

National-scale Management and Protection of Desalination Plant Water Supplies

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Abstract

Freshwater demand is set to outstrip supply in many parts of the world, with the effects of changing climate, evolving land use, and industrial development. Several countries already rely on seawater desalination as their key source of potable water. Desalination plants require a constant supply of clean seawater, and are therefore vulnerable to pollution from marine outfalls, coastal construction activities, and shipping. National-scale management plans are necessary to ensure that coastal developments and facilities are coordinated to prevent harmful effects on these vital plants, and to protect the environment. This involves management and integration of multiple stakeholders and governing bodies. The authors use multiscale hydrodynamic and pollutant dispersion modelling to provide advice to national water authorities, who are consultees in the permitting processes for new developments close to sensitive desalination plants. In this paper, key strategies of management and mitigation are presented.

Keywords: Desalination; Outfalls; Intakes; Water Quality, Hydrodynamic Modelling

1. INTRODUCTION

Seawater desalination is an essential component in the supply of potable water to arid regions. For GCC countries such as Saudi Arabia, seawater desalination is the principal source of freshwater. Demand is set to increase (see, for example, DeNicola et al., 2015), due to several factors including climate change. Modern methods of desalination based on seawater reverse osmosis (SWRO) provide freshwater with low energy input, but rely on filtration through membranes that are sensitive to clogging by sediments and scale, and contamination and degradation due to pollution and biofouling.

Desalination plants are often built near major industrial complexes or rapidly expanding cities, where water demand is high, but coastal access is in short supply. Examples include the large SWRO plants at Al Jubail in Saudi Arabia, and Taweelah in Abu Dhabi, UAE. The marine intakes of the plants are therefore vulnerable to a variety of anthropogenic pressures, including construction activities, pollution from nearby marine outfalls, coastal development, and navigation.

For the last two decades, the authors have been working with national environmental regulators, government planning departments, national power and water authorities, developers and industries to manage and mitigate against the cumulative effects of new developments on the intakes of a range of desalination plants and other coastal facilities. Most recently, techniques have been applied to develop so-called buffer zones to regulate and guide sustainable development, while protecting intake operation.

2. THREATS TO DESALINATION PLANT OPERATION

Coastal desalination plants draw seawater through marine intakes and discharge reject brine at a higher salinity through marine outfalls. These structures may consist of simple culverts at the shoreline, or more complex and expensive submerged pipelines in deeper waters offshore. Desalination developers and operators implement a range of preventative measures to control the quality of seawater entering the plant. These start at the design stage, by ensuring adequate separation between the intake and reject brine outfall, and other known sources of pollution. The plant may include settling basins to remove suspended solids, as well as pre-treatment and filtering to reduce the concentration of potential foulants. Nevertheless, regular maintenance and replacement of SWRO membranes can be required during operation, leading to downtime, reduced output, higher energy costs and expense. Anthropogenic factors can increase the need for maintenance/replacement and, in severe cases, threaten water production entirely. Such anthropogenic factors can include:

- Nearby construction activities and navigation that can directly damage the intake structure;

- Development of new marine outfalls that can increase local pollutant concentrations;
- Nearby dredging and/or reclamation construction activity, which can release high concentrations of fine suspended material, or lead to waste materials forming diffuse pollution;
- Alteration of local and regional hydrodynamics through construction of reclamations, causeways, etc., which can lead to new or worsened areas of stagnation, where poor water quality can develop;
- Deflection and ingress of thermal-saline plumes from other nearby power and desalination facilities;
- Ingress of accidental oil spills from shipping and offshore oil and gas exploration.

Many of these factors are studied through the initial design and planning stages for individual plants, and are often addressed in the Environmental Impact Assessment required before a plant's development is approved. However, particularly in regions that are developing rapidly, it can be difficult for water authorities to collate and review all information on new developments in the vicinity of their plants, in order to provide No Objection letters during consultation.

National-scale "buffer zone" systems can be developed to help in this regard. These define geographical areas in which particular care must be taken when planning developments ("high risk" zones), or where coastal developments should be avoided completely ("exclusion" zones). This enables authorities to screen new developments, track potential risks, and specify mitigation where required.

3. BUFFER ZONES TO PROTECT DESALINATION PLANT OPERATION

This section outlines three key stages in the development and implementation of national-scale buffer zones. These are: stakeholder consultation; hydrodynamic assessment and buffer zone development; and implementation, management and mitigation.

3.1 Stakeholder consultation

Stakeholders in the process may include plant operators, water authorities, planning departments, environmental regulators, and developers.

Plants are visited to gather evidence and raw data to establish baseline marine conditions for the study area. In regional-scale studies, this may cover the coastal waters of a large industrial area; in national-scale studies, this may cover the entire coastal waters of the country.

Plant operators and engineers are interviewed, and secondary data collected (including any records of water sampling), to understand known incidents of poor water quality at the intake. In the authors' experience, this may include periods of high suspended solids, or ingress of waste material that may have blocked intake screens or damaged pumps. The evidence may be analysed to determine whether:

- the incidents occur at particular times of year (indicating, for example, the effects of storms or high seawater temperatures), or
- whether they can be correlated (through discussion with planning authorities) with construction activities that were occurring at the time, and/or daily satellite image analysis to track the potential source of sediment plumes, etc.

