane Distillation of brine wastes by N. Dow WQRA research report No.63. 2008
- Concentrate Disposal for Inland Desalination Plants, 2008
- Menzies Water Treatment Plant Concentrate Disposal, 2004
- P. Okely, J.P. Antenucci, J. Imberger, C.L. Marti, “Field investigations into the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound”, Centre for Water Research, University of Western Australia, June 2007, WP2150PO
- D. Luketina, S. Christie, Marine Impact – Proving the models, AWA De-salting – Seawater and Brackish Water Conference, Perth, Sept. 2008.
- J Woodworth, “Marine Toxicity Tests – Report prepared for the Water Corporation” Geotechnical Services, December 2007
- P.S. Yeates, P. Okely, J.P. Antenucci, J. Imberger, “Hydrodynamic modeling of the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound”, Centre for Water Research, University of Western Australia, November 2006, WP2127PY
- P. Okely, J.P. Antenucci, P.S. Yeates, C.L. Marti, J. Imberger, “Summary of Investigations into the Impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound”, Centre for Water Research, University of Western Australia, August 2007, WP2160PO
- P. Okely, P.S. Yeates, J.P. Antenucci, J. Imberger, M.R. Hipsey, “Modeling the Impact of the Perth Seawater Desalination Plant discharge on dissolved oxygen in Cockburn Sound”, Centre for Water Research, University of Western Australia, November 2006, WP2136PO
- WateReuse Foundation, survey on high recovery and zero liquid discharge technologies for water utilities, December 2010
- WateReuse Foundation, Regional solutions for concentrate management, March 2010

3. Ongoing projects

Both these projects are being undertaken with support from NCEDA and external partners:

- **Management of Brine Disposal into Inland Ecosystems**
  The project is focussed on developing guidelines for the management of brine waste in inland environments. This will include assessment of possible benefits from enhanced/new ecosystem services.

- **Evaluation of Vibratory Shear Process Membrane Technology for Waste Brine Minimisation & Demonstrating Brine Recovery/Recycling**
  The aim of the project is to develop and validate a novel method for managing brine waste and concentrate produced from desalination plants, particularly from inland locations. This project will also combine the membrane technology with other waste minimisation technologies to achieve a zero liquid discharge (ZLD) system.

- **Dissolved oxygen monitoring in Cockburn Sound (PSDP)** as part of regulatory compliance

- **Yalgoo Hero Trial** - Explored the use of an alternative treatment process to reduce brine volume when limited by Silica levels in bore water

- **Wiluna EDR Trial -** Explored the use an alternative treatment process to reduce brine volume when limited by Silica levels in bore water

- **RMIT sludge disposal** – sludge disposal with focus on UF and NF (WC declined involvement)

4. Current practises for brine disposal/treatment

- Currently blend some brine stream (MIEX) with wastewater ocean outfalls.
- Dissolved oxygen monitoring in Cockburn Sound (PSDP) on PSDP diffusers.
- Solids separated from backwash and brine plus residual water sent to PSDP ocean outfall and solids to landfill.

5. Identified main issues for brine disposal/treatment

- Regulatory – continues to be a lack of understanding by regulators on the overall complexity and trade offs in managing through regulation.
- Landfill costs and availability - separation of solids before discharging brine.
- Energy costs – should the brine need to be pumped to discharge location.
- Dealing with the aggressive corrosive nature of brine relative to material selection for hardware and components that contacts the brine stream.
- OSH - as levels of some elements (such as selenium and Arsenic) are quite high in concentrate at some sites (such as Wiluna and Yalgoo, WA).
- Environmental impacts (as mentioned above, concentrate in evaporation ponds might be harmful for birds or animals due to some elements' presence in concentrate at high levels; reuse of concentrate or discharge to surface water or infiltration would have impacts to receiving environment).
- Loss of water resource if they are not being reused.

Sydney Water

Organization: Sydney Water
Contact person: Steve Roddy
Email address: Steve.RODDY@sydneywater.com.au

1. Data on Desalination

Volume of water treated	Capacity (million m^3/year)	Application [(1)]	Technology[(2)] (RO/Thermal/IX/ ..)	Brine vol. (million m^3/year)	Contaminants [(3)]
Drinking Water	91x 10^6	SW	RO	111x10^6	NaCl, Ca, Mg, other salts
Agriculture/irrigation					
Industrial use	7.3 x10^6	TTE	RO	1.8x 10^6	NaCl, other salts, organics
Other use: Supplementing river flows to offset environmental flow release from dam.	18x10^6	TTE	RO	4.5x10^6	NaCl, other salts, organics,

[1] SW: softening BW: brackish water SW: seawater Other : Please specify TTE: Tertiary Treated Effluent
[2] RO/Thermal/IX
[3] NaCl, Ca, Mg, metals, heat, solids….(and level on concentration)

2. Available reports

There are a number of reports for these projects, which could be made available on request.

