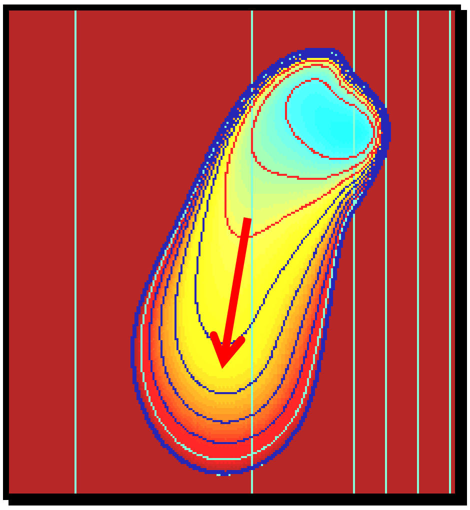
Adelaide Desalination Project

Review of the Environmental Impact Statement with a focus on marine modelling studies and including findings of additional independent modelling studies



Expert Witness Statement by Dr Jochen Kaempf

Prepared for City of Onkaparinga

December 2008

Table of Contents

Summary……………………………………………………3

1. INTRODUCTION……………………………………..4

1.1 Name and Qualifications……………………………………………….4

1.2 Instructions and Information…………………………………………..4

1.3 Investigation approach…………………………………………………5

2. REVIEW OF SELECTED TECHNICAL REPORTS…6

2.1 General comments…………………………………………………….6

2.2 Near-field dilution and outfall hydraulics………………………….....7

2.3 Plume dispersion modelling………...………………………………....9

3. INDEPENDENT MODELLING STUDY……………..12

3.1 Model description……………………………………………………12

3.2 Experimental design…………………………………………………13

3.3 Results…………………………………………………………………16
a) Instant mixing height of 3 m……………………………………………16
b) Instant mixing height of 6 m………………………………………......23

4. CONCLUSIONS & RECOMMENDATIONS……….25

References…………………………………………………..27

Appendices

Curriculum Vitae of Dr J. Kaempf

Summary

This statement presents findings of independent hydrodynamic modelling studies indicating that the risk of marine pollution caused by discharge of desalination brine has been significantly underestimated in the Environmental Impact Statement (EIS). The main reason of this underestimate is an unrealistic assumption about the volume over which the brine mixes as it enters the water column. Therefore, the assessment of predicted and residual risks of brine discharge on water quality in the EIS as "moderate" and "low" are substantially biased by these assumptions.

Findings of this study suggests establishment of quasi-continuous near-field dilutions in a range between 10:1 and 15:1, in agreement with hydraulic considerations, therefore compromising the target dilution set in the EIS of 50:1 most of the time. Moreover, this study identifies dodge tides as absolute critical times during which the area exceeding the dilution target of 50:1 increases to sizes between 400 and 500 ha (1 hectare = 1 ha = 100 m by 100 m). This exceeds the allowable size of 1 ha under the Environment Protection (Water Quality) Policy 2003 by far; that is, by 400 to 500 times. Areas with reference to dilutions <25:1 (close to the minimum requirement set for the Victorian Desalination Project) are predicted to still occupy areas between 100 ha and 200 ha in size. On the basis of these findings, the risks of brine discharge on water quality can be classified as "high" with major/severe consequences and almost certain likelihood.

From these findings it can be concluded that the proposed desalination plant might not be operational with the proposed discharge design without severely compromising the health of the marine environment. In order to achieve a near-field dilution of close to 50:1, the author recommends consideration of an improved discharge design consisting of three or more separate discharge lines of, at least, 150 m in length each. To avoid interference of resultant brine plumes, the spacing between the lines should exceed 2 km. Best practice, however, would be an environmentally sustainable solution void of any discharge of pollutants to the sea.

1. INTRODUCTION

1.1 Name and Qualifications

Name and Address:

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Qualifications and Experience

Academic Qualifications
    Diploma in Physical Oceanography, University of Hamburg, Germany, 1994
    PhD in Physical Oceanography, University of Hamburg, Germany, 1996

Professional Associations
    American Geophysical Union (AGU)
    Australian Meteorological & Oceanographic Society (AMOS)
    Australian Marine Sciences Association (AMSA)

Statement of Professional Expertise
    Coastal oceanography
    Development and use of hydrodynamic models in oceanography
    Design and conduction of oceanic fieldwork
    Analysis and interpretation of oceanic data

A copy of my Curriculum Vitae is provided in Appendix A

1.2 Instructions and Information

I have been engaged by the City of Onkaparinga to provide an Expert Witness Statement that addresses issues raised in the EIS related to my area of expertise, in particular:

To identify deficiencies in research or methodology in the EIS.

Issues related to the hydrodynamic modelling of brine discharge plumes as presented in the EIS.

To review technical reports including hydrodynamic models used to predict salinity anomalies and dilution associated with brine discharge.

To undertake additional hydrodynamic modelling studies to provide an independent estimate of dilution.

1.3 Investigation Approach

This investigation is based on the assumption that desalination brine will be discharged into Gulf St. Vincent at Port Stanvac, although there are alternative options regarding inland salt production with minimum marine pollution. The latter technology is successfully used in Eilat (Red Sea) where high-quality table salt is produced and a discharge line is not needed (Ravizky and Nadav, 2007). Clearly, the proposal to discharge of desalination brine into slow flushing semi-enclosed gulfs such as Gulf St. Vincent does not take into consideration the best technology available.

In Section 2, I critically review technical reports with a focus on marine modelling studies undertaken for the EIS. Instead of a comprehensive review of all reports, I decided to exclusively discuss the most critical points and deficiencies in the methodology that I could identify.

In preparing my comments to the EIS, I have applied a hydrodynamic model to complement to the marine modelling studies undertaken for the EIS. Section 3 presents findings of this independent modelling study. Section 4 presents a summary of this investigation and gives recommendations for further consideration.

This statement and the supporting work do not exhaustively investigate the issues raised; rather it is presented to demonstrate issues in the EIS that require further consideration, which, if not addressed, and if the development goes ahead, may lead to serious problems.

2. REVIEW OF SELECTED TECHNICAL REPORTS

2.1 General Comments

Hydrographic field observations, undertaken for the EIS and including data from the Adelaide Coastal Waters Study, are of reasonably high quality, accurate and sufficient for the purpose of the EIS. Tidal currents and the gulf's circulation in vicinity of the proposed development are reasonably well understood. Gulf-wide model predictions and flushing time/salt budget calculations (Appendices D3 & D4 prepared by Cardno Lawson Treloar Pty Ltd) are reasonably well calibrated against field observations and reliable.

This investigation focuses only on the most critical aspect of desalination brine discharge —levels of effluent concentration establishing in vicinity of the discharge location. Pollutant levels in the sea depend on levels of chemical properties in the discharge and mixing and dispersal by ambient currents. Resultant polluted levels are therefore strongly influenced by the dilution of brine concentrate in the water column. Dilution is defined as the volume of ambient seawater mixed with one volume unit of brine concentrate as is expressed by a mixing ratio such as 30:1.

The EIS defines a target dilution (minimum dilution requirement) of 50:1. Usually, minimum dilution requirements are derived from comprehensive ecotoxicity testing and water quality analysis. On the basis of this, the Victorian Desalination Project, , for instance, has defined a "safe dilution" of 30:1 or higher. For unknown reasons, ecotoxicity studies for the Adelaide Desalination Project remained incomplete (see Appendix C2). Therefore it can be questioned whether the postulated "highest level of environmental scrutiny" has been applied here.

According to the Environment Protection Act, to obtain the required authorisation, SA Water will have to demonstrate that neither the seawater discharge nor the chemicals within that discharge will cause any harm to the receiving marine environment or the flora and fauna species within that environment. Model predictions of dilution around the discharge location play a crucial role in the assessment of the feasibility of the Adelaide Desalination Project and its approval.

2.2 Near-Field Dilution & Outfall Hydraulics

Following the recommendations outlined in Appendix D2, the design of the discharge can be summarised as follows:

- 1.4 km long pipeline out to a depth of about 20 m
- 246 m long diffuser section
- 42 tee risers spaced at 6 m intervals along the diffuser pipe and protruding from the main sub-marine pipe to 1m above the seabed
- 84 ports of 0.11m in diameter with duckbill valves directed upward at 60^o from the horizontal

The subject of the field of hydraulic engineering is to create an optimum design of the discharge with the target to produce the maximum mixing efficiency with ambient water. Various methods such as the empirical model of Roberts et al. (1997) can be employed to predict the pathway and mixing characteristics of dense discharge from a single port until it meets the seafloor (**Figure 1**).

