Linking near- and far-field hydrodynamic models for simulation of desalination plant brine discharges
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ABSTRACT

A desalination plant is proposed to be the major water supply to the Olympic Dam Expansion Mining project. Located in the Upper Spencer Gulf, South Australia, the site was chosen due to the existence of strong currents and their likely advantages in terms of mixing and dilution of discharged return water. A high-resolution hydrodynamic model (Estuary, Lake and Coastal Ocean Model, ELCOM) was constructed and, through a rigorous review process, was shown to reproduce the intricate details of the Spencer Gulf dynamics, including those characterising the discharge site. Notwithstanding this, it was found that deploying typically adopted ‘direct insertion’ techniques to simulate the brine discharge within the hydrodynamic model was problematic. Specifically, it was found that in this study the direct insertion technique delivered highly conservative brine dilution predictions in and around the proposed site, and that these were grid and time-step dependent. To improve the predictive capability, a strategy to link validated computational fluid dynamics (CFD) predictions to hydrodynamic simulations was devised. In this strategy, environmental conditions from ELCOM were used to produce boundary conditions for execution of a suite of CFD simulations. In turn, the CFD simulations provided the brine dilutions and flow rates to be applied in ELCOM. In order to conserve mass in a system-wide sense, artificial salt sinks were introduced to the ELCOM model such that salt quantities were conserved. As a result of this process, ELCOM predictions were naturally very similar to CFD predictions near the diffuser, whilst at the same time they produced an area of influence (further afield) comparable to direct insertion methods. It was concluded that the linkage of the models, in comparison to direct insertion methods, constituted a more realistic and defensible alternative to predict the far-field dispersion of outfall discharges, particularly with regards to the estimation of brine dilution in the immediate vicinity of an outfall location.

Key words | brine discharge, desalination, hydrodynamic modelling, outfall discharges, Spencer Gulf

INTRODUCTION

Desalination plants are increasingly becoming one of the key elements of securing public and industrial water supply. In Australia, all major urban centres in the Australian continent (except Darwin) have desalination plants either in operation (Perth, Brisbane, and Sydney) or under construction (Adelaide, Melbourne, and another in Perth). In addition to the major capital city plants, a desalination plant to be located at Port Bonython, South Australia (Figure 1), is being considered as the major water supply to the Olympic Dam Expansion Mining project, located near Roxby Downs, which is about 320 km inland from the site. The project requires 280 ML/day of water at peak production rates, which translates to 650 ML/day extraction and 370 ML/day desalination plant discharge (DPD). At the site the ambient salinity varies approximately from 39.0 to 41.0, and brine discharge has an approximate salinity of 75.0. Port Bonython was chosen due to the existence of an approximate 25 m deep channel in a constriction known as ‘The Rip’ (i.e. between Point Lowly and Ward Spit), in which water velocities can reach up to 1.5 m/s, and therefore would likely promote good conditions in terms of mixing and dilution of the discharge.

The proposed DPD would discharge to an area within the Upper Spencer Gulf Marine Park, where some sensitive
Figure 1 | Location of the desalination plant and identified environmental receptors (adapted from BHP Billiton (2009)).
marine receptors exist. These receptors include spawning grounds from the giant cuttlefish, and endemic seagrass, reefs and sponge gardens species (Figure 1). Occurrences of protected species such as the Great White Shark are also common in the area. Increased salinity levels may impact the local biota osmoregulation capability and, if discharges are not sufficiently diluted, may adversely impact growth, reproduction, and survival of some existing local species (BHP Billiton zorra).

Associated with the water production from desalination plants is the potential impact on the marine environment caused by the discharge of concentrated brine to receiving waters, as well as the efficiency of the fresh water production. To these ends, numerical hydrodynamic and dispersion modelling of the saline water can play a key role in the assessment of the associated environmental impacts and short-circuiting between plant discharge and intake (i.e. recirculation). In the particular case of environmental impacts, the modelling of the brine dispersion aims to provide the spatial-temporal evolution of salinity to which the marine environment would be subjected, and subsequently to assist in determining the likely environmental conditions for ecological investigations.