3. Ongoing projects

At present we have an R&D project on removal of salt from SWRO pre-treatment residuals. This is being carried out at Melbourne Uni.
We attempted to start another project on reclamation of ferric from the ferric hydroxide residuals of the SWRO pre-treatment but could not find suitable personnel. This may be restarted in the future

4. Current practises for brine disposal/treatment

Brine from the seawater desalination plant is disposed of directly back into the ocean via two outlet arrangements, each with four inclined nozzles. Brine from the recycled water desalination plants is disposed of either directly to the ocean (with STP effluent) or via a major sewer to an ocean outfall plant.

5. Identified main issues for brine disposal/treatment

We have not identified any further issues with brine disposal at this stage.

Water Corporation Western Australia

Contact person: Mike Dixon
Email address: mike.dixon@sawater.com.au

1. Data on Desalination

Volume of water treated	Capacity (million m^3/year)	Application [(1)]	Technology[(2)] (RO/Thermal/IX/ ..)	Brine vol. (million m^3/year)	Contaminants [(3)]
Drinking Water	300	SW	RO	160	NaCl, Boron
Agriculture/irrigation					
Industrial use					
Other use :_______					

[1] SW: softening BW: brackish water SW: seawater other: Please specify
[2] RO/Thermal/IX
[3] NaCl, Ca, Mg, metals, heat, solids….(and level on concentration)

2. Available reports

Adelaide Desalination Pilot Plant report currently under production

3. Ongoing projects

No brine projects currently being undertaken besides contractual monitoring of seawater salinity levels. This data will become available on the SA EPA website.

4. Current practises for brine disposal/treatment

Saline concentrate is mixed with seawater via 6 outlet 'duckbills'. These are designed to maximise velocity as the saline concentrate enters the seawater and direct it to the surface. An arc forms as saline concentrate falls back to the seabed and within 80m there is no measurable difference in salinity from background fluctuations in salinity. Samples are taken at various distances from the outlet structure, with a control sample being taken several kilometres from the site.

5. Identified main issues for brine disposal/treatment

As the Adelaide Plant is not as yet online, we will wait till we have some operational data to make decisions on main outlet issues.

Appendix 9: Brine Survey of GWRC Members (SE)

Contact person: Jean-Michel LAINE
Email address: jean-michel.laine@suez-env.com

1. Data on Desalination

Volume of water treated	*Capacity (m3/year)*	*Application (1)*	*Technology(2) (RO/Thermal/IX/ ..)*	*Brine vol. (m3/year)*	*contaminants(3)*
Drinking Water	Melbourne	SW	RO	170	Clarified filter backwash waters and neutralized RO CIPs waters combined to brine Salinity:70g/L
Drinking Water	Al Dur	SW	RO	105	Clarified both DAF sludge and filter backwash waters and neutralized RO CIPs waters combined to brine Salinity:80g/L
Drinking Water	Barka II	SW	RO	55	Clarified filter backwash waters and neutralized RO CIPs waters combined to brine Salinity:70g/L
Drinking Water	Barcelona	SW	RO	85	Clarified both DAF sludge and filter backwash waters and neutralized RO CIPs waters combined to brine Salinity:70g/L
Drinking Water	Perth	SW	RO	65	Clarified filter backwash waters and neutralized RO CIPs waters combined to brine Salinity:70g/L
Drinking Water	Fujairah	SW	RO	80	Clarified filter backwash waters and neutralized RO CIPs waters combined to brine Salinity:70g/L

2. Available reports

Perth, Australia: Two-year Feed Back on Operation and Environmental Impact
Steve Christie
Senior Engineer, Desalination - Perth Seawater Desalination Plant - Water Corporation - Australia
IDA World Congress – Atlantis, The Palm – Dubai, UAE November 7-12, 2009

P. Okely, J.P. Antenucci, J. Imberger, C.L. Marti, "Field investigations into the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound", Centre for Water Research, University of Western Australia, June 2007, WP2150PO,
http://www.watercorporation.com.au/D/desalination_environment.cfm

D. Luketina, S. Christie, Marine Impact – Proving the models, AWA De-salting – Seawater andBrackish Water Conference, Perth, Sept. 2008.

