Chapter 23
Innovations in Design and Monitoring of Desalination Discharges

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Abstract Seawater reverse osmosis desalination systems produce brine (concentrate) that normally must be discharged back to the sea. The concentrate can have up to twice the salinity of the feedwater and can cause environmental impacts to the marine environment. Innovation in the design and evaluation of diffuser systems has led to reductions in potential environmental impacts by causing rapid dispersion of the high salinity plume. The nearfield and farfield models used to assess potential environmental impacts of the dense water discharge have also been improved to allow assessment of impacts and to make design changes that lessen them. The selection of discharge sites has been improved by the ability of obtaining rapid and accurate bathymetric and water quality data that can be used in models to assess circulation and other aspects of outfall design and to monitor and assess potential discharge impacts.

23.1 Introduction

Continued population growth and insufficient natural freshwater supplies in arid and semi-arid regions press the need for increased use of seawater desalination as a new freshwater supply source. These needs often conflict with the desires and regulations of the regions that demand preservation of environmental quality to maintain healthy natural ecosystems. The environmental impacts from desalination plants lay both on the intake and discharge sides of the operation. The desalination reject water consists of not only of the brine and other components concentrated through the desalination process, but also includes antifouling agents, antiscalants, coagulants, anti-foaming agents and cleaning chemicals added to the water to maintain efficient operation of the facility (Lattemann and Höpner 2008).

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Thus, implementation of desalination facilities that minimize impacts on the coastal environment requires mechanisms to offset the characteristics of the discharged effluents. Discharge outfalls that create adequate dilution continue to be a primary tool for reducing the alteration of the ambient environment near the discharge. Effective dilution is accomplished through the design of outfalls with diffusers that facilitate the dilution of the effluent within the ambient environment. The design and evaluation of these outfalls is most often accomplished with laboratory fluid modeling where a range of flow and stratification conditions can be readily tested. Numerical modeling is much more effective. The effectiveness of these approaches can be evaluated in the planning stages with modeling and once in place, continued modeling and monitoring efforts provide a evaluation of the desired performance and environmental impacts on the local system.

23.2 Innovations in Outfall and Diffuser Design and Evaluation

Recent advances in laboratory fluid modeling and imaging along with the dimensional analysis that is common practice in environmental fluid mechanics have provided insights into the complexities of the initial mixing processes. These techniques provide analysis of individual port configurations (such as single port, multiport, rosette style diffusers, etc.) and in the process provide 3-dimensional resolution of the flow and turbulence within the resulting effluent flows (Chaps. 17, 18 and 19). These experiments have led to optimization of port design in terms of port angle, alternating port directions and alignment angle of the ports for rosette diffusers. The complexity of the fluid dynamic processes, such as Coanda dynamical interaction, is often difficult for numerical modeling to simulate. But scaled laboratory models provide sufficient resolution of these processes that they can be transferred to inputs for far-field models.

The results from the nearfield modeling and parameterization of nearfield processes can then be incorporated into a tiered approach to planning, design and implementation of new effluent discharges. These tiered approaches utilize the capabilities of the nearfield models along with evaluation of the environment of the receiving waters, and environmental regulations to evaluate optimal locations, diffuser and outfall design and desired performance objectives for the design and construction of the outfall. Following the initiation of the operation of the outfall, the tiered approach can be applied to performance evaluation and environmental monitoring to validate the performance of the models and predictions.

The nearfield models provide input into the farfield models that are used to evaluate the larger scale effects and dispersion of coastal effluent plumes. Some of these results are useful at the scale of the facility itself where the desire is to minimize the interaction between the discharge effluent and the seawater intake for the desalination plant (e.g., Chap. 21). The farfield models provide innovation at the much larger spatial scales that have relevance to regional and extended temporal impacts from the discharge.

23.3 Innovations in Nearfield and Farfield Modeling

A variety of approaches are taken for farfield modeling of effluent plumes. As there are various numerical approaches to the farfield modeling, the approach taken will depend on the environment and scale where the model is to be applied. Often 2-dimensional approximations can be quite effective in shallow coastal regions where a combination of tidal currents and/or wind mixing are likely to create a well-mixed water column that can be treated with two-dimensional solutions. These techniques can be applied to all types of effluent discharges, and as is happening more frequently, outfalls may combine discharges from thermal, waster water, and/or desalination discharges (Chaps. 18 and 20). In many coastal situations where stratification is important, and the accompanying stratification complex with vertical and horizontal current variability, more sophisticated three-dimensional modeling will be needed (Chap. 21; Uchiyama et al. 2014). The models often used for the farfield coastal modeling come from both commercial software systems such as Delft-3D (Chap. 18) and from various community tools such as the Regional Ocean Modeling System (ROMS), or the MIT Global Circulation Model (MIT-gcm). While these models may differ in the specific details of how they handle the numerical details of the model, they are usually similar in that they solve the Navier-Stokes equations with the Boussinesq approximation. However, the ability of these models to provide detailed, accurate representations of the farfield dispersion processes is improving at least as rapidly as the sophistication of our computing resources, with new, larger multi-core supercomputing resources providing ability to run models at finer spatial scales and, if needed, time steps.