In general, the large-scale (far-field) hydrodynamic processes are simulated by far-field hydrodynamic and transport models, which aim to reproduce the physical processes induced by tides, winds and atmospheric exchange. On the other hand, the local-scale or near-field process associated with the outfall jet discharge is obtained from so-called near-field models. Fundamentally, a problem of integration arises because the jet or plume dynamics occur on the scale of 0.01–10 m, whereas numerical grids used in far-field hydrodynamic models typically have horizontal scales of 50–100 m (or greater). The initial dilution of brine is thus a sub-grid-scale process for the far-field hydrodynamic model and involves inherently different physics. As the scales reduce, the non-hydrostatic effects induced by the vertical accelerations of the diffuser discharge become important, and must be included in the near-field predictions. As a result, the physics and flow equations adopted in the near- and far-field models are inherently different.

Through detailed studies, we have found that the manner in which near-field predictions of brine dilution are linked with far-field hydrodynamic models that examine broader scale advection and dispersive processes is critical to the robust execution of dispersion studies. Further, we have found that this linking can have a significant influence on the spatial distribution of subsequent hydrodynamic model dilution predictions, particularly in the direct vicinity of diffusers or other outfalls.

In this paper, brief descriptions of different linkage techniques reported in the literature are reviewed and their advantages and disadvantages are summarised. This assessment is then used to derive and describe a linkage method appropriate for cases in which sensitive environmental receptors are located relatively near the diffuser. The application of this methodology is then applied to the DPD in Spencer Gulf.

**LINKAGE TECHNIQUES**

Linkage techniques found in the literature are briefly described below and their applicability to the present study assessed. The proposed new linkage technique is then described.

**Insertion types**

**Direct insertion**

Direct insertion delivers the ‘point of discharge’ brine flow rate and salinity (i.e. as leaving the desalination facility prior to delivery to a diffuser) directly to the hydrodynamic model, generally in a single cell, depending on the model resolution. This direct insertion method has been applied as part of the Port Stanvac DPD modelling assessments (SA Water 2009) where the insertion cells were set to be those located along the diffuser alignment between the seabed and 10 m height of rise of the discharging jets. A slightly different approach is used by Bleninger (2010), in which a near-field model provides the resulting plume thickness and width, and these are apportioned over a similar volume in the far-field model, but maintaining the discharge characteristics (i.e. flow rate and ‘undiluted’ salinity).

**Pre-diluted brine insertion**

This method delivers a brine flow that has been altered in an attempt to capture the dilution delivered by a selected diffuser arrangement. This method acknowledges the fact that the near-field dynamics (especially mixing) are not captured well by far-field hydrodynamic models (due to the spatial scale and physics mismatch mentioned above), but that hydrodynamic models will ‘see’ inflows that have already been subjected to dilution as a result of the action of a diffuser. As such, this linkage technique forces the hydrodynamic
model with an inflow boundary condition informed by a (separate) near-field model. The inflow boundary condition corresponds to specification of (1) flow rates, which consist of the outfall discharge plus the required ambient entrainment to achieve the dilutions obtained in the near filed predictions, and (2) salinity, which takes into account the dilution imparted by the entrained ambient flow salinity, also according to the near-field predictions. In essence, this linkage technique draws directly on complementary near-field modelling and employs near-field results to force hydrodynamic models with appropriately resolved and matched inflow boundary conditions. In this case it is noted that introduction of pre-diluted water requires a separate extraction to balance mass overall). Such a pre-dilution and extraction technique was successfully applied for the Cockburn Sound modelling studies \cite{Okely2007}. Marti et al. \cite{Marti2011} reported excellent agreement between modelled and subsequently measured salinities and brine dilutions at the Cockburn Sound DPD, having used this pre-dilution technique as the linkage approach in the supporting, and preceding modelling studies.

**Flux approximation insertion**

It assumes that the rate of change of salinity in a hydrodynamic model insertion cell (that contains the diffuser) is a function of the cell salinity \(S\), undiluted brine salinity \(S_b\) and flow rate \(q_b\), and the volume of the selected hydrodynamic model insertion cell \(V\), such that:

\[
\frac{\partial S}{\partial t} = (S_b - S) \frac{q_b}{V}
\]  

\(1\)

This technique has been applied by Kaempf et al. \cite{Kaempf2009}.

