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Environmental Issues of Desalination

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Environmental issues related to desalination are a major factor in the design and implementation of desalination technologies. An acceptable desalination plant is expected to meet environmental regulations; be cost-effective in terms of construction, operation and management, as well as the costs associated with monitoring and permit fees. Some major environmental concerns include issues related to location of desalination plants and water intake structures, and concentrate management and disposal. This chapter provides an overview of the environmental issues related to desalination.

Desalination Plant Location

The first step in planning a desalination plant is to select a site where the plant will be located. Many factors affect site selection such as available energy sources, costs and the risks associated with transporting the feedwater to the plant, as well as the location of concentrate discharge. The proximity of a desalination plant to population centers and environmentally protected and sensitive areas are also critical factors.

Proximity of Population Centers

A major issue to consider is land use in the proximity of a proposed desalination plant site (Mahi 2001). If planners place a desalination plant in densely populated areas, it may impact the residential environment. Some desalination plants generate noise and gas emissions. For example, reverse osmosis plants generate noise because of the use of high-pressure pumps. If located near population centers or other public facilities, plans should include steps to mitigate the noise pollution such as using canopies or acoustical planning (Einav et al. 2002).

Desalination plants can have an indirect impact on the environment because many plants receive energy from the local grid instead of producing their own. The burning of fossil fuels and increased energy consumption allows more air pollution and gas emissions to occur. Gaseous emissions from desalination stacks include carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). These air pollutants can have a harmful impact on public health (Al-Mutaz 1991). There is also concern regarding the large amounts of chemicals stored at the plants. Chemical spill risks require storing chemicals away from residential areas.

Possible Environmental Effects

The construction process can be time-consuming, inconvenient, loud, and disruptive to the environment. It is ideal to have as little construction as necessary. If the fuel resources, electricity connection, and water connections are near the proposed plant site, then there will be less construction. Existing nearby infrastructure decreases the construction impact even more. After construction begins, planners should begin to develop an environmental monitoring plan to track issues identified in the earlier stages that will help monitor the project's success toward meeting the established guidelines. Management plans are also necessary during the plant's operation to ensure consistent environmental acceptability (Everest and Murphree 1995).

Construction of water intake structures and pipelines to carry feedwater and concentrate discharge may cause disturbances to environmentally-sensitive areas. Concentrates are high in salinity and may contain low concentrations of chemicals as well as elevated temperatures. These properties of concentrate can pose problems for the marine habitats and receiving water environments. A later section of this report discusses concentrate management issues in detail. Environmental impact studies are necessary to protect environmentally-sensitive areas.

The potential contamination of groundwater aquifers in the proximity of desalination plants can be an environmental concern. There is a risk of polluting the groundwater from the drilling process when installing feedwater pumps. Leakage from pipes that carry feedwater into the desalination plant and highly concentrated brine out of the plant may percolate underground and cause damage to groundwater aquifers. To prevent this, plants should include sensors and monitoring devices and workers should notify plant operators if leaks develop in the pipes.

Desalination projects require an environmental impact assessment (EIA) study to determine the impact the project can have on the environment. The EIA considers all environmental parameters and criteria. It evaluates the potential impacts to air, land, and marine environments and also proposes mitigation measures to reduce environmental impacts. The EIA report discusses the chosen desalination process, the emissions the process will generate, the implications the facility will have on the environment, the considerations to be made about the energy supply, the benefits the facility will have on the community, and the proposed mitigation measures to reduce problems associated with the facility (Bene et al. 1994).

Concentrate Management

Desalination plants generate two products (clean water) and concentrate (reject or residual stream). Proponents recognize that cost-effective and environmentally-sensitive concentrate management can be significant obstacles in the widespread use of desalination technologies. Proper concentrate disposal and construction methods incorporated in the plant's design can mitigate the concentrate's impact on the receiving water environments and groundwater aquifers. The following section describes concentrate characteristics and concentrate management options.