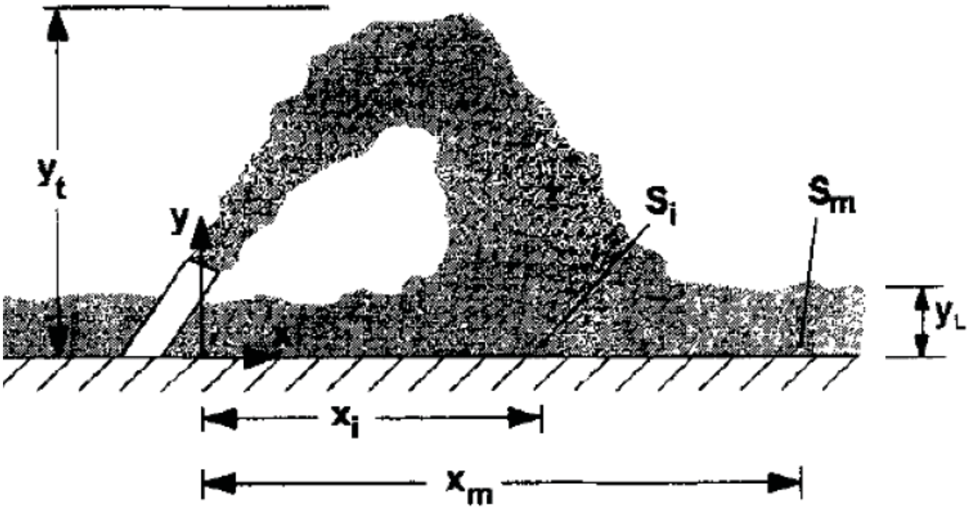

Figure 1: Schematic representation of dense discharge from a single port. Modified from Appendix D2.

Figure 2 displays the initial stages of an inclined dense discharge in a laboratory setting (Bloomfield and Kerr, 2002). As the discharge jet enters the ambient water its width increases. This increase is caused by turbulent entrainment and triggers a certain dilution of the discharge along the pathway of the plume. At some distance, owing to negative buoyancy, the turbulent fluid is peeling off from the jet (called detrainment) to form the falling part of the dense plume. The dilution of the fluid in contact with the seabed depends on whether the resultant mixture is continually removed from the near field by ambient currents or the resultant density-driven flow. If not, salinity anomalies can accumulate adjacent to the discharge location.

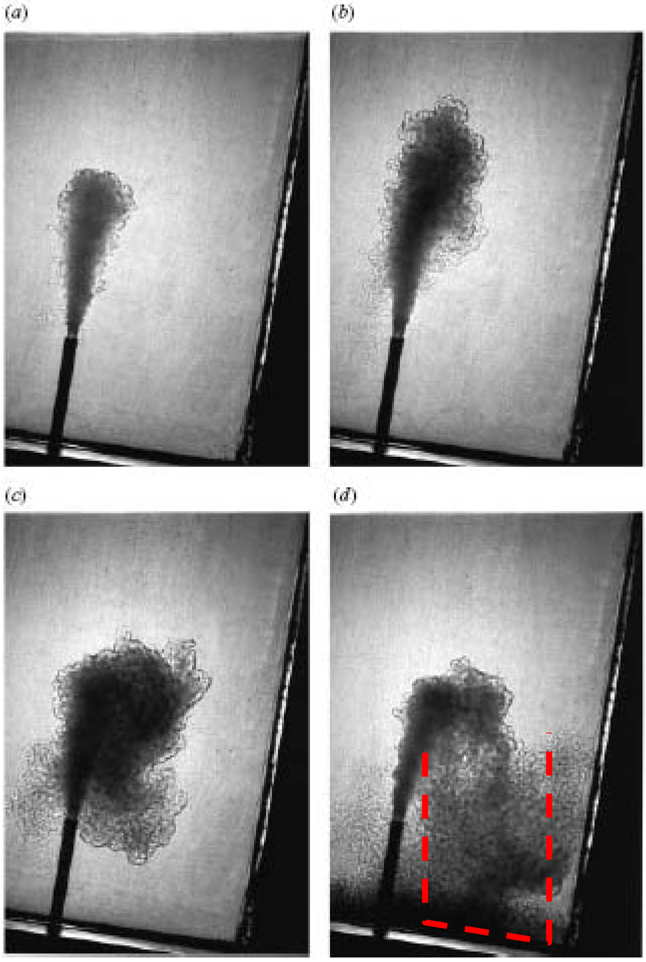

Figure 2. Photographs of a turbulent axisymmetric fountain formed from a source inclined at 10° to the vertical. (a) The initial flow is jet-like. (b) The downward buoyancy force brings the fluid to rest at an initial maximum height. (c, d) The fluid then falls as a plume and partially interacts with the upflow, resulting in smaller final height of the fountain. The dashed region in (d) indicate the area in which diluted fluid can accumulated if not removed by ambient currents or the resultant density-driven flow. From Bloomfield and Kerr (2002).

Because the removal rate of salinity anomalies is not known a priori, a conservative estimate of dilution is determined from the rising jet (rather than from the falling part) at a location where the upward volume flux is at maximum (Lee and Chu, 2003). It can be shown (see Lee and Chu, 2003) that the maximum average dilution is given by:

Maximum average dilution = 0.384 Fr (1)

where Fr is the jet densimetric Froude number, whereas the centerline dilution is slightly smaller; that is;

Centerline dilution = 0.23 Fr (2)

With densimetric Froude numbers given in Appendix D2, we yield maximum average dilutions in a range between 7:1 and 19:1 and centreline dilutions between 4:1 and 11:1. Lower dilutions in the latter ranges correspond to reduced discharges. The author considers these values (being well below the dilution target of 50:1) as realistic estimates of dilutions establishing in the near field for the Adelaide desalination project for the proposed diffuser design.

These dilution values are much smaller than those derived in Appendix D2 that were taken from the location where the plume meets the seabed based on the unrealistic assumption that the diluted brine in this region be instantly removed by currents. On the basis of this, the author deems predictions of Appendix D2 as far too optimistic.

2.3 Plume Dispersion Modelling

Salinity anomalies forming near a discharge location depend on:

- the excess salt flux associated with the discharge;
- initial dilution in the near field
- the dynamics of density-driven flow created by the brine discharge;
- mixing and dispersal by ambient flow

Plume dispersion modelling (as applied in Appendix D1) is a method used to predict dilution values in the mid field; that is, within distances of few kilometres from the discharge location. This approach, however, depends crucially on the assumption of the volume (hereafter referred to as “initial mixing zone”) over which the dense discharge is being distributed. It is difficult to estimate this initial “footprint” of brine plumes, given a) the existence of “shadow” regions (**Figure 3**) being excluded from entrainment of desalination brine, and b) uncertainly about the volume over which salinities accumulate in the near field (see Figure 2).

Pattiaratchi (Appendix D1) employed a sophisticated hydrodynamic model to predict salinity anomalies forming around the discharge outlet. This approach is sometimes called “mid-field modelling”. <u>Findings of such mid-field studies crucially depend on how the brine discharge is implemented in the model and how realistic this implementation is.</u>

