Chapter 4
Disposal to Surface Water

Abstract This chapter discusses disposal to surface water, the most common method of concentrate management. This includes concentrate that is directly disposed of into rivers, creeks, lakes, oceans, bays, and other bodies of water. Concentrate is piped to the site of disposal, where it is discharged to the receiving body of water via an outfall structure. The environmental impacts of surface water disposal may be lessened by diluting the concentrate prior to discharge, or by dilution of the concentrate through the design of the outfall structure and diffusers. Pretreatment processes that lessen the impact on the environment should also be considered.

Keywords Concentrate blending · Concentrate transport · Costs · Disposal regulations · Environmental concerns · Outfall design

4.1 Site Selection

The availability of a body of water for disposal is a major consideration in the siting of desalination plant. Even with a suitable body of water, the outfall needs to be designed and located to reduce environmental impact. The extent of mixing and dilution based on the properties of the concentrate and the receiving water must therefore be considered. The behavior of concentrate following discharge is determined by its salinity, density and flow rate, as well as the hydrography and biological properties of the receiving body of water. These include depth, volume, temperature, water composition and additionally for ocean outfalls, tides, waves and currents (Lattemann and Höpner 2008). Due to the variation in these conditions, each receiving body of water will be unique, and so the specific conditions and impacts must be determined on a case-by-case basis before any discharge can occur.

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Perhaps the most pertinent characteristic that will determine its mixing and dilution is its density. The density of the concentrate varies with salinity; concentrate with a salinity higher than the receiving water will be negatively buoyant, and that with a lower salinity will be positively buoyant. Unless diluted prior to discharge, membrane concentrate will have a greater salinity and hence greater density than the receiving water. This results in a plume which sinks upon discharge.

Seawater desalination plants almost exclusively use surface water disposal, and they are often sited so that concentration may be discharged directly back to the ocean with minimal environmental impact. It is recommended that ocean discharges be located along open coast, as opposed to locations where there will be minimal water movement, such as estuaries (Watson et al. 2003). Ideal ocean bottom profiles are ones which achieve a sufficient depth quickly, as this reduces the require length of the outfall pipe and decreases costs (Mauguin and Corsin 2005).

Inland desalination plants are much more limited in the availability of a suitable discharge site. Inland water bodies are often high in quality and have potential for use as water sources, limiting their suitability. Disposal is only feasible if the quality of the concentrate is high enough to be compatible with the receiving body of water (Younos 2005).

If the concentrate is discharged to the same body of water as the feed water source, both the intake and outfall should be located so as to not to interfere with one another. The presence of any other local desalination or wastewater discharge is an important factor, as these may increase the salinity of the receiving water or reduce its quality, thereby reduce the compatibility of the concentrate.

4.2 Design

The two major design factors for surface water discharge are the transport of concentrate to the outfall site, and the design of the outfall structure. The design of the transport system and the outfall structure will depend upon the proximity of the plant to the site of disposal, and the body of water into which the concentrate will be discharged.

4.2.1 Concentrate Transport

Concentrate must be transported from the desalination plant to the site of disposal, typically done via above or underground pipework. Tunneling and the installation of underground pipework is more costly than aboveground pipework, however this can be necessary when the outfall is located underwater, or when the plant is located some distance from the discharge point. The pipes used to transport concentrate should be resistant to corrosion. This can be done by constructing them from corrosion resistant steels with coatings to prevent oxidation, utilising cathodic protection, or using plastic instead of steel (Bergman 2007). When there are no other feasible concentrate disposal options, some inland sites may be required to haul brine to an ocean site for disposal.

4.2.2 Outfall Structure

At the site of discharge, the concentrate is released into the water via an outfall. A well-designed outfall structure should be effective in promoting mixing and helping minimize potential environmental impacts. The variety of outfalls range from simple discharge from the end of a pipe, to more complex structures involving long multi-port diffusers. The specific design of the outfall will be based on the expected mixing and dilution of the brine, and its compatibility with the receiving water. This particularly refers to the density and buoyancy of the concentrate.

Unless the body of water has a high flow rate or high turbulence that allows for sufficient dilution, simple discharge from the end of a pipe should be avoided. This type of simple outfall is more suited to small discharges into ocean tidal zones where large amounts of energy allow for rapid dilution and mixing (Voutchkov et al. 2010). Larger concentrate volumes should avoid discharge into tidal zones to prevent the accumulation of salt in these areas (Voutchkov et al. 2010). The use of diffusers is far more common, which is a pipe or series of pipes with numerous discharge ports. These can be designed to meet mixing and dilution requirements based on the concentrate and the receiving water. A longer pipe with multiple ports increases dilution by spreading the discharge out over a wider area. To maintain a constant discharge flow along the pipe and to allow for a better dilution, the size of the discharge ports increases along the pipe as the pressure head decreases.