**Key characteristics of above insertion methods**

**Salt mass conservation**

The direct insertion and pre-dilution insertion techniques ensure salt conservation. The former achieves this by definition as it sees insertion of exactly the pre-diffuser flow rate and salinity to the hydrodynamic model (i.e. \(S_b \times q_b\) in Equation \(1\)). The latter acknowledges that the pre-dilution approach introduces additional salt mass and so sets up appropriate compensatory extractions to exactly conserve salt mass \cite{Okely2007}. The flux approximation modulates local salinity without addition of water (unless other equations are deployed to do so). Equation \(1\) can be rearranged to show that the rate of change of salt mass is less than \(S_b \times q_b\) (by subtraction of an always positive \(S\) from \(S_b\)), and as such it is unclear as to whether salt mass is actually conserved in terms of its delivery from the desalination plant. This may warrant further exploration.

**Controllable linkage with near-field predictions**

It is necessary to ensure that the boundary condition flows (and hence dilutions and salinities) at the site of the diffuser are not artificially determined by the cell sizes and time steps of the hydrodynamic model for subsequent advection and dispersion through its domain. In other words, maximal control over the flow, dilution and salinity at the hydrodynamic boundary insertion location(s) is required to minimise uncertainty and avoid unnecessary conservatism in dilution predictions at sensitive receptors relatively close to the diffuser.

The direct insertion method does not readily allow for controllable linkage of near-field and hydrodynamic models. For example, in the Port Stanvac modelling study \cite{PortStanvac2009} and the technique described by Bleninger \cite{Bleninger2010}, it is understood that brine was directly inserted (i.e. not pre-diluted) to the hydrodynamic model over a range of cells both horizontally and vertically. As there is no explicit pre-dilution technique applied in the model, the only dilution available is numerical. Specifically, the collapse (reported to be in one time step in \cite{PortStanvac2009}) and associated mixing of the vertically inserted brine concentrate within the hydrodynamic model set the effective insertion flow dilution and salinity at bed level for subsequent advection and dispersion at depth. Thus, this boundary condition was not entirely controlled with reference to near-field predictions. It is not our intent here to make an assessment of the suitability of this approach for those studies, but rather to flag the use of this technique with respect to the proposed discharge at Port Bonython.

The pre-dilution method does make an attempt to link near-field and hydrodynamic models with a degree of control. It does so by delivering diluted brine (with the dilution determined by a near-field model) directly to the hydrodynamic model. A constant pre-dilution was adopted by Okely et al. \cite{Okely2007}, which is most likely in response to the relatively uniform tidal/wind-driven currents (hence near-field performance) in Cockburn Sound. The specification of the salinity boundary conditions is often based on dilutions of the brine assuming background ambient salinities (i.e. either from measurements or a baseline hydrodynamic simulation).
The flux approximation method takes no account of near-field modelling, so is unrelated to any near-field modelling predictions.

**Controllable dynamic response to tidal forcing**

An important requirement for the current study at Port Bonython was to be able to dynamically vary, in a controlled fashion, the hydrodynamic model boundary condition for flow, dilution and salinity, primarily to capture variations in the performance of diffuser dilution as a result of varying tidal current magnitudes. The direct insertion method does not support such control, and it is not clear to the authors how the initial numerical dilution and/or subsequent collapse-driven mixing could controllably vary the resultant dilution as a function of current speed, and, importantly, how this would then match the dilutions to near-field dilution predictions in a controllable fashion.

The pre-dilution method, as encountered by the authors to date, has been implemented using a constant (temporally invariant) pre-dilution, so has not, so far, allowed for dynamic alteration of injected dilutions. The flux approximation method takes no account of near-field modelling, so does not have the ability to deliver a controlled time variant flow, dilution and salinity that is tied to near-field modelling studies.

**Hydrodynamic model grid and time-step independence**

This is required to ensure that grid and time-step related numerical artefacts are minimised or eliminated entirely, primarily to reduce associated predictive uncertainties. In addition, it is considered important to be able to apply the same methodology to different hydrodynamic models (or model configurations) and facilitate consistency of prediction without needing to retrospectively alter a grid-dependent insertion method to suit.