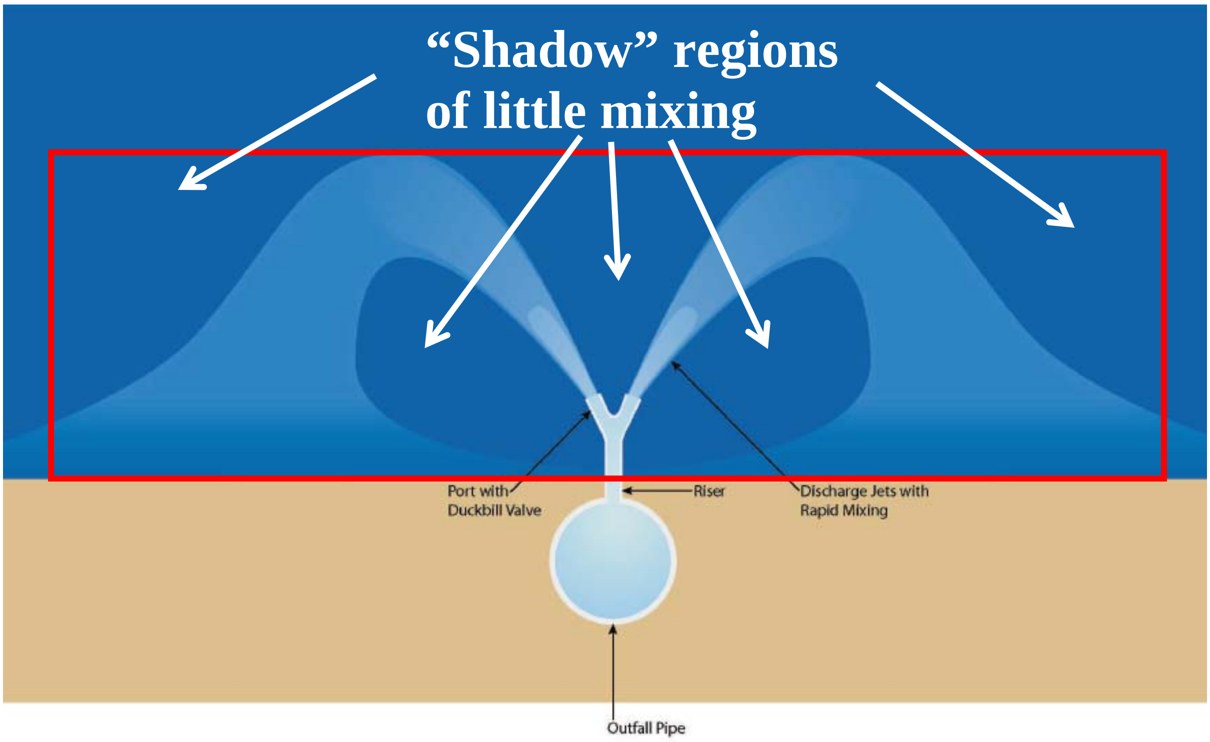

Figure 3: Schematic representation of dense discharge from two ports. Shadow regions are the zones not exposed to turbulent mixing. The red rectangle shows the instant mixing zone assumed by Pattiaratchi. Modified from Appendix D2.

In Pattiaratchi’s work, the excess salt flux is distributed over an instant mixing zone of 150 m in length (diffuser length), 100 m in width, and 10 m in height. The latter vertical scale has been based on predicted plume rise heights of Y_t = 10-15 m (Appendix D2). This instant mixing zone has a volume of 150 m × 100 m × 10 m = 150,000 m^3. Given the existence of shadow regions, clearly the proposed diffuser design cannot accomplish complete mixing over this vast volume. Hence, the methodology used by Pattiaratchi leads to an overestimation of dilution.

Pattiaratchi (Appendix D1) states that “this (instant mixing zone) was required to match the design 1:50 dilution of the diffuser”. For this reason, it is no surprise that the predicted minimum dilutions are close to the target of 50:1 (**Figure 4** shows an example). The predictions are strongly biased by the unrealistic assumption of the size of the instant mixing zone and therefore scientifically unreliable. Important questions as to how dilution changes for variations of the size of the instant mixing zone are not addressed in Appendix D1.

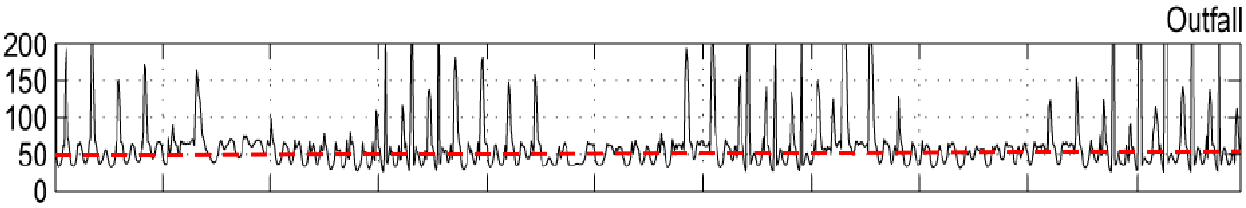

Figure 4: Example of Pattiaratchi’s dilution predictions. The dashed line shows the dilution target of 50:1. Taken from Appendix D1.

It should be made very clear that simulation results presented in Appendix D1 are <u>only valid if desalination brine is completely mixed</u> over a distance of 150 m, a width of 100 m and a height of 10 m. Hydraulic engineers need to confirm whether this is accomplished with the proposed diffuser design. Otherwise dilution values will be smaller, as demonstrated in the following, and <u>the risk of environmental damage can dramatically increase</u>.

3. INDEPENDENT MODELLING STUDY

3.1 Model Description

This study employs the three-dimensional hydrodynamic model COHERENS (COupled Hydrodynamic Ecological model for REgioNal Shelf seas) (Luyten et al., 1999). This model is based on conservation principles for momentum, mass and energy for an incompressible fluid and is formulated in terrain-following sigma coordinates. This model is based on the same physical principles as the model used by Pattiaratchi.

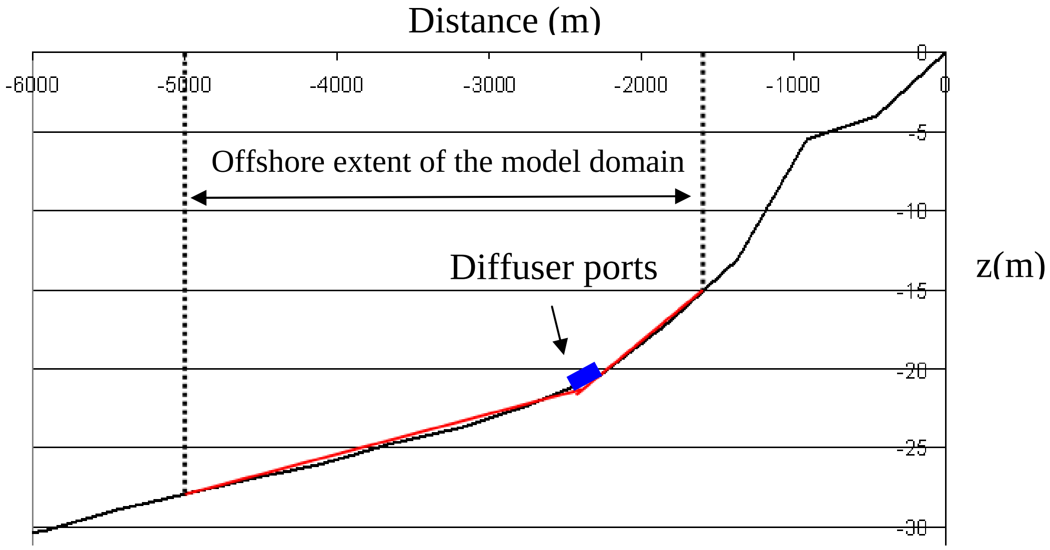

Figure 5. Simplified shape of the seafloor near Port Stanvac (red lines) used in the model based on Geoscience Australia data.

COHERENS is employed in its standard configuration. Bottom friction is described by means of a quadratic bottom-friction law using a bottom roughness length of 5 mm. Use of a higher value of 2 cm gave similar results. A Richardson-number based turbulence closure scheme by Pacanowski and Philander (1981) is used to calculate vertical eddy diffusivity and viscosity. Other turbulence closure schemes yielded similar results. Horizontal eddy viscosity and diffusivity are assumed constant, both of a value of 0.5 m^2/s. The author has employed this model many times before for various purposes including regional applications in studies of the circulation and flushing characteristics of Bass Strait (Sandery and Kämpf, 2007), the Persian Gulf (Kämpf and Sadrinasab, 2005), and South Australian gulfs (Kämpf et al., in press).

3.2 Experimental Design

The idealised bathymetry used has been constructed from Geoscience Australia data (**Figure 5**). The model domain is a rectangular channel of 6 km in length and 3.4 km in width (**Figure 6**) resolved by a horizontal grid spacing of 25 m. This is half the grid spacing used by Pattiaratchi. Twenty model layers are used in the vertical.

Two different heights of the instant mixing zone are considered: 3 m and 6 m. A fixed fine vertical grid spacing of 30 cm or 60 cm (corresponding to 10 model layers) is used to adequately resolve the plume dynamics on these vertical scales. The other ten model layers are evenly spread over the remainder of the water column. Notice that the near-shore coastal regions are not included in the model domain. This is not necessary given that the density forcing produces flows that tend to move downward on the sloping seafloor.