Dilution can be promoted by the velocity of the discharge at each port, and the angle of discharge. Figure 4.1 shows the general geometry of a jet of dense concentrate discharging into a body of water. The optimal angle and velocity of the discharge will vary with the outfall depth, the incline of the sea bed, and the local currents and tides. Discharge velocity, and hence the level of dilution that can be achieved, is largely influenced by the nozzle diameter. Smaller nozzles help to promote greater dilution, and increase the vertical and horizontal distance of the jet (Cipollina et al. 2004). Currents and tides can also improve the mixing of concentrate if the discharge is orientated correctly.

The modeling and optimisation of concentrate discharge to reduce environmental impacts has been the focus of numerous studies (Al-Barwani and Purnama 2007, 2008; Alameddine and El-Fadel 2007; Bleninger and Jirka 2008; Malcangio and Petrillo 2010; Purnama and Al-Barwani 2004; Purnama et al. 2003). Much of this research has been for a project by the Middle Eastern Desalination Research Center, Environmental Planning, Prediction and Management of Brine Discharges from Desalination Plants.

Numerous software packages can be used to assist in the design and optimisation of outfall structures. *CORMIX* is a software modeling package designed to

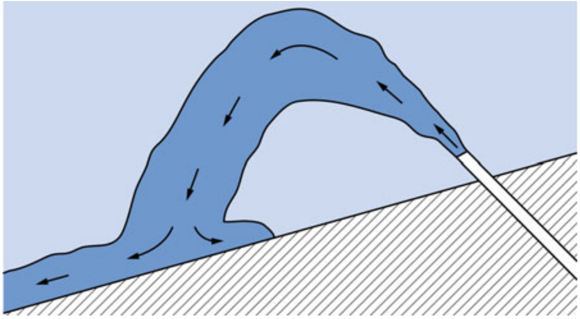

Fig. 4.1 A negatively buoyant discharge jet releasing concentrate into a body of water with a inclined bed

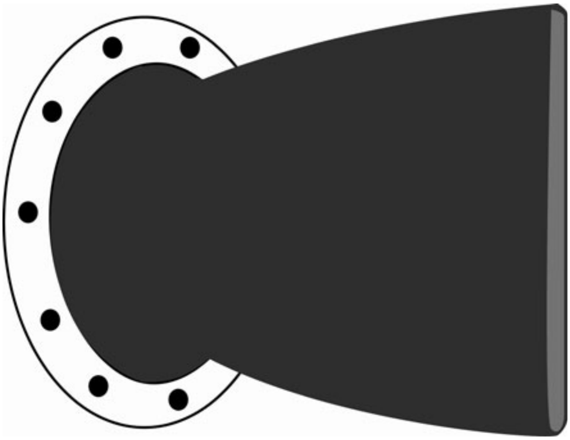

Fig. 4.2 Typical duckbill valve in a closed position that may be used on an outfall to prevent backflow

model mixing zones of brine discharges and is a useful tool for environmental impact assessments (Mixon Inc 2011). Additionally, *Plumes* has been developed by the American EPA to primarily model wastewater discharge, however it can also be applied to concentrate discharge (United States Environmental Protection Agency 2011).

To prevent backflow and to prohibit organisms entering the pipe, duckbill valves can be installed on the end of diffuser ports. An example of this can be seen in Fig 4.2. These valves can be selected with varying operating pressures to ensure all valves along a diffuser open at the same time as the pressure of the concentrate drops along the pipe (Mauguin and Corsin 2005).

4.3 Costs

Discharge to surface water is the most economical form of concentrate management for seawater desalination plants, regardless of the discharge volume. Due to the availability of ocean discharge for seawater desalination plants, the cost of disposal tends to be less costly than for inland desalination. Costs include pumps and pipes, any pretreatment prior to discharge, the outfall structure, and the monitoring of the receiving water quality. In some instances, pumps may not be required if the pressure of the concentrate is high enough to transport it to the site of disposal.

Pipe costs increase with increasing volume and increasing distance between the desalination plant and the site of disposal. While discharge from the end of a pipe can be quite inexpensive, costs will begin to increase the further the outfall is from the shore, the deeper the outfall is, and the more complex the outfall structure design is. This is particularly due to dredging, trenching and tunneling, which can be three to four times more expensive underwater than on land (Mickley 2006). The cost of these civil works are approximately 3% of the total construction cost for a seawater reverse osmosis plant (Sommariva 2010). The cost of monitoring will vary based on the environmental sensitivity of the discharge area (Schliephake et al. 2005). The overall cost of disposal may be reduced through the simultaneous discharge of multiple effluent streams from different sites.

