Perth Metropolitan Desalination Proposal – Water Quality Management, Change to Implementation Conditions

Water Corporation

Section 46 Report and recommendations of the Environmental Protection Authority

Environmental Protection Authority
Perth, Western Australia
Report 1327
May 2009

Environmental Impact Assessment Process Timelines

Date	Progress stages	Time (weeks)
18/05/05	Request received from Minister	
17/03/08	Proponent Document Released for Public Comment	146
14/04/08	Public Comment Period Closed	4
23/12/08	Final Proponent response to the issues raised	36
25/05/09	EPA report to the Minister for the Environment	22

Released: 25/5/09
No appeals on s46 Reports

ISSN 1836-0483 (Print)
ISSN 1836-0491 (Online)

Assessment No. 1570

Summary and recommendations

The Minister for the Environment requested the Environmental Protection Authority (EPA) to undertake a review of the implementation conditions in Ministerial Statement 655 for the Perth Metropolitan Desalination Proposal on 18 May 2005. The Minister requested the review include the revision of the conditions to be consistent with the requirements of the *State Environmental (Cockburn Sound) Policy 2005* (Cockburn Sound SEP), and to reinforce the importance of the Water Quality Management Plan (WQMP) in the conditions, including recommending a set of dissolved oxygen trigger levels to ensure that relevant standards are not exceeded.

Section 46(6) of the *Environmental Protection Act 1986* (EP Act) requires the EPA to report to the Minister for Environment on whether or not the proposed changes to conditions and procedures should be allowed. In addition, the EPA may make recommendations as it sees fit.

This report provides the EPA's advice and recommendations to the Minister for Environment on the key environmental factors, conditions and procedures for the proposal.

Key environmental factors

It is the EPA's opinion that Marine Water Quality is the key environmental factor for the proposal, which requires detailed evaluation in the report.

Conclusion

The EPA has considered the then Minister for the Environment's request to review a number of conditions relating to the management of discharge from the PMDP and has concluded that the significance of impacts to the marine environment from the discharge of brine by the Perth Metropolitan Desalination Plant (PMDP) is still uncertain and the marine environment of Cockburn Sound continues to be under stress. Therefore the EPA has recommended that a change to the implementation conditions should be made to provide further assurance that the objectives of the State Environmental (Cockburn Sound) Policy 2005 and the EPA's objectives are met for the key environmental factor of marine water quality.

The EPA has also concluded that the operational licence issued under Part V of the EP Act is the appropriate vehicle to provide a legally enforceable regulatory regime for monitoring and management of the impacts of the brine discharge from the PMDP on the marine environment of Cockburn Sound.

Recommendations

The EPA submits the following recommendations to the Minister for Environment:

1. That the Minister notes that this report is pursuant to section 46(6) of *the Environmental Protection Act 1986* and thus is limited to consideration of proposed changes to the Ministerial Statement 655 conditions.
2. That the Minister considers the report on the key environmental factor as set out in Section 4.
3. The Minister notes that the proposed changes are to amend Condition 5 to comply with the current implementation standard and also to include an additional condition,

Condition 8, to ensure that the marine water quality of Cockburn Sound is not adversely impacted by the operation of the PMDP.

4. The Minister imposes the amended conditions and procedures recommended in Appendix 4 of this report.

Conditions

The EPA recommends that the following conditions, which are set out in detail in Appendix 4, be imposed:

1 The existing implementation conditions applied to the project (Ministerial Statement 665 published on 9 July 2004), be subject to modifications necessary to:

- Ensure the conditions are consistent with the requirements of the Cockburn Sound SEP;
- Set a minimum dissolved oxygen saturation level in Cockburn Sound upon which management and monitoring related to the discharge from the PSDP should be based.

2. Condition 5 is replaced by the current standard implementation condition.

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1. Introduction and background

In May 2005, under Section 46(1) of the *Environmental Protection Act 1986* (EP Act), the Minister for the Environment requested the EPA consider and provide advice on changes to the environmental conditions relating to the Perth Metropolitan Desalination Plant (PMDP) operated by Water Corporation of Western Australia. The Minister's request relates to the discharge of hypersaline effluent (brine) from the PMDP into Cockburn Sound and requires the EPA to consider revising conditions so that they:

1. are consistent with the requirements of the *State Environmental (Cockburn Sound) Policy 2005* (Cockburn Sound SEP);
2. reinforce the importance of the Water Quality Management Plan (WQMP); and
3. recommend a set of Dissolved Oxygen trigger levels to ensure that relevant 'standards' are not exceeded.

There is considerable history concerning the PMDP and the potential impact of the brine plume on stratification events and dissolved oxygen levels of the marine waters in Cockburn Sound which is briefly outlined below.

On 26 May 2003, the Minister for the Environment issued approval of the proposed PMDP at a site either in East Rockingham or Kwinana with a potable (drinking) water production rate of 30 gigalitres (GL) per year (Ministerial Statement 626). Ministerial Statement 626 ensured that the discharge of brine, containing higher concentrations of salt than the ambient seawater and some chemical additives, would be managed through the proponent's commitment to produce and implement a WQMP.

Subsequent to Ministerial Statement 626 the Water Corporation requested approval to increase the production of drinking water from 30GL per year to 45GL per year. The EPA provided advice to the Minister on this change to conditions under section 46(1) of the EP Act. The Minister issued approval for this change to conditions on 9 July 2004. A new Ministerial Statement (665) was issued which included clarification regarding the objectives of the WQMP and the proponent's commitment (Commitment 9) to commission studies to assess the likelihood of increased stratification due to the brine discharge.

As required under the above approval, studies were carried out on behalf of the proponent to determine whether the discharge of brine would cause any change in stratification and dissolved oxygen regimes in the deep basin of Cockburn Sound. The studies were separate but interlinked and the reports were provided in March 2005. From these reports the proponent concluded that the minimum 60% dissolved oxygen saturation standard required in the recently published (January 2005) Cockburn Sound SEP, was unlikely to be compromised by the brine discharged from the PMDP.

The Department of Environment and Conservation (DEC) advised the EPA that it lacked confidence in the outcomes of the modelling undertaken in the studies. As a result the EPA requested that two expert reviews be undertaken, one by the National Institute of Water & Atmospheric Research Ltd (NIWA 2005) and one by the Commonwealth Scientific and Industrial Research Organisation (CSIRO 2005). The 2005 reviews determined that the modelling used was simplistic and was not adequately tested against data, and the conclusions were not well supported by the analysis and left a high degree of uncertainty about the likely impact of the discharge. The expert reviews recommended that a more sophisticated 3-D hydrodynamic –ecosystem model be used and more data be gathered to verify the accuracy of the model and conclusions.

The Minister for the Environment requested the EPA to undertake this current section 46 review into the implementation conditions in Ministerial Statement 655 on 18 May 2005.

To inform the section 46 review the EPA commissioned Professor Barry Hart & Dr Tony Church (Hart & Church 2006) to undertake an independent peer review of the proposed dissolved oxygen criteria and management decision scheme for the PMDP.

The Water Corporation's section 46 document (Water Corporation 2008a) was released for a four weeks public comment period on 17 March 2008. This document set out the proponent's proposed revisions to environmental conditions, most notably recommending that dissolved oxygen trigger levels for management intervention are not required to protect overall water quality. This recommendation was based on the findings of the further studies and modelling commissioned by the Water Corporation and undertaken by the Centre for Water Research (CWR), which were provided as an attachment to the section 46 document.

In addition to these amendments the proponent indicated that the project characteristics table should be modified to more accurately reflect the project as constructed. These changes include the length and diameter of the seawater intake pipes, the volume of discharge of concentrated seawater and the diameter of the product water pipeline.

On behalf of the EPA, the DEC commissioned a second peer review to appraise the key findings of the technical reports produced by the CWR. This peer review was conducted by Dr Robert Spigel of NIWA (NIWA 2008) whose commission was supported by the Water Corporation as being an independent expert, highly respected in his field.

In December 2008 Water Corporation produced its Response to Public Comments document (Water Corporation 2008b), which addressed issues raised during the consultation period and the outcomes of the NIWA (2008) peer review.

During this period the Minister for the Environment amended the environmental regulations to require that large capacity desalination plants obtain operational licences under Part V (administered by DEC) of the EP Act.

The first operational licence for the PMDP was issued for a year in September 2006. This was reissued for a further year in September 2007 and reissued again in September 2008 for a three year period. The operational licences set a minimum dilution rate that should be achieved at the edge of the designated mixing zone, dissolved oxygen trigger circumstances at the North, Central and South monitoring sites within the deep waters of Cockburn Sound, operating management measures and reporting procedures.

Further details of the project are presented in Section 2 of this Report while public consultation is discussed in section 3. Section 4 discusses the key environmental factor for the project. The conditions and procedures to which the project should be subject, if the Minister determines that it may be implemented, are set out in Section 5. Section 6 presents the EPA's conclusions and Section 7, the EPA's Recommendations.

A list of people and organisations that made submissions is included in Appendix 1 and References are listed in Appendix 2. Environmental Condition Statement No. 655, published on 9 July 2004 is presented in Appendix 3. The recommended conditions and procedures are provided in Appendix 4.

Appendices 5 and 6 respectively contain the peer reviews commissioned by the EPA and DEC (on behalf of the EPA) by independent expert peer reviewers Professor Barry Hart and Dr Tony Church (Hart & Church 2006) and Dr Robert Spigel, National Institute of Water & Atmospheric Research Ltd (NIWA 2008).

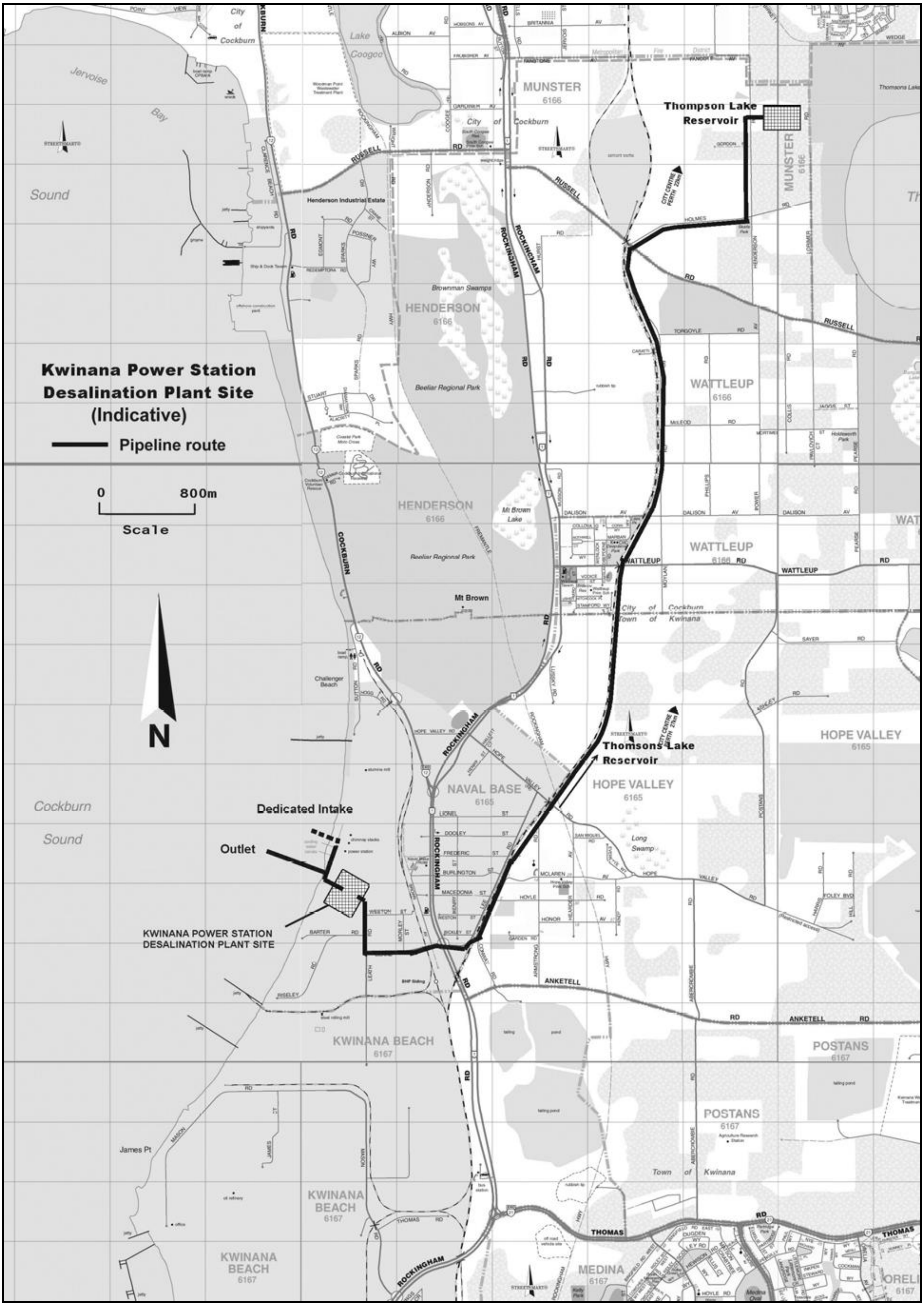

Figure1: Location of Perth Metropolitan Desalination Plant and infrastructure, Kwinana

2. The project

The Water Corporation of Western Australia operates the PMDP at Kwinana (Figure 1), which has approval to produce 45GL per year of drinking water through the reverse osmosis process. This process involves the intake of seawater from Cockburn Sound, pre-treatment to remove solids and suspended particles and then pressurising the seawater over a membrane so that freshwater is driven through the membrane and hypersaline effluent (brine) is left behind. The brine is then discharged back to Cockburn Sound via an outfall pipe and diffuser.

3. Consultation

A summary of the public submissions and the Water Corporation's response can be found in the proponents Response to Public Comments (Water Corporation 2008b) document in the Matrix Summary of Public Issues (pages 6 to 12). This document is located on the Water Corporation's website www.watercorporation.com.au. The EPA has considered issues arising from this process relating to identifying and assessing key environmental factors.

Submissions received from agencies and the public during the four week consultation process did not raise any concerns relating to the changes to the project characteristics requested by the Water Corporation. The EPA considers that the changes, with the exception of the zero net greenhouse gas emissions, to be non-substantial changes and as such it is deemed more appropriate that a s45C (approval for minor amendments) be undertaken.

4. Key environmental factors

Section 46(6) of the *Environmental Protection Act 1986* requires the EPA to report to the Minister for Environment on whether or not the proposed changes to conditions or procedures should be allowed. In addition, the EPA may make recommendations as it sees fit.

The Minister's section 46 request requires the review of conditions relating to the current Cockburn Sound SEP and the monitoring and management of dissolved oxygen within the Sound and as such this report focuses only on the key factor of Marine Water Quality.

4.1 Marine Water Quality

Description

Cockburn Sound is a sheltered marine embayment which is the most varied and intensely used marine embayment in Western Australia. It provides an important resource for a mix of users and activities as diverse as the Navy, Kwinana commercial industries, commercial fishing and mussel farming, as well as recreational activities such as boating, fishing, dolphin watching, recreational diving and swimming. The Sound is also a significant breeding and nursery area for Blue Swimmer crabs and Pink Snapper and is consequently of importance to the fish stocks of the South West coast including the Perth metropolitan region.

State Environmental (Cockburn Sound) Policy 2005

In the past the wide range of commercial activities, both within the waters of the Sound and upon land in the surrounding catchment have adversely impacted the marine water quality and marine biota of the Sound and have the potential to continue to cause adverse impacts.

To achieve the Government and community desire to maintain a high level of environmental quality in Perth's coastal waters in perpetuity, the State Government endorsed the EPA's Cockburn Sound SEP. The Cockburn Sound SEP ensures the environmental values of ecosystem health; fishing and aquaculture; recreation and aesthetics; and industrial water supply would be maintained into the future. To achieve this the SEP set Environmental Quality Criteria (EQC) to protect and maintain the environmental values of Cockburn Sound from the adverse effects of pollutants, waste discharges and deposits through common management goals. Particularly relevant to this review is the EQC for dissolved oxygen that includes the standard for High and Moderate Ecological Protection areas of a minimum saturation of 60%.

The Cockburn Sound SEP was published in 2005, a year after the last review of PMDP conditions and at a time when the EPA was progressing an Environmental Protection Policy (EPP). On the basis of advice, the EPA decided not to proceed with the EPP and instead progressed the Cockburn Sound SEP. The Minister therefore requested a further section 46 review to incorporate the requirements of the Cockburn Sound SEP.

Water Corporation's section 46 document (Water Corporation 2008a) recommends an amendment to Commitment 10 of Ministerial Statement 655 so that the objective of whole effluent toxicity (WET) testing ensures that the discharge complies with the requirements of the Cockburn Sound SEP.

Dissolved Oxygen and Stratification trigger levels

In Cockburn Sound and coastal waters generally, the oxygenation of the marine waters mainly depends upon diffusion of oxygen from the atmosphere through the sea-air interface and mixing processes that can distribute the dissolved oxygen through the water column including bottom waters. Oxygen is also produced as a by-product of photosynthesis by marine algae and seagrasses and this also contributes to the dissolved oxygen concentration of marine waters during daylight hours, albeit to a lesser extent than diffusion from the atmosphere which occurs continuously. Oxygen is consumed during respiration of marine plants, animals and bacteria in the sediment and the water column. If the rate of respiration exceeds the rate of oxygen replenishment then the dissolved oxygen concentration will steadily decline over time. The waters of Cockburn Sound are known to become stratified under certain conditions whereby water of high density (e.g. higher salinity and/or lower temperature than ambient) will tend to gravitate towards the seabed and form a layer underneath the lighter, lower density waters above it. This layering is termed stratification and intensity of stratification is proportional to the density difference between surface and bottom waters, the greater the difference the more intense the stratification. Stratification can result in discrete layers that do not mix freely with layers above or below. This layering also interferes with the mixing and diffusive processes that bring oxygen from surface waters down to the seabed.

Wind intensity and duration has been found to be the key process that breaks down stratification and allows substances such as dissolved oxygen to mix through the water column. During calm conditions when the waters tend to stratify and there is no mixing between layers, microbial respiration in the sediments and consumption of organic matter in the water column consume oxygen at a greater rate than it is produced or received leading to reduced dissolved oxygen concentrations in bottom waters.

Stratification events can reduce normal dissolved oxygen levels from greater than 90% saturation throughout the water column to 60% saturation or lower in the bottom of the water column which can cause direct adverse effects on the benthic biota (e.g. Blue Swimmer Crabs & prawns) and to ecological processes. There is also the potential for a biogeochemical reaction to take place in the sediment releasing previously deposited pollutants such as nutrients, which may lead to excessive algal growth or heavy metals that can be harmful to marine life or contaminate seafood. Both these direct and indirect impacts have the potential to reduce the water quality, and the general environmental quality, of Cockburn Sound.

The PMDP discharges brine from the plant into the Sound through a multi-port diffuser, designed to achieve rapid mixing of the brine with seawater to 1 practical salinity unit (psu) above ambient salinity within 50 m of the diffuser. After this initial mixing, the diluted brine (still slightly denser than surrounding seawater) has the potential to then flow along the bottom of the deeper shipping channels into the deep basin and gravitate to the sea floor where it may enhance or prolong the period of vertical stratification during calm weather conditions (particularly late Summer and Autumn).

The EPA commissioned an independent review of the proposed dissolved oxygen criteria and management decision scheme for the PMDP (Hart & Church 2006). This review provided recommendations including the adoption of the Cockburn Sound SEP standard of 60% saturation as the lowest bottom-water dissolved oxygen concentration allowable. Also a number of amendments to the WQMP were recommended along with a programme of investigations to inform an on-going adaptive and proactive management process. This peer review also included a recommended trigger value table, which was considered during the creation of the first operational licence issued under Part V of the EP Act.

The Water Corporation commissioned CWR to undertake the two highest priority recommendations from the Hart & Church Review, namely 3-D hydrodynamic/water quality modelling and field monitoring program. CWR were also commissioned to model the impact of the PMDP discharge on dissolved oxygen in Cockburn Sound. The results of these studies and a summary document were provided as attachments to its section 46 document. The summary document (Water Corporation 2008a, Appendix 4) states that:

- there is no possibility of a denser saline plume from the desalination hypersaline effluent entering the deep waters of Cockburn Sound and sufficiently prolonging stratification such that dissolved oxygen is drawn down to low levels; and
- the effluent from the PMDP is so highly diluted that it does not have a measurable impact on stratification or dissolved oxygen in the deep basin of Cockburn Sound.

Based on the CWR investigations the Water Corporation recommended that:

1. no further investigations into stratification and/or dissolved oxygen levels be conducted;
2. dissolved oxygen criteria do not need to be applied to the PMDP discharge to protect the deep basin;
3. the dissolved oxygen monitoring being conducted under the Water Quality Monitoring Plan cease;

4. any further monitoring of dissolved oxygen should be undertaken as part of the regular Cockburn Sound Management Council (CSMC) monitoring programme; and
5. the Water Corporation make a one-off donation of $10,000 to the CSMC's monitoring programme (Water Corporation 2008a, p. 17-18).

The NIWA (2008) independent expert peer review was commissioned to appraise the key findings of the technical reports produced by the CWR. This review states that there is an impact to dissolved oxygen levels through increased potential for stratification events in Cockburn Sound due to the desalination plant effluent plume; however, the extent and magnitude of this impact is uncertain and further monitoring is required so that this can be determined. The Peer Review also noted that the desalination plant would add a further increment to the existing stress on the Cockburn Sound ecosystem. As a result the Peer Review identifies the risks associated with this large volume brine discharge and recommend further monitoring of dissolved oxygen levels of the Sound. The peer review advised:

1. There is evidence in the measured data from Water Corporation's monitoring and from CWR's field measurements that the saline plume does enter the deep waters of Cockburn Sound, although the extent to which it does so, and its ultimate effect, remain unknown.
2. The model simulations can lead to an overestimation of mixing of the plume and therefore an underestimation of its effects on stratification and, potential, dissolved oxygen drawdown.
3. Desalination discharge does have an influence, as yet undetermined, on stratification and dissolved oxygen in the Sound.
4. It is possible that salt stratification may cause oxygen drawdown, either by itself or by reinforcing the effects of thermal stratification.
5. The length of observations has not been long given year-to-year variability in climate and in coastal ocean conditions, and it is likely that more extreme conditions than those observed over the time span of the modelling, or since the start of monitoring, will occur in the future.
6. The thickness of the layer is probably less than or of the same size (0.5 m) as both the depth resolution of the model and the lowest depth at which monitoring data is currently required to be collected.

Since collecting further monitoring data, receiving submissions and reviewing the advice of the independent review (NIWA 2008), the Water Corporation has stated in its Response to Public Comment document that "…while the brine discharge from the PMDP may be detectable up to 1 to 1.5 km from the exit of the Stirling Channel, and marginally increases the strength of naturally occurring stratification in the deep basin, it has no measureable affect on the duration of the stratification and therefore does not extend the time available for dissolved oxygen lowering" (Water Corporation 2008b, p. 4).

Water Quality Management Plan

Water Corporation's WQMP (Revision 1/V9), which addressed the implementation of both Ministerial Statement 655 and the requirement of DEC's Part V operational licence, was provided to DEC as a final version in March 2007. This WQMP incorporated both stakeholder and DEC comments.

Since the first operational licence was issued by DEC in September 2006, dissolved oxygen monitoring and management has been regulated under Part V of the EP Act. The current licence (a revised and reissued version of the first) was issued in September 2008 and will expire in 2011, unless amended prior to this date.

The licence provides monitoring conditions for real time monitoring sites (RTMS) at three locations (North, Central and South) in the Sound. A set of trigger circumstances are provided for the nearest North and Central sites ranging from a dissolved oxygen saturation of 60% to 80% dependent upon the site and the predicted meteorological conditions which would cause suitable mixing events. When the trigger circumstances commence the proponent is required to manage impacts through reducing plant output to 1/6 capacity ('shut down') until such time as a suitable mixing event is predicted or the trigger circumstance no longer applies.

Due to poorer ambient water quality at the furthest monitoring site (South) 'shut down' of the plant is not required unless dissolved oxygen saturation falls to 60% or below. However when dissolved oxygen saturation reaches 67% at this monitoring station the proponent is required to inform DEC and undertake intensive monitoring of the Stirling channel. This intensive monitoring requires conductivity temperature depth (CTD) salinity tracking of the brine plume to determine whether the effluent plume is exiting the channel and if so the extent to which it is dispersing in the deep basin and across the Sound.

Water Corporation has concluded that the PMDP poses no significant risk to Cockburn Sound and therefore believes that no further investigations into dissolved oxygen and stratification, monitoring obligations and dissolved oxygen criteria are needed to protect the deep basin of the Sound (Water Corporation 2008a, 2008b). As such Water Corporation recommended a new WQMP (Revision B) which was provided in the proponent's section 46 document (Water Corporation 2008a, Appendix 8). WQMP Version B, provides a broad outline of the monitoring undertaken and previous findings.

The NIWA (2008) peer review recommended that further modified monitoring be conducted to continue to progress the understanding of the impact of the brine plume and identify the frequency, intensity and cause of the more significant dissolved oxygen drawdown events. A monitoring approach was suggested for consideration, this approach included a single real time monitoring station at the South location rather than the current three, with an improved measurement resolution and quality. It was also suggested that the single monitoring station had an additional sensor positioned closer to the seabed than the current limit of 0.5 m, at 0.2 m above the bed. An expanded CTD salinity tracking survey was recommended during the more severe episodes of dissolved oxygen drawdown that trigger compliance monitoring as well as profiling at enough sites in the central and southern parts of the Sound to allow maps of surface and bottom temperature, salinity and dissolved oxygen to be drawn.

In March 2009, at the request of the EPA, the Water Corporation provided a letter outlining an alternative monitoring regime which proposes that real time monitoring of the plant cease in November 2009 and be replaced with a monitoring regime to be decommissioned after two years. This alternative regime would include:

- Fortnightly salinity, temperature and dissolved oxygen samples between March and July;
- Monthly samples between August and February;

- Salinity tracking twice per year for 24 months, once during summer and once during autumn, which attempt to pick a sampling time then there has been a period of calm weather for 2 or more days; and
- Diffuser performance testing to remain unchanged.

Agency and public comments

The draft *Perth Seawater Desalination Plant – Water Quality Management – Section 46* (Water Corporation 2008a) document was advertised on 17 March 2008 for a four week public comment period. A total of eight submissions were received. The key concerns raised in submissions included:

- Monitoring had been undertaken for a relatively short period of time and had not provided scientific certainty. As such a precautionary approach was advocated, this approach should include continued monitoring and management of dissolved oxygen under a full range of climatic conditions for a total of three years at full operational capacity. Monitoring should be consistent with the Cockburn Sound SEP.
- The proponent's proposed donation of $10,000 to the CSMC was not considered to be appropriate as:
    - the funds were not sufficient to run an effective monitoring program; and
    - the monitoring of environmental impacts of the PMDP should be the responsibility of the proponent especially as it is the sole emitter of saline discharge in Cockburn Sound.
- An independent review of the technical reports which support the proponent's conclusions should be undertaken.