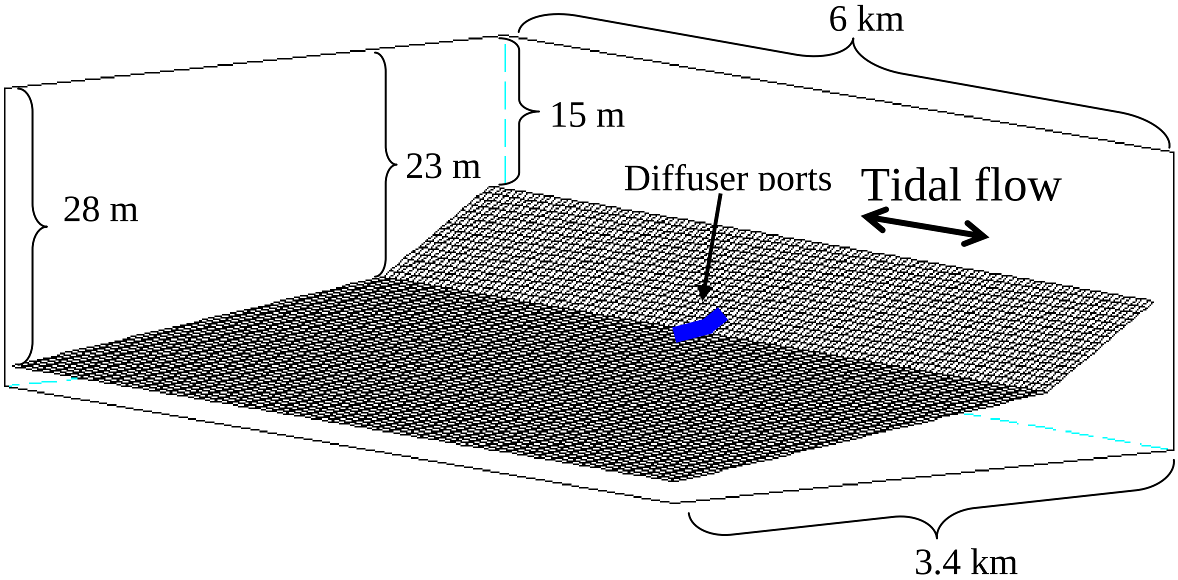

Figure 6. Simplified bathymetry considered in this study. The blue line denotes the discharge design covering an area of 150 m in length and 50 m in width.

Ambient tidal flows are created via prescription of tidal sea-level elevation at the southern open boundary using the semi-diurnal lunar and solar tides M_2 and S_2. Amplitudes of these tidal constituents are set to observed values of 43 cm and 41.9 cm, respectively, which lead to a realistic tidal range of 1.7 m during spring tides and almost vanishing values during dodge tides (**Figure 7**). Other tidal constituents are irrelevant for the purpose of this investigation and were ignored. Simulated tidal near-bottom flows attain maximum speeds of 13-16 cm/s (not shown), which is in agreement with observational evidence (see Appendix D5). To represent the worst-case scenario, wind-driven or other steady ambient flows and wind/wave-induced mixing are ignored here.

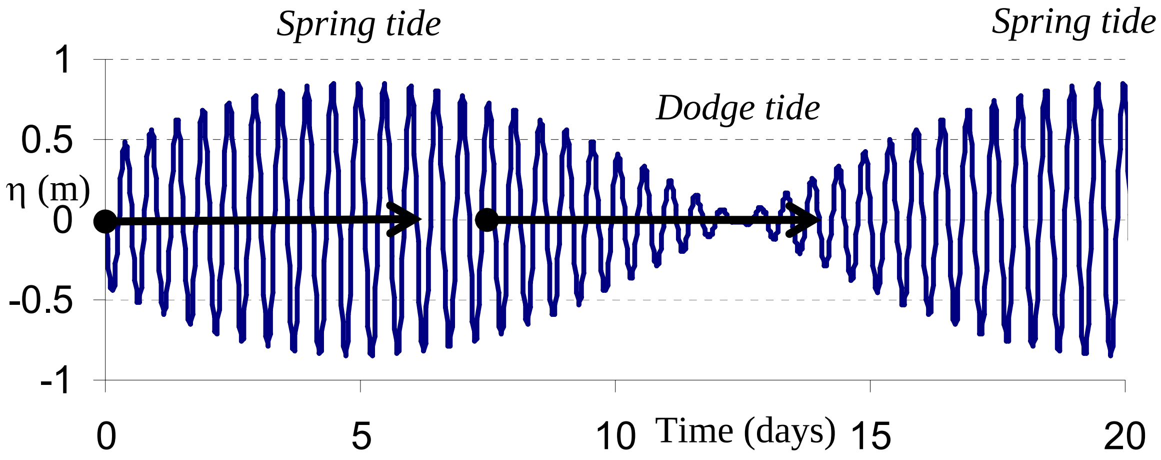

Figure 7: Evolution of tidal sea-level elevation. Arrows indicate the simulation times of different experiments.

For simplicity, the ambient sea is assumed initially uniform in density. Temperature effects are ignored in this study. The initial salinity of ambient seawater is uniform with a value of S_o = 37 ppt. The total simulation time of experiments is 6 days commencing at different times of the tidal cycle (see Figure 7) to capture situations of either spring tides or dodge tides. Time constraints did not allow for continuous longer simulations.

3.3 Implementation of Brine Discharge

Local brine discharge is implemented via the Eulerian flux condition:

$$\frac{\partial S}{\partial t} = \left(S_{brine} - S\right)\frac{q_{brine}}{V}, \tag{3}$$

where S is the salinity in the grid cell containing a discharge outlet, t is time, S_{brine} = 68.7 ppt is the salinity of the discharge brine, q_{brine} is the discharge rate and V is the volume of the instant mixing zone over which this flux is applied. A discharge rate of q_{brine} = 4.46 m^3/s is adopted here corresponding to the maximum value considered by Pattiaratchi.

This salinity flux is evenly distributed over an instant mixing zone of 150 m in length (6 grid cells), 50 m in width (2 grid cells), and the lowermost 3 m of the water column. This zone covers the proposed 84 diffuser ports. Width and height are based on values of X_i and Y_L values (see Figure 1) given in Appendix D2. Note that this instant mixing zone corresponds to a volume of 22,500 m^3 and it is 6.7 times smaller compared with the setting used by Pattiaratchi. Choice of a diffuser length of 250 m gave similar results. Additional experiments consider a thickness of the instant mixing zone of 6 m. The corresponding instant mixing zone is 3.3 times smaller than assumed by Pattiaratchi.

As in Appendix D1, dilution values are derived from the ratio:

$$\text{Dilution} = \frac{\Delta S_{brine}}{\Delta S_{mix}} \tag{4}$$

where ΔS_{brine} = 31.7 ppt is the excess salinity of the desalination brine compared with ambient levels, and ΔS_{mix} is the predicted (or observed) salinity anomaly.

3.3 Results

a) Instant mixing height of 3 m

The salinity forcing imposed produces a density-driven bottom-arrested plume that tends to flow downward on the sloping seabed (**Figure 8**). During spring tides, the tidal flow modifies the spreading direction of this plume. The plume attains a maximum extent of about 2 km, which agreed well with the observed tidal excursion during spring tide (see Appendix D5).