The direct insertion method is grid dependent to the extent that the initial numerical dilution that occurs when the brine concentrate is injected into the model varies with different model grid sizes. The starting dilution varies with grid size as the same brine concentrate is spread over varying initialisation volumes as grid sizes are different. This variation applies in the horizontal and vertical, and the effect becomes more pronounced as the incremental brine concentrate volume becomes smaller relative to the volume of the initialisation cells. Similarly, it is time-step dependent in that it numerically mixes a given volume of brine concentrate within a suite of pre-selected cells. A doubling in time step, for example, would result in a doubling of the volume of brine concentrate injected into the suite of insertion cells, and a doubling of the resultant initial brine concentration computed by the hydrodynamic model by virtue of numerical dilution, advection aside and assuming zero brine background conditions.

The pre-dilution insertion technique is also somewhat susceptible to grid and time-step dependence, but to a lesser extent than the direct insertion method. This is because the pre-dilution volumes (for a given brine concentrate flow rate) are generally much larger than the concentrate flow rate itself (by a factor of the dilutions achieved by a diffuser), so form a greater proportion of the insertion cell volumes within a given time step. In time, this method ‘fills’ the insertion cells with diluted brine (representing diffuser performance) at a rate greater than the direct insertion method. This increased rate is at least equal to the lowest dilution predicted by near-field modelling.

Notwithstanding this, however, both the direct and predilution techniques mix inserted brine with some volume of background water that (potentially) has already felt the influence of previously discharged brine. The extent to which this mixing occurs is different in the two techniques by a dilution factor related to the performance of the near-field diffuser.

The flux approximation method is grid dependent as the insertion cell volume \( V \) appears explicitly in the flux equation (Equation (1)). For example, as the insertion cell volume reduces, the rate of change of salinity in that cell (and hence the predicted salinity) increases. The flux approximation method employs a rate-of-change approach to salinity in a receiving cell, so it is possible (although unclear) that this method is also time-step dependent.

**An improved linkage technique**

Given the above, a linkage technique was developed that preserves discharged salt mass whilst ensuring delivery of flows, salinities and dilutions to the hydrodynamic model that directly reflect near-field (computational fluid dynamics (CFD)) modelling predictions across a range of background tidal conditions. These conditions provided the motivation for the development of the technique as our measurements of tidal currents at the site (the duration of which spans more than one year and includes several separate deployments at multiple locations) show that the range in ambient tidal velocities, and hence ambient dilution, is large at the point of interest, with 50th and 99th percentile velocities over the water column being 0.49 and 1.18 m/s, respectively. The method is an extension of the pre-dilution
technique described above with provisions for the variability of dilutions generated by the ambient flow conditions. In this case, CFD simulations were used, but the method could be applied seamlessly using any near-field modelling platform.

In essence, the method consists of integrating the near- and far-field models interchangeably, such that the far-field model provides the environmental conditions for the near-field model, which in turn, provides the required dilutions to be adopted at the outfall discharge boundary condition in the far-field model. Use of far-field modelling results requires that the far-field model be thoroughly validated against field data for a range of conditions. In the case of Spencer Gulf, the tides represent the main forcing of the Gulf dynamics, such that environmental conditions were described in terms of depth-averaged velocity percentiles for each of the ebb and flood phases.

CFD simulations were then set up and executed taking these velocities as boundary conditions, such that dilution predictions were cast as a function of depth-averaged velocities in the form of a ‘lookup table’. A baseline far-field simulation was then executed, such that background velocities could be used as input to obtain the dilutions given in the lookup table. Taking into consideration the background simulation, salinities and other scalar fields at the proposed diffuser boundary were computed as a function of these dilutions. The fluid entrained in the plume was assumed to have scalar (i.e. temperature, salinity, and tracer concentration) characteristics of the depth-averaged scalars in the background (baseline) simulations. For DPD this assumption is consistent with the CFD prediction that plume travel paths reach higher parts of the water column and as such plumes entrain relatively unaffected background waters, once they are well clear of the bottom salinity layer. This has also been qualitatively confirmed by field experiments presented by Okely et al. (2007). Accordingly, the outfall discharge was increased in such a manner to reflect the entrained ambient fluid. This assumption should hold, at least approximately, for conditions similar to Spencer Gulf, in which flows are very energetic and the water column is weakly stratified. For more strongly stratified systems, a more appropriate linkage strategy has to be considered. Particularly, a different, perhaps more comprehensive, choice of surrogate boundary conditions for the CFD modelling (i.e. considering height of thermocline, buoyancy frequency) as well as a different choice of baseline ambient conditions (i.e. layer-averaged scalars) to derive the far-field model boundary conditions should be devised.