Concentrate Characteristics

Concentrate is the byproduct from desalination. Concentrates are generally liquid substances that may contain up to 20% of the treated water. Brine is a concentrate stream that contains a TDS concentration greater than 36,000 mg/L. Critical concentrate parameters are TDS, temperature, and specific weight (density). The concentrate may also contain low amounts of certain chemicals used during pretreatment and post-treatment (cleaning) processes. Characteristics of the generated concentrate depend on the type of desalination technology used. Table 1 shows characteristics of concentrates from various types of desalination plants (Mickley 2001).

The amount of concentrate produced from a desalination plant is a factor of the desalination process' recovery rate (product water/feedwater). Generally, membrane plants have a higher recovery rate than distillation plants, resulting in a higher salt amount in the concentrate. As shown in Table 1, concentrate produced from seawater reverse osmosis (SWRO) plants can have up to two times more salt concentration than the receiving water, while the concentrate produced from a distillation process may have only a 10 percent higher salt concentration than the receiving water. In distillation processes, the system mixes the concentrate with once-through cooling water to dilute the salt concentration. Table 1 also shows that concentrate from distillation processes is typically warmer, 10-15°F above the ambient water temperature. Concentrate temperature from the reverse osmosis process remains at the ambient water temperature.

Specific weight (or density) is another critical concentrate parameter. Compared to freshwater, concentrate has a higher density due to the increased salt concentration. When concentrate with a higher density is disposed into waters of lower salinity (lower density), the concentrate tends to sink. In comparison, typical discharge from wastewater treatment plants will float, because its density is normally less than the receiving water. The tendency of the concentrate to sink when interacting with the receiving water introduces problems for the marine environment. In some cases, plants reduce the concentrate density by diluting it before being discharging it into a receiving water. The concentrate disposal section discusses this in more detail.

Table 1. Concentrate Characteristics for Various Desalination Technologies

Process	RO	RO	MSF/MED
Feedwater	Brackish	Seawater	Seawater
Recovery	60-85%	30-50%	15-50%
Temperature	Ambient	Ambient	10-15°F above ambient
Concentrate Blending	Possible, not typical	Possible, not typical	Typical, with cooling water
Final Concentration Factor	2.5-6.7	1.25-2.0	<1.15

Pretreatment

- Somewhat similar schemes may be used in all processes
- Chlorination where biological growth may be present (more for surface waters)
- Polymer additives used for scale control
- Acid sometimes used in addition to additives (particularly for RO)
- Corrosion inhibitors used in thermal processes
- Dechlorination for some membrane processes where chlorination is used

Post-treatment

Degasification for CO_2, H_2S (Brackish-RO) aeration for adding O_2 (Brackish-RO)

pH adjustment for corrosion protection (RO)

BRO = brackish water reverse osmosis

SWRO = seawater reverse osmosis

MSF = multistage flash evaporation

MED = multiple effect distillation

Source: Mahi 2001

Pretreatment can include processes such as chlorination, clarification, coagulation, acidification, and degasification used on the feedwater to minimize algae growth, scaling, and corrosion. The pretreatment chemical agents are important to consider because they remain in the concentrate before disposal. The following list notes some possible pretreatment chemicals:

- NaOCl or free chlorine - prevents biological growth
- $FeCl_3$ or $AlCl_3$ - flocculation and removal of suspended matter from water
- H_2SO_4 or HCl - pH adjustment
- $NaHSO_3$ – neutralizes chlorine remains in feedwater
- Various scale inhibitors – prevents scale formation on the pipes and membranes

If a membrane becomes fouled or scaled, the fouling or scaling material has to be removed by chemical cleaning. Therefore, concentrate from membrane processes often contains cleaning chemicals. The type of chemicals used for cleaning depends on the type of membrane. For RO and NF systems, chemical cleaning agents fall into the following categories (American Water Works Association 1999):

- Enzymes to break down bacterial slimes
- Detergents and surfactants to resuspend particulate material and dissolve organic material
- Biocides to kill bacteria
- Chelators to remove scale
- Acids to dissolve inorganics
- Caustics to dissolve organic substances and silica