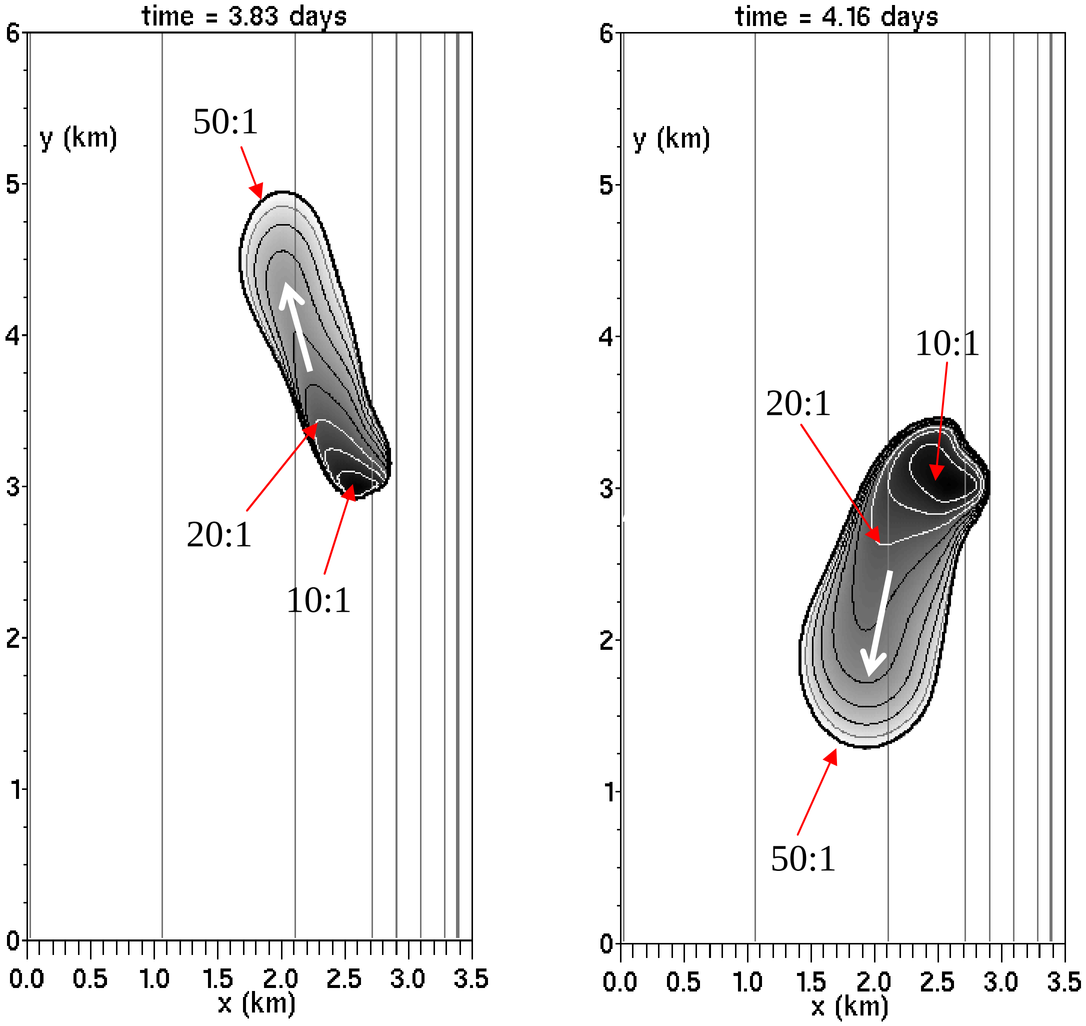

Figure 8: Spring tide distributions of near-bottom salinity anomalies expressed by dilution ratios (dark shading and contours) after 92 and 100 hours of simulation. Gray lines are bathymetric contours. White arrows indicate the direction of spreading.

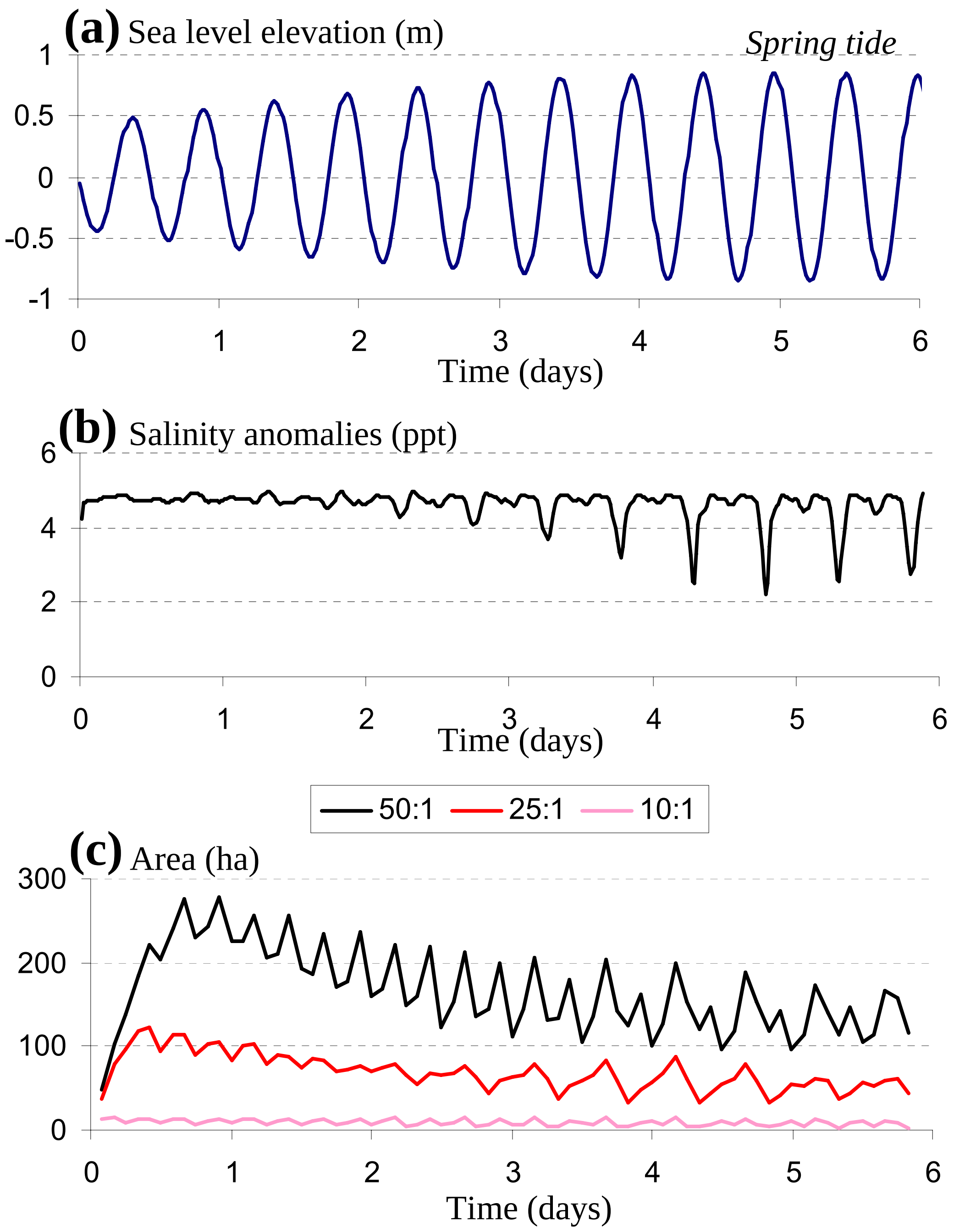

Figure 9: Spring tide simulations. Evolutions of a) tidal sea level, b) salinity anomalies (ppt), and c) size of areas (ha) with reference to certain dilution thresholds (see legend). The "spiky" appearance of curves in b) and c) is associated with low-resolution data outputs at every 2 hours of the simulation.

A major difference to the findings presented in Appendix D1 is that dilution ratios <50:1 are found in excessive areas and that dilutions of <10:1, corresponding to salinity anomalies >4 ppt, establish on a permanent basis near the discharge location (**Figure 9**). Near-field dilutions only increase temporarily to values of ~15:1 for short periods of the swiftest tidal currents during spring tides. On the basis of this, the target dilution of 50:1 is compromised near the discharge at all times.

The area occupied by brine concentrate of dilution <50:1 is about 140 ha (1 hectare = 100 m by 100 m) whereby variations of ±40 ha occur during a tidal cycle. This is in stark contrast to the predictions presented in Appendix D1 where areas of dilution <50:1 are virtually absent. Here, there are areas of much lower dilution. For instance, dilutions <25:1 are found in areas of around 50 ha in size, and minimum dilutions <10:1 still occupy an area ranging between 4 ha and 14 ha in size.