These advances enable high resolution coastal models that are nested within larger ocean schemes that provide realistic open-ocean forcing and coupling with global processes (Chap. 22; Chao et al. 2009; Uchiyama et al. 2014). These models have the capability to function in real-time providing both nowcasts and forecasts of the region and the relevant discharge plumes through the assimilation of the more comprehensive data streams that are becoming available through coastal ocean observatories (e.g. Chao et al. 2009; Hoteit et al. 2008; Korres et al. 2012). Retrospectively, these models provide the ability to estimate detailed statistical analysis of plume dispersion over a wide range of realistic oceanographic conditions. Ultimately, as these techniques improve these modeling efforts will include full characterization or the wave field and wave-induced nearshore circulation. While not likely to attain the resolution down to the jet scale, the models are already approaching the resolution of the nearfield (tens of meters) required to resolve the entrainment into the coastal circulation.

23.4 Innovations in Environmental Monitoring

As with design and modeling of outfalls, techniques for monitoring of ocean outfalls are also rapidly evolving. From the early days of outfall monitoring where positioning a boat that could obtain water or benthic samples over some sort of sampling grid agreed upon with the regulators, to the modern ocean observatories, sensor and observing platforms and resources have changed dramatically.

Tracer techniques have been routinely used to evaluate the actual performance of ocean outfalls once the outfalls are activated. Monitoring of outfalls off the coast of New South Wales, Australia have utilized dye studies to measure the initial dilution and dispersion from a desalination brine discharge. Dyes are often introduced when unambiguous indicators from a discharge source are required (Percly and Roldao 2013). With wastewater outfalls, there is often sufficient dissolved organic matter in the wastewater, that it provides a signal well above ambient concentrations that also provides an unambiguous tracer for the discharge (e.g. Petrenko et al. 1997; Rogowski et al. 2013; Chap. 22).

Because brine discharges, especially from RO plants, are dense plumes, they spread horizontally near the bottom and therefore are most likely to affect epibenthic and benthic assemblages of organisms. The impacts of these discharges on the local benthic communities are a large concern for the long-term operation of desalination facilities. Examining both the existing population and the recruitment to the area are required to evaluate the effect of the discharge on the environmental health (Natural Solutions 2006; Natural Solutions and SKM 2006). Examples from New South Wales indicate that significant effects are constrained within the zone of initial dilution and that the natural annual variability of species abundance and community structure is greater than the differences that appear between the near-field community and the reference communities. Although not discussed within this book, modern molecular biology techniques may provide more sensitive measurements of organismal response to environmental stress. Genomic and transcriptomic methods may provide sensitive indices of environmental stress that may not be immediately evident in the more traditional environmental impact assessment methods where community structure is often used to evaluate differential effects of a discharge.

The rapid development of more sophisticated in situ sensors and autonomous vehicles has transformed our ability to observe discharge plumes in the environment. Modern chemical and optical sensors combined with both propelled and buoyancy driven vehicles enable rapid and sustained (respectively) monitoring of these discharge plumes. Propelled vehicles such as the Hydroid Remus vehicle are capable of terrain following with precise navigation so that a dense brine plume can be more easily traced (van der Merwe et al. 2014; Rogowski et al. 2013). An additional advantage of the propelled vehicles is their ability to cover a relatively large area rapidly, traveling at 3–4 knots (5.5–7.4 km/h).

Buoyancy driven gliders, while lacking the speed of the propelled vehicles, have the ability to sustain continued observations over periods up to several months

(Chap. 22). An example of deploying a glider equipped with physical and optical sensors near a wastewater outfall demonstrates that the sustained observations provide snapshots of the plume over time and these observations can be transformed into statistical products that are useful for comparison with the statistics from model simulations (e.g. Uchiyama et al. 2014). These tools also provide inputs of temperature, salinity, and density that can be transmitted in near real-time for assimilation into real-time operational nowcast/forecast models, thus improving model estimates in real-time.

23.5 Discussion and Conclusions

The combined capabilities of laboratory and numerical models for design and implementation, improved monitoring techniques for the coastal environment, with real-time observations and modeling enable us to better understand, manage, and predict the impacts of placing desalination facilities in strategic areas of freshwater need. Bleninger and Morelissen (Chap. 18) have outlined a tiered approach to analysis and design of new discharges from various types of discharges. Lattemann and Höpner (2008) have indicated that an integrated, methodological approach to design, placement and monitoring of desalination facilities is required. Modeling tools from the initial dilution and nearfield (Chaps. 17, 18, 19 and 22) to the farfield (Chaps. 21 and 22) are now available for evaluation of plume processes at all relevant scales. Monitoring approaches and the required tools have evolved rapidly (Chap. 22), but it is expected that these capabilities will continue to evolve and improve.

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