Assessment

The area considered for assessment of this factor is Cockburn Sound.

The EPA's environmental objectives for this factor are:

- to ensure that emissions do not adversely affect environmental values or the health, welfare and amenity of people and land uses by meeting statutory requirements and acceptable standards; and
- to maintain the environmental values of the seabed and marine waters.

<u>State Environmental (Cockburn Sound) Policy 2005</u>

The Cockburn Sound SEP is the first of its kind in Western Australia and was produced by the EPA due to significant concern for the increasing pressures on the environment of the Sound. The objective of the SEP is to establish a common and agreed set of objectives for the environmental quality of the Sound and to promote a spirit of cooperative management across all sectors including regulators and dischargers.

To ensure consistency with the Cockburn Sound SEP the proponent has proposed an amendment to Commitment 10 of Ministerial Statement 665, which relates to Whole Effluent Toxicity (WET) testing. The EPA is aware that the actions outlined in this commitment have already been completed.

Taking into consideration the advice provided in the two peer reviews (Hart & Church 2006; NIWA 2008), the concerns raised during the public comment process and to ensure consistency with the objectives, EQC and standards set by the Cockburn Sound SEP, the EPA considers that a precautionary approach should be taken to the management of the wastewater discharges from the PMDP. The EPA considers that the PMDP should not contribute to a decline of dissolved oxygen below 60% saturation in the bottom waters of the Sound. The 60% saturation limit, defined under the SEP's environmental quality standards for high and moderate ecological protection areas, was supported by the Peer Reviews. Therefore the EPA recommends Condition 8 (Appendix 4) which ensures the brine discharge does not contribute to a decline in dissolved oxygen in bottom waters below 60% saturation. The condition acknowledges that this trigger level is not appropriate within the low ecological protection area/mixing zone.

The EPA considers that Condition 8 fulfils the Minister's requirement that the conditions be consistent with the requirements of the Cockburn Sound SEP.

The EPA also considers that the legally enforceable operational licence issued under Part V of the EP Act for brine discharge from the PMDP was developed in accordance with the objective of the SEP to declare, protect and maintain the environmental values of Cockburn Sound and therefore should be retained.

Dissolved Oxygen and Stratification trigger levels

In the Response to Public Comment document (Water Corporation 2008b) the Water Corporation claims that the NIWA (2008) peer review "agrees that there is no significant risk to dissolved oxygen levels across extensive areas of Cockburn Sound due to the desalination plant discharge". The EPA does not agree that the NIWA (2008) makes this conclusion and indeed suggest that the significance of the impact of the brine discharge from the PMDP remains uncertain. The EPA concurs with the NIWA view "…the desalination discharge does have an influence, as yet undetermined, on stratification and dissolved oxygen in the Sound." "The effect may be small or even negligible much of the time; it may become significant only infrequently; and it may be so localised geographically that affected areas are recolonised over time. But it undoubtedly adds a further increment to existing stress on the Cockburn Sound ecosystem." The EPA notes that NIWA (2008) recommends further monitoring to determine the impacts and the significance of the desalination plant's brine plume on stratification events and dissolved oxygen saturation levels.

When formulating the first Part V operational licence in 2006, the DEC incorporated expert advice of the EPA Service Unit and the Hart and Church (2006) peer review to formulate the set of dissolved oxygen trigger levels. The EPA considers that the trigger levels of the Part V operational licence to be the appropriate set of dissolved oxygen trigger levels to ensure that dissolved oxygen saturation levels in Cockburn Sound do not reach the EPA minimum acceptable level of 60% or lower.

The EPA considers that its recommended minimum dissolved oxygen saturation trigger level of 60% should not prevent the DEC from requiring monitoring and management measures (including requiring a range of risk-based trigger values) in any revision of the current Part V operational licence or future operational licence as it has in previous operational licences.

The setting of a minimum dissolved oxygen saturation bottom level of 60% and the trigger levels of the Part V operational licence combine to satisfy the Minister's section 46 request in terms of providing a recommended set of dissolved oxygen trigger levels to ensure that Cockburn Sound SEP standards are not exceeded.

Water Quality Management Plan

In its section 46 document (Water Corporation 2008a) the Water Corporation proposed to amend Commitment 2 of Ministerial Statement 665 to simply require that the WQMP be implemented. The revised WQMP (Version B) which was provided in the Water Corporation's section 46 document (Water Corporation 2008a, Appendix 8), does not contain detail regarding monitoring, trigger values and actions to be taken if or when these values are breached.

In February 2009 the EPA requested that the Water Corporation consider and provide an alternative monitoring regime that would be suitable to monitor the effects of brine discharge on the marine water quality of the Sound and outline how this might be considered within the operational management of the PMDP. The Water Corporation's alternate monitoring regime, which was provided via letter in March 2009, is considered to be:

- unlikely to improve understanding of stratification and dissolved oxygen; and
- less useful than the current requirements of the operational licence in determining the impact of the saline plume on Cockburn Sound as the proposed twice yearly salinity tracking would not be event driven and 'attempt' to pick sampling times during calm weather events.

No alternate management measures were proposed by the Water Corporation at this time.

Having regard for the findings of the peer reviews, the EPA considers that the Water Corporation's proposed amendment and alternative management regime are not adequate and underplays the importance of the key environmental factor of Marine Water Quality.

The EPA supports the continued monitoring and management under the legally enforceable operational licence issued under Part V of the EP Act. The EPA is aware that DEC intends to modify the existing operational licence subject to the outcome of this section 46 review. After consideration of DEC and NIWA (2008) advice the EPA recommends the following amendments be made:

- Real time monitoring should continue at a minimum of two monitoring stations and is to include the Southern monitoring station;
- Requirements for monitoring during storm events where dissolved oxygen levels are high should be flexible;
- Real time monitoring should continue to occur all year round for the next two years to better determine the months where dissolved oxygen saturation levels are likely to be affected by prevailing weather conditions. Future monitoring times of the year can then be determined as part of a review at the end of two years (2011);
- Monitoring should occur at a minimum of 0.5 m from the seabed and lower (0.2 m above seabed) wherever practical;
- Short term probe deployments (with appropriate maintenance regimes) should be used to establish empirical relationships (further informed by modelling) between dissolved oxygen measured at the 0.5 m sensor and nearer to the seabed; and
- The monitoring and management regime is to be subject to a review after two years.

Monitoring and management of water quality is currently required under Schedule 2 of Ministerial Statement No. 655. Schedule 2 of the Statement contains the Water Corporation's environmental management commitments which are not legally enforceable, hence the Ministers request in May 2005 to undertake a section 46 review to reinforce the importance of the WQMP. The EPA considers that the legally enforceable operational licence issued under Part V of the EP Act has and will continue to be the appropriate way to provide a regulatory regime for monitoring, management and reporting of dissolved oxygen levels.

Summary

Having particular regard to the:

(a) *State Environmental (Cockburn Sound) Policy 2005;*

(b) advice of the Hart & Church (2006) and NIWA (2008) Peer Reviews;

(c) requirements of the operational licences issued under Part V of the *Environmental Protection Act 1986;*

(d) recommendations for future Part V operational licence or revisions of the current operational licence*; and*

(e) recommended conditions relating to the *State Environmental (Cockburn Sound) Policy 2005,* minimum dissolved oxygen saturation level for High and Moderate Ecological Protection areas;

it is the EPA's opinion that the project can be managed to meet the EPA's environmental objective for Marine Water Quality.

Other Advice

The Cockburn Sound Management Council (CSMC) was established in 2000 by the State Government to manage the multiple uses contributing to the pressures on the Sound. The CSMC developed an Environmental Management Plan, which requires a cooperative management approach that involves all stakeholders. The Environmental Management Plan implements the environmental management framework set out in the Cockburn Sound SEP and uses EQC to provide quantitative benchmarks for measuring success in achieving the environmental quality objectives and to guide when and where management attention should be focussed. The SEP also authorises the CSMC to report annually on the 'State of the Sound' and have this report tabled in Parliament.

The EPA recognises that the CSMC's coordination and management of remedial or preventative action has contributed to the health of the Sound which has been maintained overall since 2000.

The EPA notes that Water Corporation's current assessment of the desalination plant's impacts on the Sound are based on no change (no future development). However continued development in, on and around Cockburn Sound has the potential to affect the environmental quality of the Sound. Although it is the respective proponents' responsibility to manage and mitigate these impacts there will be a resulting cumulative impact on the Sound. This cumulative impact will affect the overall environmental health of the Sound and is likely to require that the current users of the Sound monitor and manage their discharges more closely.

The EPA expects that all current and future Cockburn Sound stakeholders (including Water Corporation) manage their impacts in accordance with the Cockburn Sound SEP and actively assist the CSMC to continue the cooperative management of the environmental pressures on the Sound to maintain and possibly improve the water quality into the future.

5. Conditions and commitments

Section 46(6) of the *Environmental Protection Act 1986* requires the EPA to report to the Minister for Environment on whether or not the proposed changes to conditions or procedures should be allowed. In addition, the EPA may make recommendations as it sees fit.

5.1 Recommended commitments

The EPA recognises that the commitments provide a clear statement of the action to be taken as part of the proponent's responsibility for, and commitment to, continuous improvement in environmental performance. Some of those commitments have been modified and included as recommended conditions, as set out in Appendix 4 to which the project should be subject.

5.2 Recommended conditions

The EPA recommends that the following conditions, which are set out in detail in Appendix 4, be imposed:

1 The existing implementation conditions applied to the project (Ministerial Statement 665 published on 9 July 2004), be subject to modifications necessary to:

- Ensure the conditions are consistent with the requirements of the Cockburn Sound SEP;
- Set a minimum dissolved oxygen saturation level in Cockburn Sound upon which management and monitoring related to the discharge from the PSDP should be based.

2. Condition 5 is replaced by the current standard implementation condition.

6. Conclusions

The EPA has considered the then Minister for the Environment's request to review a number of conditions relating to the management of discharge from the PMDP and has concluded that the significance of impacts to the marine environment from the discharge of brine by the Perth Metropolitan Desalination Plant (PMDP) is still uncertain and the marine environment of Cockburn Sound continues to be under stress. Therefore the EPA has recommended that a change to the implementation conditions should be made to provide further assurance that the objectives of the State Environmental (Cockburn Sound) Policy 2005 and the EPA's objectives are met for the key environmental factor of marine water quality.

The EPA has also concluded that the operational licence issued under Part V of the EP Act is the appropriate vehicle to provide a legally enforceable regulatory regime for monitoring and management of the impacts of the brine discharge from the PMDP on the marine environment of Cockburn Sound.

7. Recommendations

The EPA submits the following recommendations to the Minister for Environment:

1. That the Minister notes that this report is pursuant to section 46(6) of *the Environmental Protection Act 1986* and thus is limited to consideration of proposed changes to the Ministerial Statement 655 conditions.
2. That the Minister considers the report on the key environmental factor as set out in Section 4.
3. The Minister notes that the proposed changes are to amend Condition 5 to comply with the current implementation standard and also to include an additional condition, Condition 8, to ensure that the marine water quality of Cockburn Sound is not adversely impacted by the operation of the PMDP.
4. The Minister imposes the amended conditions and procedures recommended in Appendix 4 of this report.

Appendix 1

List of Submitters

State/Local Government

- City of Rockingham
- City of Swan
- Department of Environment and Conservation
- Department of Industry and Resources

Organisations

- Cockburn Sound Management Council
- Swan Catchment Council – Coast Care
- Conservation of Rockingham Environment
- Binningup Desalination Action Group

Appendix 2

References

CSIRO (2005) *Peer Review of Studies for Desalination Plant Discharge, Cockburn Sound,* Peter Craig and Karen Wild-Allen, Commonwealth Scientific and Industrial Research Organisation, 11 April 2005.

EPA (2004) *Perth Metropolitan Desalination Proposal: Bulletin 1070,* Environmental Protection Authority, October 2002.

EPA (2004) *Perth Metropolitan Desalination Proposal, Amendment of Implementation Conditions by Inquiry: Bulletin 1137,* Environmental Protection Authority, May 2004.

EPA (2005) *Environmental Quality Criteria Reference Document for Cockburn Sound (2003-2004), A supporting document to the State Environmental (Cockburn Sound) Policy 2005: Report 20,* Environmental Protection Authority, January 2005.

Government of Western Australia (2005) *State Environmental (Cockburn Sound) Policy 2005,* Government of Western Australia Perth, Western Australia, January 2005.

Hart & Church (2006) *Review of the Proposed Dissolved Oxygen Criteria and Management Decision Scheme for Perth Seawater Desalination Plant,* Professor Barry Hart and Dr. Tony Church, August 2006.

NIWA (2005) *Review of studies for desalination plant discharge, Cockburn Sound,* Robert Spigel et al., National Institute of Water & Atmospheric Research Ltd, April 2005.

NIWA (2008) *Review of studies relating to the discharge from the Perth Seawater Desalination Plant in Cockburn Sound,* Robert Spigel, National Institute of Water & Atmospheric Research Ltd, April 2008.

Water Corporation (2008a) *Perth Seawater Desalination Plant Water Quality Management: Section 46 (Revision C),* Water Corporation of Western Australia, March 2008.

Water Corporation (2008b) *Perth Seawater Desalination Plant - Response to Public Comments for the Section 46, Amendment of Implementation Conditions By Inquiry, Submitted to the Environmental Protection Authority*, Water Corporation of Western Australia, December 2008.

Appendix 3

Statement of Environmental Conditions of Approval No. 655
(9 July 2004)

9-{100?

Statement No.

000655

MINISTER FOR THE ENVIRONMENT

STATEMENT TO AMEND CONDITIONS APPLYING TO A PROPOSAL (PURSUANT TO THE PROVISIONS OF SECTION 46 OF THE ENVIRONMENTAL PROTECTION ACT 1986)

PERTH METROPOLITAN DESALINATION PROPOSAL

Proposal: The construction and operation of a seawater desalination plant at a site in the Kwinana / East Rockingham area, and associated seawater intake, concentrated seawater discharge pipelines, and product pipeline to Tamworth Hill or Thomson's Reservoir.

Upgrading of the capacity of the plant to 45 Gigalitres per year at the Kwinana site will include increasing the production of potable water, use of seawater, and discharge of concentrated seawater and further options for combining intake seawater with cooling water discharged from Western Power's Kwinana Power Station, as documented in schedule 1 of this statement.

This statement does not relate to a desalination plant at the alternative East Rockingham site.

Proponent: Water Corporation

Proponent Address: 629 Newcastle Street, LEEDERVILLE WA 6007

Assessment Number: 1512

Previous Assessment Number: 1454

Previous Statement Number: 626 (published on 26 May 2003)

Report of the Environmental Protection Authority: Bulletin 1137

Previous Report of the Environmental Protection Authority: Bulletin 1070

The implementation of the proposal to which the above reports of the Environmental Protection Authority relate is subject to the following conditions and procedures, which replace all previous conditions and procedures for the Kwinana site:

Published on

- 9 JUL 2004

1 Implementation

1-1 The proponent shall implement the proposal as documented in schedule 1 of this statement subject to the conditions of this statement.

2 Proponent Commitments

2-1 The proponent shall implement the environmental management commitments documented in schedule 2 of this statement.

3 Proponent Nomination and Contact Details

3-1 The proponent for the time being nominated by the Minister for the Environment under section 38(6) or (7) of the *Environmental Protection Act 1986* is responsible for the implementation of the proposal until such time as the Minister for the Environment has exercised the Minister's power under section 38(7) of the Act to revoke the nomination of that proponent and nominate another person as the proponent for the proposal.

3-2 If the proponent wishes to relinquish the nomination, the proponent shall apply for the transfer of proponent and provide a letter with a copy of this statement endorsed by the proposed replacement proponent that the proposal will be carried out in accordance with this statement. Contact details and appropriate documentation on the capability of the proposed replacement proponent to carry out the proposal shall also be provided.

3-3 The nominated proponent shall notify the Department of Environment of any change of contact name and address within 60 days of such change.

4 Commencement and Time Limit of Approval

4-1 The proponent shall substantially commence the proposal within five years of the date of this statement or the approval granted in the statement of 26 May 2003 shall lapse and be void.

Note: The Minister for the Environment will determine any dispute as to whether the proposal has been substantially commenced.

4-2 The proponent shall make application for any extension of approval for the substantial commencement of the proposal beyond five years from the date of this statement to the Minister for the Environment, prior to the expiration of the five-year period referred to in condition 4-1.

The application shall demonstrate that:

1. the environmental factors of the proposal have not changed significantly;

2. new, significant, environmental issues have not arisen; and

3. all relevant government authorities have been consulted.

Note: The Minister for the Environment may consider the grant of an extension of the time limit of approval not exceeding five years for the substantial commencement of the proposal.

5 Compliance Audit and Performance Review

5-1 The proponent shall prepare an audit program and submit compliance reports to the Department of Environment which address:

1. The status of implementation of the proposal as defined in schedule 1 of this statement;

2. evidence of compliance with the conditions and commitments; and

3. the performance of the environmental management plans and programs.

Note: Under sections 48(1) and 47(2) of the *Environmental Protection Act 1986*, the Chief Executive Officer of the Department of Environment is empowered to audit the compliance of the proponent with the statement and should directly receive the compliance documentation, including environmental management plans, related to the conditions, procedures and commitments contained in this statement.

5-2 The proponent shall submit a performance review report every five years after the start of operations, to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority, which addresses:

1. the major environmental issues associated with the project; the targets for those issues; the methodologies used to achieve these; and the key indicators of environmental performance measured against those targets;

2. the level of progress in the achievement of sound environmental performance, including industry benchmarking, and the use of best available technology where practicable;

3. significant improvements gained in environmental management, including the use of external peer reviews;

4. stakeholder and community consultation about environmental performance and the outcomes of that consultation, including a report of any on-going concerns being expressed; and

5. the proposed environmental targets over the next five years, including improvements in technology and management processes.

6 Decommissioning Plans

6-1 Prior to construction, the proponent shall prepare a Preliminary Decommissioning Plan, which provides the framework to ensure that the site is left in an environmentally acceptable condition to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority.

The Preliminary Decommissioning Plan shall address:

1 rationale for the siting and design of plant and infrastructure as relevant to environmental protection, and conceptual plans for the removal or, if appropriate, retention of plant and infrastructure;

2 a conceptual rehabilitation plan for all disturbed areas and a description of a process to agree on the end land uses(s) with all stakeholders;

3 A conceptual plan for care and maintenance phase; and

4 management of noxious materials to avoid the creation of contaminated areas.

6-2 At least 12 months prior to the anticipated date of decommissioning, or at a time agreed with the Environmental Protection Authority, the proponent shall prepare a Final Decommissioning Plan designed to ensure that the site is left in an environmentally acceptable condition to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority.

The Final Decommissioning Plan shall address:

1 removal or, if appropriate, retention of plant and infrastructure in consultation with relevant stakeholders;

2 rehabilitation of all disturbed areas to a standard suitable for the agreed new land use(s); and

3 identification of contaminated areas, including provision of evidence of notification and proposed management measures to relevant statutory authorities.

6-3 The proponent shall implement the Final Decommissioning Plan required by condition 6-2 until such time as the Minister for the Environment determines, on advice of the Environmental Protection Authority, that the proponent's decommissioning responsibilities have been fulfilled.

6-4 The proponent shall make the Final Decommissioning Plan required by condition 6-2 publicly available, to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority.

7 Management Plans and Monitoring Reports

7-1 Prior to finalisation of the management plans referred to in commitments 1, 2, 3, 4, 6, 7 and 12, the proponent shall make each draft management plan available for public comment and provide evidence to the Department of Environment that any matters arising have been addressed, to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority.

7-2 The proponent shall make monitoring reports publicly available, to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority.

Procedures

1 Where a condition states "to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority", the Environmental Protection Authority will provide that advice to the Department of Environment for the preparation of written notice to the proponent.

2 The Environmental Protection Authority may seek advice from other agencies or organisations, as required, in order to provide its advice to the Department of Environment.

3 Where a condition lists advisory bodies, it is expected that the proponent will obtain the advice of those listed as part of its compliance reporting to the Department of Environment.

Notes

1 The Minister for the Environment will determine any dispute between the proponent and the Environmental Protection Authority or the Department of Environment over the fulfilment of the requirements of the conditions.

Judy Edwards

Dr Judy Edwards MLA
MINISTER FOR THE ENVIRONMENT

- 9 JUL 2004

Schedule 1

The Proposal (Assessment No. 1512)

Upgrading of the capacity of the plant from 30 GL per year to 45 GL per year at the Kwinana site. This includes increasing the production of potable water, use of seawater, and discharge of concentrated seawater, and further options for combining intake seawater with cooling water discharged from the Kwinana Power Station, as specified in the key characteristics table below.

This does not relate to the plant at the alternative East Rockingham site.

The location of the plant is shown in Figure 1 (attached).

Table 1 – Key Proposal Characteristics

Project characteristic	**Quantities/Description**
Location	Kwinana Power Station site
Capacity	45 GL per year
Power requirement	24.1 MW average demand
Greenhouse gas emissions (tpa CO_2-equivalent)	85,000 gas-fired power 231,000 state grid power
Clearing of vegetation required	Likely to be 2-3 ha of mostly completely degraded vegetation
Seawater intake	300 ML/day (weekly average)
Seawater intake pipelines	
Location (indicative).	See Figure 1. Option for combined intake with Western Power facilities.
Length (indicative)	0.8 km
Number	1
Diameter	1500 mm
Concentrated seawater discharge	
Volume	180 ML/day (weekly average)
Salinity	65,000 mg/L
Temperature	If the dedicated intake from Cockburn Sound is used, the discharge temperature will be not more than 2°C above ambient. If KPS cooling water is used, the discharge temperature will be up to 13°C above ambient. (The temperature will be less than 0.3°C above ambient after initial mixing.)
Location of outlet	In 10m depth of water approximately 300 m offshore from KPS
Diffuser design	Approximately 80 – 180 m long Design to be based upon an average initial dilution of 45

Product water pipeline	
Location (indicative)	See Figure 1
Capacity	Greater than 150 ML/day
Length (indicative)	10 km
Number	1
Diameter	1000 mm
Destination	Thomson's Reservoir

Abbreviations

GL	gigalitres
ML	megalitres
km	kilometres
mm	millimetres
mg/L	milligrams per litre
ha	hectares
MW	megawatt
tpa CO_2-e	tonnes per annum CO_2 equivalent
KPS	Kwinana Power Station

Figure (attached)

Figure 1 - Location of desalination plant and infrastructure at the KPS site.

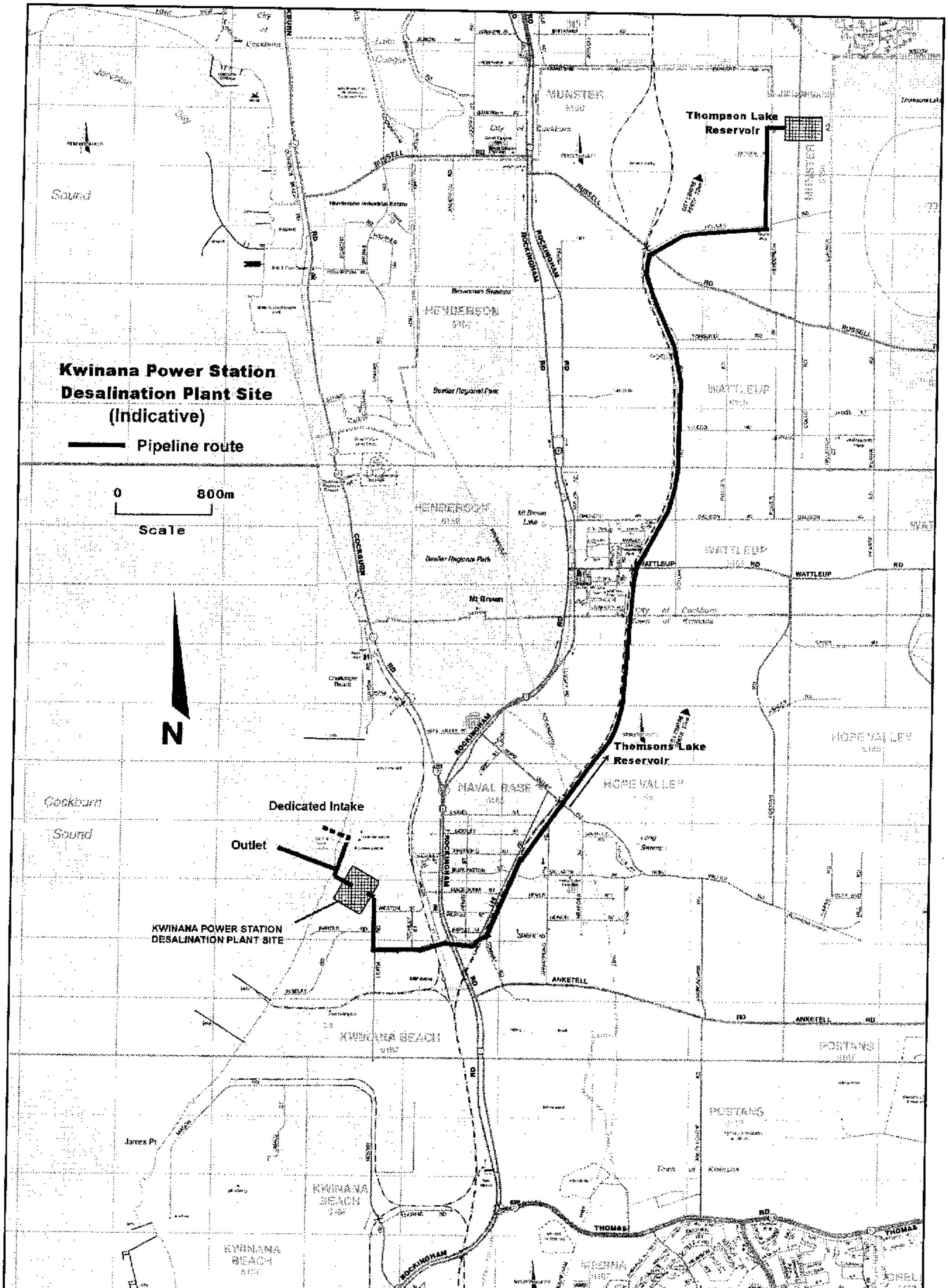

Figure 1: Location of desalination plant and infrastructure at the KPS site

Schedule 2

Proponent's Environmental Management Commitments

July 2004

Perth Metropolitan Desalination Proposal (Kwinana Site)

(Assessment No. 1512)

Water Corporation

PERTH METROPOLITAN DESALINATION PROPOSAL (Assessment No. 1512)
July 2004

Note: The term "commitment" as used in this schedule includes the entire row of the table and its six separate parts as follows:

- a commitment number;
- a commitment topic;
- the objective of the commitment;
- the 'action' to be undertaken by the proponent;
- the timing requirements of the commitment; and
- the body/agency to provide technical advice to the Department of Environment.