The National Pollutant Discharge Elimination System (NPDES) program regulates concentrate discharge to surface waters. The NPDES requires Whole Effluent Toxicity (WET) testing of concentrate to determine potential impacts on aquatic species. Several utilities in Florida that use membrane technologies failed WET tests for unknown reasons necessitating research to determine failure causes (Mickley 2001). The follow-up research investigated concentrate characteristics from nine utilities in Florida. The research results pointed to the existence of excessive ions in the concentrate as the cause of WET test failures. Excessive calcium and fluoride levels in concentrate were major contributors to ion toxicity of concentrate (Mickley 2001). Furthermore, research showed that the chemical properties of groundwater (used as feedwater) caused the occurrence of major ion toxicity, not the membrane treatment process.

In coastal areas, due to the dynamic nature of freshwater and saltwater interaction, the composition of brackish groundwater is not uniform or chemically balanced. In these waters, calcium carbonate and calcium sulfate concentrations are dominant over sodium chloride. Groundwater may also contain low levels of dissolved oxygen and high levels of other gases such as carbon dioxide and hydrogen sulfide that contribute to the toxicity of concentrate (Mickley

2001). This fact somewhat validates the hypothesis that groundwater characteristics may influence the ion toxicity of concentrate from desalination plants.

Concentrate Disposal Methods

At present, approximately 48% of desalination facilities in the U.S. dispose of their concentrate to surface waters (Hoepner and Lattemann 2002). Some other concentrate disposal options include deep well injection, land application, evaporation ponds, brine concentrators, and zero liquid discharge (ZLD) technologies. Table 2 shows the percent distribution of current concentrate disposal techniques common in the U.S.

Table 2. Distribution of Concentrate Disposal Methods in the U.S.

Means	FL	CA	Rest of U.S.	Average
Surface	39	6	21	66
	46%	50%	51%	48%
POTW	12	5	15	32
	14%	42%	37%	23%
Land	17	0	0	17
	20%	0%	0%	12%
Deep Well	18	1	0	14
	21%	8%	0%	10%
Evaporation-	3	0	5	8
Ponds	4%	0%	12%	6%
Total	84	12	41	137
	100%	100%	100%	100%

Source: Everest and Murphree 1995

Planners consider a variety of factors to choose the best disposal option. These factors include the volume or quantity of the concentrate, the quality of the concentrate, the location of the desalination plant, and environmental regulations. Other factors include public acceptance, capital and operating costs, and the ability for future plant expansion. The next section describes various concentrate disposal methods.

Surface Disposal. Surface disposal methods include surface water disposal and submerged disposal.

Surface Water Disposal. Disposing of concentrate in surface water is the most common method of concentrate disposal. Surface water disposal includes disposal into freshwater, tidal rivers and streams; coastal waters such as oceans, estuaries, and bays; and freshwater lakes or ponds. As concentrate enters the receiving water, it creates a high salinity plume in the receiving water. Depending on the density of the concentrate in comparison to the seawater, this plume sinks, floats, or stabilizes in the water. The radius of the plume impact varies. The type of dispersion and natural dilution of the concentrate plume that may occur depends on the discharge pipe's location. Factors such as waves, tides, bathymetry, currents, water depth and the presence of waves are all important factors that determine natural dilution and the amount of mixing that may occur at the concentrate disposal point (Mickley 2001).

Without proper dilution, the plume may extend for hundreds of meters, beyond the mixing zone, harming the ecosystem along the way. Mixing zones are quantified limits within the receiving waters where the law allows surface water to exceed water quality standards due to the existence of point source disposal. State governments determine these limits and utilities monitor them. For example, Florida's mixing zone limitations are 2,625 ft for canals, rivers, and streams; 31 acres for lakes, estuaries, bays, lagoons, and bayous; and 124 acres for oceans (Truesdall et al. 1995).