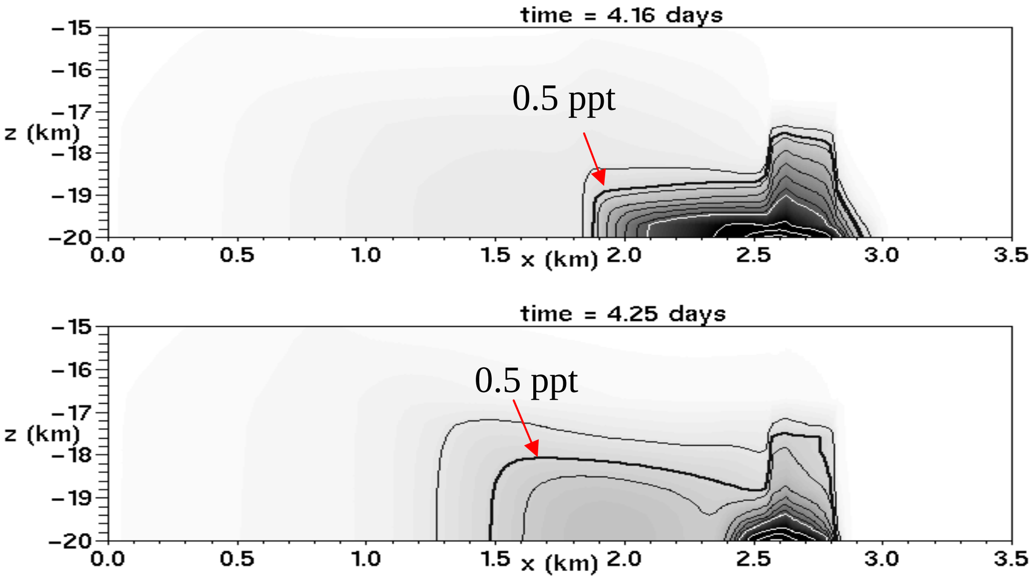

Figure 10: Spring tide simulations. Cross sections of near-bottom salinity anomalies at y = 3 km after 99 and 100 hours of simulation. The salinity contour at 0.5 ppt, corresponding to a dilution of ~60:1, is highlighted.

Diluted brine plumes attain a thickness of 1-2 m (**Figure 10**) and extend over several kilometres from the discharge location (see Figure 8). These scales are in agreement with measurements of a recent monitoring study of the brine discharge produced by the SWRO desalination plant of Alicante (SE Spain) where salinity anomalies exceeding 0.5 ppt could be traced in the area up to 4 km from the discharge location (Fernández-Torquemada et al., 2005).

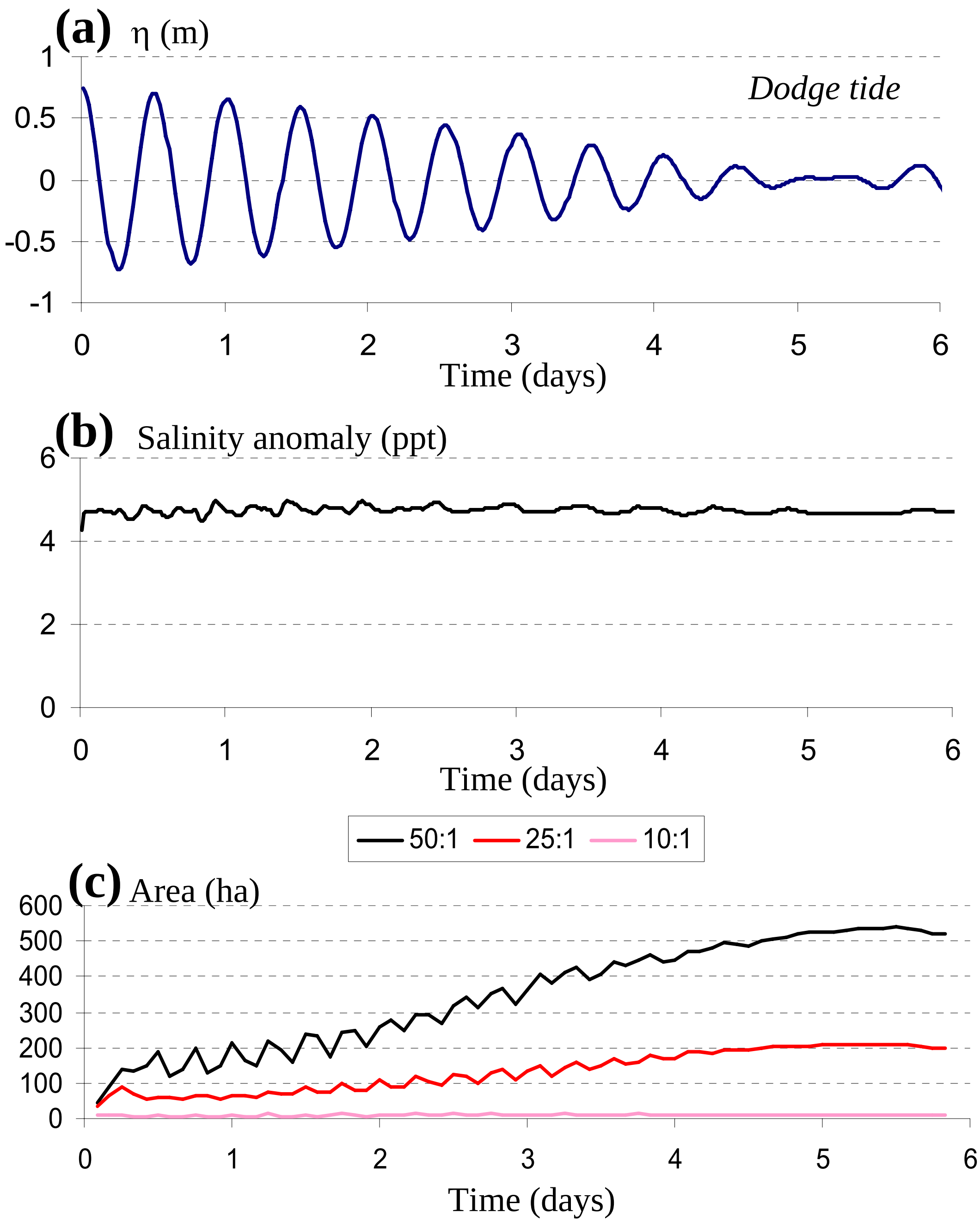

Figure 11: Dodge tide simulations. Evolutions of a) tidal sea level, b) salinity anomalies (ppt), and c) size of areas (ha) with reference to certain dilution thresholds (see legend).

During the dodge tide, while the salinity anomaly in the near field remains largely unmodified, but the area extent of the brine plume dramatically increases to maximum values of >500 ha when based on minimum dilution ratios of 50:1 (**Figure 11**). Areas of dilution <25:1 increase to 200 ha in size, whereas dilution ratios <10:1 are found in an area surrounding the discharge of ~ 15 ha in size.

Density-driven flow, created by the brine discharge, is the principle agent removing salt from the near field during dodge tides (**Figure 12**). This explains why the near-field salinity anomaly remains largely unaffected during dodge tides while the brine plume spreads over a much larger distance compared with the spring tide situation.

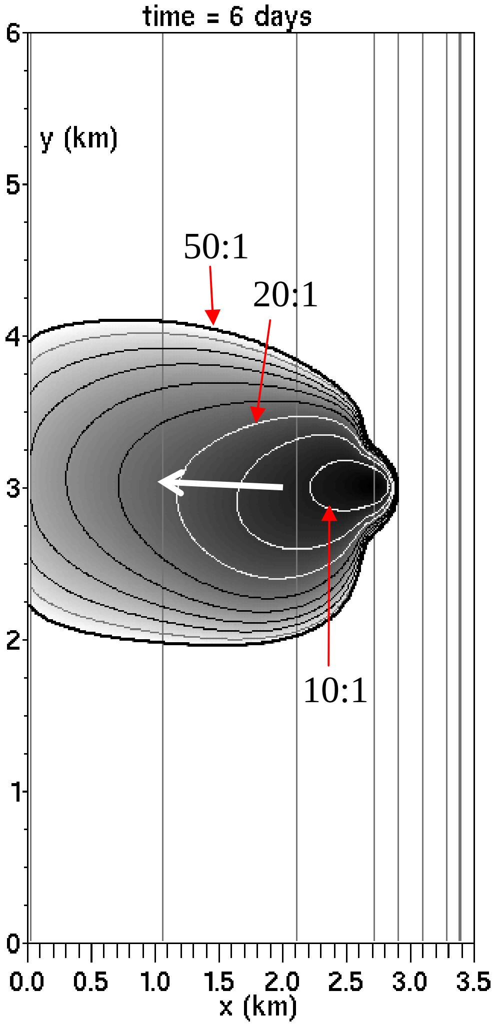

Figure 12: Dodge tide distribution of near-bottom salinity anomalies expressed by dilution ratios (dark shading and contours) after 6 days of simulation. Gray lines are bathymetric contours. The white arrow indicates the direction of spreading.