No	Commitment	Objective	Action	Timing	Advice
1	Consultative Environmental Management Plan (CEMP)	To minimise environmental impacts from implementation of the proposal.	Prepare a Consultative Environmental Management Plan which will include the following; • Water Quality Management Plan (see commitment 2). • Flora and Fauna Management Plan (see commitment 3). • Greenhouse Gas Management Plan (see commitment 4). • Noise Management Plan (see commitment 6). • Hazardous Materials Management Plan (see commitment 7). • Cooling Water Monitoring Programme (see commitment 2). The Management Plan will be developed in consultation with the Cockburn Sound Management Council, the Town of Kwinana and the City of Rockingham.	Within four months following a decision to construct	CALM CSMC Kwinana Rockingham

2	Water Quality Management Plan	To ensure protection of the water quality of Cockburn Sound.	1. Prepare a Water Quality Management Plan which will include the following: • Procedures to mitigate potential impacts of construction of the discharge pipeline and intake. • A monitoring program for TDS (salinity), temperature and DO (dissolved oxygen) of water surrounding the discharge site, a nearby reference site, and a site in the deeper waters of Cockburn Sound. • A monitoring programme to ensure that the diffuser is performing to specifications and achieving the required level of dilution. • Monitoring of sediment habitat pre- and post-commissioning. • A contingency plan that examines the risk of contamination and procedures to mitigate any unanticipated impacts. • Whole of effluent testing methodology and protocols. • A monitoring programme for Kwinana Power Station cooling water, if used as input water, will be conducted. Analysis will be of sufficient accuracy and precision to enable comparison with appropriate standards and criteria for Cockburn Sound. • An annual inspection programme to check the physical integrity of the outlet pipe and diffuser. 2. Implement the Water Quality Management Plan described in commitment 2.1 above.	Within four months following a decision to construct Construction and Operation, as appropriate	DoE (Marine Branch)
3	Flora and Fauna Management Plan	To ensure protection of flora and fauna.	1. Prepare a Flora and Fauna Management Plan which will include the following: • Locating the plant and pipelines to minimise clearing and effects on conservation values. • Mitigating impacts on Priority Flora. • Dieback management measures. • Weed control measures. 2. Implement the Flora and Fauna Management Plan described in commitment 3.1 above.	Within four months following a decision to construct and prior to commence-ment of ground-disturbing activities. Construction and Operation, as appropriate	DoE (Terrestrial Section), CALM

4	Greenhouse Gas Management Plan	To minimise the generation of greenhouse gases.	1. Prepare a Greenhouse Gas Management Plan which will include: • Use of sources of renewable energy as far as is practicable. • Calculation of the greenhouse gas emissions associated with the proposal, as indicated in "Minimising Greenhouse Gas Emissions, Guidance for the Assessment of Environmental Factors, No 12" published by the Environmental Protection Authority. • Specific measures to minimise the greenhouse gas emissions associated with the proposal. • Monitoring of greenhouse gas emissions. • Estimation of the greenhouse gas efficiency of the proposal in comparison with the efficiencies of other comparable projects producing a similar product. • An analysis of the extent to which the proposal meets the requirements of the National Strategy using a combination of: o "no regrets" measures, o "beyond no regrets" measures, o land use change or forestry offsets, and o international flexibility mechanisms. 2. Implement the Greenhouse Gas Management Plan described in commitment 4.1 above.	Within four months following a decision to construct Operation	DoE (Air Quality Management Branch)
5	Greenhouse Gases	To minimise the generation of greenhouse gases	The proponent will take all reasonable and practicable steps to obtain an electricity contract for the plant which will specify that the electricity will be sourced from gas-fired generating units at least 95% of the time.	Operation	
6	Noise Management Plan	To minimise noise impacts from implementation of the proposal.	1. Prepare a Noise Management Plan which includes detailed modelling of noise emissions and cumulative affect of emissions. 2. Implement the Noise Management Plan described in commitment 6.1 above, where appropriate.	Within four months following a decision to construct Construction and Operation, where appropriate	DoE (Noise Management Branch).

7	Hazardous Materials Management Plan	To minimise public risk from materials associated with the plant.	1. Prepare a Hazardous Materials Management Plan. 2. Implement the Hazardous Materials Management Plan described in commitment 7.1 above, where appropriate.	Within four months following a decision to construct Construction and Operation, where appropriate	DoIR
8	Ocean outlet for seawater return	Achieve compliance with Cockburn Sound EPP and associated criteria.	Design the ocean outlet diffuser system and locate it to ensure the discharge complies with the requirements of the *Revised Draft Cockburn Sound Environmental Protection Policy 2002* and the *Revised Environmental Quality Criteria Reference Document (Cockburn* Sound). The design is to be certified by an expert as soon as the optimised design of the diffuser is available.	Prior to construction and Construction	
9	Seawater return	To ensure the concentrated seawater released by the plant does not cause stratification in the far field.	Obtain an expert assessment of the likely stratification build up and any subsequent dissolved oxygen effects in the deeper area of Cockburn Sound.	Within 3 months following approval	
10	Whole Effluent Toxicity (WET) testing	To ensure that the discharge complies with the requirements of the Cockburn Sound Environmental Protection Policy and the Revised Environmental Quality Criteria	1. Conduct WET testing of the high salinity seawater discharge including added chemicals (anti-scalants and biocides) as soon as the chemicals to be used and their likely dosing rates are known to a reasonable level of certainty. Conduct the testing following the principles contained in the USEPA, APHA and ASTM protocols at a NATA accredited laboratory in accordance with the protocols set out in ANZECC/ARMCANZ (2000) whole effluent toxicity protocols, at various concentration levels as stated in the Water Quality Management Plan. 2. Report the results of WET testing as described in commitment 10.1 to the DoE.	Prior to construction	

		Reference Document (Cockburn Sound).	3. Conduct WET testing of the high salinity seawater discharge as described in commitment 10.1 above 12 months after commissioning. 4. Report the results of WET testing as described in commitment 10.3 to the DoE.	Operation (12 months after commission-ing).	
11	Vegetation, Declared Rare and Priority Flora and Fauna Habitat	Protect vegetation, Declared Rare and Priority Flora and Fauna.	1. Conduct a survey of product pipeline routes to determine final alignments to avoid areas identified by CALM or DoE. 2. Conduct detailed surveys for Rare and Priority Flora, to contribute to the Flora and Fauna Management Plan.	Spring season, and prior to ground-disturbing activities.	CALM
12	Nitrogen loading to Cockburn Sound	To ensure there is no net increase in nitrogen added to Cockburn Sound.	Prepare a management plan to ensure that the upgraded desalination plant is nitrogen-neutral relative to the 30 GL/a desalination plant. The management plan will be developed in consultation with the Cockburn Sound Management Council, the Town of Kwinana and the City of Rockingham, and will be submitted to the EPA for consideration.	Prior to operation	CSMC Kwinana Rockingham
13	Nitrogen loading to Cockburn Sound	To minimise the amount of nitrogen added to Cockburn Sound.	Nitrogen-free alternatives will be used for process chemicals where appropriate and practicable.	Operation	CSMC Kwinana Rockingham

Abbreviations

CALM	Department of Conservation and Land Management
CSMC	Cockburn Sound Management Council
DoE	Department of Environment
DoIR	Department of Industry and Resources
EPA	Environmental Protection Authority
Kwinana	Town of Kwinana
Rockingham	City of Rockingham

Appendix 4

Recommended Environmental Conditions

Statement No.

RECOMMENDED ENVIRONMENTAL CONDITIONS
[25 May 2009]

STATEMENT THAT A PROPOSAL MAY BE IMPLEMENTED
(PURSUANT TO THE PROVISIONS OF THE
ENVIRONMENTAL PROTECTION ACT 1986)

PERTH METROPOLITAN DESALINATION PROPOSAL

Proposal: The construction and operation of a seawater desalination plant at a site in the Kwinana / East Rockingham area, and associated seawater intake, concentrated seawater discharge pipelines, and product pipeline to Tamworth Hill or Thomson's Reservoir.

Upgrading of the capacity of the plant to 45 Gigalitres per year at the Kwinana site will include increasing the production of potable water, use of seawater, and discharge of concentrated seawater and further options for combining intake seawater with cooling water discharged from Western Power's Kwinana Power Station, as documented in schedule 1 of this statement.

This statement does not relate to a desalination plant at the alternative East Rockingham site.

Proponent: Water Corporation

Proponent Address: PO Box 100, LEEDERVILLE WA 6000

Assessment Number: 1570

Previous Assessment Number: 1454 and 1512

Report of the Environmental Protection Authority: Report 1327

Previous Report of the Environmental Protection Authority: Report 1070 and 1137

Previous Statement Numbers: Statement No. 626 (published on 26 May 2003) and Statement No. 655 (published on 9 July 2004)

The implementation of the proposal to which the above reports of the Environmental Protection Authority relate is subject to the conditions and procedures contained in Ministerial Statement No. 655, as amended by the following:

Published on

5 Compliance Reporting

5-1 The proponent shall prepare and maintain a compliance assessment plan to the satisfaction of the CEO of the Department of Environment and Conservation.

5-2 The proponent shall submit to the CEO of the Department of Environment and Conservation, the compliance assessment plan required by condition 4-1 at least six months prior to the first compliance assessment report required by condition 4-6.

The compliance assessment plan shall indicate:

1 the frequency of compliance reporting;

2 the approach and timing of compliance assessments;

3 the retention of compliance assessments;

4 reporting of potential non-compliances and corrective actions taken;

5 the table of contents of compliance assessment reports; and

6 public availability of compliance assessment reports.

5-3 The proponent shall assess compliance with conditions in accordance with the compliance assessment plan required by condition 4-1.

5-4 The proponent shall retain reports of all compliance assessments described in the compliance assessment plan required by condition 4-1 and shall make those reports available when requested by the CEO of the Department of Environment and Conservation.

5-5 The proponent shall advise the CEO of the Department of Environment and Conservation of any potential non-compliance as soon as practicable.

5-6 The proponent shall submit a compliance assessment report annually from the date of issue of this Implementation Statement addressing the previous twelve- month period or other period as agreed by the CEO of the Department of Environment and Conservation.

The compliance assessment report shall:

1 be endorsed by the proponent’s Managing Director or a person, approved in writing by the CEO of the Department of Environment and Conservation, delegated to sign on the Managing Director’s behalf;

2 include a statement as to whether the proponent has complied with the conditions;

3 identify all potential non-compliances and describe corrective and preventative actions taken;

4 be made publicly available in accordance with the approved compliance assessment plan; and

5 indicate any proposed changes to the compliance assessment plan required by condition 4-1.

8 Marine Water Quality

8-1 To protect the water quality of Cockburn Sound in accordance with the State Environmental (Cockburn Sound) Policy 2005 (SEP) the proponent shall:

1) ensure that the operation of the Perth Metropolitan Desalination Plant does not increase the intensity and/or duration of density stratification and consequential declines in dissolved oxygen of bottom waters, defined as less than or equal to 0.5 metres above the seabed, to 60% saturation or less in the high to moderate protection areas of Cockburn Sound as defined by the SEP;

2) monitor the dissolved oxygen levels of the bottom waters (as defined in Condition 8-1-1) of Cockburn Sound to the satisfaction of the CEO of the Department of Environment and Conservation (DEC);

3) undertake a management response to ensure that dissolved oxygen does not reach a saturation of 60% or lower to the satisfaction of the CEO of DEC; and

4) from the date of amendment, undertake the monitoring and management required under conditions 8-1-2 and 8-1-3 for a further two years, at which time the CEO of DEC will review the requirement for further monitoring and management.

Appendix 5

Review of the Proposed Dissolved Oxygen Criteria and Management Decision Scheme for Perth Seawater Desalination Plant, Professor Barry Hart and Dr. Tony Church, August 2006.

Report to Western Australian Environment Protection Authority (EPA)

Review of the Proposed Dissolved Oxygen Criteria and Management Decision Scheme for Perth Seawater Desalination Plant

Review Panel:

Professor Barry Hart and Dr Tony Church

August 2006

Executive Summary

This report contains a review of the proposed dissolved oxygen (DO) trigger criteria and management decision schemes for the operation of the Perth Seawater Desalination Plant.

The Review Panel consisted of Professor Barry Hart (Director, Water Science Pty Ltd, Echuca (previously Director, Water Studies Centre, Monash University)) and Dr Tony Church (Sinclair Knight Merz, Sydney).

In brief the Panel's Terms of Reference were:

- To review the dissolved oxygen criteria and management decision schemes for the operation of the Perth Seawater Desalination Plant proposed by the Department of Environment and Conservation (DEC) and the Water Corporation.
- To provide written advice to the EPA on the most appropriate DO criteria and management decision scheme that should apply during the operation of the Plant to provide protection of environmental values within Cockburn Sound.

The Panel met with relevant staff of both Department of Environment and Conservation and the Water Corporation during the three-day period 31 July to 2 August 2006, and studied the many documents and reports relevant to this issue.

After discussions with relevant staff and examination of all the available information, the Review Panel concludes that:

- There should be no change to the DO criteria specified in State Environment Policy (2005) for the protection of the high ecological protection area for Cockburn Sound.
- There should be an additional DO criteria being that the daily median should not be less than 60 percent saturation.
- The Review Panel's modified Water Quality (DO) Management Plan (Table 1), or the alternative also suggested, should be adopted as an interim plan, with an initial review of the Plan undertaken when suitable additional information becomes available and no later than after one year of full operation (i.e. after April 2008). It may also be necessary to continue this review process (at 1-2 yearly intervals) as further data progressively becomes available.
- The recommended program of investigations should be implemented as a priority.

Contents

1. Introduction

This report contains a review of the proposed dissolved oxygen (DO) trigger criteria and management decision schemes for the operation of the Perth Seawater Desalination Plant.

The Review Panel consisted of Professor Barry Hart (Director, Water Science Pty Ltd, Echuca (previously Director, Water Studies Centre, Monash University)) and Dr Tony Church (Sinclair Knight Merz, Sydney).

The Panel's Terms of Reference were:

- In the context of the Ministerial request for the EPA to undertake a Section 46 review of the conditions applying to the Perth Seawater Desalination Plant, review documentation provided by the EPA Service Unit (Marine Ecosystems Branch) of the Department of Environment and Conservation (DEC) and the Water Corporation explaining their proposed dissolved oxygen (DO) criteria and management decision schemes and any supporting rationale.
- Seek clarification from either the EPA Service Unit or Water Corporation, as required.
- Provide written advice to the EPA on recommended DO criteria and a management decision scheme within which those criteria should apply, during the operation of the Plant, to provide protection of environmental values within Cockburn Sound.

The Panel met with relevant officers of both DEC and the Water Corporation during the three-day period 31 July to 2 August 2006, and studied the many documents and reports relevant to this issue.

The Review Panel elected to use a risk-based approach to assess the risks to the ecology of Cockburn Sound from low DO concentrations, and to recommend a sensible management approach to minimise this risk.

Ecological risk management is increasingly being used in the management of natural resources such as Cockburn Sound. The ecological risk assessment methodology is robust and well suited for situations characterised by uncertainty and variability (AS/NZS, 2004; Burgman, 2005).

Risk is defined as the chance of something happening that will have an impact on the objectives (in this case the protection of the environmental values of Cockburn Sound), with *residual risk* is the risk remaining after implementing some management action.

The assessment of ecological risk is dependent on two sets of information - the *consequences* (or severity) of a particular adverse situation, and the *likelihood* (or probability) of that event or situation occurring. Thus, ecological risk is the consequence of an adverse effect times the likelihood that the effect will occur.

2. The Issue

2.1 General

The Perth Seawater Desalination Plant (PSDP) is over 90 percent complete and will be commissioned in November 2006. The plant will provide an additional 45 GL/year of potable water into Perth's Integrated Water Supply System, augmenting Perth's water supply by 17 percent

The PSDP is located on eastern shore of Cockburn Sound, and will discharge approximately180 ML/day of brine solution to Cockburn Sound (Figure 1).

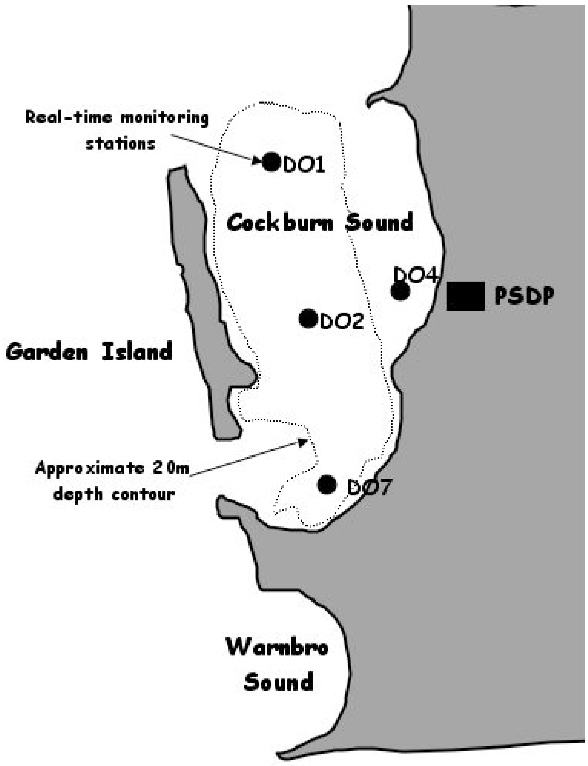

Figure 1: Map of Cockburn Sound showing the in situ dissolved oxygen probe locations

The issue for the Panel is the concern that this brine discharge will increase the stratification in the deeper central part of Cockburn Sound, and under calm weather conditions typical of late summer and autumn, that this will result in very low DO concentrations, and unacceptable impacts on the ecology of Cockburn Sound (particularly the benthic animals such as crabs and prawns). The situation is shown conceptually in Figure 2.

The *conceptual model* (Figure 2) seeks to identify the main *cause-effect relationships*. In this case, brine is discharged into Cockburn Sound through a multi-port diffuser, designed to achieve rapid mixing of the brine with seawater (about 50-fold dilution) within 50m of the diffuser. After this initial mixing, the diluted brine (still slightly denser than surrounding seawater) then flows into the deeper basin where it may enhance natural stratification. Under persistent still conditions microbial respiration in the sediments and consumption of organic matter in the water column will reduce DO concentrations in the bottom waters, and possibly cause adverse effect on the benthic biota and to ecological processes.

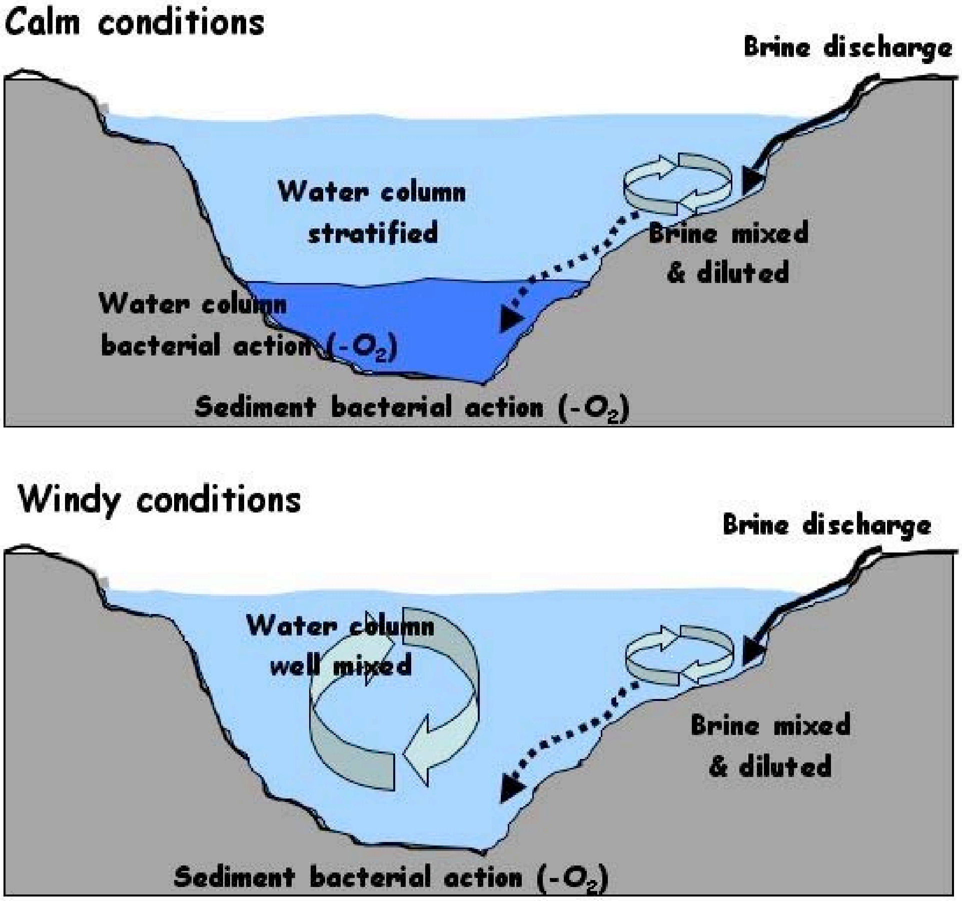

Figure 2: Conceptual model showing the deep basin under stratified and fully mixed conditions

The Panel notes that while the focus of this review is on the direct effects of low DO concentrations on bottom fauna in Cockburn Sound, it is also possible that very low DO will result in biogeochemical changes to the sediments (release of heavy metals and nutrients (e.g. ammonia and phosphorus).

2.2 Current condition of Cockburn Sound

Cockburn Sound is the most intensively used marine embayment in Western Australia for recreation and commercial activities. It is an active commercial and naval port and receives industrial and cooling water discharges from a range of industries. Development in the region is projected to increase with a range of proposals and approved developments currently being implemented. The Sound supports Blue Swimmer Crab and bait fisheries, and is also the primary feeding ground for the northernmost Little Penguin colony in Western Australia and the breeding area for the Pink Snapper on the metropolitan coast. It is also an important nursery and feeding area for female Bottlenose Dolphins, which in turn supports an eco-tourism enterprise. The Sound also supports a Blue Mussel aquaculture industry.

The ecological condition of Cockburn Sound was at its lowest in the 1970s, with poor water quality, high chlorophyll-a levels and almost the total loss of *Posidonia* seagrass meadows from the eastern margin of the Sound. During the mid to late 1980s and early 1990s chlorophyll *a* concentrations and water clarity improved, and have generally stabilised since then (DEP, 1996).

More recent monitoring of nutrient-related environmental quality against the objectives of the SEP (2005) in *High Ecological Protection Areas* has shown that in 2005 (Wilson & Paling, 2006):

- chlorophyll a concentrations met the relevant guidelines, but were elevated in Jervoise and Mangles Bays,
- water clarity met the guideline, but was poorest in northern sites and Jervoise Bay,
- seagrass health met the standard in all sites except Mangles Bay.

Environmental quality met the guideline in all *Moderate Ecological Protection Areas* except Jervoise Bay Northern Harbour. In this harbour:

- chlorophyll a and light attenuation were chronically elevated, and
- algal biomass exceeded the standard that signify ‘blooms’.

The trends described above were based on 16 weeks of water quality sampling between December and March each year. Dissolved oxygen concentrations showed that the guidelines were met in both High and Moderate Ecological Protection Areas[1]. The waters of Cockburn Sound are generally well oxygenated (Wilson and Paling, 2006).

Inputs of nitrogen (most significant nutrient) has declined significantly from about 2,000 kg N/day the 1970s to 300 kg N/day in 2000, and about 70 percent of this load now enters via groundwater (CSMC, 2001). Groundwater nutrient concentrations remain high, but estimates of groundwater nutrient loads into the Sound are poorly quantified and trends are uncertain.

2.3 Environmental Policy for Cockburn Sound

In 2005, the Western Australia government established the State Environmental (Cockburn Sound) Policy 2005 (SEP, 2005) to protect and maintain the environmental values[2] of Cockburn Sound (EPA, 2005). Environmental quality objectives (EQO) are established for each environmental value. For ecosystem health, the levels of protection required to maintain ecosystem integrity are described in terms of ecosystem structure (e.g. biodiversity, biomass & abundance of biota) and ecosystem function (e.g. food webs, nutrient cycles) (SEP, 2005; EPA, 2005).

The Panel notes that the central basin of Cockburn Sound has a high ecological protection status under the State Environmental (Cockburn Sound) Policy 2005 (SEP, 2005). It is relevant to this review that the SEP requires that the median bottom water DO concentration in this zone should be above 60 percent saturation (ca. 4.5 mg/L) for a median based upon a defined period of not more than 6 weeks (EPA, 2005; Table 1a,b).

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[1] Weekly samples over the 16 weeks.

[2] These environmental values are: ecosystem health, fishing and aquaculture, recreation and aesthetics, and industrial water supply.

3. Dissolved oxygen criteria

In addressing this part of ToR1, the Panel sought to answer the question - What is the minimum bottom water DO concentration that must be maintained to ensure there are no adverse effects on the biota or important ecosystem processes particularly in the deep basin of Cockburn Sound?

The Water Corporation provided the Panel with two useful reviews of the effects of low DO on marine fauna. Both of these reviews were commissioned by the Water Corporation and were taken in 2005 and 2006 respectively. The first was a review of the relevant international literature (Oceanica, 2005a), and the other was a more specific review of the DO effects data for four important indicator species for Cockburn Sound (Blue Swimmer Crab, Western King Prawn, Pink Snapper and Western Rock Lobster) (Travers, 2006).

In summary these reports show that:

- although there is a large amount of DO effects data on many marine organisms, there is limited data available on the species of Cockburn Sound,
- the most sensitive species are those inhabiting generally well-oxygenated environments that are not normally exposed to low DO concentrations,
- although different taxa have different sensitivities, the general order of increasing sensitivity is:

  fish > crustaceans > bivalves > polychaetes (worms),
- the international literature shows: (a) DO concentrations of 5-6 mg/L are not toxic to sensitive marine species, (b) DO concentrations of 3-5 mg/L can be stressful to many organisms particularly if they are exposed for prolonged periods, and (c) DO concentrations below 2 mg/L are fatal to many species,
- the most sensitive species so far tested were Blue Swimmer Crab eggs which were adversely effected at DO concentrations below around 5 mg/L (or 70 percent saturation)[3],
- overall there is little site-specific effects data for Cockburn Sound, and even less data on the possible effects on sensitive life stages (e.g. eggs, larvae, ecdysis).

