DESIGN OF LARGE DESALINATION DISCHARGES WITH MULTIPLE JETS

Brett Miller

Brett Miller, Water Research Laboratory, University of New South Wales, Sydney, Australia, b.miller@wrl.unsw.edu.au

Abstract
The Water Research Laboratory (WRL) of the University of New South Wales has completed a range of investigations for the large seawater desalination plants projects in Australia (Sydney, Melbourne and Perth) during the planning and design stages. Investigations comprised collection of current and wave data, analysis of oceanographic and water quality data, far field current and dispersion modeling, near-field dilutions modeling for the diffuser design of the seawater concentrate outfall, conceptual diffuser design and diffuser hydraulic testing (riser cap head loss).

WRL has found through extensive physical modeling that numerical modeling tools available generally over predict the amount of mixing brine for outfalls with many jets in close proximity. This paper presents an overview of the of over 40 physical model tests with various riser spacing, number of ports per riser and angles of risers. This paper will also summarise the design considerations for a large desalination outfall including determining: the appropriate regulatory requirements; the number and design of the ports; internal riser hydraulics; dilution targets; operational issues with changing production regimes; and post-commissioning monitoring.

Keywords
Outfall, Diffuser, Desalination, Seawater, Dilution, Brine, Plume, Mixing, Near Field

INTRODUCTION

Australia has constructed several large seawater desalination plants over the past decade. Generally these have involved a subsurface tunnel conveying brine from the plant into one or more risers. These risers have been configured with diffuser nozzles which are oriented upward and placed above the sea bed to limit entrainment of marine biota in the discharge plume so that the plumes are jetted upwards into the water column before settling back towards the bed.

Australia's desalination plants have had stringent environmental targets. The approach to the large Australian desalination plant outfalls has been to target getting all possible dilution in the near field and have little reliance on far field dispersion. As such, designing outfall must be within the limitations of the available hydraulic head, water depth and mixing between jets (proximity of each jet and interaction of adjacent jets when entrainment capacity begins to be limited) and the window of discharges and density differences during day to day operation.

Since 2005, the Water Research Laboratory (WRL) of the University of New South Wales has completed a range of investigations for the large seawater desalination plants projects in Australia (Sydney, Melbourne and Perth) during the planning and design stages. Investigations comprised collection of current and wave data, analysis of oceanographic and water quality data, far field current and dispersion modeling, near-field dilutions modeling for the diffuser design of the seawater concentrate outfall, conceptual diffuser design and diffuser hydraulic testing (riser cap head loss).

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REGULATORY REQUIREMENTS AND DILUTION TARGETS

Australian water quality guidelines provide no generic guideline for elevated salinity and hence site specific studies were required for each plant. The regulatory requirements were commonly focused on: elevated salinity, reduced dissolved oxygen, ecotoxicology and visual amenity.

It is not the intent to discuss all aspects of each set of regulatory requirements, but rather provide an overview of the main environmental concerns.

Each location had subtly different environmental conditions and as such the approach to determining the regulatory requirements was different. In Perth, discharge was to Cockburn Sound where the annual fluctuation in natural salinity levels was more than 3ppt, but a natural stratification exists which might be exacerbated by discharged brine. As such, the salinity requirements were determined by balancing stratification with natural environmental mixing such as winds. In Sydney and Melbourne, discharge was to the open coast and the salinity requirements were determined through the natural variation in background salinity.

The specific salinity requirements were different for each plant but were at most 1 ppt above background by the end of the near field. During the design phases, the salinity of the discharge usually had not been finalized, but on the basis of 65ppt into seawater of 35ppt, this equates to a dilution of 30 times. Considerable time was spent during the design of each plant to "the end of the near field" both in engineering and legal terms.

Dissolved oxygen was of no concern except in the case of increased stratification where sediment oxygen demand might reduce oxygen levels below this additional stratification. However, it was found that the environmental mixing from winds was adequate to breakdown any stratification from a 1ppt salinity gradient in all but the most calm conditions.