Of particular importance is the derivation of tracer concentrations and salinities, which under this method directly reflect the spatially and temporally variant performance of the diffuser under the full range of tidal current conditions. It is also noted that the dilutions predicted by CFD are conservative (BHP Billiton 2012a).

As discussed above with reference to the work undertaken in Cockburn Sound (Okely et al. 2007), a salt sink was introduced to remove excess entrained salt (generated via pre-dilution). In the present methodology, the required sink is distributed at specified cells in the domain in such a way that the sink flow rate to balance the salt mass can be accurately computed.

**SPENCER GULF DPD MODELLING**

**Far-field modelling**

The three-dimensional Estuary, Lake and Coastal Ocean Model (ELCOM) (e.g. Botelho et al. 2009; Barry et al. 2010) was used to simulate the far-field hydrodynamics and transport in Spencer Gulf. The model was validated against several data sets spanning seasonal and tidal time scales and over several spatial scales in the Spencer Gulf. Locations of measurements undertaken for model validation are shown.
in Figure 2. Horizontal model resolution focused in the location of the diffuser (40 m) and a time step of 24 s were used in the simulations. Vertical model resolution in the location of the diffuser varied between 1.0 and 2.0 m. Full description of the model set-up and validation exercise is presented in BHP Billiton (2013b). Here, we present an
illustration of the model comparisons against a sub-set of a 40-day data set collected near the proposed diffuser location (Figure 3 and Figure 4). The period illustrates the model’s ability to capture the spatial variability of the dynamics in the location of the diffuser (site B) and near sensitive receptors (i.e. giant cuttlefish habitat, site C) during both spring and neap tides. It is noted that the model results at site C sit at an increased depth in comparison to the field measurements. This difference is due to inaccuracies in the model bathymetry in a region where relatively large slopes occur. The overall hydrodynamic features (i.e. flow essentially east–west and similar flow magnitude) were nevertheless well represented, despite the depth differences.

Near-field modelling

Near-field modelling was conducted in the software OpenFOAM (Open Field Operation and Manipulation) using steady state (nonhydrostatic) flow equations adopting the effects of salinity and temperature in the density field. A $\kappa - \omega$ formulation was used for the turbulent closure scheme.

An adaptive mesh refinement technique was used to dynamically and iteratively adjust the mesh during the computations, in such a way to provide maximum resolution in the vicinity of the diffuser ports and in regions where salinity gradients and velocity shear were above a pre-defined threshold. Over 2.5 million cells were used in the final computational domain with finer cells adjacent to the diffuser ports being in the order of 15 mm. Computations were processed on a multi-CPU computer with 128 processors. Simulation for a given tidal condition (see below) took approximately 10 h to be completed.

A rigid lid approximation was used to represent the free surface. Representative profiles for each depth-averaged velocity percentile provided boundary conditions for one of the sides of the model domain (i.e. the one in the upstream side

Figure 4 | Model and field data comparisons of depth-averaged velocity components at sites B and C (see Figure 2).
of the diffuser according to the tidal flow direction). The boundary condition at the other side was unconstrained in velocities except that total volume flux was conserved. The dilutions that were adopted in ELCOM were obtained when the steady state solutions and further mesh refinement converged to the same results. Further details of the CFD model and its validation are presented in BHP Billiton (2011a).

**Methodology application**

The application of the modelling methodology described above was adapted to a set of diffuser configurations of the Spencer Gulf DPD. This allowed the diffuser configuration to be optimised and sensitivity analyses of the adaptive pre-dilution insertion method to be performed.

The diffuser configuration investigated herein consisted of a 200 m linear diffuser aligned approximately normal to the tidal flow direction (SW–NE direction, see Figure 1). A total of 50 alternating sides ports at a 60° angle with the horizontal were equally distributed over its length. It is noted that this configuration (and results presented) does not reflect the final adopted and optimised diffuser design, or the final location of the proposed diffuser (see BHP Billiton 2011a).