Tidal excursions during the dodge tide of 300-500 m (see Appendix D5) are short compared with the plume width of about 2 km and play a minor role in the dynamics during this period of the tidal cycle. It should be emphasised that the brine plume intersects the western model domain, leading to an underestimate of the true area extent of polluted water of dilution <1:50.

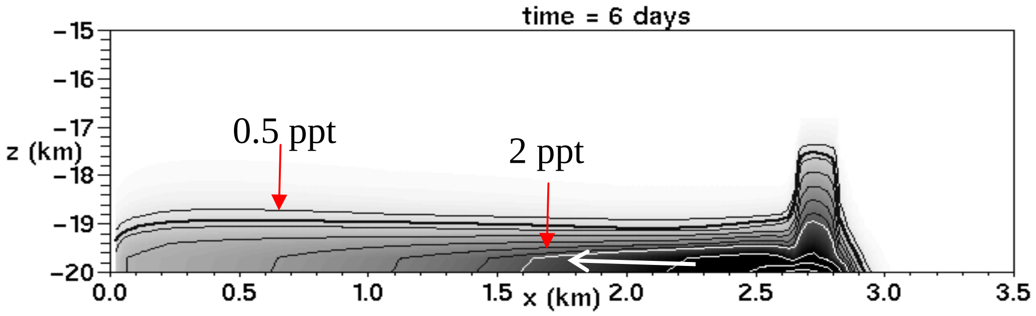

Figure 13: Dodge tide simulation. Cross sections of near-bottom salinity anomalies at y = 3 km after 6 days of simulation. Salinity contours at 0.5 ppt (dilution ~60:1) are 2 ppt (dilution ~15:1) are highlighted. The white arrow indicates the flow direction.

Clearly, dodge tides are the critical times supporting the establishment of bottom-arrested density plumes that distribute diluted brine concentrate downward on the sloping seafloor over distances of several kilometres (**Figure 13**). Associated with this is the risk of “pooling” of this water, i.e. accumulation of diluted brine in seafloor depressions, which could pose a severe danger to the marine environment in the far field. The choice of an unrealistically large volume of the instant mixing zone suppressed the development of pronounced density-driven flows in Pattiaratchi’s work.

b) Instant mixing height of 6 m

An increase of the volume of the effective instant mixing zone leads to a decrease of maximum salinity anomalies to ~2.3 psu and a near-field dilution in a range of 12:1 16:1. These values do not change significantly over the spring-neap tide cycle apart from short episodes during the spring tide during which dilutions temporarily increase to values >50:1 (not shown).

In this scenario, the area extent of polluted seawater of dilution <50:1 ranges between 100 and 150 ha during the spring tide, whereas seawater containing >4% of brine concentrate (dilution <25:1) still occupies an area of up to 35 ha during the spring tide (**Figure 14**).

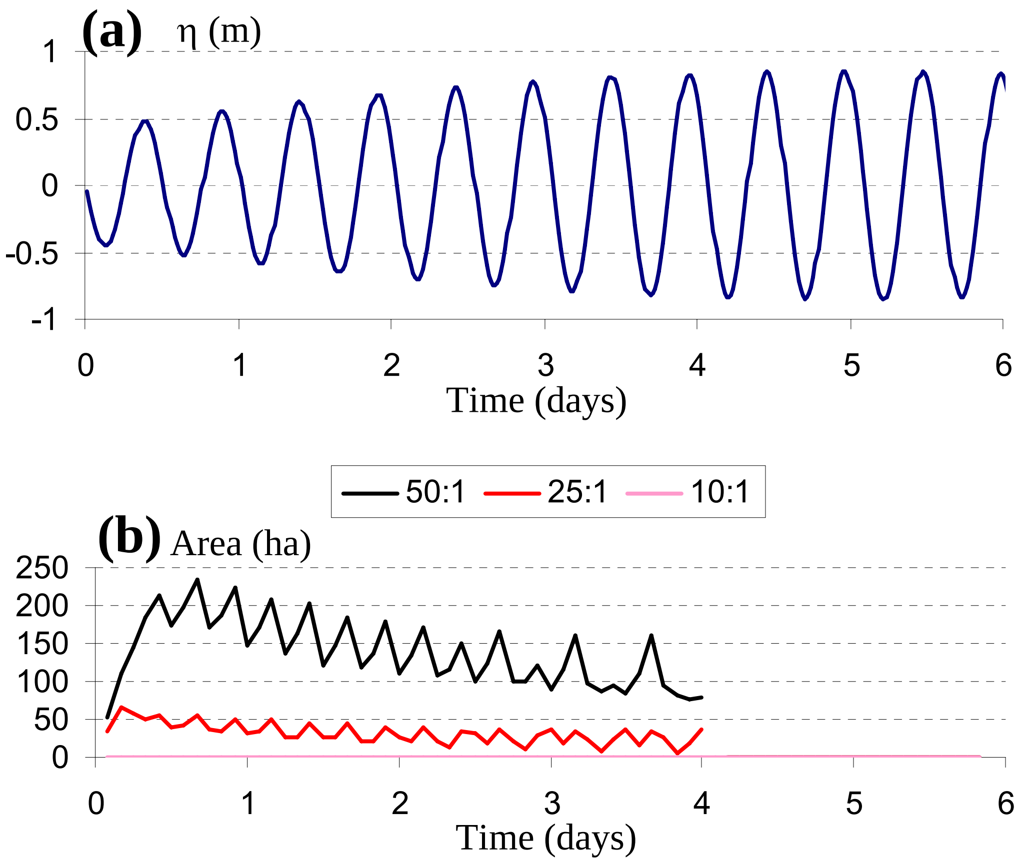

Figure 14: Spring tide simulations. Evolutions of a) tidal sea level, and b) size of areas (ha) with reference to certain dilution thresholds (see legend). Owing to time constrains the total simulation time had to be limited to 4 days.

With weaker ambient tidal currents during the dodge tide, the area extent of water of dilutions <50:1 dramatically increases to values exceeding 400 ha, whereas dilutions <25:1 are found in a region of ~100 ha in size (**Figure 15**). Dilutions of 10:1 and below do not occur in this simulation. Again the dodge tide supports spreading of the brine plume over a vast area (**Figure 16**) which is much larger than predicted in Appendix D1 of the EIS. In contrast to the latter, findings presented here reveal a clear influence of the dodge tide leading to a substantial increase of the "mixing zone", defined as the zone in which dilution can be below the minimum dilution requirement under approval of the EPA. If the minimum dilution is set to 50:1 according to the EIS, the mixing zone will expand to areas of ~500 ha during dodge tides, which is well beyond the usually accepted size of 100 m × 100 m = 1 ha (see Environmental Protection (Water Quality) Policy (2003).