The Panel notes that State Environmental (Cockburn Sound) Policy 2005 (SEP, 2005) requires that the median DO concentration in bottom waters is maintained above 60 percent saturation (ca. 4.5 mg/L at winter temperatures)[4] for a period not exceeding 6 weeks.

The Panel concludes that the DO effects data presented is not sufficient to cause us to recommend lowering of the current SEP (2005) DO criteria. Further, the panel recommends that an additional criterion be set such that the DO daily median is maintained above 60 percent saturation

The Panel recommends that the current SEP (2005) DO criteria should remain and that an additional criterion requiring the daily median to be at or above 60 percent saturation be implemented. This will provide the required level of protection for the central basin of Cockburn Sound, although there is some uncertainty about the actual DO concentrations that adversely effect sensitive life stages of biota in

[3] The Panel notes that this species spawns from early spring to mid-summer.

[4] The Panel recommends that DO be quoted at all times as both mg/L and %saturation.

Cockburn Sound.

The Panel therefore recommends that these DO criteria be adopted for the purpose of establishing the initial Water Quality Management Plan for operation of the Perth Seawater Desalination Plant. The Plan needs to be based on the duration and extent of possible low DO events as well as the absolute DO concentration.

Further, the Panel recommends that additional studies be undertaken to determine the sensitivity of important species (and their life stages) living in and using Cockburn Sound to different levels of DO (see Section 6).

4. Ecological risk

In this section, the Panel first assesses the information available on the likelihood that low DO concentrations will exist in the deeper section of Cockburn Sound both with and without the brine discharge.

The Panel reviewed two sets of data – the available DO monitoring data and the DO concentrations predicted by a hydrodynamic/water quality model.

4.1 Existing situation

A number of data sets of bottom water DO concentrations in Cockburn Sound have been provided to the Panel, and these have provided a basis for assessing the current condition of the bottom waters.

A measure of the condition of bottom waters in Cockburn Sound around 10 years ago is provided by the data collected as part of the Southern Metropolitan Coastal Waters Study (DEP, 1996). Weekly vertical profiles of DO concentration in Cockburn Sound and Warnbro Sound (Dec 1993-1994) showed reduced DO concentrations more frequently and more pronounced in Cockburn Sound compared with Warnbro Sound. The lowest values were commonly found in the southern region of Cockburn Sound, with the lowest value of 2.8 mg/L recorded in Mangles Bay in March 1994.

The Cockburn Sound Management Council has monitored the water quality in Cockburn Sound and Warnbro Sound each year over a 16-week period (December to March) since 2001[5] (Wilson & Paling, 2006). The database of surface and bottom water DO concentrations collected annually since 2001 should be reanalysed with a view to the brine discharge from the PSDP.

A baseline Water Quality Monitoring Program was initiated in February 2005 by the Water Corporation further to consultation with DEC on the program indicators. By far the best database of DO concentration in the bottom waters in Cockburn Sound basin is that collected over the past 18 months (commencing in February 2005) by the Water Corporation (Oceanica Consulting, 2006a,b). *In situ* loggers were used to record bottom water DO concentration at 4 sites throughout Cockburn Sound (DO1, DO2, DO4, DO7)[6].

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[5] Weekly sampling at 18 sites (15 in Cockburn Sound, 2 in Warnbro Sound & 1 in between) for temperature, salinity, DO, pH, secchi depth, ammonia, nitrate, total N, filterable reactive P, total P, chlorophyll-a & irradiance.

[6] These are positioned at 0.5m from bottom and measure DO every 30 minutes.

The Panel notes that these data (Figure 3) are patchy in that some sensors were not working routinely. The Panel understands that the problems have been largely overcome and these sensors are now working well.

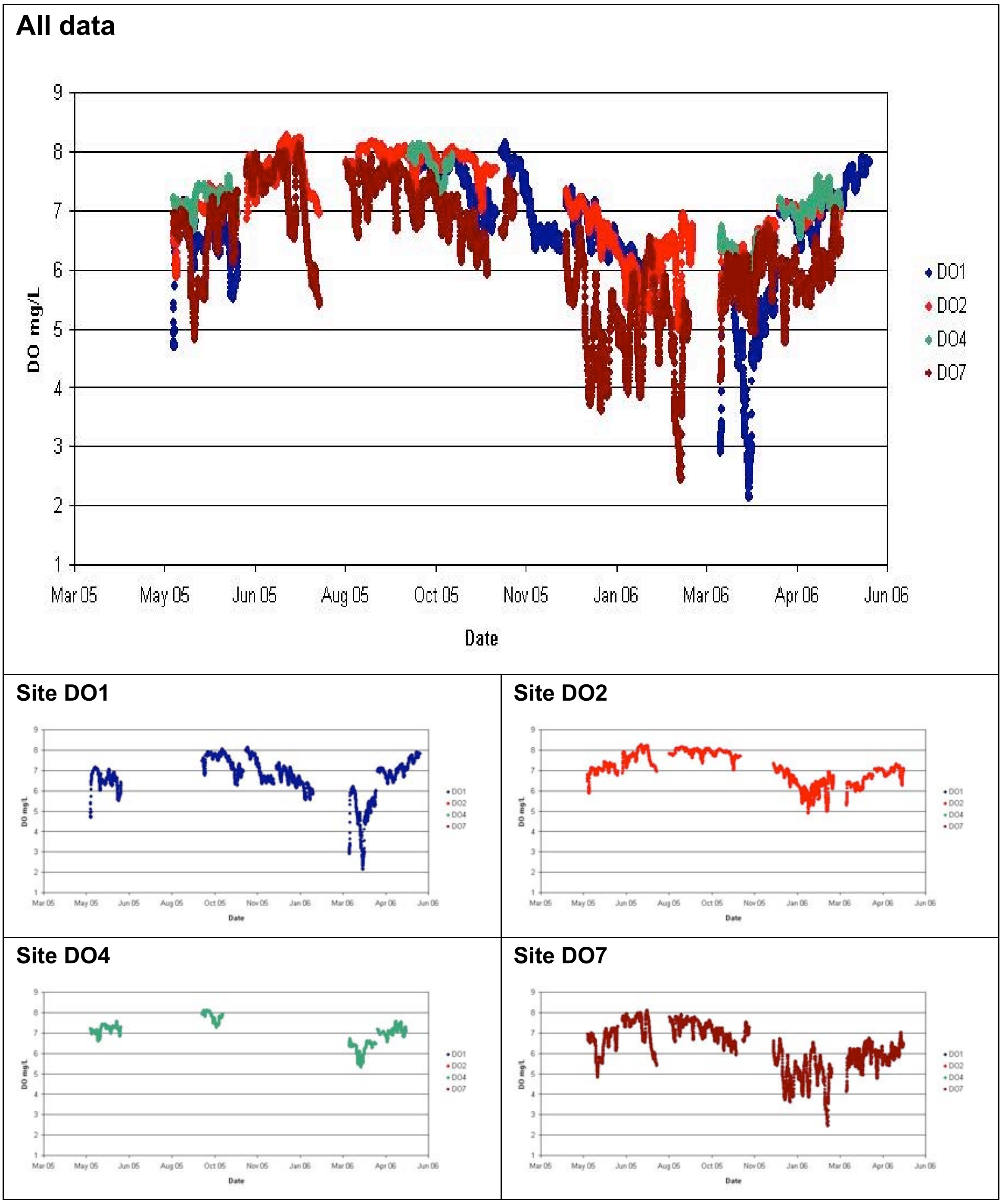

Figure 3: Bottom water daily median DO concentrations for period May 2005 to May 2006

Figure 3 shows a seasonal pattern in the bottom water DO concentrations in Cockburn Sound where low DO concentrations occur in summer through autumn. In 2005 the lowest DO was 4.2 mg/L (57 percent saturation) at site DO1 and 4.5 mg/L

(61 percent saturation) at site DO7 both in May 2005[7]. In 2006, the lowest DO measured at site DO1 was 1.1-2.0 mg/L during the period 24-28 March 2006 (Oceanica Consulting, 2006b).

The Panel concludes that the available monitoring data provides a reasonably broad picture of the current behaviour of DO in the bottom waters of Cockburn Sound, with bottom water DO concentrations generally greater than 60 percent saturation during winter and spring, and lower and at times less than 60 percent saturation during later summer and autumn.

Until further data becomes available, the Panel recommends that this seasonal pattern be adopted as typical for the purposes of DO management in Cockburn Sound.

The Panel also considers that the available baseline data for bottom water DO concentrations in Cockburn Sound is inadequate (in both length and spatial extent) to provide the required confidence in establishing a robust DO management regime for the PSDP. For this reason, the Panel recommends a precautionary approach be adopted in developing the initial Water Quality Management Plan (see Section 5 for details).

4.2 Predictive studies

The Water Corporation engaged the Water Research Laboratory, University of NSW to model the behaviour of the brine discharge in Cockburn Sound, with particular focus on stratification and DO concentrations (Van Senden & Miller, 2005; Miller et al., 2006).

A simple box model was used to predict general behaviour of stratification and subsequent bottom water DO concentrations resulting from the discharge of the brine. This box model predicted that the influence of the brine discharge could under worst case conditions result in DO reductions of 1-2 mg/L below that predicted to occur without the brine discharge (Miller et al., 2006).

The Panel notes that this modelling has been reviewed by CSIRO, NIWA and DEC, and has been found to have a number of limitations.

The Panel concludes that this simple box model:

- does not appear to be able to predict the absolute DO concentrations in Cockburn Sound basin that are apparent in the monitoring data,
- is not a sufficiently robust predictive tool of the location, behaviour and effects of the brine discharge plume.

A key component of any model to predict DO concentrations is a good understanding of the oxygen uptake by the microbial processes occurring in the sediments (known as sediment oxygen demand (SOD) - see Figure 2). The Water Corporation contracted the Centre for Water Research at University of Western Australia to undertake a series of laboratory studies to measure the SOD in core samples taken from 3 sites in the deep basin of Cockburn Sound (Read & Oldham, 2005, 2006).

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7 In May, the water temperature in Cockburn Sound is around 19C; at this temperature 100% saturation equates to 7.4 mg/L.

Despite some methodological issues with these experiments, a number of conclusions are apparent, namely that:

- sediment respiration is limited by available organic carbon,
- the sediment oxygen demand in control cores (no added organic carbon) was in the range 0.0-0.3 g/m^2 day,
- at very low DO concentrations these sediments will release Fe, Mn and ammonia.

Given the importance of sediment processes in controlling DO in bottom waters, the Panel is concerned that so little is known about the processes driving sediment respiration. The limited studies undertaken to date suggest that available organic matter limits respiration. However, the reasons for this, and possible effects from the PSDP, are poorly known[8]. Further studies of the biogeochemistry of the sediments are needed if the understanding of sediment processes is to be improved.

The Panel recommends that:

- a precautionary approach to management of DO in Cockburn Sound should be adopted, because of the uncertainties associated with the available model predictions,
- a reliable predictive 3D hydrodynamic/water quality model be developed for Cockburn Sound and used as a predictive tool in the management of stratification and DO concentrations in the Sound now that sufficient DO data is available to validate such a model,
- further studies be undertaken (probably need to employ in situ benthic chambers) with the aim of providing a better understanding of the processes driving the biogeochemistry of the sediments in Cockburn Sound (see also Section 6).

4.3 Assessment of ecological risk

There are considerable uncertainties in the data and information relating to both the likelihood and effects of DO in Cockburn Sound, and for this reason the Review Panel considers a precautionary approach is necessary until additional robust information becomes available.

Generally, the bottom waters of Cockburn Sound are well oxygenated and meet the SEP criteria for high ecological protection areas. However, there are obvious periods (mostly during late summer and autumn) when low DO concentrations are currently experienced for short periods of time. Unfortunately the temporal and spatial scale of the available continuous monitoring DO data is limited (approximately 1 year), and not sufficient to produce a robust baseline to assess ecological risk.

There is also considerable uncertainty associated with the available predictions of DO concentrations (and stratification) in the Cockburn Sound basin resulting from the release of brine. But, it seems clear that the brine discharge will potentially increase the extent and intensity of stratification in the basin and add further pressure on the Sound's ability to mix vertically and replenish DO concentrations at depth.

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[8] Questions include: What is the source of the bioavailable organic carbon (phytoplankton, river inputs, dredging)? What is the role of benthic algae (microphytobenthos) in the sediment processes in Cockburn Sound?

However, the ability to predict the DO status of Cockburn Sound for different operational and climatic scenarios is limited because an appropriate hydrodynamic/water quality model is not yet available.

The Review Panel has assessed the current ecological risk to Cockburn Sound basin as low to moderate, but notes that we have little confidence in this assessment given the limited evidence that is available.

Unfortunately, the Review Panel is not able to make a definitive statement on the ecological risk after the brine discharge commences, because of the uncertainty in the predicted bottom water DO concentrations with the brine discharge.

5. Water quality management plan

5.1 Current management propositions

Both the Department of Environment and Conservation (DEC) and the Water Corporation have proposed operational water quality management plans for Cockburn Sound during the operation of the desalination plant. The Panel is concerned only with that part of the plan that addresses dissolved oxygen.

Both management plans set an absolute limit on the lowest bottom water DO concentration permitted, and below which the desalination plant would be shut down. Further, both plans allow for an adaptive management strategy where action is triggered at higher DO concentrations and the resultant action depends upon the predicted climatic conditions (specifically the wind mixing ability) over the subsequent 1-3 days.

While there is broad agreement between the two organisations on the logic underpinning the water quality management plan, there are two key areas of disagreement. These are:

- the lowest DO concentration allowable (DEC – 60 percent saturation (4.2-4.5 mg/L); Water Corporation - 3.5 mg/L (45 percent saturation)),
- the number of real-time DO monitoring probes to be used in calculating the median DO concentrations for triggering action (DEC – any one probe; Water Corporation – more than one probe).

5.2 Panel's proposition

The Panel supports the basic structure of the dissolved oxygen decision schemes proposed by DEC and the Water Corporation. However, we believe that this form of the scheme should be regarded as interim only, and that the management plan should be reviewed after the first year of full operation.

The Panel has reviewed both plans in detail, with particular reference to the two areas of disagreement. We have already commented upon the first area of disagreement and have recommended that an additional daily median value of 60 percent saturation be adopted as the lowest bottom water DO concentration allowable.

Further, and in view of the lack of information on the possible spatial heterogeneity in bottom water DO concentration around the three real-time monitoring sites, the Panel recommends that data from any one probe be used to calculated the trigger DO concentration.

In making this recommendation, the Panel acknowledges that the Water Corporation have currently sited the real-time probes in the deepest locations in Cockburn Sound, where it is reasonable to expect that stratification would be more likely to occur and for the longest duration, and the bottom water DO concentrations would be at their lowest. The real time monitoring system also records data over a 24-hour period, which will capture naturally reduced DO concentrations from evening respiration. The Panel believes it may be possible to modify this requirement for one probe after a full year of operation (i.e. April 2008), when it is proposed that further information on the bottom water DO concentrations in the regions between the probes will be better understood. Also, results from the recommended 3D modelling may assist in providing a basis to refine the requirement for one probe.

The Panel has reviewed both DO decision schemes and recommends that the interim scheme adopt:

- the SEP (2005) criteria along with a daily median of 60 percent saturation as the lowest bottom water DO concentration allowable,
- the calculated trigger DO concentration be based upon the data from any one probe (this to account for the possible heterogeneity within Cockburn Sound).

The Panel also recommends that the modified dissolved oxygen management plan outlined in Table 1 be adopted as the interim approach. Note: the Panel has also recommended an alternative to the Table 1 plan (modified Table 1 plan) that is sightly less precautionary, but nevertheless would still provide adequate protection of the Cockburn Sound environmental values.

The Panel believes this modified plan, given the present uncertainties, will achieve the following objectives:

- a more proactive approach to the occurrence of decreasing DO concentration,
- inclusion of trigger values more consistent with the maintenance of SEP (2005) values,
- account for the possible spatial heterogeneity around the 3 real-time monitoring sites,
- account for the frequency and duration of full mixing events,
- adopt a sensible approach to the frequency of the potential shut-down of the PSDP.

The Panel has also considered a slightly modified version of the plan outlined in Table 1. The modified Table 1 plan changes the DO rule for Step 4 to ‘at two or more sites’ rather than ‘at any site’.

Analysis of this scheme using available data (DO monitoring data from Cockburn Sound, actual wind speeds at Garden Island and wind mixing criteria set B[9]) shows

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[9] The number of shut-down days is sensitive to the wind conditions chosen to achieve full mixing. These conditions will become better known with the collection and analysis of the real-time monitoring to be collected.

that the plant would have been required to shut down for around 60 days[10] over the period May 2005 to May 2006. Most of these shut down days are predicted to occur during late summer to autumn period.

Analysis of the modified Table 1 plan using the same data as above, shows that the plant would be required to shut down for around 30 day over the period May 2005 to May 2006 (Kevin McAlpine, personal communication, August 2006).

> The Review Panel recommends that the proposed dissolved oxygen management plan should be implemented within an adaptive management framework (see Section 6).
>
> The Review Panel also recommends that a more sophisticated management plan be implemented after the first year of full operation, where the required decisions are informed by both the real-time DO measurements and the predictions of mixing (and bottom water DO reductions) from a 3-D hydrodynamic/water quality model of Cockburn Sound.

Table 1: Modified dissolved oxygen management plan for Cockburn Sound during the operation of the desalination plant

1	Is daily median DO concentration <80% saturation at any site? Y – Go to 2 N – Continue monitoring
2	Is daily median DO concentration <60% saturation at any site? Y – Shut down PSDP, go to 6 N – Go to 3, continue monitoring
3	Is daily median DO concentration <67% saturation at any site and no mixing event is forecast within 1 day? Y - Shut down PSDP, go to 6 N – Go to 4, continue monitoring
4	Is daily median DO concentration <75% saturation at any site and no mixing event is forecast within 2 days? Y - Shut down PSDP, go to 6 N – Go to 5, continue monitoring
5	Is daily median DO concentration <80% saturation at 2 or more sites and no mixing event is forecast within 3 days? Y - Shut down PSDP, go to 6 N – Go to 1, continue monitoring
6	Are the answers to Steps 2-5 all “NO”? Y – Restart PSDP and go to Step 1 N – Do not restart and go to Step 2

Notes:

1. For the purposes of this plan, the Panel has assumed that the following conversions hold: 80% saturation - 6.0 mg/L, 75% saturation - 5.5 mg/L, 67% saturation - 5.0 mg/L, 60% saturation - 4.5 mg/L.
2. DO values are daily median values.
3. This management plan assumes the daily DO consumption rate of is 0.5 mg/L/day.

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10 These calculations do not account for ramp-up and ramp-down time.

The Panel appreciates that this number of shut down days (30-60) is considerably more than desirable. However, it is our view that a conservative approach is justified at this stage. As more data becomes available and the uncertainties are reduced, it is possible that the DO management scheme can be modified and that the shut down days will be reduced.

The implications of these shut downs on the Perth water supply could be partially mitigated by appropriate scheduling of the expected 20 days maintenance plant shut downs required each year.

6. Adaptive Management (future)

6.1 Further investigative studies

The Panel has noted a number of important uncertainties in the knowledge underpinning the management of the brine discharge from the Perth Seawater Desalination Plant. In view of these uncertainties, the Panel has been influenced to recommend actions that are precautionary, and aimed to provide the community with confidence that the Plant will not cause adverse effects in Cockburn Sound.

However, it is possible that some of these actions may be too stringent and have the effect of closing the Plant down at times when this is not warranted.

The Panel therefore recommends the following program of investigations to provide knowledge that will inform the on-going adaptive management processes, arranged in order of priority.

- A 3-D hydrodynamic/water quality model should be developed and used in the real-time management of DO in Cockburn Sound. As part of this study we believe plume tracer experiments should also be undertaken to examine plume behaviour and dynamics under various seasonal climatic conditions if practicable. The Panel has sought advice on the feasibility of developing such a hydrodynamic/water quality model – our advice is that this should take no longer than 6 months to complete the model, although full validation of the model with real data may take another 12 months depending upon data requirements.
- A field-monitoring program should be undertaken to provide information on the ability of the 3 real-time DO monitoring probes to represent the bottom water DO concentrations in Cockburn Sound. A well designed program, using either manual or *in situ* DO probes, should also provide information on plume dynamics, contingent DO events and quality of the real-time DO monitoring system (QA/QC auditing).
- The potential to use Warnbro Sound as a reference site to assist in the interpretation of regional and localised DO events, should be investigated.
- Further studies should be undertaken with the aim of providing a better understanding of the processes driving the biogeochemistry of the sediments in Cockburn Sound. The use of *in situ* benthic chamber experiments to examine primary production, sediment oxygen demand, nutrient and metal fluxes and possible sources of organic carbon, should be considered.
- Consideration should also be given to undertaking a series of DO bioassays to examine the effect levels of DO (NOEC, LOEC and LC50 concentrations) on

susceptible life cycle stages of relevant species including blue swimmer crab, western king prawn and snapper.

The Panel notes that a number of these studies could be done as PhD research projects, and urges the Water Corporation to explore possible links with local Universities.

6.2 Review Process

The Panel recommends that a Water Quality Management Plan be included in the Prescribed Premises Licence associated with the discharge of brine to Cockburn Sound, and that this plan should provide comprehensive details of the QA/QC system for the real-time monitoring system and associated monitoring activities.

The Review Panel also recommends that an initial review of the proposed Water Quality Management Plan be undertaken when suitable additional information becomes available and no later than after one full year of operation. It may also be necessary to continue this review process (at 1-2 yearly intervals) as further data progressively becomes available.

The Panel suggests that this review should consider the recommended trigger values, management rules and management regime in the light of additional monitoring and investigation information collected over the first full year of operations.

The Panel also considers it vital to ensure that the data from the real-time monitoring system are provided to stakeholders including the community to ensure a transparent approach to the management of the resource. This would be best achieved by posting verified data to the Web.

7. Panel conclusions

Both the DEC and the Water Corporation are aware of the high ecological protection status of the deep basin of Cockburn Sound, and are focused on adequately protecting this valuable resource.

The evidence presented to the Panel shows that the bottom waters of Cockburn Sound may be seasonally stressed due to DO depletion (without the desalination plant), although the available information is not sufficient to predict with certainty exactly how the brine discharge will affect the Sound under particular conditions.

For this reason, the Panel has taken a precautionary approach in ensuring the Perth Seawater Desalination Plant operations do not adversely effect the environmental values of Cockburn Sound.

The Panel is conscious of the potential impact on Perth's water supply if the approach is too conservative, and has recommended a program of investigations to be undertaken during the first full year of operations that will provide the necessary information to reduce the uncertainty in the Water Quality Management Plan.

After discussions with relevant staff and examination of all the available information, the Review Panel concludes that:

- There should be no change to the DO criteria specified in State Environment Policy (2005) for the protection of the high ecological protection area for Cockburn Sound.
- There should be an additional DO criteria being that the daily median should not be less than 60 percent saturation.
- The Review Panel's modified Water Quality (DO) Management Plan (Table 1), or the alternative also suggested, should be adopted as an interim plan, with an initial review of the Plan undertaken when suitable additional information becomes available and no later than after one year of full operation (i.e. after April 2008). It may also be necessary to continue this review process (at 1-2 yearly intervals) as further data progressively becomes available.
- The recommended program of investigations should be implemented as a priority.

8. Acknowledgements

The Panel wishes to thank Colin Murray (DEC) for his assistance throughout the review – he made things happen!

The Panel is also extremely grateful for the assistance provided by Dr Ray Masini and Kevin McAlpine of the Marine Ecosystems Branch, DEC, and Dr David Luketina and Michelle Rhodes of the Water Corporation.

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Appendix 6

Review of studies relating to the discharge from the Perth Seawater Desalination Plant in Cockburn Sound, Robert Spigel, National Institute of Water & Atmospheric Research Ltd, April 2008.

Review of studies relating to the discharge from the Perth Seawater Desalination Plant in Cockburn Sound

NIWA Client Report: CHC2008-027
April 2008

NIWA Project: DEC08501

Review of studies relating to the discharge from the Perth Seawater Desalination Plant in Cockburn Sound

Robert Spigel

Prepared for

Department of Environment and Conservation, Western Australia

NIWA Client Report: CHC2008-027
April 2008
NIWA Project: DEC08501

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Executive Summary

This report provides an appraisal of key findings in technical reports that document modelling and field studies commissioned by the Water Corporation on the impact of the Perth Seawater Desalination Plant discharge on density stratification and dissolved oxygen in Cockburn Sound. Additional material from Water Corporation monitoring has also been used in the appraisal.

The findings of the technical reports are summarised in the Water Corporation's S46 report to the Minister for the Environment. The S46 report concludes that "the discharge of seawater concentrate does not affect dissolved oxygen levels in the deep basin of Cockburn Sound" (Water Corporation 2008, p. 17). Similar conclusions are presented in the supporting technical reports.

The monitoring, field work and modelling have increased the understanding of PSDP plume dynamics considerably, and some excellent and impressive work has been done in this respect by the Centre for Water Research (CWR), University of Western Australia, and is well-documented in the technical reports.

The Water Corporation has clearly made a sizeable investment in financing modelling and field investigations, in procuring and installing high-quality sensors, in improving its monitoring and quality assurance procedures, and in trying to overcome problems associated with making the demanding measurements required by their operating license.

However, after reviewing the reports and supplementary data from monitoring, I feel that the conclusions regarding lack of influence of the desalination plume on stratification and oxygen in Cockburn Sound should be qualified.

Data show that the plume can enter the main basin as a thin bottom boundary layer under calm conditions, with only slightly higher density compared to overlying water, and as such is difficult to resolve with the computer model or the monitoring measurements as they are currently made The thickness of the layer is probably less than or of the same size (0.5 m) as both the depth resolution of the model and the lowest depth at which monitoring data are required to be collected.

The length of observations has not been long given year-to-year variability in climate and in coastal ocean conditions, and it is likely that more extreme conditions than those observed over the time span of the modelling or since the start of monitoring will occur in the future.

While the most severe oxygen drawdown event yet observed was associated with thermal stratification rather than salt stratification, this does not preclude the possibility that salt stratification also causes oxygen drawdown, either by itself or by reinforcing the effects of thermal stratification, as shown by profiles measured at the southern monitoring site.

The extent of the impact of the PSDP discharge on stratification and dissolved oxygen in Cockburn Sound is masked by the natural variability in temperature and salinity in the Sound. This, together with limitations of the modelling, lead me to believe that modelling alone cannot resolve all the questions related to the impact of the discharge. It seems likely that further understanding will depend on careful and refocused measurements.