The CFD model domain consisted of a Cartesian box aligned with the diffuser, spanning 160 m either side of the centre of the diffuser alignment in both directions (i.e. producing a 320 m wide domain). The top surface of the model was the $z = 0$ m (Australian height datum) plane and the bottom surface was fitted to digital elevation model data from the ELCOM model (which is derived from BHP Billiton survey data and other supplementary data sets).

Modelled velocities at Site B (Figure 3) were used to derive the velocity profiles for the near-field boundary conditions. Examples of the resulting dilution fields from the CFD simulations are illustrated in Figure 5. The light blue surfaces indicate the 45:1 dilution iso-surfaces and the vertical curtains show the dilution field 100 m downstream of the diffuser alignment. Note that the colour bar was scaled from the minimum dilution seen on the 100 m curtain to an upper limit of 1,000:1, and that the actual currents speeds for ebb and flood were not necessarily equal and opposite.

From results similar to the ones presented in Figure 5 for other velocity percentiles, dilutions as a function of the cumulative distributions of depth-averaged velocities were obtained. Figure 6 presents the measured and modelled depth-averaged current percentiles that were used as boundary conditions in the near-field model to establish the relationship between dilutions and the depth-averaged velocities (Figure 7, i.e. a graph of the ‘lookup’ table). The steady state simulations were performed for a set of pre-defined tidal conditions encapsulating the range of modelled tidal velocities. A total of 11 simulations were undertaken corresponding to zero background flow and 10th, 50th, 50th, 70th, and 90th velocity percentiles for both ebb and
flood tides. For velocities larger than the 90th percentile, the dilution factors obtained from 90th percentile simulations were adopted (i.e. the flat tail of the curves in Figure 7). Examples of boundary conditions for discharge rate and tracer (C) are presented in Figure 8. The variations that are seen in Figure 8 were associated with slack and running water and the spring-neap cycle modulation, and reflected the range of environmental conditions and associated near-field dilutions to which the discharge would be subjected.

The boundary conditions shown in Figure 8 (i.e. flow rate, salinity, and tracer concentration) were used in the far-field model. In ELKCOM, these boundary conditions were set as flow across horizontal faces at the bottom of the domain and were designed to be located approximately at the line of impact of the descending dense plume. This line of impact was assumed to be the outfall length (200 m) and in the model consisted of five $40 \times 40$ m square cells that were located either right on the diffuser location (i.e. at slack water) or downstream of the tidal flow direction (i.e. north-east of the diffuser during flooding tides and south-west of the diffuser during ebb tides).

In the far-field model, the salt sinks to correct for mass conservation were located in such a way that: (1) they occupied a relatively broad area, such that the sink discharge would have minimal disruption to the local hydrodynamics; (2) they were, however, within the general vicinity of the proposed outfall such that excess salt did not accumulate in the Northern Spencer Gulf; but (3) the outflow boundaries, where water was extracted from the domain, were specified at a distance from the outfall (i.e. away from the deep basin where dilutions were relatively low) and at least 5 m above the seabed where salinities at the outflow cells were similar to the reference simulations. This placement ensured that the salt sink could be accurately computed.

**FAR-FIELD MODELLING RESULTS**

**Control points**

Results of simulations spanning a 40-day period (3 December 2008 to 13 January 2009) were used to compare the...
effects of different insertion methods at control points located at increasing distances away from the diffuser (Figure 9). The simulations include a reference background case, the effect of discharge using a direct insertion method case, and the effects of the discharge using the adaptive linkage method with an 8 and 24 s time-step cases.