Primary data collection may be required to give longer records of water quality, to establish a clear baseline. This can be helpful at facilities where routine sampling is sporadic (for example, with measurements quarterly, or only at times of noticeable poor water quality). The primary data collection may also include hydrodynamic measurements for subsequent calibration and validation of the hydrodynamic model, and vessel-based surveys to track visible sources of pollution back to their source.

Consultation with environmental regulators, urban planning departments, ministries of works and sanitation, etc., is necessary to gather information on all planned and approved developments in the area. This is essential to help to identify potential sources of pollution.

Finally, the water authority will be consulted to determine its regional and national plans for water production and capacity expansion. This will often be tied in to national power generation plans, as the desalination plants are often built alongside power stations. The information gathered from the water authority may include pre-approved locations for new plant development, or decommissioning plans for older plants, which may affect the sensitivity of the intakes in question.

At the end of the consultation stage, a comprehensive data set is established on the baseline and future marine environment, for subsequent hydrodynamic modelling.

3.2 Hydrodynamic assessment and development of buffer zones

The data and information gathered during consultation is used to build a regional/national hydrodynamic model, which will underpin the development of the buffer zones. Hydrodynamic models are established tools for regional coastal planning. When properly applied and validated by experienced modellers, they can predict the effects of proposed coastal developments, including changes to local/regional currents, water quality, the dispersion of outfall discharges, and the transport of suspended sediments and other pollutants.

Modelling the dispersion of reject brine discharged from desalination plants requires high resolution hydrodynamic models. The models must be three-dimensional, to capture the fine vertical structure of the thermal-saline plumes. As water quality at an intake may depend on hydrodynamic conditions and transport from multiple remote sites, the models need to cover regional or national coastal waters. Multiscale finite-element models are required that can cover wide areas efficiently, while providing high fidelity at key sites. Examples include TELEMAC-3D (Hervouet, 2007), which the authors have validated for the simulation of dense plumes from desalination and other facilities (Wood et al., 2014). In the authors' experience, parallel processing and High Performance Computing are essential for this type of assessment, to enable rapid simulation times. This is particularly important to enable the next stage of analysis, in which large numbers of simulations are required.

Once a model has been established for the site and validated using the data collated during the consultation stage, the baseline hydrodynamic conditions can be analysed to identify the key pathways to the site, including streamlines for transport towards and away from each intake. Time-averaging of the predicted current fields allows nodal points to be established (areas of net-zero transport). Flushing patterns are studied to determine areas that are likely to collect pollutants and waste material, and identify areas of high dispersal.

The validated model is then used in a series of forecasting simulations, to establish the regions of influence around each intake. Hypothetical fine sediment plumes, dissolved pollutants and other markers (such as oil) are released into the model, using information gathered during the consultation. The choice of pollutant source locations can be based on nearby streamlines, known hotspots for potential pollution (such as proposed or expanding industrial areas), or simply spread radially or uniformly around the intake (as identified in Figure 1).

The authors have found that identifying pathways to each intake through so-called "backward trajectory" models, which are commonly used in the maritime sector to identify sources of oil spills (for example, Zodiatis et al., 2017), does not work. As simulation time-scales increase, the predicted areas of influence become excessively large, and the level of influence cannot be reliably estimated from the concentration field. This is most likely because the time-scales over which the method is successfully used to identify the source of oil spills are typically just a few days to weeks, whereas establishing buffer zones must include longer-term pollutant releases from outfalls (with timescales of months). While computationally more expensive, arrays of hypothetical release points were found to give more reliable indications of the areas of influence.

The pollutant sources that reach the intakes at threshold concentrations agreed with the water authority, are then used to define the key zones of influence, or "minimum exclusion" buffer zones around each plant. A simple example is shown in Figure 1.



Figure 1. Example of (left) hypothetical pollutant / sediment release points around a coastal SWRO submerged pipeline intake system and (right) establishment of "minimum exclusion" buffer zone using release points found to affect the intake at an agreed threshold level.

The model is then used to explore the sensitivity of water quality and pollutant ingress to hypothetical coastal developments outside these main buffer zones. Potential developments are tested, either through analysis of cadastral land allocation, or pre-approval plans for nearby industrial areas, housing developments, marinas, and coastal resorts. It can be difficult to predict the likely scale of construction, as early development plans held by regional planners are often sketches indicating separate regions of future land use, and rarely include precise landforms or full reclamation maps. Examples of future coastal developments for testing can include:

- Extensions to existing industrial areas, either with further reclamations, jetties or outfalls;
- Blocking off bridges, culverts, etc., to predict the outcome if a key hydrodynamic pathway to an intake is cut off or restricted;

- Opening of existing solid causeways (either with culverts or bridges);
- Hypothetical testing of new developments at areas known to have previously caused problems at an intake (identified during the initial consultation, with the plant operators or environmental regulator).

While not exhaustive, the results of these wider area tests are used to define “high risk” zones around the intake, which supplement the minimum exclusion zones, and can be included in the subsequent management plans. An example is shown in Figure 2.