4.4 Environmental Concerns

Concentrate can be harmful to the environment due to either its higher than normal salinity, or due to pollutants that otherwise would not be present in the receiving body of water. These include chlorine and other biocides, heavy metals, antiscalants, coagulants and cleaning chemicals. Of particular concern is the effect of pollutants on delicate ecosystems and endangered or threatened species. However, with appropriate measures in place, the discharge of concentrate to surface water can remain a viable method for seawater desalination plants.

4.4.1 Increased Salinity

As a result of the high density and negative buoyancy of membrane concentrate, benthic communities and other non-mobile species are most affected by increases in ambient salinity. Most organisms will generally be able to adapt to minor changes in salinity, and while some species may adapt well to an increase in salinity, many will not be able to withstand long-term exposure to higher than normal concentrations (Lattemann and Höpner 2008). Unfortunately, little data is available regarding the tolerance of various species to changes in salinity. It has been estimated that benthic communities can withstand variations in salinity of ±1000 ppm (Del Bene et al. 1994). For most marine organisms that live in seawater, the salinity tolerance can be up to and potentially even greater than 40% of the average annual ambient ocean salinity concentration (Voutchkov et al. 2010).

4.4.2 Pretreatment Chemicals

Any FRC that may be present in the concentrate is known to be toxic, and can have severe impacts on marine life. However, following dechlorination with sodium bisulfite, the level of free residual chlorine in the concentrate is often quite low, and quickly decreases after discharge as it dissipates and degrades (Lattemann and Höpner 2008). Chlorine also has potential to form halogenated compounds, and although these can be dangerous to marine life, their concentrations are often well below the FRC concentrations, and hence considered less toxic (Lattemann and Höpner 2008).

Antiscalants are found in small concentrations in desalination discharge. Polymer antiscalants are of low toxicity, and have little environmental impact (Lattemann and Höpner 2008). In aquatic environments, polymer antiscalants behave in a similar manner to humic substances, and they are unlikely to accumulate in aquatic life (Lattemann and Höpner 2003).

Coagulants, which are present in filter backwash, are of low toxicity and are not considered a major environmental concern. One of the greatest effects of coagulants comes through the use of ferric salts, which are likely to cause colouration and increase the turbidity of the backwash (Lattemann and Höpner 2008). The quantity of coagulants in the concentrate can in part be regulated by the slow release of filter backwash from a buffer tank into the concentrate flow.

4.4.3 Cleaning Chemicals

Most cleaning chemicals used for membrane desalination plants are harmful to the environment. Common cleaning chemicals are outlined in Table 2.5. These cleaning solutions should be treated prior to discharge with membrane concentrate, or sent to a location where appropriate treatment can occur.

Discharge of solutions which are either basic or acid are dangerous to marine life, and should be neutralised prior to discharge. This can be achieved with a buffer tank to store and neutralise acidic and alkaline solutions with each other. Seawater may also be used to neutralise cleaning solutions.

Compared with the volume of concentrate, the volume of cleaning solution is relatively small. To reduce environmental impacts, as well as costs associated with cleaning, the quantity of chemicals that are used can be reduced through an effective pre-treatment process.

4.4.4 Heavy Metals

Metal in the discharge can come from the source water, or be a product of corrosion. Note that due to their operation at elevated temperatures, when compared with membrane desalination plants, thermal desalination plants are more likely to have occurrences of pipe corrosion and hence metals present in the discharge.

Upon discharge, metals form organic and inorganic complexes, or absorb to reactive surfaces, and subsequently sink, leading to an accumulation in sediments (Höpner 1999). Due to this, benthic organisms may be more likely to assimilate metals from the discharge (Lattemann and Höpner 2008). Metals can have acute effects on marine organisms, however membrane concentrate has very low concentrations of metals, and so their environmental impact is usually minimal.

4.4.5 Dissolved Gases

Concentrate from membrane desalination plants may have low levels of dissolved oxygen, and high levels of hydrogen sulfide and carbon dioxide. Low levels of oxygen can be harmful to aerobic marine organisms. This may be a result of the characteristics of the feed water, or from the use of sodium bisulfite for dechlorination (Lattemann and Höpner 2003). Increasing salinity contributes slightly to the amount of dissolved oxygen in the concentrate, since the solubility of oxygen decreases as the salinity increases. High levels of hydrogen sulfide and carbon dioxide may also occur in the discharge as a result of the feed water characteristics. Low amounts of dissolved oxygen and high amounts of dissolved hydrogen sulfide and carbon dioxide are more likely to occur from brackish water sources than from seawater. Prior to discharge, the concentrate can undergo processes of aeration and degasification to increase dissolved oxygen content and to reduce the concentration of hydrogen sulfide and carbon dioxide.