Table 3 displays the main concerns with surface water disposal, as well as mitigation methods to reduce those concerns. If the concentrate does not pass the WET test and natural dilution is not enough to properly diffuse the concentrate, then desalination plants use artificial dilution methods. The concentrate can be diluted through efficient blending, diffusers, or within mixing zones prior to surface disposal. Blending is simply mixing the concentrate with cooling water, feedwater, or other low TDS waters before disposal. Diffusers are jets that dilute the concentrate at the concentrate disposal outlet for maximum mixing. Factors to consider for jet dilution include the difference in densities between the concentrate and the receiving water, and the momentum and velocity of the water at the outlet.

Pretreatment prior to disposal consists of aeration, i.e., adding oxygen to the concentrate, and degasification to remove hydrogen sulfide from the concentrate (Hoepner 2002). Using non-toxic additives and dechlorination techniques limits the toxic chemical concentrations that enter the environment. The need for these techniques is site-specific depending on the maximum concentrations of the additives and chlorine

Table 3. Surface Water Disposal Problems and Mitigation

Environmental Concern	Process	Mitigation Method
from raw water…		
Contaminants present in raw water	Brackish-RO	Limit degree of concentration, blending, mixing zones, post-treatment
Imbalance in essential ions (some groundwater)	Brackish-RO	Diffusers, blending, mixing zones
Low dissolved oxygen, high H_2S, etc. (some groundwater)	Brackish-RO	Aerate, degasify, or otherwise treat prior to discharge
from pretreatment…		
Toxicity of additives	All	Use non-toxic additives
Low pH (due to acid addition)	RO	Raise pH prior to discharge
from the concentrate salinity…		
Different salinity than receiving water	RO more than thermal	Diffusers, blending, mixing zones, ZLD

Source: Mahi 2001

allowed in the discharge, which are set by regulatory agencies. Using materials in the desalination process that are less likely to corrode can limit the occurrence of corrosion products in the water.

Submerged Disposal. Submerged disposal is defined as the disposing of concentrate underwater, rather than disposing on the surface which could occur in brackish tidal waters or estuarine environments. Submerged disposal is practiced via long pipes that stretch far into the ocean, in contrast with surface disposal that happens immediately at the coastline. Usually, regulatory agencies establish mixing zones around the outlet of the surface or submerged disposal pipe in order to control the salinity of the receiving water. Regulations can define the zones as "'allocated impact zones' within which the numeric water quality limits may be exceeded for the non-toxic category of pollutants" (Kimes 1995). Normally, with surface water disposal, the concentrate sinks to the ocean bottom and a quantitative boundary is established where the salinity regulations allow it to exceed normal limits. With submerged disposal, an initial dilution zone is established where the mixing zone definition is the distance the plume travels before it contacts the ocean bottom (Kimes 1995). Most at risk are the benthic marine organisms living at the sea bottom. The increase in salt concentration disrupts the ecosystem, leading to dehydration, decrease of turgor pressure, and death. The species' tolerances to the increase in salinity vary. Studies have shown that long abdomen invertebrates are more sensitive to high salinities than short abdomen invertebrates (Mickley 2001).

Discharge at the coastline may be appropriate, depending on the surroundings and the properties of the receiving water. If the area is highly populated, coastline disposal may be a problem, because of the interference of the mixing zone with recreation on the beach. This is especially noticeable on days when the sea is calm and little to no natural dilution occurs.

Small-scale desalination plants studied in Florida, those which dispose directly into the sea or use a short discharge pipe, showed no environmental impact on the animal and plant life near the outlet pipes (Mickley 2001).

The EPA has developed two different computer models to study the dispersion of buoyant discharges (Kimes 1995): the B-CORMIX code developed at the EPA Environmental Research Laboratory in Athens, Georgia, and the PLUMES code developed at the EPA Pacific Ecosystems Branch in Newport, Oregon. These computer programs are helpful in predicting different dispersion rates and environmental effects of concentrate disposal.

Disposal to Front of Wastewater Treatment Plant. The option to dispose the concentrate to the front or headworks of a wastewater treatment plant or publicly owned treatment works (POTWs) is the second most common practice for concentrate disposal (Mickley 2001). The major concern with this disposal method is that if the concentrate volume is too large, the level of TDS in the concentrate influent can have a significant impact on the biological treatment process, possibly to the point of disrupting treatment performance. Another concern with this disposal method is the potential for TDS increase in the processed water (wastewater treatment plant effluent) and the probable reduction of plant treatment capacity. Conventional wastewater treatment plants do not remove TDS, which remains in the discharge water from the treatment plant. The high TDS content of treated wastewater poses an environmental concern if the plant returns the treated water into surface water systems. Some reuse options such as land application, as described later, may be considered.