A possible approach for such measurements is proposed in this report that involves modifications to the present real time forecasting and compliance monitoring method. These modifications are intended to help answer questions regarding the frequency, intensity and cause of the more severe oxygen drawdown events, and remove some of the ambiguity and speculation that surrounds these issues at present. At the same time an effort has been made not to increase the burden of monitoring unduly. It may not be possible to implement all of these modifications for technical or legal reasons, but they are presented for the sake of discussion. Real time monitoring efforts could be focused on a single mooring in the south instead of three as at present; this might allow for improved maintenance of the sensors, better quality data and better depth resolution of oxygen and salinity. The trigger for compliance monitoring at low oxygen levels 0.5 m above the bed could remain the same, but the monitoring itself could be extended to include not only intensive profiling around the exit to the Stirling Channel, but also profiling at enough sites in the central and southern part of the Sound to allow maps of surface and bottom temperature, salinity and oxygen to be drawn like those prepared by CWR at the beginning of their two field campaigns.

1. Introduction and information supplied for the review

The Department of Environment and Conservation, Western Australia (DEC), has asked the National Institute of Water and Atmospheric Research, New Zealand (NIWA), to provide an appraisal of the key findings in technical reports on computer modelling and field studies that were commissioned by the Water Corporation to investigate the possible impacts of the plume from the PSDP on density stratification and dissolved oxygen concentrations in Cockburn Sound.

The technical reports were produced by the Centre for Water Research (CWR), University of Western Australia, who did all of the computer modelling and carried out the field work for two short field campaigns that included dye releases. The reports are contained as appendices in the Water Corporation's S46 report submitted to the Minister for the Environment (Water Corporation 2008) as follows (see Reference section for complete citations):

1. Appendix 4 (2007). Summary of investigations into the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound. 29 p.

2. Appendix 5 (2006). Modelling of the impact of the Perth Seawater Desalination Plant discharge on dissolved oxygen in Cockburn Sound. 43 p.

3. Appendix 6 (2006). Hydrodynamic modelling of the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound. 106 p.

4. Appendix 7 (2007). Field investigations into the impact of the Perth Seawater Desalination Plant discharge on Cockburn Sound. 102 p.

On 5 February 2008, low oxygen concentrations recorded at the Water Corporation's southern real-time monitoring site (RTMS), together with a prediction for continued calm wind conditions, triggered compliance monitoring that included tracking of the PSDP saline plume through the shipping channels on the eastern shelf of Cockburn Sound. This event, the first to trigger the plume-tracking protocol, was subsequently described in a revision of the Water Corporation's S46 report (Water Corporation 2008, Section 3.4), and a report on this event containing profiles of salinity, temperature and density, was included as Appendix 10 to the S46 report.

During the course of this review I have requested and been given access to additional field measurements and monitoring data from DEC, the Australian Bureau of

Meteorology (BOM) and the Water Corporation, and have taken these into account when assessing the findings of the technical reports and the conclusions of S46 report.

The findings in the technical reports form the basis of the Water Corporation's conclusion, contained in the Water Corporation's S46 report to the Minister for the Environment, that "the discharge of seawater concentrate does not affect dissolved oxygen levels in the deep basin of Cockburn Sound" (Water Corporation 2008, p. 17). The S46 report recommends that the Water Corporation be relieved of its current obligations to conduct investigations and monitoring of stratification and dissolved oxygen levels in Cockburn Sound, and of the need to apply dissolved oxygen criteria to the PSDP discharge to protect the deep basin of Cockburn Sound. (The Water Corporation's conclusion and recommendations are reproduced in full in Appendix A of the present report).

The conclusions presented in the technical reports themselves are similar to that of the Water Corporation quoted above. For example, the Summary report (Appendix 4, 2007, p. 3), states: "There is therefore no possibility of a saline plume from the desalination plant entering the deep waters of Cockburn Sound (>10m) and sufficiently prolonging stratification such that dissolved oxygen is measurably affected."

For reasons that are given in more detail in subsequent sections of this report, my interpretation of the measured data and the results from modelling are that these conclusions should be qualified somewhat. The monitoring, field work and modelling have clearly increased the understanding of PSDP plume dynamics considerably, and some excellent and impressive work has been done in this respect. However, I think data show that in fact the plume does enter the main basin as a thin bottom boundary layer under calm conditions, with only slightly higher density compared to overlying water, and as such is difficult to resolve with the computer model or the monitoring measurements as they are currently made (e.g., Water Corporation 2008, Appendix 10, Figure 5a,b,c; shown in Figure 1 [a map of sites] and Figure 2 [profiles] of this report). The thickness of the layer is probably less than or of the same size (0.5 m) as both the depth resolution of the model and the lowest depth at which monitoring data are required to be collected. The data and modelling show that the occurrence of events that cause oxygen drawdowns below 60% saturation in bottom waters, at 0.5 m above the bed, are not common, and severe drawdowns to levels measured in 1994 at a height of 0.2 m above the bed (below 30% saturation; Masini 1994) have not yet been observed within the current monitoring framework.

However, the length of observations has not been long given year-to-year variability in climate and in coastal ocean conditions, and it is likely that more extreme conditions than those observed over the time span of the modelling or since the start of monitoring will occur in the future. Furthermore, while the most severe oxygen drawdown event yet observed was associated with thermal stratification rather than salt stratification, this does not preclude the possibility that salt stratification may also cause oxygen drawdown, either by itself or by reinforcing the effects of thermal stratification. I think that inspection of even a small selection of profiles measured at the south RTMS shows this to be the case (e.g., profiles for 2 and 3 January 2008, shown in Figure 3 of this report; all profiles from 2 January – 8 February 2008 are shown in Appendix D of this report). If it is accepted that the PSDP saline plume can contribute, even if infrequently, to stratification in the main basin of Cockburn Sound, then given the connection between duration of stratification and extent of oxygen drawdown that has now been unequivocally confirmed, I feel that the PSDP plume does have an effect on dissolved oxygen concentrations in Cockburn Sound. The effect may be small or even negligible much of the time; it may become significant only infrequently; and it may be so localised geographically that affected areas are recolonised over time. But it undoubtedly adds a further increment to existing stress on the Cockburn Sound ecosystem. In this regard I note that D'Adamo (2002, p. 1) has described Cockburn Sound as "a poorly flushed coastal basin requiring remedial action to redress ecological problems caused by the chronic input of contaminants from industrial and domestic discharges over the past 30 – 40 years."

A point made in this report is that the extent and magnitude of this increment remains to be determined, and it will not be a simple matter to do so. The extensive modelling and data collection efforts undertaken over the last 2 – 3 years have shown that the effect is masked by the natural variability that already exists in salinity and temperature in the Sound. This, together with limitations to modelling (as discussed in this report), lead me to think that the question is probably beyond resolution by modelling alone, and only careful and refocused measurements can lead to further progress. Possible modifications to existing monitoring strategies are presented in Section 6.

The Water Corporation has clearly made a sizeable investment in financing modelling and field investigations, in procuring and installing high-quality sensors, in improving its monitoring and quality assurance procedures, and in trying to overcome problems associated with making the demanding measurements required by their operating license. In this regard I refer to Janzen et al (2007), posted on the Seabird Electronics web site, that documents difficulties encountered by Water Corporation and Seabird Electronics engineers in maintaining expensive and sensitive equipment for long-term monitoring in Cockburn Sound.

2. Overview of this report

Section 3 contains a brief summary of the dynamics of the saline plume from the PSDP. This provides some basic background information necessary for interpretation of the results from modelling, field measurements and monitoring.

Section 4 contains subsections that discuss each of the technical reports.

Section 5 considers an index of the year to year variability in the duration of periods of low winds.

Section 6 presents suggestions for a revised monitoring strategy.

Section 7 gives overall conclusions for the report.

3. Plume dynamics and possible flow into the main basin of Cockburn Sound

The processes governing release and subsequent propagation of the PSDP saline plume are fundamental to any interpretation of the modelling, field and monitoring results, and a brief summary is as follows, based on the descriptions in the technical reports and Water Corporation (2008). Detailed observations of plume behaviour are presented in the technical report on field investigations (Appendix 7).

The PSDP, located on the eastern shore of Cockburn Sound, withdraws a weekly average of 320 ML per day (3.70 $m^3\ s^{-1}$) of seawater at a salinity of around 36 psu, of which 190 ML per day (weekly average; 2.20 $m^3\ s^{-1}$) of hypersaline water at a salinity around 65 psu is returned to the Sound (Water Corporation 2008, Table 5, p. 24). The return discharge flows through a 160m long multi-port diffuser located in 10m depth of water 500 – 580m offshore, designed to dilute the discharge by a factor of about 45 and reduce the discharge salinity to within approximately 1 psu of ambient salinity within 50m of the diffuser. The diffuser appears to be doing its job.

As originally designed, flow leaves the diffuser ports at an angle of 60° to the horizontal, and then falls to the sea floor under the influence of its negative buoyancy. Although its salinity, and hence density difference, has been greatly reduced by dilution with ambient seawater, and its temperature is slightly warmer than that of the surrounding seawater, the discharge maintains enough negative buoyancy to flow away from the diffuser on the sea bed as a gravity current. As such it follows depth contours downhill, and will preferentially follow any local depressions in the bottom. It thus flows into and along the local dredged shipping channels, unless strong winds mix the water column completely before the gravity current can reach the channels. These channels have variable width, on the order of 100 – 200 m, and depth of between 2 – 3 m. Part of the flow is then directed northward along the Calista Channel, and part south and then westward along the Stirling Channel. The partitioning between the two directions will depend on ambient currents, and model results (Figure 6, Appendix 4; reproduced as Figure 4 in this report) indicate that on average the greatest flow of salty water is to the north.

It is the westward flow in the Stirling Channel, however, that has the greatest potential to enter the central and southern parts of the main basin. The southern part of Cockburn Sound is the least well flushed part of the Sound, by virtue of its nearly fully enclosed boundary compared with the Sound's more open and wider boundary to the north. Examination of the dissolved oxygen time series posted on the Water Corporation's web site shows that while oxygen drawdown events often occur concurrently at all three monitoring sites, they tend to be more severe and more frequent at the southern site. This is consistent with observations made by CWR of the relation between stratification and oxygen depletion (Appendix 4, p. 23): "These data clearly indicate a spatial gradient in dissolved oxygen depletion, such that for a certain stratification, oxygen depletion in the south will be greater than in the north. These data are in agreement with sediment characteristics, which show a greater proportion of fine material in the south of Cockburn Sound (Oceanica 2007)."

As flow reaches the western end of Stirling Channel and nears the exit of the channel into the main basin, the slope of the bottom increases and the current speed would therefore tend to increase, causing the thickness of the plume to decrease. If the plume were still intact when it reached the channel exit, lateral spreading and further thinning would occur along the flatter and less channelised bed of the main basin. Appendix 4, in summarising results from the two CWR field studies conducted in December 2006 and April 2007, states (p. 3): "In all cases the plume was undetectable approximately 500m from the exit of Stirling Channel." However, the salinity and temperature profiles that were collected during the compliance monitoring on 6 February 2008, show that on that occasion the plume was still intact, with a thickness on the order of 0.5 m and with varying degrees of maximum salinity, at the seven sites (R16 – R22) that were sampled at 100m intervals along the 500m radial arc that is centered on the Stirling Channel exit (Water Corporation 2008, Appendix 10, Figure 5a, 5b, 5c; reproduced in Figure 1 [map of sites] and Figure 2 [profiles] of this report). No profiles were measured beyond this arc, other than at the much more distant RTMS sites, so the fate of the plume beyond 500m on this occasion is not known.

4. The technical reports

4.1. Appendix 4 –summary report

Appendix 4, dated August 2007, summarises the results contained in the other three reports that deal with hydrodynamic modelling, oxygen modelling and two field experiments involving release and tracking of Rhodamine dye. The objectives of the modelling and field studies were to determine the impacts of the desalination plant saline effluent on stratification and on dissolved oxygen in the Sound.

Hydrodynamic modelling was conducted over a 369-day period, 23 February 2005 – 27 February 2006, during which time salinities measured at the central monitoring station varied between 35.3 – 37.2 psu, and temperatures between 15 – 24°C. The main modelling effort for dissolved oxygen covered two periods, one in summer and one in autumn, the two seasons during which stratification is generally agreed to be most critical in causing oxygen depletion: 13 December 2005 – 24 February 2006 (summer, 74 days), and 6 March 2006 – 3 May 2006 (autumn, 59 days). As the PSDP began operation in November 2006, all of the data available for model calibration and validation are for pre-PSDP conditions.

Data for model calibration and validation were collected near the three sites in the deepest parts of the main basin of the Sound near the Water Corporation's RTMS mooring locations, and at one site on the shallower eastern shelf near the PSDP diffuser. Salinity and dissolved oxygen data recorded by moored instruments were not thought reliable enough during these periods to be used (Appendix 5, p. 14; Appendix 6, p. 48). Data for the northern open boundary were interpolated in time and space from profiles at two sites, also collected as part of the monitoring programmes – one within the Sound and also used for model validation, and one to the northwest of the Sound. It is not clear how data for the southern boundary causeway openings were specified. Meteorological data were from a BOM site at Swanbourne, approximately 30 km north of the PSDP.

Bathymetric data were available at 100m x 100m resolution. The model used a "plaid grid" with 200m x 200m horizontal resolution, except in the vicinity of the outfall and the shipping channels, where resolution was increased to 100m x 100m. Depths were resolved to 1m intervals over the top 10m with increased resolution to 0.5m over the deeper regions (down to approximately 20.5m).

The combined three-dimensional hydrodynamic-aquatic ecosystem models ELCOM-CAEDYM, developed and used extensively by CWR and overseas, were used for the simulations. These are excellent models and have produced many impressive simulations in a variety of lake and estuarine settings. They are competently and skillfully applied by CWR. However, even ELCOM-CAEDYM are subject to limitations due to a variety of factors, as discussed in more detail in the following sections. For the seasonal-scale simulations particularly, I believe that these limitations can lead to an overestimation of mixing of the plume, and therefore an underestimation of its effects on stratification and, potentially, dissolved oxygen drawdown.

The basic approach followed for both the hydrodynamic and oxygen modelling was to use all available data to calibrate and validate the models for pre-PSDP conditions. These provided the "control" simulations against which results from other scenarios could be compared. The models were then rerun under the same boundary and initial conditions, except that an input of saline water was included at the location of the PSDP diffuser to simulate the PSDP discharge. Comparisons were then made between pre-PSDP and post-PSDP operation conditions for a number of parameters relating to temperature, salinity, density and dissolved oxygen. Additional scenarios included an extended period (10 days, 24 May – 3 June 2005) of artificially low wind speeds, 1 m s^{-1} from the south. From my examination of wind records from Swanbourne from 1993-2008, I agree with the conclusion (Appendix 4, p. 27) that such wind "conditions are unlikely to ever be experienced in Cockburn Sound." The modelling predicted that while such an artificially extended calm period would lengthen the period of already predicted (under normal conditions) oxygen drawdown events, it would have virtually no effect on salinity stratification in the deeper parts of the Sound.

Outcomes from the modelling are summarized in Appendix 4 in a variety of ways, all of which show a small, but finite, effect of the saline discharge on stratification and dissolved oxygen. Figures 8, 9 and 10 in Appendix 4 (reproduced in Figure 5, this report) summarise effects on stratification at the three monitoring sites in terms of histograms giving relative frequencies of occurrence of bottom – surface density differences for simulations with and without the PSDP operating. As expected the strongest density differences occur at the southern site. At all three sites there is a slight change in frequencies such that stronger density differences occur slightly more often with the PSDP operating than without. There appears to be some discrepancy in Figure 10, Appendix 4, for the southern site, however. In this figure the greatest density differences occur more often without the PSDP operating than with. This seems puzzling. There also appears to be an error in the figure, in that the frequencies for all classes only add to approximately 94%, rather than 100%, as they do for the case without the PSDP operating (and for all cases in Figures 8 and 9, Appendix 4). It would be good if this could be clarified.

Similar histograms for dissolved oxygen show even smaller changes between the cases of with and without the PSDP operating. In the plot for the southern site, the same puzzling shift in relative occurrences occurs, with slightly more occurrences of lower dissolved oxygen events (60-70% and 50-60%) without the PSPD operating than with.

A possible explanation is that oxygen deficits are actually being offset by supply of dissolved oxygen contained in the plume itself. On the other hand, it seems more likely that the discrepancies are so small (on the order of 0.4% of the total number of occurrences) that they are well within the noise level for the model predictions. No error bars are shown in these graphs, and in fact no quantitative error measures are supplied for any of the simulations (other than correlation coefficients, which cannot be used alone to estimate errors). Given the limitations on the data available for model validation, especially for oxygen and salinity as noted above, I suspect the error bars could be fairly large, probably larger than the effects that the modelling is trying to detect.

The two field experiments summarized in Appendix 4 and described in detail in Appendix 7 included basin-wide data collection by CWR over two calm periods, one in summer (13 – 21 December 2006, with a 22.5-minute dye release at 08:00 19 December 2006) and one in autumn (25 – 28 April 2007, with a 19.5-minute dye release at 0940 on 26 April 2007). Modelling with ELCOM-CAEDYM was carried out in conjunction with the field experiments, using a 0.5m depth resolution over the full depth, and much more extensive data collected locally for validation and for boundary conditions. Meteorological data were also collected by CWR from a mooring they installed near the PSDP diffuser. From my experience, CWR conducts field work in a highly competent and professional manner. They use state-of-the-art instrumentation and take care that it is properly calibrated and maintained. Appendix 7 contains valuable results.

4.2. Appendix 5 – report on oxygen modelling

Appendix 5, dated November 2006, is a detailed report on the seasonal time scale oxygen modelling done using CAEDYM, coupled to the hydrodynamic model ELCOM, for the periods 13 December 2005 – 24 February 2006 (summer, 74 days), and 6 March 2006 – 3 May 2006 (autumn, 59 days). I have commented on the overall results in Section 4.1 above, and will focus here on more technical aspects of the modelling.

CAEDYM is an aquatic ecosystem model that simulates, in varying degrees of detail, most processes that impinge on dissolved oxygen concentrations, including transfer of oxygen through the water surface from the atmosphere; sediment oxygen demand; phytoplankton, benthic and seagrass respiration and photosynthesis; bacterial respiration; and transformations due to the nitrogen cycle. It is an excellent model, documented in the international scientific literature (citations in the report), originally developed at CWR and skillfully applied by them. Its chief limitations include those common to all aquatic ecosystem models, and are associated with the complexity of the biological and chemical processes that exist in aquatic ecosystems. These processes are greatly simplified in any model, and inevitably require the use of a multitude of empirical coefficients that need to be calibrated for each application. In this application, fortunately for the modelling effort, it is clear that three processes dominate the concentrations of dissolved oxygen in Cockburn Sound: supply of oxygen from the atmosphere through the water surface; uptake of oxygen by respiration at the sediment-water interface (parameterized as sediment oxygen demand in the model); and the transfer of oxygen by advection and mixing throughout the Sound and over the depth. This latter process – transport by mixing and advection – is chiefly the responsibility of the hydrodynamic driver ELCOM.

As noted in Section 4.1, the modelling produced a variety of comparisons for dissolved oxygen between pre- and post-PSDP operation conditions. These led to the conclusion, similar to those expressed in the summary report, that (p. 41, Appendix 5): "There will be no impact of the desalination plant discharge on dissolved oxygen conditions in the deep basin of Cockburn Sound, as the desalination plant discharge does not impact stratification in the deep basin of the Sound and stratification is required for significant oxygen drawdown." This conclusion emphasizes the dependence of the oxygen modelling predictions on hydrodynamic model predictions.

The report acknowledges that only a small amount of data are available with which to calibrate parameters associated with phytoplankton and nutrient cycles. It makes the point that this is not a critical issue for this application, given that oxygen concentrations are the main focus of the study and that these are dominated by the three processes listed above. This assertion is well supported by their Figure 5.2 (reproduced as Figure 7 of this report), and I think it is a reasonable assertion.

The model's parameterization of oxygen uptake at the sediment surface has been calibrated using measured data, resulting in an effective sediment oxygen demand that exceeds maximum demands previously measured, and in this sense the model is conservative. Masini (1993) measured a rate of 0.49 g O_2 m^{-2} day^{-1} in the southern basin of Cockburn Sound, whereas the CWR report states that the nearest equivalent measure in the model is 0.56 g O_2 m^{-2} day^{-1}. In relation to this, however, I note that the report also concludes (p. 41): "In order for oxygen conditions to be drawn down to low levels, bottom water would need to be isolated for approximately 10 days with *no* replenishment of this water from surrounding areas due to vertical mixing or horizontal advection." I am not sure how this conclusion was arrived at. Masini (1993) showed that the depletion rate of 0.49 g O_2 m^{-2} day^{-1} would lower the average dissolved oxygen concentration in a layer 1m thick from 7 g O_2 m^{-3} to 2.1 g O_2 m^{-3} in 10 days without replenishment. In a layer of thickness 0.5m or less, the time would be 5 days or less. On 29-30 April 1994 Masini (1994) did measure dissolved oxygen concentrations less than 2 g O_2 m^{-3} at 0.2 m above the bed in the southern basin of Cockburn Sound.

Having acknowledged the capabilities of the CAEDYM model and the skill with which it is applied by CWR, I do feel that there are some further limitations to the modelling (beyond the general one common to all such models mentioned in the second paragraph of this section). These limitations, described below (and in the following section for the hydrodynamic model), lead me to believe that the degree of certainty that CWR has assigned to the predictions should be tempered somewhat.

Firstly, any problems associated with the transport and mixing predicted by ELCOM will be propagated through the oxygen predictions. In particular, if ELCOM overestimates the degree to which a thin bottom gravity current is mixed and diluted by overlying water, this will cause the effects of density stratification and oxygen drawdown to be underestimated. This possibility is considered in more detail in Section 4.3.

Aside from limitations associated with hydrodynamic effects, the chief limitation that applies to the oxygen modelling itself involves validation. Data for model calibration and validation came from profiles measured as part of either the Water Corporation's or the Cockburn Sound Management Council's monitoring programmes. These were collected at three sites in the deepest parts of the main basin of the Sound near the Water Corporation's RTMS moorings, and at one site on the shallower eastern shelf near the PSDP diffuser.

Dates for which profiles were available for validation are given in Appendix B of this report. In contrast to the validation for the hydrodynamic model (discussed in Section 4.3), there are several dates for the critical autumn period, although they do not extend into May. The comparison between measured and predicted profiles is shown mainly in Figures 5.4, 5.5, 5.8 and 5.9 of Appendix 5 (reproduced in Figure 8 of this report). With regard to the summer period (January-February), the report states (p. 18) that there is "generally … good correlation between the measured and simulated results at all sites, with absolute values and the nature of the vertical stratification captured," although it does note that there are problems on some days. With regard to the autumn period (March-April) the report states (p. 24) that the "simulation results show excellent comparison with field data". When I look at the comparisons, I can agree that the simulations for autumn are better than those for summer, and in some cases agreement between measured and predicted profiles is excellent. This excellent agreement seems to occur mostly when the water column is completely mixed. However, on days when stratification occurs, the agreement is often not so good, and in some cases there are fairly significant discrepancies at the bottom of the profiles, with the measured profiles showing much lower absolute values, or much sharper gradients than the predictions. Yet it is precisely such occurrences that are of greatest concern in this study.

Finally, perhaps because of perceived limitations on data available for validation, no quantitative error measures are reported (e.g., root-mean-square deviations or other indices), so it is not possible to quantitatively assess the precision that one could expect to have confidence in for the predictions. This point is discussed further in relation to the hydrodynamic modelling (Section 4.3).

4.3. Appendix 6 – report on hydrodynamic modelling

Appendix 6, dated November 2006, is a detailed report of the seasonal time scale (23 February 2005 – 27 February 2006, 369 days) hydrodynamic modelling carried out by CWR to assess the impact of the desalination plume on density stratification in Cockburn Sound, and to prepare for subsequent modelling of dissolved oxygen (Appendix 5; see Section 4.2 above).

ELCOM is a three-dimensional, finite-difference, z-level-coordinate hydrodynamic model designed to predict currents, salinity and temperature (and concentrations of other scalar tracers) in lakes and coastal environments. It can account for the effects of the sun, wind, rain, evaporation, and air temperature at the water surface, and for absorption of solar radiation within the water column. It can also account for the effects of tides and for inflows of specified magnitude, temperature and salinity. As with CAEDYM, ELCOM is an excellent model that was developed by CWR, has been documented in the international scientific literature (citations are given in the report), and has produced many impressive simulations. It has been, and continues to be, skillfully applied at CWR and overseas in a wide variety of applications.

As noted in Section 4.1, the modelling produced a variety of comparisons for salinity, temperature, density and density stratification between pre- and post-PSDP operation conditions, and for a number of scenarios, including that of artificially extreme low winds. These led to the conclusions (p. 105, Appendix 6) that "the duration of … natural stratification events in the deeper waters (>15 metres) of Cockburn Sound will not be impacted by the desalination plant discharge due to high dilution of the discharge by natural processes", and "as a result of these natural processes, the impact of the desalination plant discharge on the stratification in the deeper waters (>15 metres) of Cockburn Sound will be negligible."

As with CAEDYM, or any model, the predictions that ELCOM is capable of making have limitations, and I think it is necessary to be aware of these in order to put the predictions into perspective. As with CAEDYM, some of these limitations have to do with the quality of the input data available to run the model and validate its predictions, while others relate more to the model itself.

Problems with data include data for boundary conditions to run the model and data available for validation of model results.

In the seasonal simulations, as noted in Section 4.1, data for the northern open boundary were interpolated in time and space from similar profiles at two sites – one within the Sound and also used for model validation, and one to the northwest of the Sound. It is not clear how data for the southern boundary causeway openings were specified. Meteorological data for the surface boundary were from a BOM site at Swanbourne, approximately 30 km north of the PSDP.

Regarding the open northern boundary, the report acknowledges that interpolation can reduce the model's predictive capability in some circumstances. In explaining a mismatch between a predicted and measured profile, the report notes (p. 31): "The boundary conditions at the northern end of the model domain are determined by interpolating available field data (Figure 3.6 [reproduced in Figure 9 of this report]), and are available at approximately monthly intervals at this time of the simulation. Thus any regional oceanographic features that appear with timescales less than this will not be forced at the boundary domain." With regard to another mismatch, the model notes (p. 24): "Boundary forcing data (Figure 3.5 [reproduced in Figure 9 of this report]) shows that interpolation between stratified and unstratified periods of measurement will limit the ability of ELCOM to resolve transient stratification features."