4.5 Concentrate Blending

When the design of an outfall is unable to produce a sufficiently diluted mixing zone that is below the maximum permitted concentration, additional dilution prior to discharge may be necessary. Brine may be diluted prior to discharge by blending it with wastewater from treatment plants, power plants, or other water sources that may be available. Blending reduces the concentration of the discharge and brings its salinity closer to that of the receiving body of water, allowing for more rapid mixing and dilution. Further benefits include reduced capital costs of building additional tunnels and outfall structures, and the possibility of a modified discharge permit, rather than an application for a new one (Mickley 2009). It is important to note that dilution may not necessarily negate the effects of chemicals in the discharge, as the total load and the accumulation over time determines the environmental impact (Höpner 1999).

4.5.1 Blending with Sewage and Wastewater

In some instances, discharge is made directly to a sewer where it subsequently passes through a wastewater treatment plant. Due to the adverse effects that high salinity can have on these plants, this is generally only suitable with small flows of concentrate into relatively large treatment facilities. Due to its low salinity, concentrate from both microfiltration and ultrafiltration plants is often discharged to sewer (Schliephake et al. 2005).

Discharge to sewer will need to be approved by the downstream wastewater treatment plant. The viability of disposal is governed by the downstream treatment plant's capability to handle both the volume and concentrate of the brine, and the final concentration of the effluent from the facility. If the salinity of the concentrate is too high, it may hinder the biological treatment process (World Health Organisation 2007). Furthermore, if the salinity of the treatment plant's effluent becomes too high, environmental and regulatory problems may be encountered during final disposal. In this case, additional permits or alternative disposal solutions may be required for the wastewater plant. Desalination plants may also be required to pay a fee to the wastewater treatment plant.

Alternatively, if the desalination plant is located near an existing wastewater treatment plant, the concentrate may be blended with the treatment plant's effluent before final disposal to water. This process improves the mixing of the discharge with the receiving water by blending a high salinity, negatively buoyant stream with a low salinity, positively buoyant stream. In this instance, the existing wastewater treatment plant outfall must be able to handle the capacity of the combined discharge. Additional fees to the wastewater treatment plant may also be necessary. Unfortunately, this method of disposal is not widely practiced and has limited applications as a result of the necessary conditions, including the capacity limitations of the outfall, and the environmental impacts of the blended streams (Voutchkov et al. 2010).

Examples of desalination plants that currently blend their concentrate with treatment plant outfall include the Thames Water Desalination Plant in London (150,000 m^3/day capacity) and the Barcelona Seawater Desalination Plant (200,000 m^3/day capacity).

4.5.2 Blending with Power Plant Cooling Water

Co-location of a power plant and a seawater reverse osmosis desalination plant allows for the cooling water from a neighbouring power plant to be blended with the waste from a desalination plant before discharge (Voutchkov 2004). In such a process, seawater is used as the cooling water for the condensers in a power plant. This water is then used as both the feed for the desalination process, and for blending to dilute the concentrate from the desalination plant.

From a concentrate disposal point of view, a number of benefits exist from the co-location of a desalination plant and a power plant (Voutchkov 2004). These include the dilution of the concentrate to improve its compatibility with the receiving water, and cost reductions in sharing an outfall structure. When the concentration of the discharge is reduced, the environmental impacts of high saline discharge are minimised. The salinity of the discharge can be as low as the natural variation in seawater, and so this lower saline discharge requires a shorter outfall and less complex diffuser design. Additionally, the dense, negatively buoyant concentrate is countered by the warm, positively buoyant power plant discharge, further increasing the compatibility of the concentrate. This reduces the extent of the mixing zone, and reduces the amount of time needed for adequate mixing and dilution. The practice of co-location has been successfully implemented in Tampa Bay, Florida, which has an input of 166,000 m^3/day from the neighbouring Big Bend Power Station (Water Technology 2011).

Co-location is not be suitable for all desalination plants. This process only becomes feasible if the volume of cooling water discharged from the power plant is at least three to four times greater than the capacity of the desalination plant (Voutchkov 2004). Furthermore, corrosion from power plant heat exchangers may elevate the levels of metal in the feed to the desalination plant, which may then damage the reverse osmosis membrane units (Voutchkov 2004).

4.6 Regulations

Regulations vary according to the discharge location and the relevant governing body. The approval of a discharge permit will depend on a comparison between the water quality standard of the receiving body, and the quality of the concentrate (Mickley 2006). If regulatory requirements cannot be met upon discharge, a mixing zone may be defined. This is a quantified area or volume of water in which the water quality may exceed regulated standards. The monitoring of TDS and pollutant levels is required within the specified mixing zone. Discharge limits can be placed upon total suspended solids (TSS), TDS, salinity and other specific contaminants (Bergman 2007).

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