Disposal to End of Wastewater Treatment Plant. Because of the disadvantages of disposing of the concentrate at the front of the wastewater treatment plant, some plants opt to dispose the concentrate to the end of the treatment process by mixing the concentrate with the treated water. Because the concentrate is free of viruses and large amounts of contaminants, it is not necessary to process the concentrate through the wastewater treatment. Mixing the low TDS effluent from the POTW with the high TDS concentrate dilutes the brine and reduces the load input to the POTW (Hoepner 2002). The major disadvantage of this method is that bringing the brine stream to the wastewater treatment plant requires constructing a separate pipeline to carry the brine stream. Because water treatment plants and wastewater treatment plants are generally located as far apart as possible, the demand for a long, large diameter pipeline (most often with pumping facilities), translates to additional costs.

Land Application. This method of concentrate disposal includes using spray irrigation, infiltration trenches, and percolation ponds. It provides an opportunity for a beneficial use of concentrate, which can be used to irrigate salt-tolerant crops and grasses such as those used on golf courses. The feasibility of land application depends on the availability of land, the local climate, vegetation tolerance to salinity, and the location of the groundwater table. According to a survey of concentrate disposal methods in the U.S., Florida is the only state that currently uses land application for concentrate disposal (Hoepner 2002).

Deep Well Injection. Deep well injection is the practice of injecting concentrate into aquifers that are not used for drinking water. Injection wells depth range from 0.2 miles to 1.6 miles below the earth's surface (Tsiourtis 2001). In many locations, deep well injection is not feasible because of geologic conditions or regulatory constraints. Florida is a state where the geologic condition is considered suitable for deep well injection (Ahmed et al. 2000). In Florida, there are at least 70 deep injection well systems used mostly for wastewater disposal, but some serve for concentrate disposal as well. An underground layer known as the 'Boulder Zone' where wells are formed from masses of fractured rock, isolated by impermeable dolomite and limestone from the surrounding aquifers, provide a suitable environment for deep well injection.

To prevent contamination of drinking water sources, injection wells must be separated from aquifers developed for drinking water purposes. Monitoring wells should be installed along with injection wells and operators should check monitoring wells regularly to detect any changes to groundwater quality. Deep injection wells should also be subjected to tests for strength under pressure and checked for leaks that could contaminate adjacent aquifers (Ahmed et al. 2000). The above constraints increase the overall cost of deep well injection for concentrate disposal.

Evaporation Ponds. Evaporation ponds are constructed ponds where water from concentrate is allowed to evaporate while the remaining salts accumulate in the base of the pond. These ponds have historically been used for salt production, but now prove to be an effective method for concentrate disposal as well. Evaporation ponds are used in areas that have warm climates and high evaporation rates. The size of an evaporation pond greatly depends on the evaporation rates in the region. It is important that evaporation ponds have liners in order to prevent saline water from leaking into the groundwater aquifer and the pond water should be maintained at a significant depth to prevent liners from drying and cracking (Tsiourtis 2001). Evaporation ponds are a cost-effective option for inland plants to dispose of concentrate. However, they are modestly land-intensive and also cause significant loss of the basic water resource through evaporation.

Zero Liquid Discharge. Zero liquid discharge (ZLD) techniques use a type of mechanism (evaporator) to convert a liquid concentrate into a dry solid. Therefore, instead of concentrate disposal, this option deals with solid waste disposal. ZLD can be the only disposal option for areas where surface water, sewer disposal, and deep well injection are either not feasible or prohibited. The solid waste generated from the ZLD process can be put in a landfill, but it may pose problems with chemical leaching into the groundwater if the landfill is not designed appropriately (for example, no liners). The ZLD process is a high-energy cost technique. ZLD warrants further research and development to reduce costs and to recover or capture water that is lost through the evaporation process.