Eco-toxicological studies were required for each site. For the range of additional substances in the brine stream, it was commonly determined 30 times dilution would be more than adequate for acceptable toxic effects. The timeframe required to undertake adequate baseline ecotoxicological studies should never be underestimated.

Visual amenity was prescribed so that the plume must be not be at the water surface. This concern was primarily for the discharge of coloured materials. However, since such materials were not finally discharged, this requirement was not particularly important.

In summary, the regulatory requirements for desalination discharges in Australia have been stringent. However, although dilution targets were mainly to meet the imposed environmental regulatory requirements, these high dilutions also allow for the spacing between the intakes and the outfalls to be reduced without significant increases in re-entrainment.

DETERMINING THE LOCATION

The location for an outlet discharge from a desalination plant is commonly determined by the plant's location itself. The location of the plant is influenced by a great number of things including available land, power, delivery of freshwater and the marine conditions.

The oceanographic component of the first pass process for determining a suitable location along a section of coastline, was dominated more by appropriate quality seawater intake than suitable conditions for discharge. To this extent, local and regional hydrodynamic models were utilised. WRL was only involved with the site selection for the Sydney Desalination Plant, so discussion here is limited to the techniques used for Sydney.

There were three main oceanographic issues relating to the Sydney desalination plant intakes [1]. These were whether known pollutant sources were likely to be drawn into the plant, whether the volume of water being drawn in was greater than the natural exchange of water in the vicinity and whether the intake was likely to draw elevated salinity levels by recirculating the discharged seawater concentrate. There were two main oceanographic issues pertaining to the outlets. These were whether adequate dilution at the point of discharge (near-field) to avoid environmental stress could be achieved and the fate of the diluted seawater concentrate as it would move away from the point of discharge (far-field).

These issues required an understanding of the oceanographic processes over the wider Sydney region. Sydney Water implemented an ocean monitoring program during 2005 and 2006 to provide data on currents, wind, water levels, salinity and water temperature in the region of the Kurnell peninsula. Through statistical and scientific analyses of these data a greater understanding of the physical oceanographic processes, in terms of current speed and direction, salinity and temperature, occurring in the region was been gained.

Numerical modelling provided the best method to assimilate and use all of the available data. Using the RMA-10 three dimensional hydrodynamic model and the 3DRWALK lagrangian particle tracking model, WRL modelled a year of ocean conditions to generating long term statistics pertaining to each of the main issues identified.

For the planning process of the desalination plant outlets, it was evident that detailed site specific mapping of geotechnical, coastal and ecological factors would not be completed until the final design for construction. This focused the outlet design to achieve all necessary dilutions within the near-field. This allowed for the greatest amount of flexibility in the final outfall location without relying on far field dispersion.