Salinities and dilutions at the bottom at the control points are presented in Figure 10. Also shown in Figure 10 are the lowest dilution obtained in the CFD simulations, which was equal to 18:1. To improve clarity in Figure 10, only a 9-day sub set of the 40-day simulation period is presented. It is readily seen that salinities from the direct insertion method (pink line) were generally larger than the adaptive linkage method (cyan and green lines) and conversely, dilutions were lower. The closer to the diffuser the control point, the more marked the differences. Well away from the diffuser (∼1.5 km at point L), differences between methods were not relevant and very similar to background conditions (blue lines). However, for all other points, including point B that was located at approximately 600 m from the diffuser, the direct insertion method predicted dilutions lower than the minimum dilutions predicted by near-field CFD simulations. The adaptive linkage method simulations tracked each other very closely, and did not present dilutions lower than the near-field simulations. The very similar results between the two adaptive method simulations indicated that the linkage method is, at least approximately, time-step independent.

Considering the results of the near-field simulations, predictions with the direct insertion method were conservative at sensitive receptors near the diffuser (points SP denote sponge communities), indicating likely unrealistic exposure to elevated salinities. Conversely, adopting the adaptive insertion method, although still conservative (see BHP Billiton 2011), predictions more consistent with the near-field simulations could be made, such that the receptors were...
exposed to elevated salinities less frequently. Also the adaptive linkage simulations predicted significantly lower salinity peaks in comparison to the direct insertion method (Figure 10).

**DPD footprint**

A map of dilution percentiles in the model bottom cells was adopted to represent the discharge footprint. The percentiles were calculated by extracting the modelled dilution time series in each of the model cells and, for each of the series, obtaining the dilution cumulative distribution. The first percentile dilution indicates that dilutions were below that level only 1% of the time and it was arbitrarily chosen to represent the discharge footprint. The footprints for the different injection methods are presented in Figure 11.

It can be seen that footprint areas given by the direct insertion were larger than the areas given by the adaptive method, particularly for the lowest dilutions. The red area for example shows dilutions lower than the lowest CFD dilution predictions, which, by design, do not appear in the adaptive linkage method. Superimposed on the footprints are the contours of dilutions 45:1 and 85:1 at the time at which the largest areas under these dilutions were predicted (approximately 22 December 2008 18:00 during a flood tide in a neap cycle). The areas enclosed by these contours are referred to as ‘Instantaneous’ in Table 1. The 45:1 and 85:1 dilutions were derived from ecotoxicology tests that indicated that 95% and 99% of species, respectively, would be relatively unaffected by the desalination discharge (see BHP Billiton (2014) for details). Table 1 indicates that both footprints and instantaneous areas for these dilution
contours were 17 to 48% smaller adopting the adaptive linkage methods.

It is also interesting to note that for the adaptive technique the instantaneous area (i.e. at 22 December 2008 18:00) for the 45:1 dilution is larger than the 45:1 footprint (Table 1). We note that both quantities are independent of each other (i.e. derived from distinct concepts) and this result simply indicates that, although the instantaneous area was relatively large, it remained so for very little time as it was quickly dispersed by the local currents. On the other hand, the footprint results indicated the area in which dilutions remained below 45:1 less than 1% of the time of simulations (i.e. analogous to a 99% dilution exceedance). We would like to point out that both were smaller than their counterpart obtained from the direct insertion method simulations.

**CONCLUSIONS**

An improved adaptive linkage method between near- and far-field models was developed such that dilution and salinity estimates of brine dispersion that were consistent with near-field models could be obtained.

Development of the technique was motivated by the inability of direct insertion techniques to produce brine dilutions that reflect results from near-field models, particularly in situations of strong tidal flow. In such cases, as the one shown in this paper, the adoption of direct insertion techniques may predict unwarranted high salinity levels, which may affect decisions regarding the feasibility of the outfall in terms of providing adequate brine dilution.

The new method was shown to have desired properties in terms of representing more accurately the predictions of the near-field model, conserving salt. The methodology was applied to a proposed DPD in Spencer Gulf, South Australia. Tests adopting simulations with different time steps indicated the adaptive technique was relatively independent of time step, at least for the application presented in this paper. For the model configurations studied, the new linkage method, in comparison to direct insertion methods used in far-field models, was shown to be less conservative in terms of salinities, dilutions, and footprint areas.

We note that results of such modelling were not validated in the field, as the proposed plant and outfall infrastructure are yet to be built. However, results from near-field modelling have been preliminarily confirmed for other desalination plants in Australia (Kildea 2012). These results are encouraging, given the closer proximity of the adaptive linkage technique with the near-field, in comparison to direct insertion methods.

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