Regarding meteorological data, the report notes (p. 24): "Meteorological data was available from Garden Island, however Swanbourne data was chosen to represent a more conservative simulation approach, as the wind speeds measured at Swanbourne are typically lower than those measured at Garden Island." The generally lower wind speeds will decrease the energy available for vertical mixing, and this will offset numerical diffusion that leads to an overestimation of mixing, described below. However this offsetting will be more effective at higher wind speeds, whereas it is the influence of the plume at low wind speeds that is of greatest concern. In this regard spatial variability of wind at lower wind speeds can also be a potential limitation for the modelling, given that a single wind seems to be applied over the entire model domain. Steedman and Craig (1983), in an earlier study of wind-driven circulation in Cockburn Sound, examined wind records from several sites around Cockburn Sound and concluded: “For wind speeds greater than 5 m s^{-1}, it appears that the horizontal wind field is fairly uniform. Below 5 m s^{-1}, the wind speed and direction are variable and there is low correlation between stations.” Laval et al. (2003b), Lemmin and D’Adamo (1996) and others have pointed out the need to resolve spatial variability in wind stress by using data from more than a single site, in order to accurately model circulation in lakes. While Cockburn Sound is not a lake, it is a semi-enclosed basin whose circulation is strongly influenced by wind. The report states (p. 7): “The seasonal behaviour of Cockburn Sound is dominated by surface wind forcing and thermodynamics, and therefore predictive modelling of the Sound requires a three-dimensional numerical model capable of resolving lateral gradients in surface fluxes, most importantly wind and evaporation.” While ELCOM is capable of resolving such lateral gradients, the data necessary for doing so simply were not available for the seasonal simulations.

Regarding data for validation, because of problems encountered with salinity measurements made by mooring instruments (Appendix 6, p. 48), validation data were restricted to profiles measured near the three RTMS sites and a site near the diffuser as part of the Water Corporation’s and Cockburn Sound Management Council’s monitoring programmes. Dates on which profiles were made are shown in Table B-1, Appendix B of this report. There are only two dates that fall within the autumn period, and on these dates no profiles were measured near the southern RTMS site. Comparisons between measured and predicted profiles are shown in Appendix 6 in Figures 5.1, 5.2, 5.3 for temperature (reproduced in Figure 10 of this report), and Figures 5.8, 5.9, 5.10 for salinity (reproduced in Figure 11 of this report). As the report points out, density is computed from temperature and salinity, so any errors in temperature and salinity will be combined in the computed density. To me, agreement between measured and predicted profiles ranges from poor to excellent. As with the dissolved oxygen profiles, agreement seems best when the water column is fully mixed, and worst under stratified conditions. Yet stratified conditions, and even small differences in stratification, are those of greatest concern in this study.

Quantitative measures of goodness-of-fit between predicted and measured values were given as correlation coefficients and presented in scatter plots (Section 5.1.5, Appendix 6; shown in Figure 12 of this report). As for oxygen, however, no statistical measures were computed that would allow quantitative estimates to be made of the level of precision of model predictions that one could have confidence in. Derivation of error estimates is becoming more common in lake and ocean modelling now (Willmott et al. 1985, Smith and Rose 1995, Holt et al. 1995, Rueda and Schladow

2003, Warner et al. 2005), and given the small signals that are being simulated, a quantitative estimate of model accuracy would be helpful. A stratification parameter could also be derived from model results and field data, and error estimates determined to quantify the accuracy of the model predictions of stratification.

A final point regarding limitations on data for validation is that no results are mentioned or presented anywhere in the report for either predicted or measured water velocities. I suspect no velocity measurements were available. It is possible to argue that temperature and salinity fields would not be predicted correctly if velocities were poorly predicted. However, I think it would help to improve confidence in the model predictions to have some consideration of velocities.

Regarding limitations associated with the model itself, the ones of most concern are those that could lead to an overestimation of mixing between the saline plume and overlying water, so that some of the "high dilution of the discharge by natural processes" is actually due to a combination of natural and numerical processes. I think these problems are particularly relevant in the Cockburn Sound application, where it has now been shown that when the desalination plume does penetrate the main basin of the Sound, it does so as a thin bottom boundary layer whose thickness is on the order of the minimum cell size used in the model (0.5m), and whose density is only slightly greater than the water above it.

There are two points that can be made. One is the more general one of numerical diffusion that is present throughout the water column in any model where a fixed grid is used. The second is specific to the problem of trying to model gravity currents with basin-scale numerical models.

With regard to the first point, the report states (Appendix 6, p. 8): "Molecular diffusion in the vertical direction is neglected as turbulent transport and numerical diffusion are generally dominant." ELCOM uses a turbulent transport scheme such that below the upper mixed layer there is no turbulence; only numerical diffusion is left, and I cannot say how important it is. Laval et al (2003a) thought it important enough to develop a correction procedure to apply to the interface between the upper mixed layer and non-turbulent water below. But this correction procedure would not be applied to a bottom boundary layer below the mixed layer.

With regard to the second point, I have seen impressive simulations produced by ELCOM of density-driven river underflows and interflows in lakes. But these have all been either of flows whose vertical extent is much greater than the depth resolution of the model, or where special modifications have been made to the model to correct for excess mixing caused by the step-like bottom in the model grid. Such modifications were developed by Dallimore et al. (2003), who pointed out: "As dense water flows down these steps, ambient water is artificially mixed into the plume through a process called 'numerical convective entrainment' (Winton et al. 1998)." In addition to Dallimore's (2003) study, there has been a reasonable amount of work performed by the ocean modelling community on this issue (Winton et al. 1998, Ezer and Mellor 2004, Legg et al. 2006, Wang et al. 2008) and the conclusion is fairly unequivocal that z-coordinate models can introduce excessive mixing of dense bottom boundary layers. Legg et al. (2006) stipulate that the horizontal and vertical resolution of the model (Δx, Δz respectively) must meet the criteria $\Delta z < \Delta h$ and $\Delta x < \Delta h/\tan(\alpha)$, where Δh is the plume thickness and $\tan(\alpha)$ is the slope of the seabed, if excessive mixing is not to be introduced into the model. These criteria are probably satisfied on the flatter parts of Cockburn Sound, but do not appear to be satisfied at the exit to Stirling Channel. I do not know whether Dallimore et al.'s (2003) modifications were incorporated into the Cockburn Sound application, as no mention is made of them in the model description, or whether the 100m x 100m resolution of the Sound's bottom bathymetry is sufficient to allow the modifications to be applied meaningfully. If they were incorporated in the simulations, then the excess mixing would have been mimimised.

4.4. Appendix 7 – report on field experiments

Appendix 7, dated June 2007, describes two sets of field measurements that included basin-wide data collection by CWR over two calm periods: one in summer, 13-21 December 2006, with a 22.5-minute dye release at 08:00 19 December 2006; and one in autumn, 25 – 28 April 2007, with a 19.5-minute dye release at 0940 on 26 April 2007. Discharges from the desalination plant were 1.20 $m^3 s^{-1}$ at a salinity of 52 psu during the December 2006 dye release and 1.93 $m^3 s^{-1}$ at 67 psu during the April 2007 dye release. Appendix 4 (p. 17) says that these discharges correspond to 50% and 83% of plant capacity.

Modelling with ELCOM-CAEDYM was carried out in conjunction with the field experiments, using a 0.5m depth resolution over the full depth, and much more extensive data collected locally for validation and for boundary conditions. Meteorological data were also collected by CWR from a mooring they installed near the PSDP diffuser.

While most of the measurements were confined to the shallower eastern basin (where the diffuser is located), some transects extended for a short distance into the main basin from the exit of the Stirling Channel on the day dye was released and on the following day. In addition, some basin-scale mapping of temperature, salinity and dissolved oxygen was done on the day prior to each dye release to provide spatially varying data for the initial conditions to run ELCOM.

As noted in Section 4.1, from my experience, CWR conducts field work in a highly competent and professional manner. They use state-of-the-art instrumentation and take care that it is properly calibrated and maintained. The two field campaigns described in Appendix 7 appear to be no exception, and the use of ELCOM predictions in real time to assist with sampling strategy is very impressive.

The report concludes (p. 101) that although the plume is "distinctly measurable" at the exit of the Stirling Channel, "the two field campaigns and the modelling provide strong evidence that under conditions tested the saline underflow is completely dissipated within about 400m of the exit point of Stirling Channel." The report cites transect plots of temperature and salinity as evidence for this conclusion. My own interpretation of the transects is that while some certainly do support the above conclusions, in others there appears to be evidence in the field transects of a very thin, slightly warmer saline layer at a distance of nearly 1 km from the channel exit, for example Figure 3.19 (temperature) and Figure 3.31 (salinity) on 27 April 2007, 13:43-14:25 (reproduced in Figure 13 of this report); and Figure 4.19 (temperature) and Figure 4.28 (salinity) on 19 December 2006, 12:20-13:41 (reproduced in Figure 14 of this report).

There also appears to be evidence both for and against plume influence in the basin-scale mappings of temperature and salinity. An example of no plume influence can be seen in the maps for 18 December 2006, 06:39-10:16, for temperature (Figure 4.13) and salinity (Figure 4.23) (both shown in Figure 15 of this report). These indicate stratification dominated by temperature, with no discernable effects of salinity. The corresponding dissolved oxygen maps (Figure 4.39, shown as Figure 16 in this report) indicate oxygen depletion in bottom waters and provide a good picture of the north – south gradient in oxygen demand mentioned in Section 3, with more severe depletion in the south. In contrast, the maps for temperature (Figure 3.5) and salinity (Figure 3.6) for 25 April 2007 (both shown in Figure 17 of this report) provide an example of what seems to me to be salt spreading from the exit of the Stirling Channel into the main basin, but with very little difference in temperature between surface and bottom. (No corresponding basin-scale maps for dissolved oxygen are given for this date.)

5. Length of observations in relation to year-to-year variability in climate; the duration of calm periods

In Section 1 I stated that the length of existing monitoring observations has not been long given year-to-year variability that exists in climate and in coastal ocean conditions. I think it likely that more extreme conditions than those observed over the time span of the modelling or since the start of monitoring will occur in the future.

I have tried to quantify this in some way in terms of wind, since wind-mixing has emerged as a key variable in terms of breaking down stratification and thereby limiting the severity of any oxygen drawdown event. In particular, it seems that a relevant measure is the duration of calm intervals that separate winds of sufficient strength to fully mix the water column. Such a measure is difficult to estimate, since required wind strength for mixing depends on ambient stratification and this changes from place to place and day to day throughout the Sound. I have used a threshold of 5 m s^{-1} for 6-hour average winds, and applied this to summer-autumn winds (1 December – 31 May) from Swanbourne for the years 1994-2007 to provide an indication of possible patterns or trends for this measure.

The Swanbourne site has the longest record of hourly winds of the BOM sites in the Cockburn Sound area (the Garden Island record begins in 2001). The duration of 6-hours was chosen as being of the same order as sea-breeze peak wind durations. The threshold of 5 m s^{-1} was chosen by estimating the wind speed necessary to supply energy for mixing a water column of total depth 20 m and of uniform temperature and salinity, except that the bottom 0.5 m was at a higher salinity; salinity increments of 0.1 psu were used, up to a maximum of 1 psu, although the 5 m s^{-1} threshold applies to an increment of 0.1 – 0.2 psu. Calculations for mixing were based on the equations for the upper mixed layer model documented in Hodges et al. (2000) that describes application of ELCOM to Lake Kinneret. The calculations are documented and results summarized in Appendix C of this report. Inspection of wind and dissolved oxygen time series from the RTMS buoy for the period prior to and including the 5 February 2008 compliance monitoring (Figure 18, this report), led me to believe that the choices of 6-hour winds with a threshold of 5 m s^{-1} were reasonable as a basis for looking at maximum annual summer-autumn calm period durations.

Results of examining the Swanbourne records year by year, using the 6-month summer-autumn period (1 December – 31 May), and looking for the maximum duration separating 6-hour winds with speeds less than 5 m s^{-1}, are summarized in Table 1 below. No attempt is made to carry out any statistical analysis or to fit a probability distribution because of the shortness of the record and the limitations on the index chosen for analysis.

The maximum durations vary from 2.75 to 8.75 days, and the seasons 2005-2006 and 2006-2007 (the time span of the modelling and field experiments) appear as slightly above average or average in terms of maximum durations of calm periods.

Clearly the analysis could be done with other wind averaging intervals and speeds, and the numerical results would differ. Furthermore, there is no causal mechanism directly linking the index and any particular mixing event, because so many physical variables are required to predict any mixing event at a specific time and location in the Sound. But I think the results are indicative of kind of natural variability that can occur from year to year in a measure that is related to the potential for small increments in density stratification to contribute to the severity of oxygen drawdown events.

Table 1: Maximum durations for Swanbourne 6-hour average winds below 5 m s^{-1} during summer and autumn (1 December – 31 May).

Summer-Autumn	Maximum duration (days)	Date at end of interval
1994-1995	7.75	31-May-1995
1995-1996	3.75	23-May-1996
1996-1997	2.75	23-Apr-1997
1997-1998	3.50	23-Apr-1998
1998-1999	2.75	27-Apr-1999
1999-2000	8.75	20-May-2000
2000-2001	4.25	29-May-2001
2001-2002	3.75	29-Apr-2002
2002-2003	6.25	28-May-2003
2003-2004	7.75	29-May-2004
2004-2005	4.25	24-May-2005
2005-2006	5.50	01-May-2006
2006-2007	5.00	17-May-2007
Mean	5.08	
Median	4.25	
Standard deviation	1.99	
n	13	

6. Possible revised monitoring strategy

In this section a possible approach is proposed for monitoring that involves modifications to the present real time forecasting and compliance monitoring strategy. It may not be possible to implement all of these modifications for technical or legal reasons, but they are presented nevertheless for the sake of discussion. The modifications are intended to help answer questions regarding the frequency, intensity and cause of the more severe oxygen drawdown events, and remove some of the ambiguity and speculation that surrounds these issues at present. At the same time, an effort has been made not to increase the burden of monitoring unduly.

Real time monitoring efforts could be focused on a single mooring in the south instead of three as at present. This might allow for improved maintenance of the sensors and hence better quality data. Better depth resolution of oxygen and salinity could be achieved if some of the SBE16 and SBE43 sensors from the northern and central sites were redeployed at the southern site. It would be helpful for scientific reasons if a sensor could be positioned even closer to the bed than the limit of 0.5m as at present. Based on Masini's (1994) measurements, I would suggest a position 0.2m above the bed.

The trigger for compliance monitoring at low oxygen levels 0.5m above the bed could remain the same, but the monitoring itself could be extended to include not only the intensive profiling survey around the exit to the Stirling Channel, but also profiling at enough sites in the central and southern part of the Sound to allow maps of surface and bottom temperature, salinity and oxygen to be drawn like those prepared by CWR at the beginning of their two field campaigns. The intensive profiling around the Stirling Channel exit seems to be very effective in terms of quantifying the properties of the desalination plume as it enters the deeper basin of Cockburn Sound. However, to offset the demands for extra time that would be required for extra profiling in the main basin of the Sound, it may be worth considering some reduction in the profiles measured at the Stirling Channel exit.

It is acknowledged that tracking of the plume in the main basin may not be practical, so a preset grid of sample sites within the main basin of the Sound is proposed. Some guidance for location and number of sites can be found in the survey conducted by CWR at the start of their December 2006 field campaign. For example, the sites along the three southernmost transects in the main basin of the Sound, as shown in Figures 4.13, 4.23, 4.39 of CWR Appendix 7 (shown in Figures 15 and 16 of this report) could be profiled. A further two or three sites in the southernmost part of the main basin should probably also be profiled, to ensure that the mapping would cover the areas most susceptible to oxygen depletion.

Finally, it is suggested that the SBE19 CTD presently used for the profiling have its cage modified so that it can make measurements at a distance of 0.2m above the bottom, rather than at the minimum 0.5m as at present.

7. Conclusions

In Section 1 I stated that I felt the rather categorical conclusions presented in the Water Corporation S46 report, that "the discharge of seawater concentrate does not affect dissolved oxygen levels in the deep basin of Cockburn Sound" (Water Corporation 2008, p. 17), and in the technical reports that "[t]here is therefore no possibility of a saline plume from the desalination plant entering the deep waters of Cockburn Sound (>10m) and sufficiently prolonging stratification such that dissolved oxygen is measurably affected" (Appendix 4, 2007, p. 3), should be qualified somewhat. As stated in Sections 1 and 4.4, I think there is evidence in the measured data from Water Corporation monitoring and from CWR field measurements that the plume does enter the deep waters of Cockburn Sound, although the extent to which is does so, and its ultimate effect, remain unknown. I have also discussed reasons for thinking that the model simulations may overestimate natural dilution processes of a thin bottom boundary layer with only a small salinity difference from the overlying water, as the plume has now been shown to be. These reasons included both problems with data required to run the model with sufficient spatial and temporal resolution, as well as limitations of the model itself.

For all of the above reasons, I think that the question of the impact of the PSDP discharge on stratification and dissolved oxygen in Cockburn Sound is probably beyond resolution by modelling alone, and only careful and refocused measurements can lead to further progress. A possible approach has been presented in Section 6 that involves modifications to the present real time forecasting and compliance monitoring strategy. It may not be possible to implement all aspects of the approach for technical or legal reasons, but it has been presented for the sake of discussion. The modifications are intended to help answer questions regarding the frequency, intensity and cause of the more severe oxygen drawdown events, and remove some of the ambiguity and speculation that surrounds these issues at present. An effort has been made not to increase the burden of monitoring unduly. The approach includes a single RTMS rather than three as at present, but with improved measurement resolution and quality, and an expanded CTD profiling survey during the more severe episodes of oxygen drawdown that trigger compliance monitoring, as during the 5 February 2008 event.

While the most severe oxygen drawdown event yet observed (5 February 2008) was associated with thermal stratification rather than salt stratification, this does not preclude the possibility that salt stratification may also cause oxygen drawdown, either by itself or by reinforcing the effects of thermal stratification. I think that inspection of even a small selection of profiles measured at the south RTMS shows this to be the case.

In addition I think that the length of observations has not been long given year-to-year variability in climate and in coastal ocean conditions, and it is likely that more extreme conditions than those observed over the time span of the modelling or since the start of monitoring will occur in the future. I have presented some analysis of year-to-year variability in the duration of calm periods to support this assertion.

In closing, I wish to acknowledge the extensive, excellent and impressive modelling and field work that has been carried out by CWR, as documented in the technical reports. I feel that the modelling has made the best possible use of data available, and that the combined results of modelling and field work have increased the understanding of PSDP plume dynamics considerably.

I also wish to acknowledge the sizeable investment made by the Water Corporation in financing modelling and field investigations, in procuring and installing high-quality sensors, in improving monitoring and quality assurance procedures, and in trying to overcome problems associated with making the demanding measurements required by their operating license.

8. Acknowledgements

I would like to thank the following people for discussions or communications that helped clarify my thinking while undertaking this review, without in any way implicating them in the conclusions presented here: Philip Gillibrand, Roy Walters, Ian Wood, Nick D'Adamo, Roger Nokes, Mark Davidson, John List, Al Preston, David Hamilton.

I thank Steve Christie, Water Corporation PSDP Environmental Engineer, for his cooperation in clarifying questions about the monitoring, and in supplying data that I requested that was collected for the Water Corporation in the time leading up to and including the 5 February 2008 event that triggered compliance monitoring.

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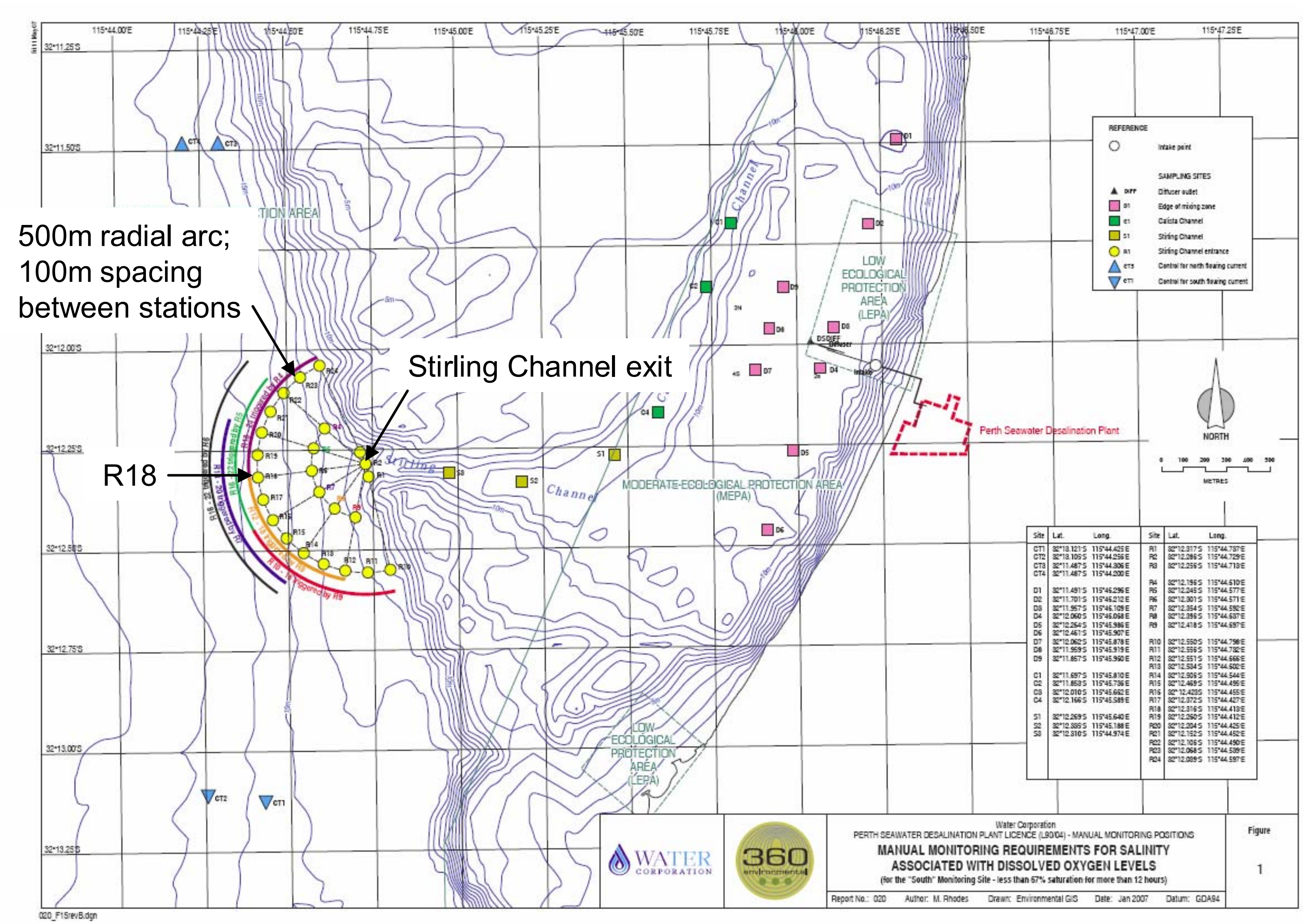


Figure 1: Map of site locations for compliance monitoring. [Figure 1, Appendix D, in Appendix 10, Water Corporation (2008); notes and arrows have been added.]

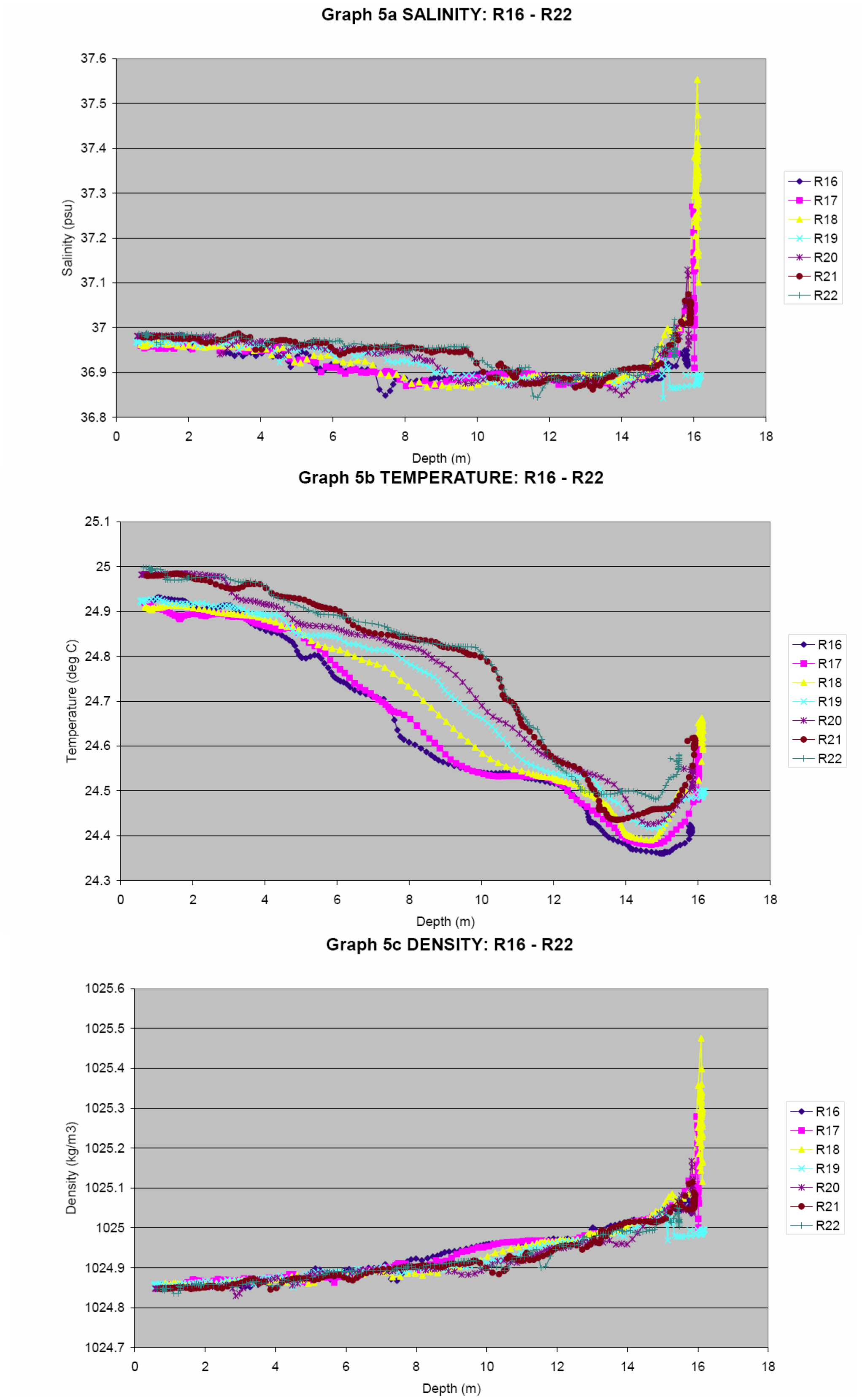


Figure 2: Profiles from 5 February 2008 compliance monitoring, measured for the Water Corporation on a 500m radial arc centered on the exit to Stirling Channel. [Figure 5a,b,c, of Appendices A,B,C, respectively, in Appendix 10, Water Corporation (2008)]

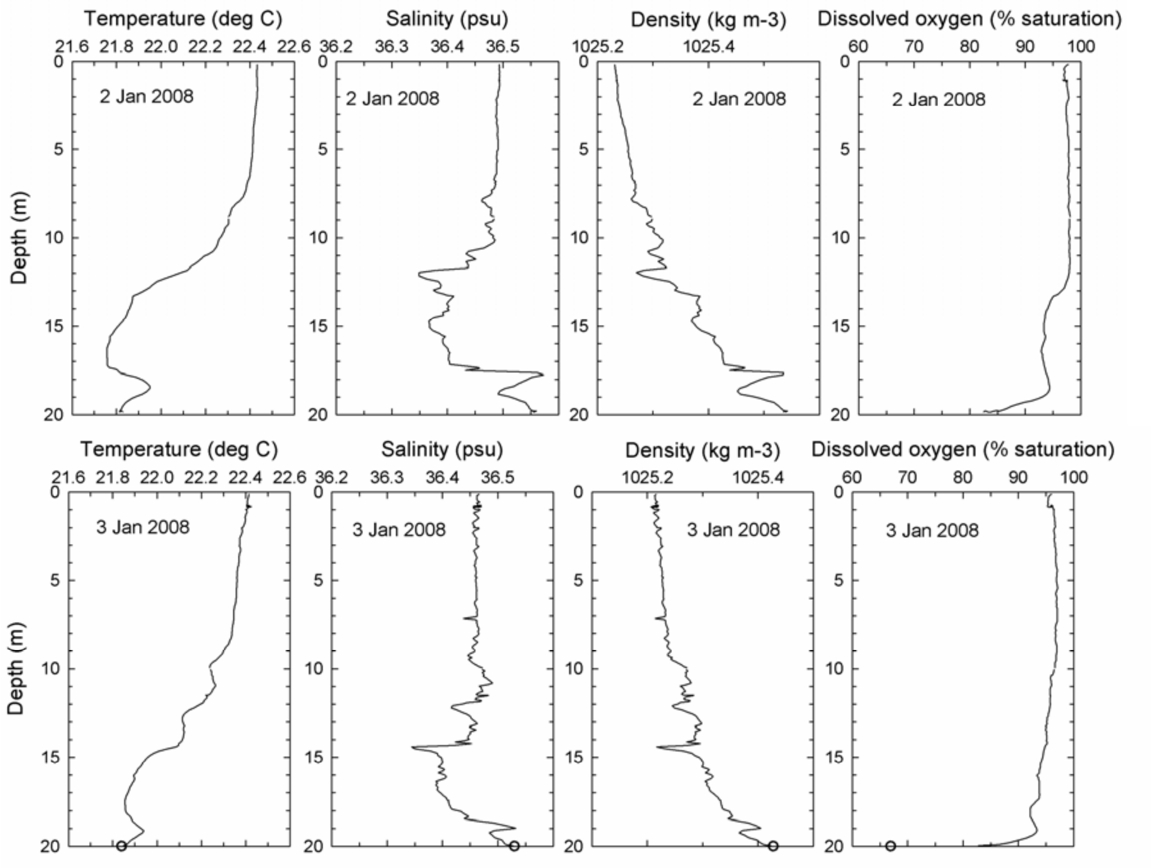


Figure 3: Profiles measured at the southern RTMS mooring for the Water Corporation by the Marine and Freshwater Research Laboratory, Murdoch University (MAFRL) on 2 and 3 January 2008, using a Seabird SBE19 CTD with an auxiliary SBE43 dissolved oxygen sensor attached. The CTD is fitted with a cage that is intended to keep the sensors 0.5 m above the bed, in accordance with the PSDP license requirements. (Steve Christie, personal communication). The above profiles reveal a complex stratification pattern with increasing salinity near the bed.