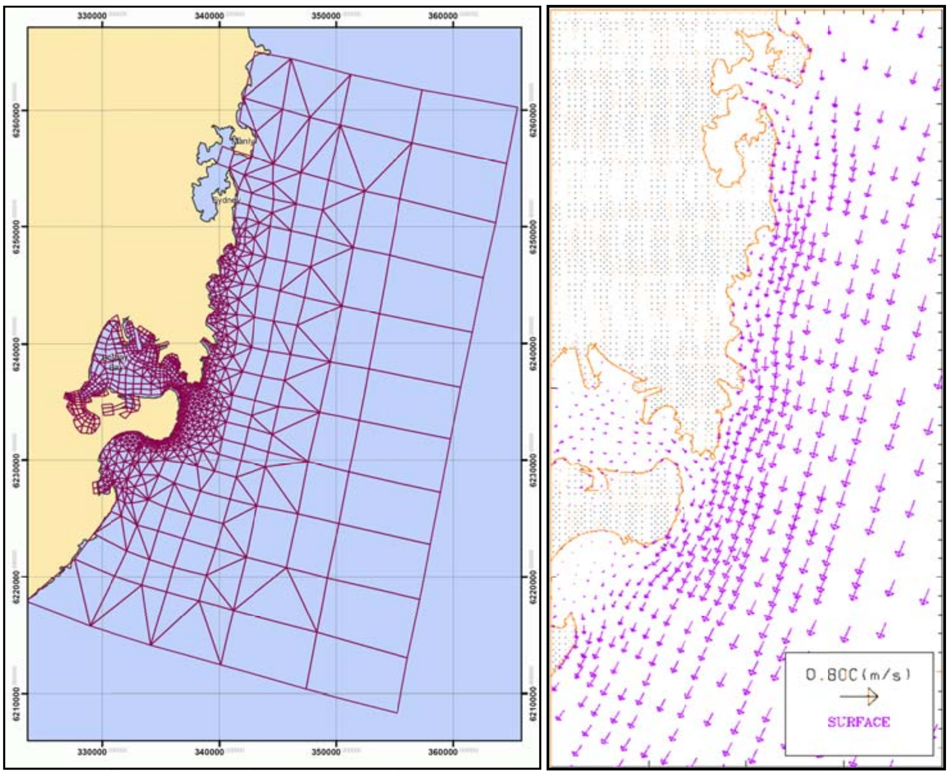

Figure 1 – RMA-10 Finite Element mesh and Sample Oceanographic Surface Currents

RISER AND PORT CONFIGURATIONS

In the first stages of each outfall planning, the decision was early to not discharge straight to the ocean with little or no near field mixing and have a greater region affected by elevated salinities. Rather the decision for the outfall pertained to whether discharge through a long seabed pipeline with many nozzles in parallel or whether to have a subsurface tunnel with a small number of risers, each with multiple ports. This decision was influenced primarily by the oceanic conditions and risk to a seabed pipeline and the availability of a persistent ocean current providing a mixing flux. In Sydney and Melbourne, a tunnelled outfall with two multiport risers was designed. In Perth the outfall is based on a pipeline with many discharge ports along the pipeline.

The main design parameters for a desalination diffuser in order to achieve the target dilution prescribed by the regulatory requirements are:

- The density difference between brine and ocean
- The water depth
- The available hydraulic head
- The diameter and number of ports
- The vertical angle of the ports
- The plan configuration of the ports on each riser
- The spacing between the risers

In order to discuss these design parameters, some locations and dimensions need to be defined. Figure 2 presents the height of rise and the distance to the impact point.