J Woodworth, "Marine Toxicity Tests – Report prepared for the Water Corporation" Geotechnical Services, December 2007

P.S. Yeates, P. Okely, J.P. Antenucci, J. Imberger, "Hydrodynamic modelling of the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound", Centre for Water Research, University of Western Australia, November 2006, WP2127PY

P. Okely, J.P. Antenucci, P.S. Yeates, C.L. Marti, J. Imberger, "Summary of Investigations into the Impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound", Centre for Water Research, University of Western Australia, August 2007, WP2160PO
http://www.watercorporation.com.au/D/desalination_environment.cfm

P. Okely, P.S. Yeates, J.P. Antenucci, J. Imberger, M.R. Hipsey, "Modelling the Impact of the Perth Seawater Desalination Plant discharge on dissolved oxygen in Cockburn Sound", Centre for Water Research, University of Western Australia, November 2006, WP2136PO
http://www.watercorporation.com.au/D/desalination_environment.cfm

S. Shute, "Perth Metropolitan Desalination Plant – Cockburn Sound Benthic Macrofauna Community and Sediment Habitat – Repeat Macrobenthic Survey", Oceanica, June 2009, 604_001/1
http://www.watercorporation.com.au/D/desalination_environment.cfm

K. Holloway, "Perth Seawater Desalination Plant Water Quality Monitoring Programme – Final Programme Summary Report 2005 – 2008", Oceanica, Jan 2009, 445_001/

3. On-going projects

The issue of brine disposal is studied in case by case to comply with the specifications by focusing on:
- Characterization of effluent discharge point (heavy metals, dissolved oxygen, pH, conductivity, TSS, etc.)
- Modeling of the horizontal and vertical dispersion of brine around the diffusers

SE is not directly involved on the issue of brine toxicity because it is generally considered by the local authority, in order to be able define then submit the specifications.

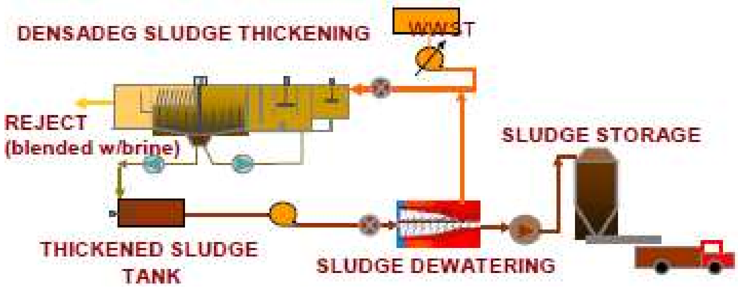
4. Current practises for brine disposal/treatment

Two examples of SE practices in terms of brine disposal into sea coastal areas:

In Perth, the Environmental Protection Authority has set stringent criteria for the plant, and the Water Corporation was required to conduct brine dispersion studies (Hydraulic modeling with local University, 1:15 scale physical modeling to confirm plant discharge design : Plume thickness and height, Impact, Ultimate dilution (< 1.2 ppt at 164 ft)) to ensure zero impact on submarine life implemented and implemented a very intensive ocean monitoring program. An independent report into the environmental impact of the plant has shown that oxygen levels in Cockburn Sound have not been affected by the discharge from the plant.

In Barcelona, the RO plant is located in El Prat, an industrial area not far from Barcelona Airport, close to one of the wastewater treatment plants. The brine from the RO plant is pumped to the WWTP outlet facility in order to use the same discharge pipe to the sea. This allows a good dilution for salts as well as for the COD coming from the WWTP effluent.

It is also important to mention that sludge (from Filters & RO cleaning and Flotators for Barcelona) from both desalination plants are treated on site (Thickening & Dewatering) and diverted to landfill for disposal. Final clarified effluent (SS< 10 mg/L) is blended with brine (TSS < 1 mg/L) before discharge to the sea.



5. Identified main issues for brine disposal/treatment

- Inland disposal of brines
- Standard methodology to measure impact of discharge
- Cost effective system to divert brine in safe condition into sea coastal areas
- Cost effective solution to recover marketable brine products
- Cost effective Zero Liquid Discharge systems

Appendix 10: Brine Survey of GWRC Members (KWR Water)