Extra values recorded with the CTD resting at maximum depth have been deleted. For most profiles there may be more than 100 such values that are virtually identical to the bottom values shown in the plots. However, in the profile of 3 January 2008, dissolved oxygen concentrations dropped from around 80% saturation to 67% percent saturation over time, and a typical data point is shown by the open circle on the graphs at just above 20 m.

The data were supplied by the Water Corporation upon request. See Appendix C for all profiles measured at the southern RTMS from 2 January – 8 February 2008.

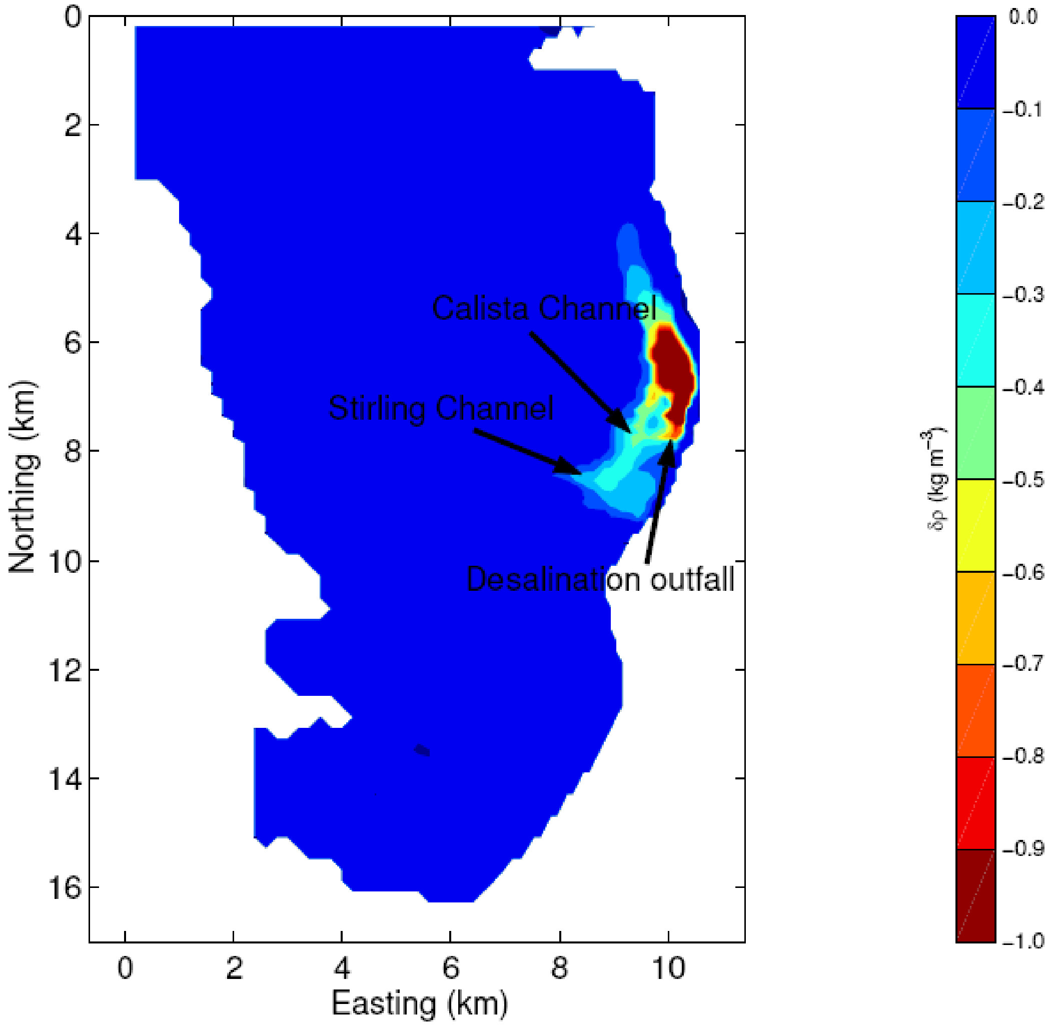


Figure 4: Annual average simulated top-to-bottom density difference due to the desalination plant effluent, showing the containment of the saline effluent to the shipping channels on the shallow eastern bank of Cockburn Sound, with the plume present both to the north and south of the diffuser. [CWR Appendix 4, Figure 6]

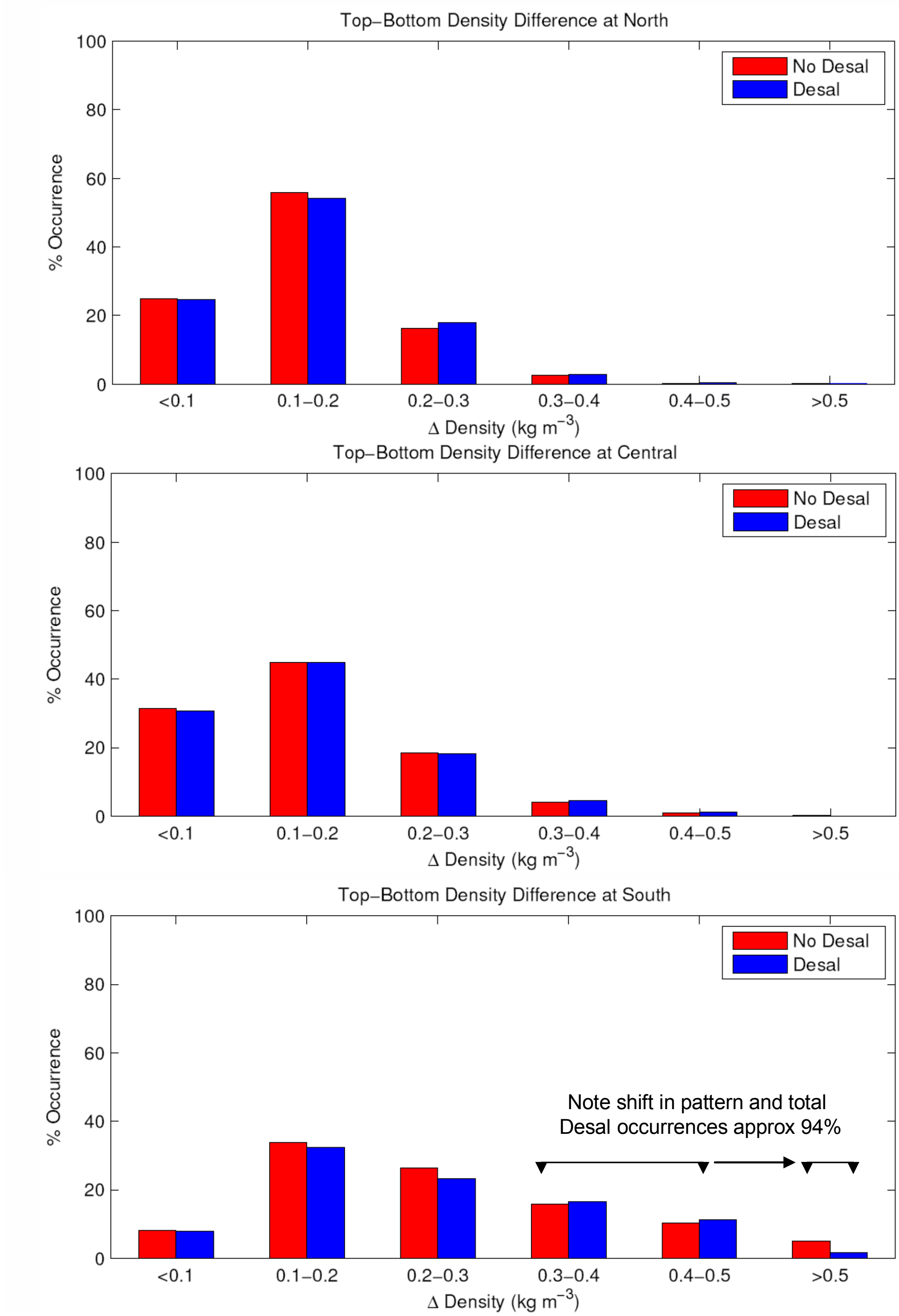


Figure 5: Percentage occurrence of top-bottom simulated density difference at the north (top panel), central (middle panel) and south (bottom panel) stations with and without the desalination plant. [CWR Appendix 4, Figure 8, 9, 10; note, brackets and arrow have been added to bottom panel, corresponding to discussion in text of this report.]

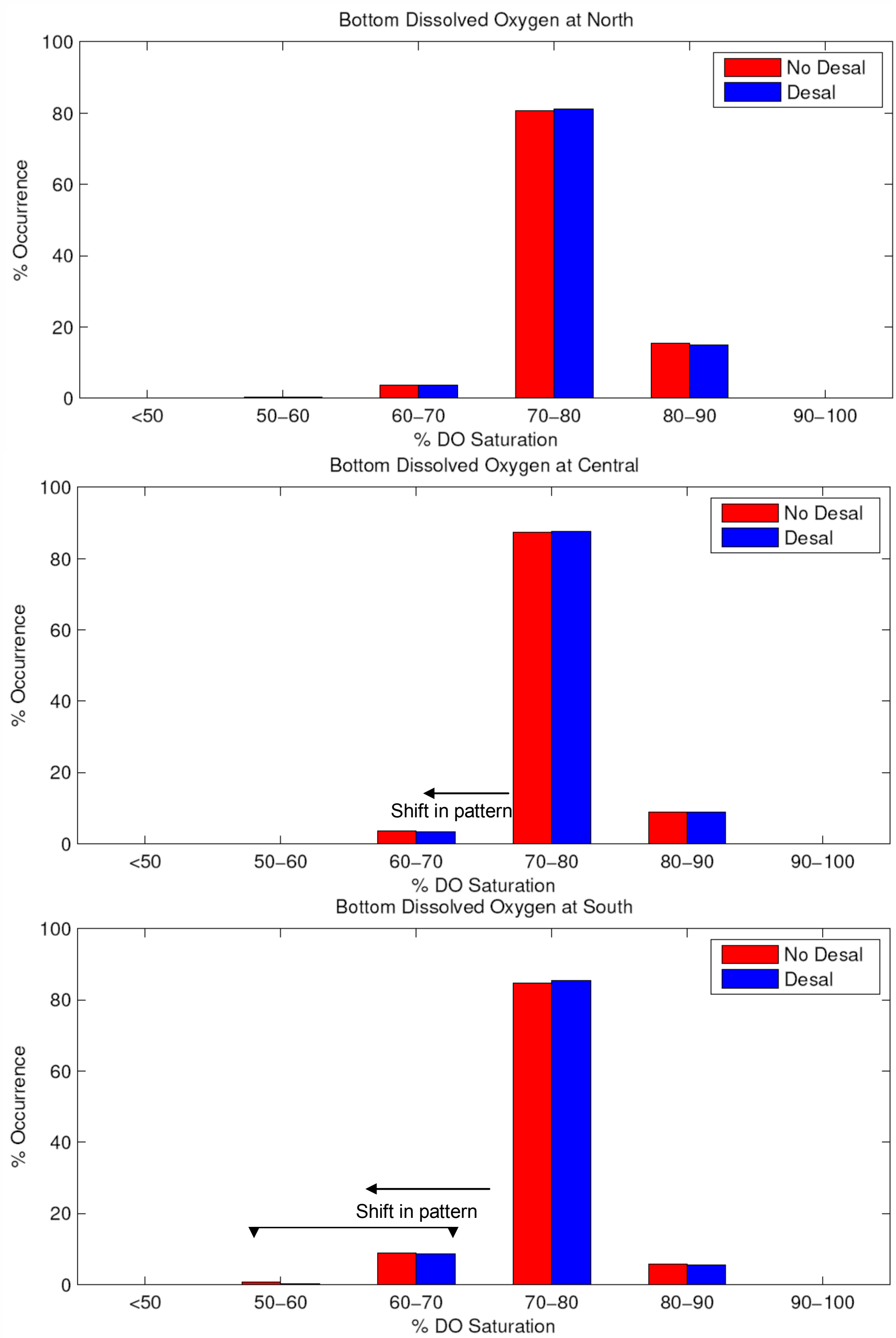


Figure 6: Percentage occurrence of simulated bottom dissolved oxygen saturation at the north (top panel), central (middle panel) and south (bottom panel) stations for the case with and without desalination. [CWR Appendix 4, Figure 12, 13, 14; notes, brackets and arrows have been added to middle and bottom panels, corresponding to discussion in text of this report.]

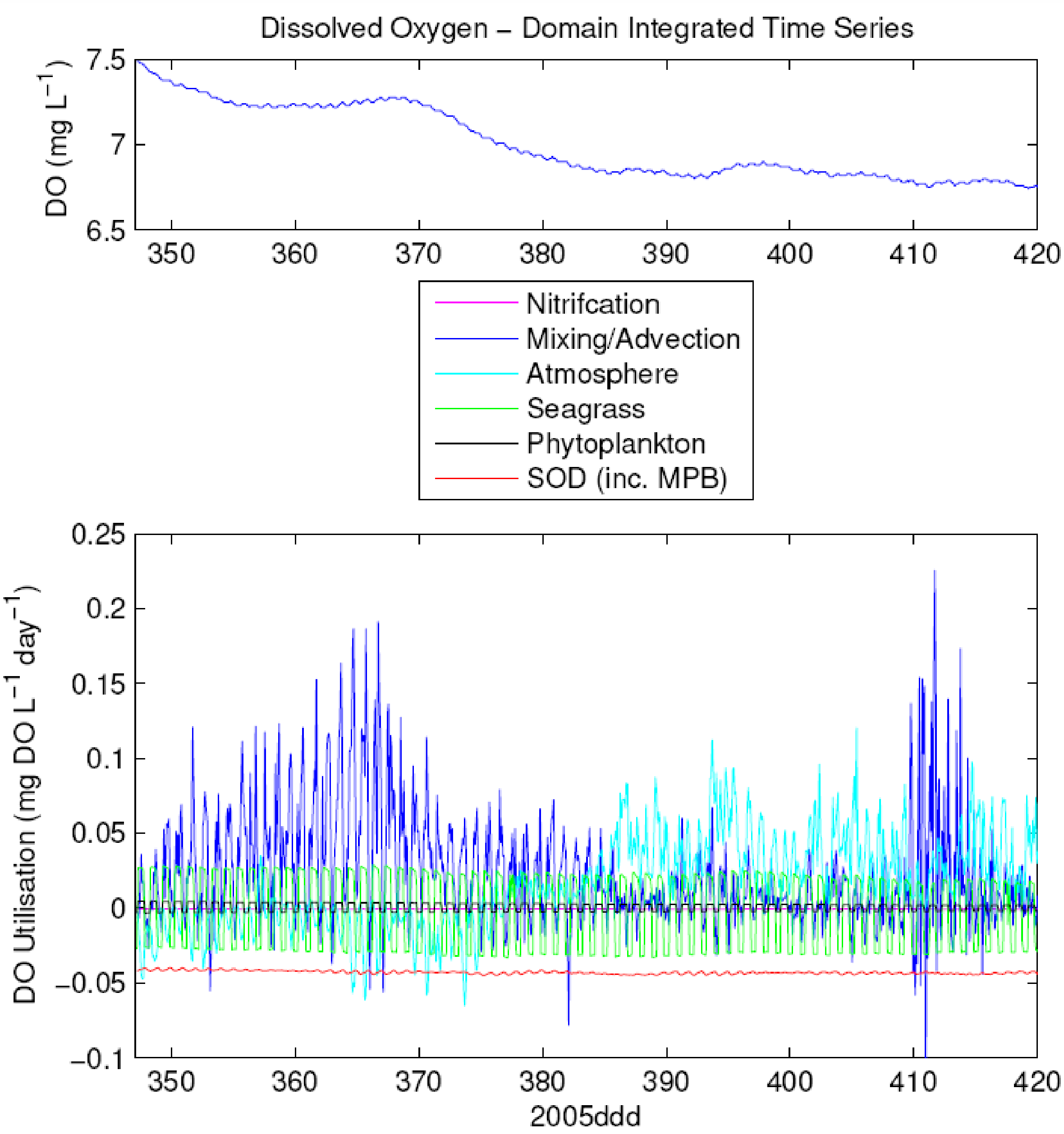


Figure 7: Components of the dissolved oxygen budget, as predicted by CAEDYM. Sediment oxygen demand (red line, bottom panel) clearly dominates all other chemical and biological oxygen utilization processes (i.e., by phytoplankton respiration, seagrass respiration and nitrification). [CWR Appendix 5, Figure 5.2]

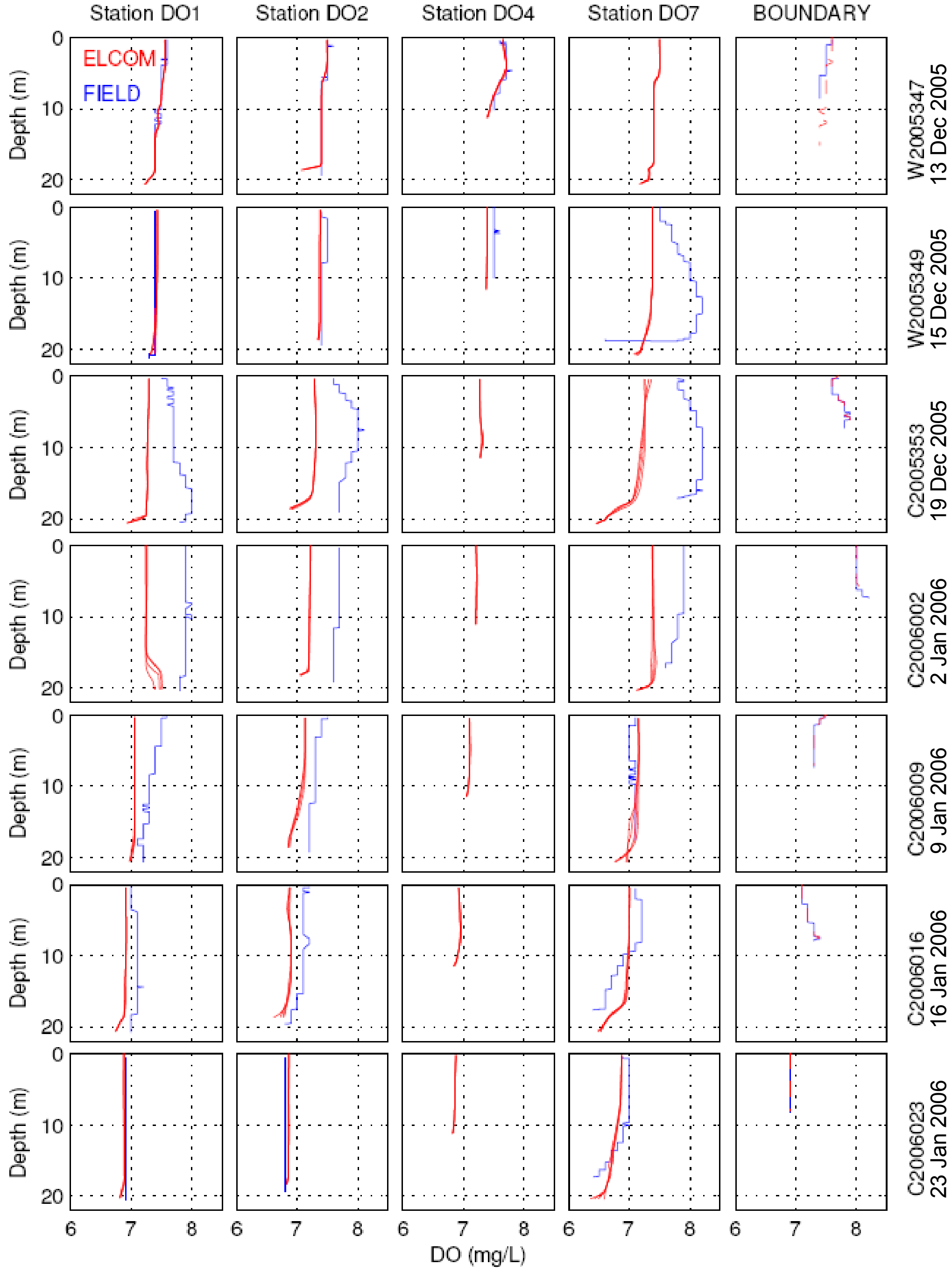


Figure 8: Comparison of measured (blue) and simulated (red) dissolved oxygen profiles for four locations (DO1, DO2, DO4, DO7) in the Sound DO1, DO2 and DO7 are near the RTMS sites in north, central and south Cockburn Sound, respectively; DO4 is near the PSDP diffuser on the eastern shelf of Cockburn Sound. The day of collection is shown on the right (as yyyyddd [dates have been added]), with each row representing a sampling day and each column representing a sampling location. The letter before the sampling date indicates if the profiles were part of the Water Corporation monitoring program (W, profiles at DO stations) or part of the KIC/CSMC [Kwinana Industries Council/Cockburn Sound Management Council]monitoring (C, CS stations). [CWR Appendix 5, Figure 5.4]

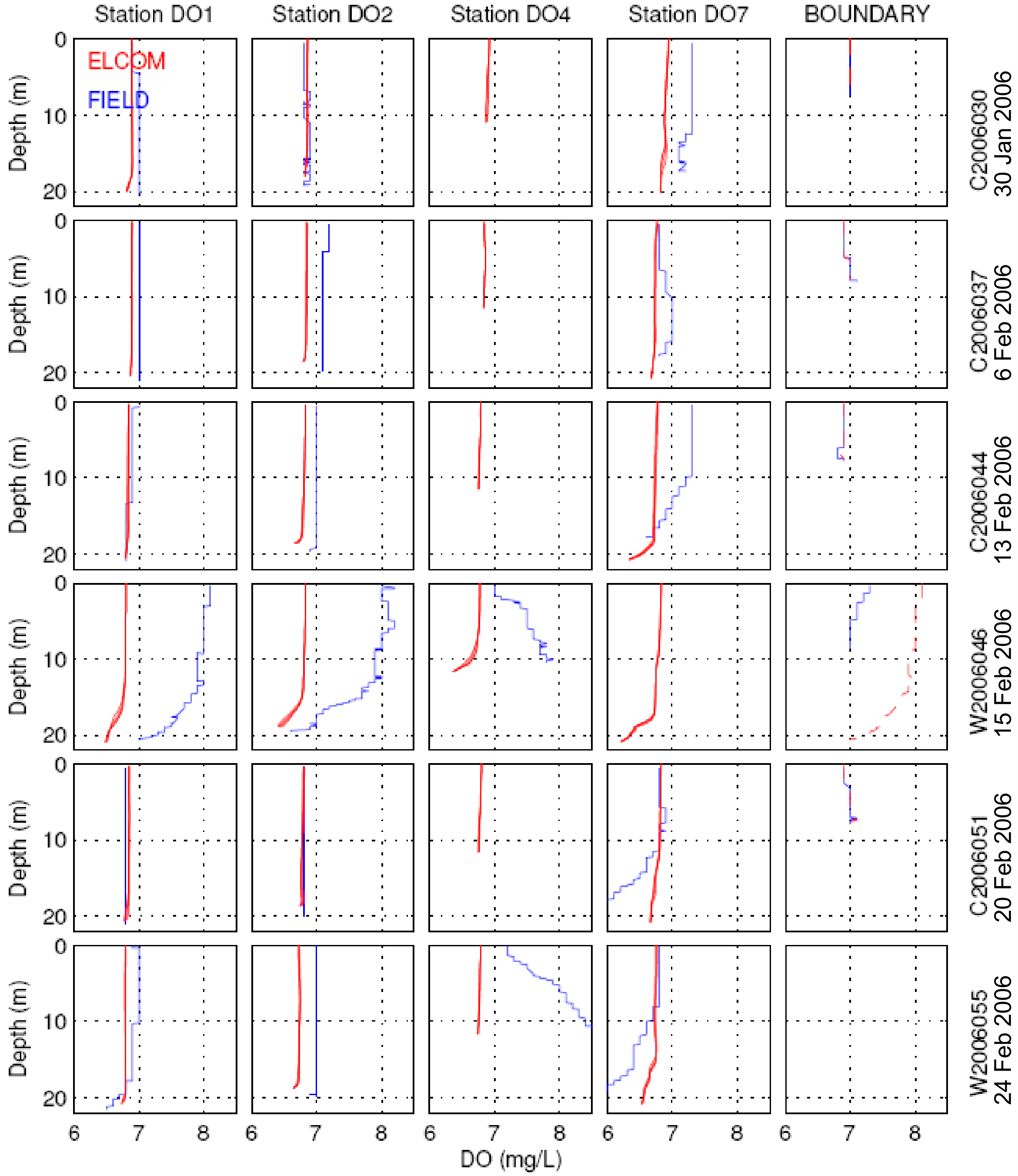


Figure 8, continued. [CWR Appendix 5, Figure 5.5]