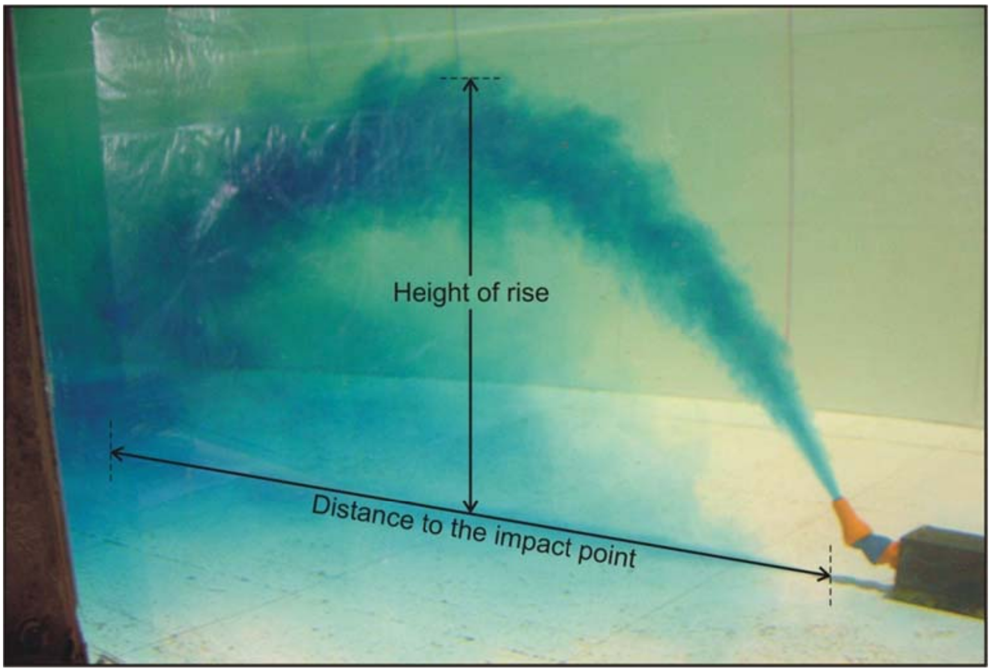

Figure 2 – Height of Rise and Distance to the Impact Point

There is no straightforward path through the design factors as there should be interaction with geotechnical, structural and hydraulic engineers.

The port densimetric Froude number is defined as:

Where

With

ρ being the density of the brine
ρ_o being the density of the seawater
u being the discharge velocity
d being the diameter of the port

It is commonly known that the dilution achieved in the near field is proportional to F and that the height of rise and distance to the impact point are proportional to F.d.

The first design parameter is the water depth required which is generally minimised in order to reduce tunnelling or pipeline costs. However reduced water depth also limits the amount of mixing that can be achieved because the height of rise is limited. With a limited water depth, the exit velocity must be reduced or the vertical angle lowered. Both of reduce limit the near field dilution.

The hydraulic head available to drive the outfall is determined by the elevation of the desalination outfall. Generally after pumping the water to the desalination plant, there is no desire to also pump it back to sea so the available hydraulic head is the gravitational head. A large component of the overall hydraulic head is through the nozzles themselves and as such, the maximum discharge velocity can be calculated as the head loss is proportional to the discharge velocity squared. For example, in Sydney the maximum exit velocity was limited to about 6 m/s (allowing for other hydraulic losses throughout the outfall system).

Once the maximum exit velocity has been estimated, the number and diameter of the ports can be estimated by dividing the total plant discharge by the exit velocity to give the total sum area of all ports. The number of the ports is determined to achieve a high enough Froude number to attain the target dilution.

However, it is unlikely as this point that there will be no conflict water depth, construction cost or available hydraulic head. As such, jets are spaced about the diffuser and techniques such as physical modelling is utilised to assess the overall dilution performance.

Figure 3 presents plan photographs of several different configurations that have been assessed.

Specific quantified test results are yet to be released by clients. However, there were some interesting findings that could be summarized here. A riser with four nozzles each 90 degrees apart had little reduction in the dilution from a single jet. A riser with six nozzles each 60 degrees apart had noticeable reduction in dilution as the jets competed for clear water to entrain. A riser with more than six nozzles had very little entrainment other than over the top of the plumes and hence dilution could be significantly reduced, especially if the height of rise was close to the surface.