Brine Concentrators. Typical concentrate flow from a desalination plant is equivalent to about 25 percent of the feedwater flow. Brine concentrators can reduce the volume of concentrate to about 2 percent of feedwater flow (Tsiourtis 2001). The brine concentrator process uses heat exchangers, deaerators, and vapor compression to convert liquid concentrate to concentrated slurry (Ionic RRC 2004). With a brine concentrator, 95 percent of wastewater can be recovered as high purity distillate with less than 10 mg/L of TDS concentration. The remaining (5 percent) concentrated slurry can be reduced to dry solids in a crystallizer to dry solid cake, which is easy to handle for disposal. The spray dryer is another method for dewatering the concentrated slurry, which transforms the slurry into a fine powder of mixed salts for disposal. It also atomizes the wastewater slurry inside a hot chamber, instantly vaporizing the water droplets and leaving only dry salts behind. The concentrated brine can be further processed by the ZLD technique, or added to lime settling ponds where the solids will form sludge. It could also be transported to a salt manufacturing company.

Concentrate Disposal Case Studies

The Suffolk, Virginia plant originally disposed concentrate from its electrodialysis reversal (EDR) desalination plant in a nearby stream. That disposal method, however, did not properly separate the concentrate and the high fluoride content of the concentrate was determined to be toxic to the aquatic environment. The plant managers developed an alternative method of disposal and to attain a discharge permit. The new method of concentrate disposal at Suffolk EDR plant incorporates diffusers to dispose of the concentrate in the Nansemond River. The plant is required to renew the permit every 5 years and submit on a quarterly basis acute toxicity tests to the Virginia Department of Environmental Quality.

The state of Florida has developed the “hothouse evaporation shed” method for brine disposal. In this method, the concentrate flows to a container, and a system of fans and sprinklers disperses the concentrate through the high humidity air encouraging evaporation to occur. In California, a new technology is under study to dispose of an inland plant’s concentrate to a saline vegetative marsh (Hoepner 2002). Another proposed method is using an oil field injection method for concentrate from a brackish water reverse osmosis plant in California (Hoepner 2002). The San Diego County Sweetwater Authority suggests using coastal

Table 4. Summary of Concentrate Disposal Techniques

Disposal Option	Environmental Concern	Mitigation Method
Surface Water	Contamination of receiving water	See Table 3
Sewer System Blending	Contamination of eventual receiving water	Reduce recovery; membrane type selection
Land Application	Contamination of underlying groundwater, and of soil	Reduce recovery; blending membrane type selection
Deep Well Injection	Contamination of overlying drinking water aquifers due to well leakage	Move disposal location or change means of disposal
Evaporation Ponds	Contamination of underlying higher quality aquifers due to pond leakage	Double lining with leachate collection system
Zero Liquid Discharge	Contamination of underlying higher quality aquifers due to landfill leakage	Double lining with leachate collection system

Source: Mahi, 2001

wetlands for the concentrate disposal. Despite the high costs, it can mitigate the project's environmental impact (Muniz and Skehan 1990).

The Sweetwater Authority in San Diego County evaluated several concentrate disposal options that included the discharge to the San Diego Bay, coastal wetlands, existing sewer networks, South Bay outfall or using deep well injection. Discharge to the Bay should meet regulatory requirements of the San Diego Regional Water Quality Control Board for the potential impact on the marine environment. The sewer system is not considered a practical choice without additional construction that could handle the concentrate transport. The South Bay discharge is an option, but the authority would need to construct 5-miles of transport pipes to carry the concentrate to the outfall. The deep well injection option requires an environmental impact assessment to demonstrate that the concentrate will not negatively affect the groundwater. The most affordable option for the authority was surface water disposal to the San Diego Bay. However, the authority is considering concentrate disposal to brackish water coastal wetlands–the best option to minimize environmental impacts (Everest and Murphree 1995).

Table 4 shows summary of common concentrate disposal techniques and mitigation methods.

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