Figure 2. Example of a wider area high risk zone around an intake, established through testing of hypothetical coastal and offshore developments, chosen to protect wider hydrodynamic pathways to the intake.

3.3 Implementation, management and mitigation

In their simplest application, the zones and testing described above can be used by the plant operators and water authorities to understand the significance of different water bodies for their site. This helps inform their responses when requested to give stakeholder approval for future developments.

Taken further, the important hydrodynamic pathways that the zones identify can be protected at a regulatory and governmental level. Urban planning departments upload the derived buffer zones in Geographical Information System (GIS) format, and share on centralised databases with central planning offices, regulators and developers, as required. If an application is received for a new development (for example, a new marina, reclamation or outfall), then the GIS automatically flags the conflict with the buffer zone, and the necessary stakeholders are alerted for comment. Developments within the minimum exclusion zone can automatically be screened, and relocated if necessary. For developments outside of the main exclusion zone, but still within the high risk zone, the GIS lists the potential risks for each development type (for example, the potential for sediment ingress, or poor water quality), and details the specific modelling studies that would be required to demonstrate the effects of the development. These studies can then be put out to tender by the developer, knowing the level of information and detail that the water authority will require to be demonstrated. Mitigation measures to be tested may include:

- Working with government planners and developers to reshape or relocate new reclamations, if they are found to significantly affect hydrodynamics near the intake;
- Improving overall water quality, by increasing the water exchange in the area (by opening channels or constructing culverts to link bodies of water);
- Improving outfall designs to minimise pollutant concentrations, or limiting pollutants through treatment processes before discharge);
- Spanning islands with bridged transport links, rather than solid causeways;
- Dredging of non-sensitive areas of seabed to increase water depths and promote flows.

While a key purpose of the zoning technique is to identify areas of exclusion, or high risk, they can also be used to identify lower risk areas that may be acceptable for development, subject to hydrodynamic assessment. The authors have applied these techniques to define feasible construction zones for future marine outfalls in industrial areas, based on predicted high levels of dispersion, and low risk of transport to nearby intakes. The results are then included in strategic environmental management plans for industrial sites.

4. BENEFITS AND LIMITATIONS OF NATIONAL BUFFER ZONES

The zoning approach has a number of benefits for water authorities, environmental regulators and developers. The planning and approval stages can be streamlined, as all parties are aware of requirements

from the outset. The extensive studies that are carried out to define the zones can also be used to support future rapid desk assessments, as they essentially form libraries of varied future development or construction scenarios. This can save time and costs for all stakeholders, and means that the effects of smaller developments (for example, an extension to a small jetty along the coast from a desalination plant intake) can be screened without a full hydrodynamic model study.

For larger planned developments, such as new marinas, causeways or larger island reclamations, the model established during the zoning effectively becomes an operational model, owned by the water authority, in which new developments can be efficiently tested. As the property of the authority, this removes the need for long identification and procurement of specialist marine services. The operational model is then continually updated with approved developments.

In the event that a proposed development has wider reaching implications, a larger assessment will be recommended. This may involve a separate assessment team (often working on behalf of the developer), but the authority may choose to apply its own operational model for cross-checking.

Although the zoning methods described are useful tools to aid planning and Development Control, it is important to note that no method can protect an intake from all harmful influences. Illegal dumping of waste material into the sea, diffuse sources of pollution, and accidental oil spills are ongoing challenges, for which the approach does not currently allow. The approach is operationally-focused, and relates to anthropogenic threats from development and future climate change. Other natural events may also pose a risk to intakes (for example, damage during storms, harmful algal blooms, etc.).

5. CONCLUSIONS

This paper has briefly outlined the use of marine buffer zones in consenting processes for developments near desalination plants. Specific examples will be presented in subsequent publications.

As the world adapts to live with the consequences of its changing climate, buffer zones may require updating. In many cases, the zones may become more stringent, as anthropogenic and natural pressures increase. However, new technologies offer glimmers of hope. For example, the introduction of Zero Liquid Discharge systems, now planned across many GCC countries, may remove most or all liquid waste material from industrial and wastewater treatment processes. Such systems, if implemented, would significantly reduce the potential for harmful effects at marine intakes.

6. REFERENCES

- DeNicola, E., Aburizaiza, O.S., Siddique, A., Khwaja, H., and Carpenter, D.O. (2015). Climate change and water scarcity: the case of Saudi Arabia. *Annals of Global Health*, 81 (3), 342-353.
- Wood, M.J., Henno, F., and Mead, C.T. (2014). Validation of computational models for hypersaline and other dense marine discharges. *Proc. 7th Int. Symp. on Environmental Hydraulics*, Singapore, 5-7 January 2014.
- Hervouet, J-M. (2007). *Hydrodynamics of free surface flows: modelling with the finite element method*. John Wiley & Sons Ltd.
- Zodiatis, G., Lardner, R., Alves, T.M., Krestenitis, Y., Perivoliotis, L., Sofianos, S., and Spanoudaki, K. (2017). Oil spill forecasting (prediction). *J. Marine Res.*, 75, 923-953.