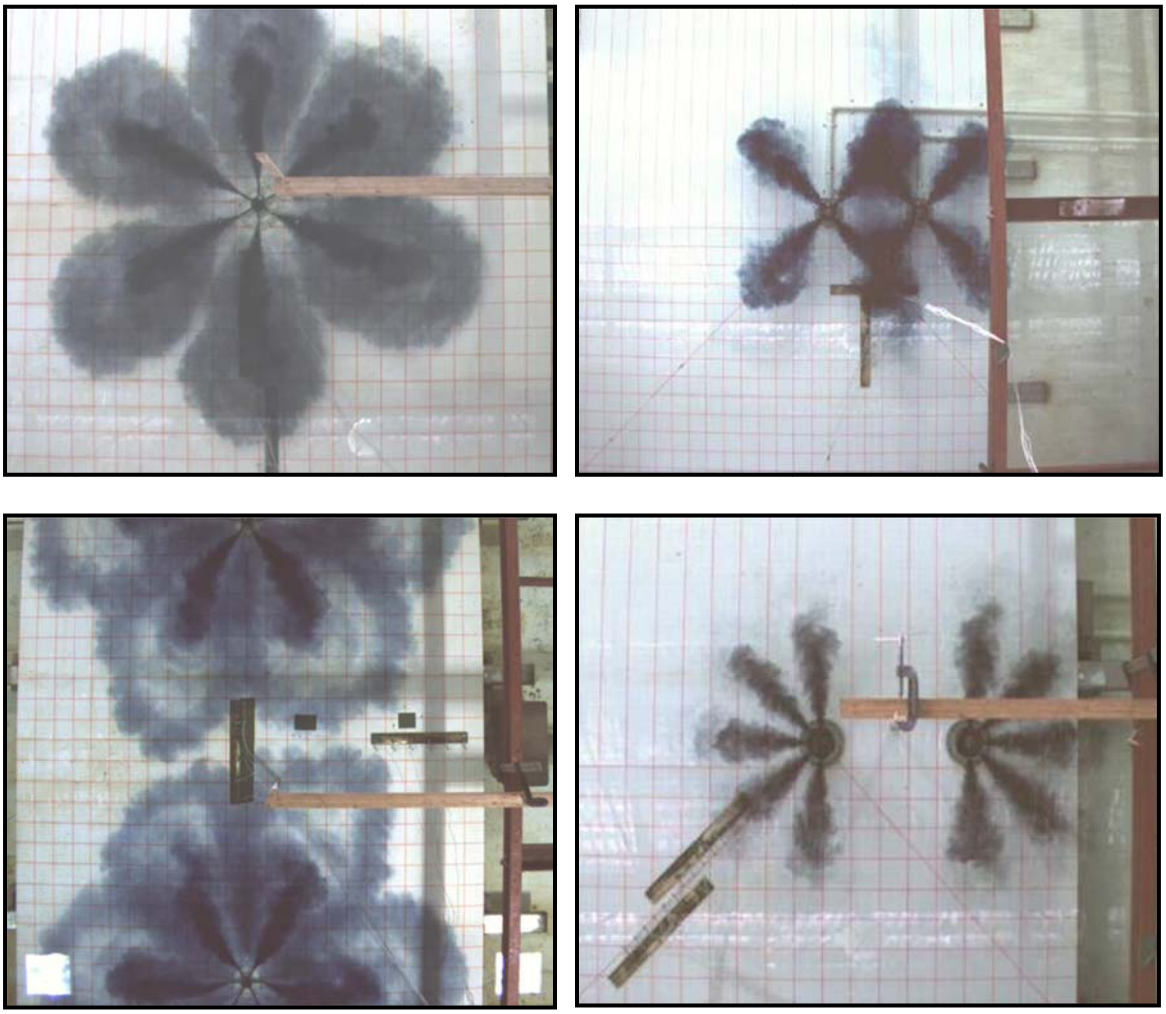

Figure 3 – Sample plan Views of Physical Model Experiments with different Riser Configurations.

However, these reductions from single jet dilutions by having nearby jets could be often justified by having reduced construction costs or timelines.

The spacing between the risers is influenced by wishing to minimise any competition for entrainment between risers while also wishing to minimise the construction costs. For example, having the spacing so that riser tunnels could be drilled from either end of a jack-up barge would half the number of times the barge needed to move.

A interesting finding was also that the discharge of large amounts of brine through a high energy and therefor high entraining diffuser would establish a circulation that would draw surface based clear seawater towards the diffusers, entrain this water into the diluting brine stream and result in a bed current moving away from the diffuser. This process ensures that provided there is an adequately large amount of seawater about the diffuser, the dilution process will continue even with very little oceanic flux through the diffuser region.