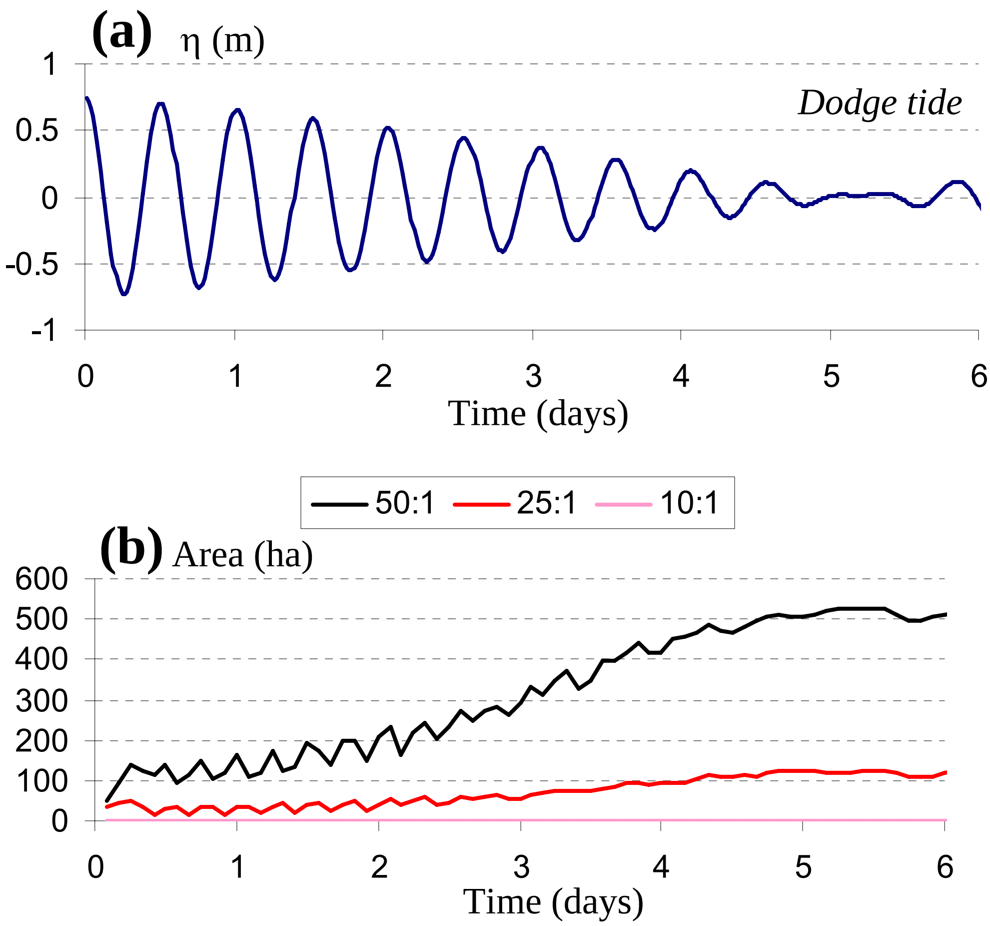

Figure 15: Spring tide simulations. Evolutions of a) tidal sea level and b) sizes of areas (ha) with reference to certain dilution thresholds (see legend). The areas are expected to further slightly increase (see Figure 11).

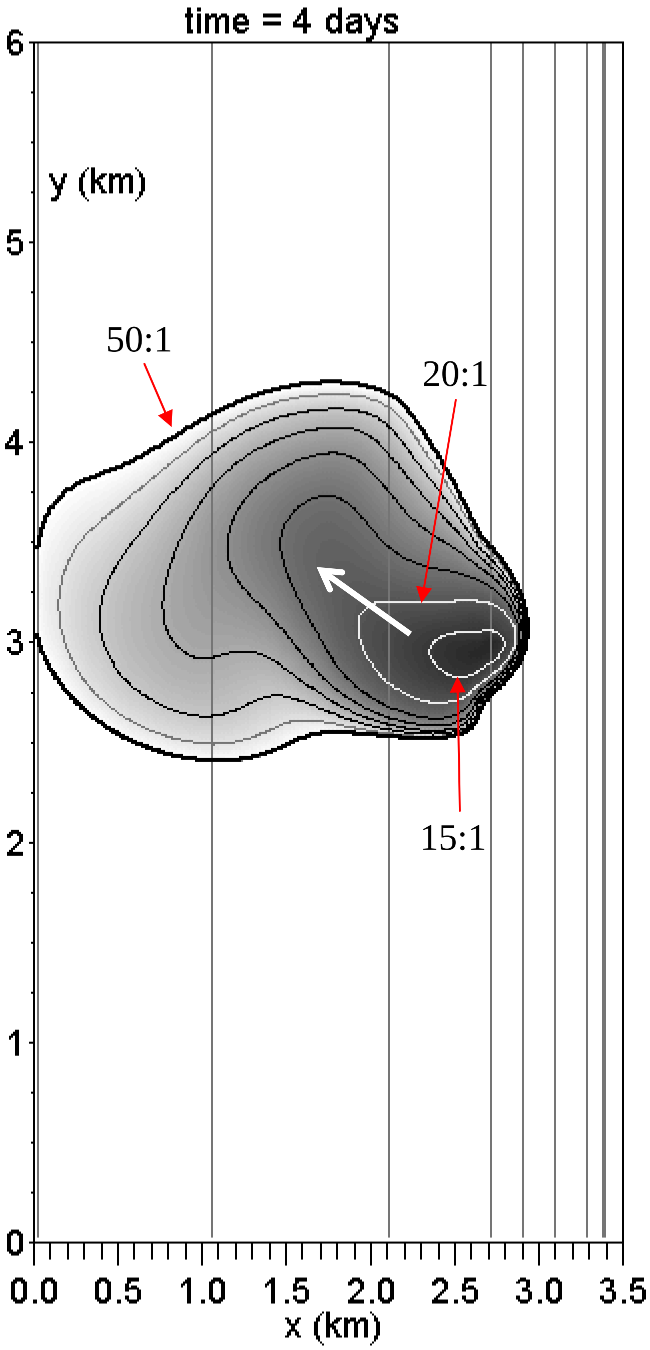

Figure 16: Dodge tide distribution of near-bottom salinity anomalies expressed by dilution ratios (dark shading and contours) after 4 days of simulation. Gray lines are bathymetric contours. The white arrow indicates the direction of spreading.

It is worth to mention that the model employed here replicates findings of Appendix D1 of the EIS when using the same configuration of an instant mixing zone with complete mixing over a volume of 150 m in length (diffuser length), 100 m in width, and 10 m in height.

4. CONCLUSIONS AND RECOMMENDATIONS

To provide a sustainable and secure supply of drinking water for metropolitan Adelaide, a desalination plant has been proposed to be built at Port Stanvac. This study utilized a three-dimensional hydrodynamic model to complement marine modelling studies undertaken as part of the EIS. Model runs considered a discharge rate of 4.46 m^3/s over a diffuser length of 150 m analogue to the treatment by Pattiaratchi in Appendix D1. Note that this flow rate is associated with the maximum operation capacity of 100 GL per annum.

A review of the methodology employed by Pattiaratchi revealed that the volume over which the brine concentrate is instantaneously distributed in the model (“instant mixing zone”) was unrealistically large and that this has led to a significant overestimation of dilution. This overestimation was also confirmed by hydraulic considerations suggesting that a conservative estimate of dilution be given by equations (1) and (2), yielding lower limits of near-field dilutions in a range between 4:1 and 19:1. It should be emphasised that a decreased discharge rate (e.g. owing to malfunctioning) will produce lower dilutions and, hence, a greater risk of damage to the marine environment.

On the basis of the above, I have conducted independent modelling studies considering instant mixing zones being 3 and 6 times smaller than considered by Pattiaratchi. This resulted in near-field dilutions of the order of values predicted by (1) and (2) that the author considers realistic. Findings presented here differed significantly from those underpinning the EIS. The major differences were:

- Near-field dilution ranged between 6:1 and 15:1 (depends on the mixing efficiency of diffuser ports) over most of the tidal cycle. Associated with this were near-field salinity anomalies between 2 and 5 ppt above ambient levels. The dilution target of 50:1 set in the EIS was compromised most of the time.
- When defining the mixing zone as the zone of dilutions less than 50:1, this zone occupied areas between 400 ha and 500 ha during dodge tides,

exceeding acceptable values of 1 ha by far. Areas of dilutions less than 25:1 increased to sizes between 100 ha and 200 ha during dodge tides.

- Dodge tides support pooling of desalination brine over distances of several kilometres from the discharge.

On the basis of the findings presented here, conclusions drawn in the EIS require substantial revision. If the model predictions presented here are realistic, risks of brine discharge on water quality have to be classified as “high” with major/severe consequences and almost certain likelihood.

On the other hand, if the project goes ahead without variation of the discharge design, my studies indicate that there is a likely risk that the operators cannot meet the licence conditions set by the EPA at certain times. This poses a dilemma given that, according to relations (1) and (2) and supported by Appendix D2, a decrease in discharge rates will lead to a decrease in dilution which will worsen the situation. Hence, it is possible that the desalination plant must be either

- switched off at all times to meet licence conditions, or
- run at maximum capacity at all times while continuing to potentially damage the marine environment.

Only a proper environmentally sustainable engineering solution can help to avoid the occurrence of this dilemma situation which implies either economic or ecologic losses. One solution could be to spread to discharge over a larger volume. In order to come closer to the dilution target of 50:1, I recommend consideration of a discharge design that is composed of three or more separate diffuser lines each of a length of 150 m or longer. To avoid interference of adjacent brine plumes, the distance between adjacent diffuser lines should be at least 2 km which is the tidal excursion during spring tides. Nevertheless, I recommend the conduction of further modelling studies in case of any alteration of the discharge design.

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Appendices

To be appended