Contact person: Jan Hofman
Email address: jan.hofman@kwrwater.nl

1. Data on Desalination

Volume of water treated	Capacity (*10^6 m^3/year)	Application[(1)]	Technology [(2)]	Brine vol. (*10^6 m^3/year)	contaminants[(3)]
Drinking Water locations					
- Heemskerk	18	BW	UF-RO	3.5	0.2% NaCl, AS
- Schiermonnikoog	0.105	SO + colour	RO	0.021	
- Weerseloseweg	1.315	SO + colour + SO4	NF	0.26	0.3% NaCl, FE, P SO4, AS
- Rodenmors	0.805	SO+ colour	NF	0.16	Fe, P
- Diepenveen	2.100	SO + colour	NF	0.42	Fe, P
- Vlieland	0.030	SO + colour	RO	0.006	
- Engelse Werk 1	3.000	SO + colour + org micro	RO	0.6	0.2% NaCl, Fe, AS
- Terschelling	0.095	SO + colour	NF	0.019	
- Witharen	1.315	SO + colour	NF/RO	0.26	0.1% NaCl, Fe, P, Cl
- Dinxperlo	2.800	SO + colour + org micro	RO	0.56	0.5% NaCl, NO_3, AS (P), pesticide
- Ameland (Buren)	0.068	SO + colour	RO	0.014	
- Engelse Werk 2	4.200	SO + colour + org micro	RO	0.84	0.2% NaCl, Fe, AS
- Zuidwolde	0.32	SO	NF	0.08	0.17% NaCl, Fe, P, Humics, AS
Agriculture/irrigation					
Industrial use locations					
- Emmen	3	WWTP effl.	UF-RO-EDI	0.75	0.25% NaCl, P, N
- Klazienaveen	0.6	BW	UF-RO	0.15	0.2% NaCl, P, N
- Veendam		BW	UF-RO		
- Terneuzen	2	WWTP Effl.	MBR-RO-(MBIX)	0.6	NaCl
- Sas van Gendt	~0.5	WWTP Effl.	UF-RO	0.15	NaCl
- Dordrecht	1.2	BW	UF-RO-MBIX	0.3	NaCl
- Botlek	12	BW	CIX-RO-MBIX	1.5	NaCl
- Geleen	10	BW	UF-RO-MBIX	2	NaCl
- Zoeterwoude	2	DW	RO	0.4	NaCl
- 's Hertogenbosch		BW	NF		
Other use :________					

[1] SO: softening BW: brackish water SW: seawater DW: drinking water Other : Please specify
[2] RO/Thermal/IX, AIX: Anion IX, CIX: Cation IX, MBIX: Mixed Bed IX
[3] NaCl, Ca, Mg, metals, heat, solids….(and level on concentration), AS: Anti Scalant

2. Available reports

All reports are in Dutch (except the publication in desalination)

Sombekke, H.D.M., Kappelhof, J.W.N.M., 1996. Possibilities for membrane concentrate disposal: an inventory (Membraanconcentraat verwijderingsmogelijkheden: een verkenning). SWE 96.011. KWR.

Post, J., Siegers, W., 2004. Ion exchange as an alternative for pellet softening and nanofiltration (Ionenwisseling als alternatief voor korrelreactoren en nanofiltratie). BTO 2004.065. KWR, Nieuwegein.

Siegers, W., Bernardhi, L., Post, J., Riemersma, M., 2004. Ion exchange as alternative for pellet softeing and NF, possibilities for reuse of spent regenerant and regulations for disposal (Ionenwisseling als alternatief voor korrelreactoren en NF, mogelijkheden voor hergebruik van de regeneratievloeistof en reguleringen voor lozingen). BTO 2004.066. KWR, Nieuwegein.

M.M. Nederlof, J.A.M. van Paassen, R. Jong (2005), Nanofiltration concentrate disposal: experiences in The Netherlands, *Desalination*, 178, pp. 303-312

Raat, K.J., Kooiman, J.W., 2011. Brackish groundwater: don't avoid but use! Report from pilot research in Noardburgum and Zevenbergen (Brak grondwater: niet mijden, maar gebruiken! Eindrapport BTO onderzoek pilots Noardburgum (Vitens) en Zevenbergen (Brabant Water)). BTO 2011.048. KWR Watercycle Research Institute, Nieuwegein, the Netherlands.

Hofs, B., Post, J.W., 2011. Eutectic Freeze Crystallization for treatment of (re-)used ion exchange regenerant (Eutectische vrieskristallisatie voor de behandeling van (her)gebruikt ionenwisselaar regeneraat). BTO 2011.103 (s). KWR, Nieuwegein.

3. Ongoing projects

Currently a new project on salty waste streams is ongoing. The focus is on membrane concentrate and spent IX regenerant. It aims to give an update on the information in the previously mentioned reports. New technologies like capacitive deionization, forward osmosis, electro membrane processes and eutectic freezing will be explored. Also new concepts like high recovery RO and low recovery RO for brackish water will be evaluated. The project will give an overview of salty waste streams in the Netherlands, update regulatory developments in the Netherlands and Europe, will give an assessment of new concentrate treatment technologies and give a vision on system integration of concentrate treatment systems. The report will be available in 2012

4. Current practises for brine disposal/treatment

Surface water discharge, sewer discharge

5. Identified main issues for brine disposal/treatment

It is becoming more and more difficult to get a discharge permit for membrane concentrate in the Netherlands. This hampers implementation of membrane technologies, both for the public water sector as for the industry. Discharge of spent IX regenerant on a large scale is not possible in the Netherlands.