THE USE OF NUMERICAL MODELLING IN THE NEAR FIELD DESIGN PROCESS

Numerical modelling of the near field was the appropriate first pass for determining the diffuser design. Use of the empirical method of Roberts et al [2] was common with subsequent use of models such as VISJET. Further, empirical methods for estimating the near field dilution from jets into cross currents [3] were used to assess the differences between minimum and median dilutions.

These numerical models and methods provide a good basis for the dilution to be achieved from a single jet. However, when trying to constrain the number of risers by maximising the number of jets per riser, it was found that the numerical models over predicted. Based on the physical modelling of port configurations investigated at WRL, the numerical modelling methods commonly available today generally over predict the amount of mixing brine outfalls when there are many jets in close proximity.

For example, a multiport riser with six nozzles spaced equally about the perimeter, the final near field dilution was approximately half of that for a single port. This indicates that care should be exercised if relying solely on numerical methods.

INTERNAL RISER HYDRAULICS

A riser cap with multiple ports can often have a total hydraulic head loss which is greater than the sum of the components if calculated individually. To assess the overall internal riser hydraulics, scale modelling was used at a scale of approximately 1 in 10. Using Reynolds scaling, it is not possible to achieve the Reynolds numbers in the model equal to the prototype (exit velocities would need to be in the order of 60m/s). Instead many different flow rates were tested to the maximum possible in the hydraulics laboratory and the head loss expressed as a ratio of the discharge velocity squared divided by 2.g. As this K factor for was not varying with Reynolds number it was deemed acceptable to also use this K for the prototype Reynolds numbers. Different configurations were tested, and the finding was that the K factor for the overall cap was between 1.3 and 1.5 when using the exit velocity at the nozzle.

Figure 4 – Riser Cap Hydraulic Testing

OPERATIONAL ISSUES

One major operational issue with a diffuser design "tuned" to the common discharge condition is that discharge volumes and density differences do not stay constant. For example the plant may be operating at less than 100% capacity, there may be periods of backwash or there may be occasions where the produced freshwater is also required to be discharged back to sea.

For example, if an outfall is operating at only 50% capacity, the exit velocity of the jets will be reduced to half and the achieved dilution will be greatly reduced. The only solution for extended operation under these conditions is for divers to cap off a certain number of ports.

For another example, for a short period the density of the brine is reduced because backwash is included. The density difference with the ocean goes down, the height of rise goes up and the plume intersects with the surface. This can be problematic if the regulatory requirement is for no visual effect.

Clearly, these issues all need to be addressed in licencing agreements. It may be acceptable to breach the conditions if only for a short periods of time. Otherwise it may be necessary to include operational control of adding seawater directly into the brine stream to compensate for these short periods.

In the case of the Sydney plant, rules relating the discharge volume and salinity of the brine are incorporated into the operational controls so that seawater can be automatically added to the discharge stream.

CONCLUSIONS

This paper has provided an overview of the design consideration for desalination outfalls in Australia. As demonstrated, a diffuser design can be achieved which minimizes to almost negligible levels the environmental impacts of brine discharge. The approach in Australian desalination plant outfalls has generally been to maximize near field mixing and have little reliance on far field dispersion.

Physical modeling has been central to refining and proving the diffuser design.

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REFERENCES

[1] Miller "Desalination Planning Study Ocean Modelling Report", Water Research Laboratory Technical Report 2005/26, 2005

[2] Roberts, PJW, Ferrier, A and Daviero G, "Mixing in Inclined Dense Jets" Journal of Hydraulic Engineering, August 1997 pp. 693-699

[3] Miller, B.M. (2008) High Exit Velocity Diffusers for the Ocean Discharge of Seawater Concentrate Brine from Desalination Plants. Engineers Australia, 9th National Conference on Hydraulics in Water Engineering, Darwin Convention Centre, Australia 23 - 26 September