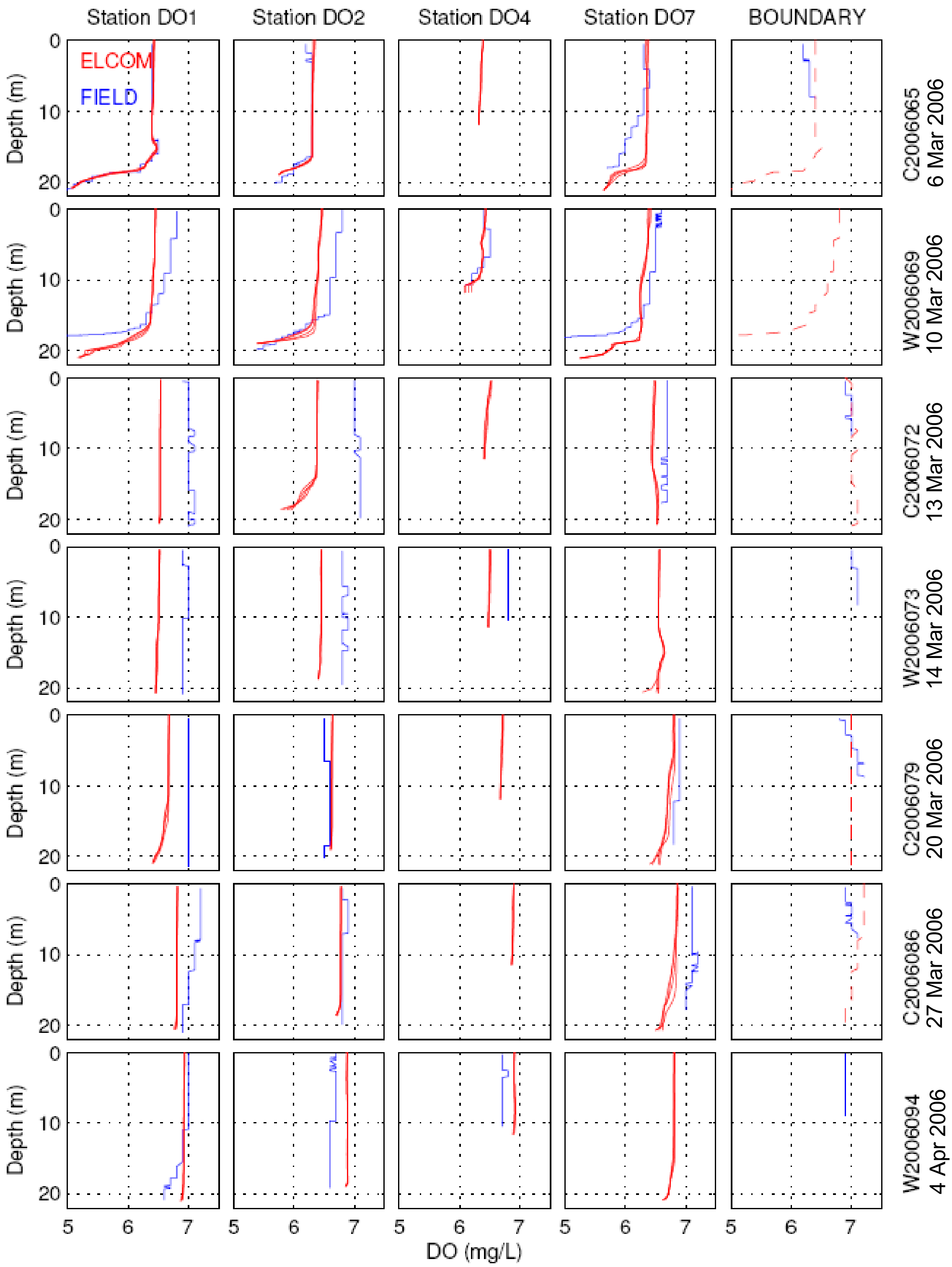


Figure 8, continued. [CWR Appendix 5, Figure 5.8]

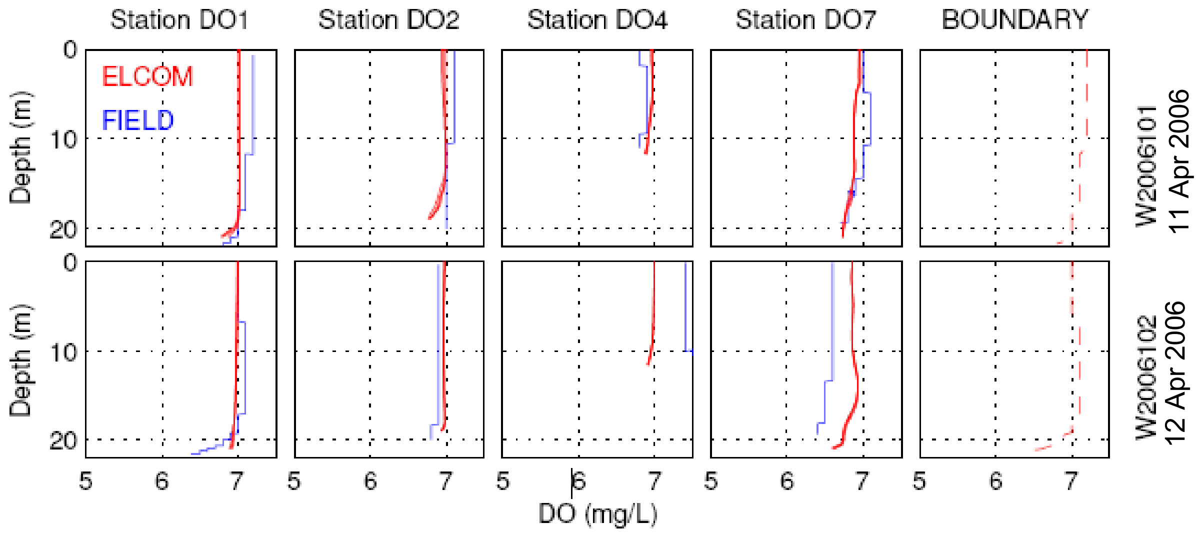


Figure 8, continued. [CWR Appendix 5, Figure 5.9]

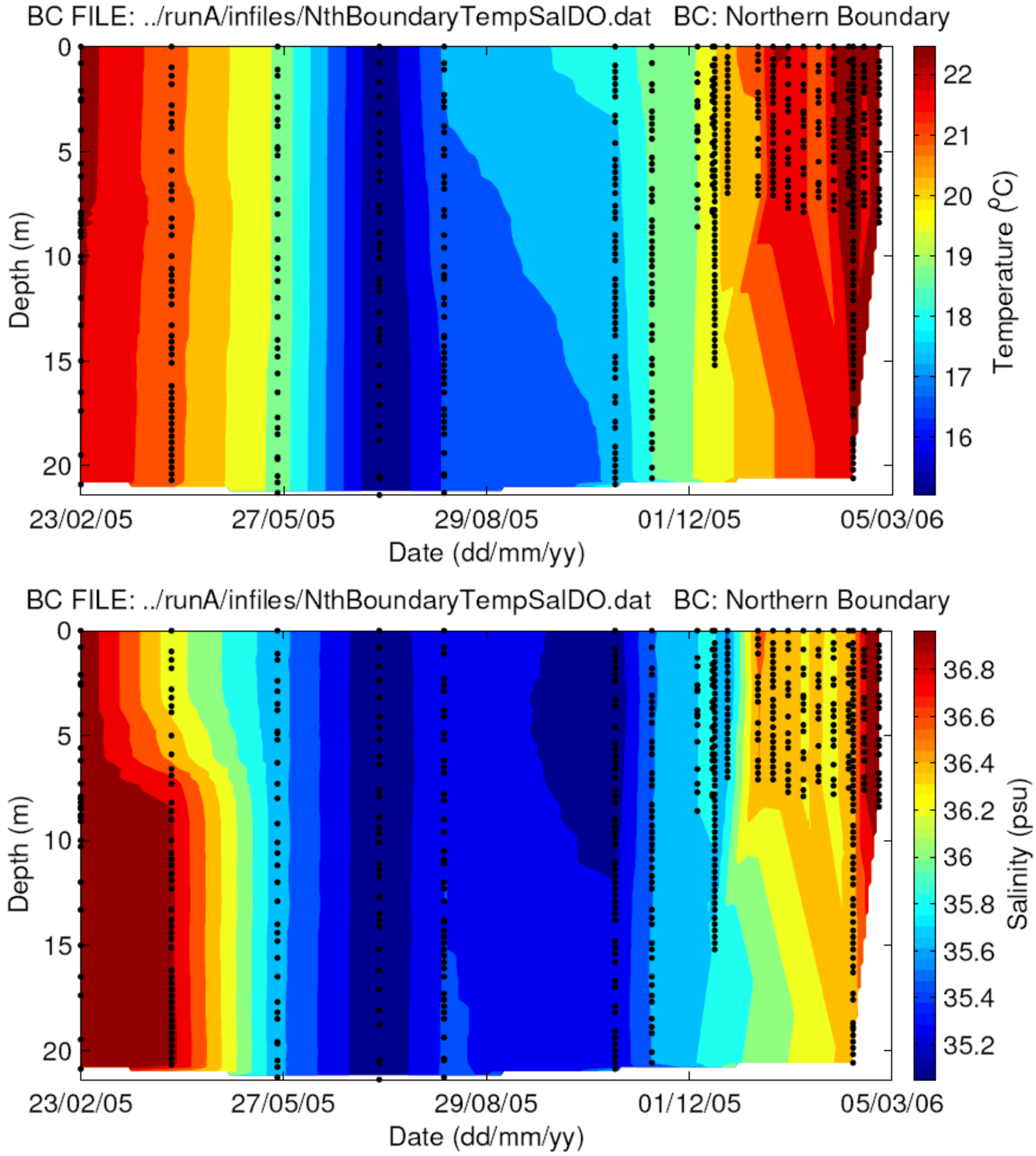


Figure 9: Boundary conditions at open northern boundary for ELCOM seasonal time scale simulations – temperature (top panel) and salinity (bottom panel). [CWR Appendix 6, Figure 3.5 (top panel) and Figure 3.6 (bottom panel).]

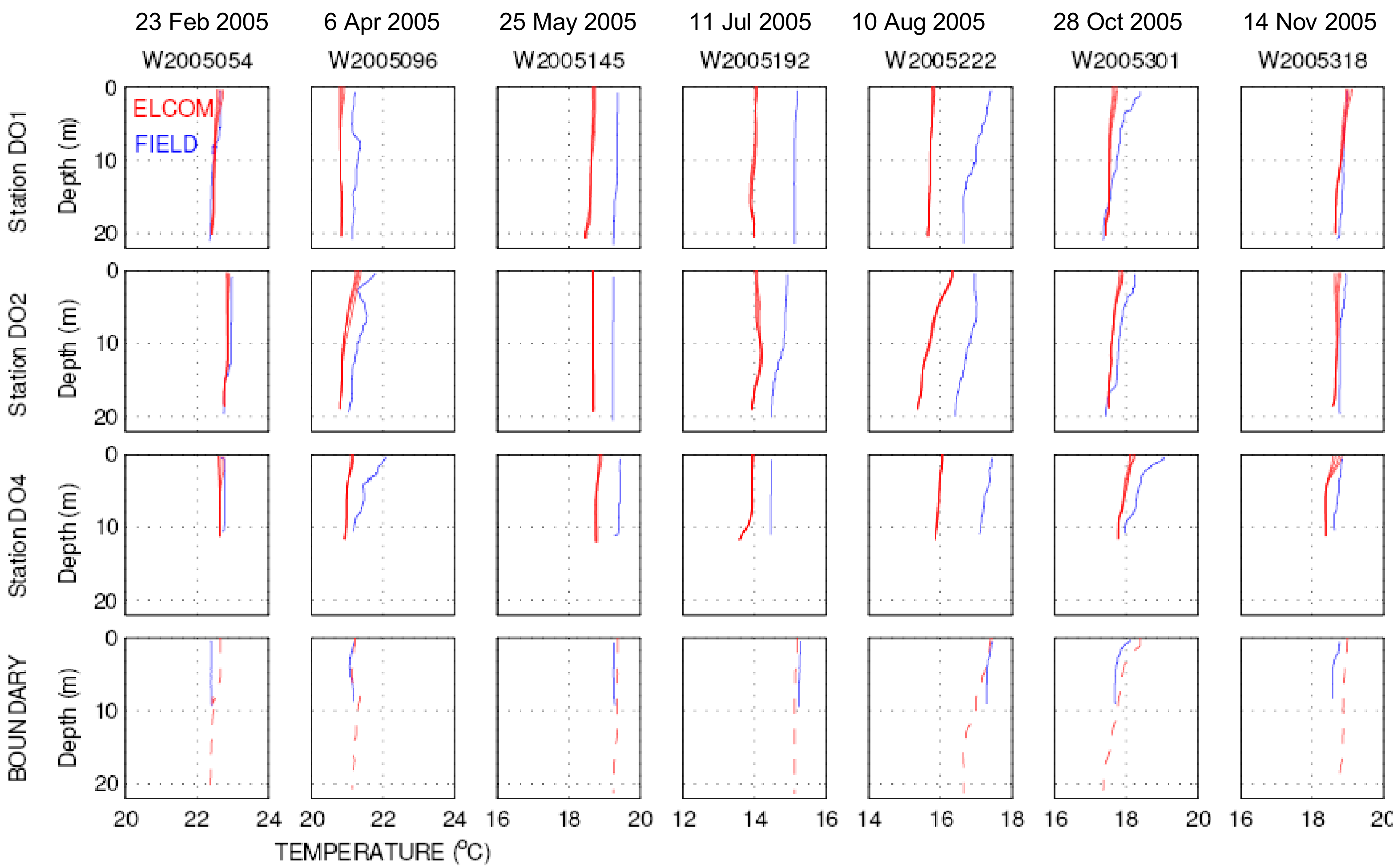


Figure 10: Comparison of measured (blue) and simulated (red) temperature profiles; see caption to Figure 8 for site descriptions. [CWR Appendix 6, Figure 5.1]

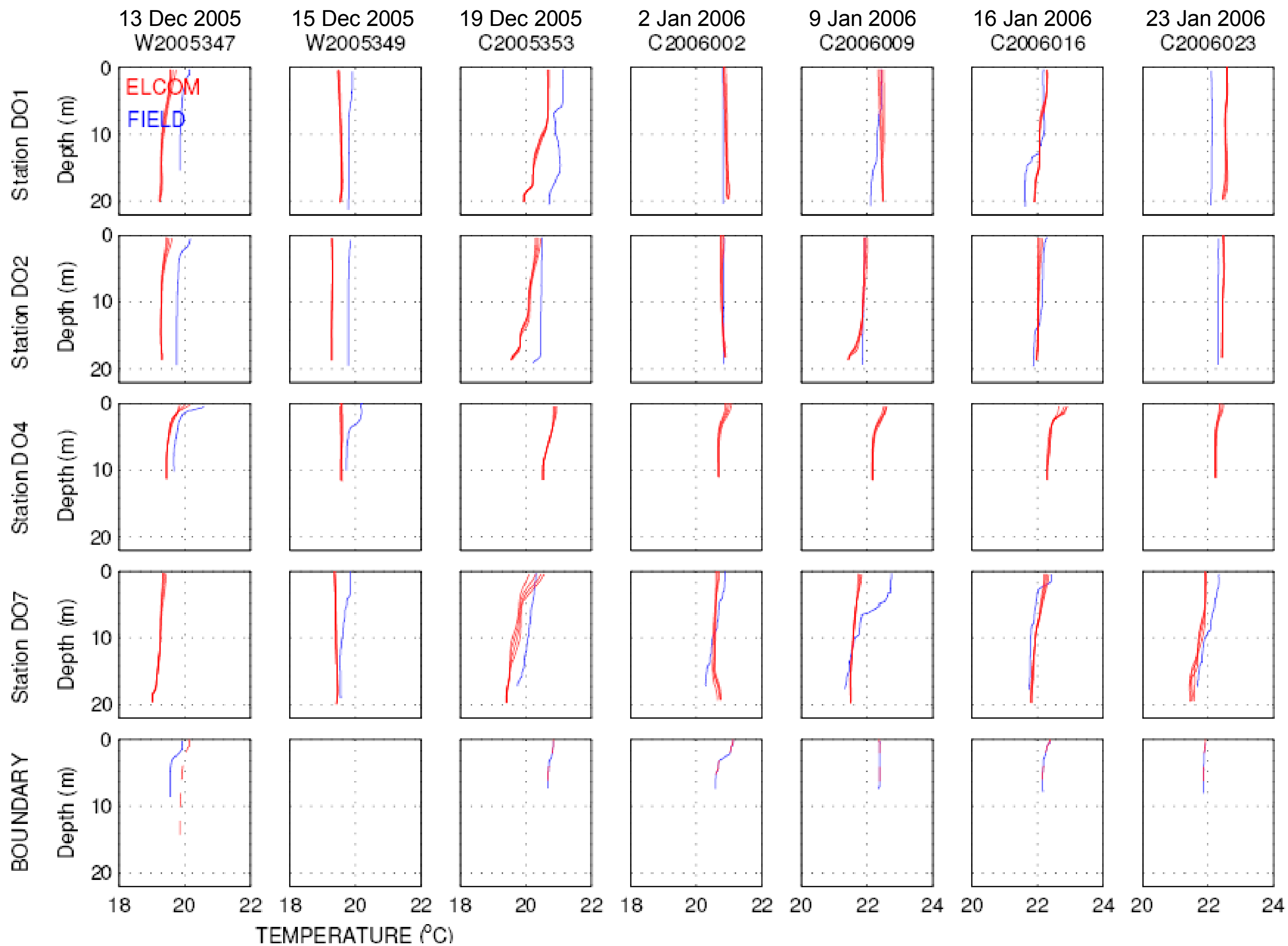


Figure 10, continued. [CWR Appendix 6, Figure 5.2]

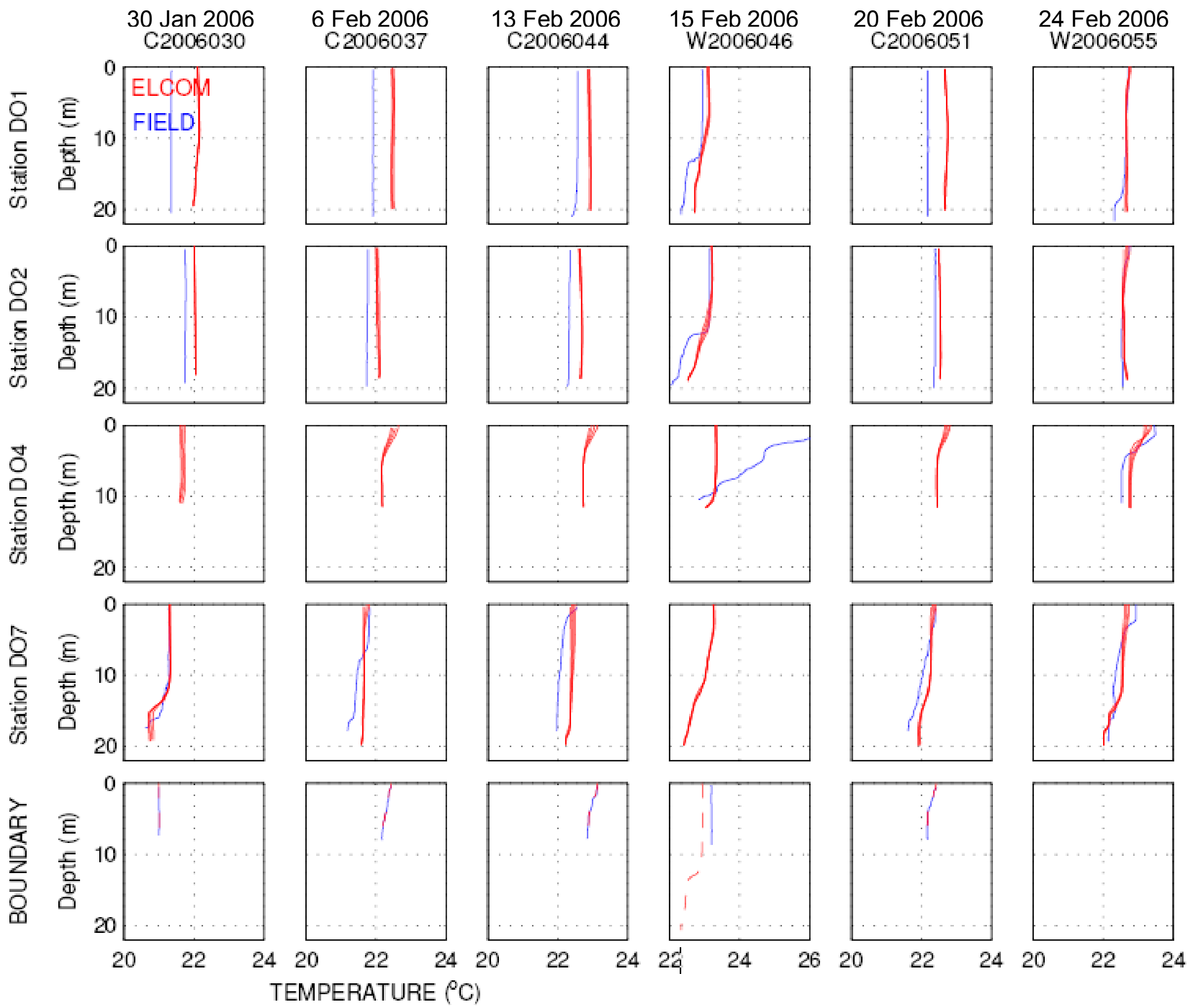


Figure 10, continued. [CWR Appendix 6, Figure 5.3]

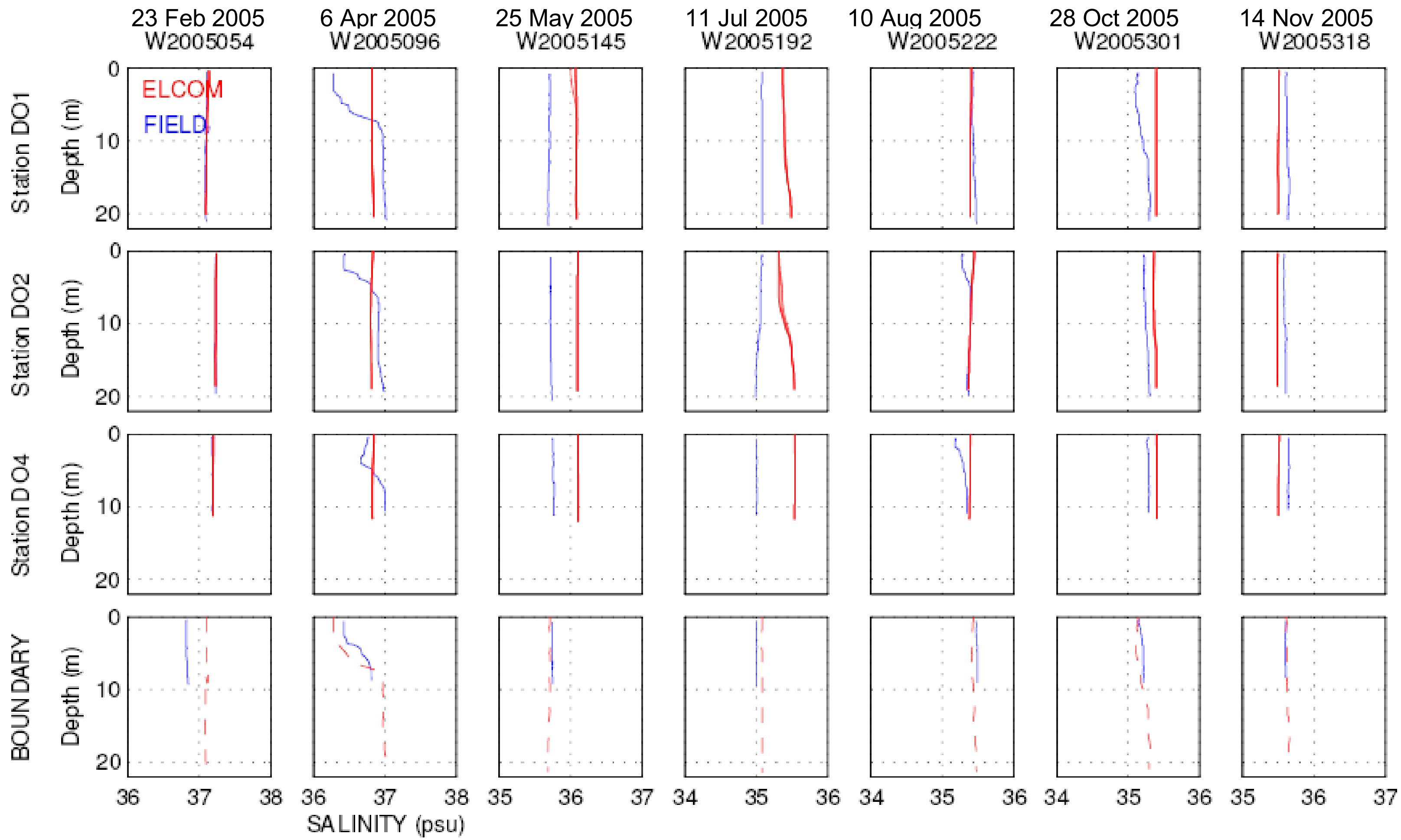


Figure 11: Comparison of measured (blue) and simulated (red) salinity profiles; see caption to Figure 8 for site descriptions. [CWR Appendix 6, Figure 5.8]

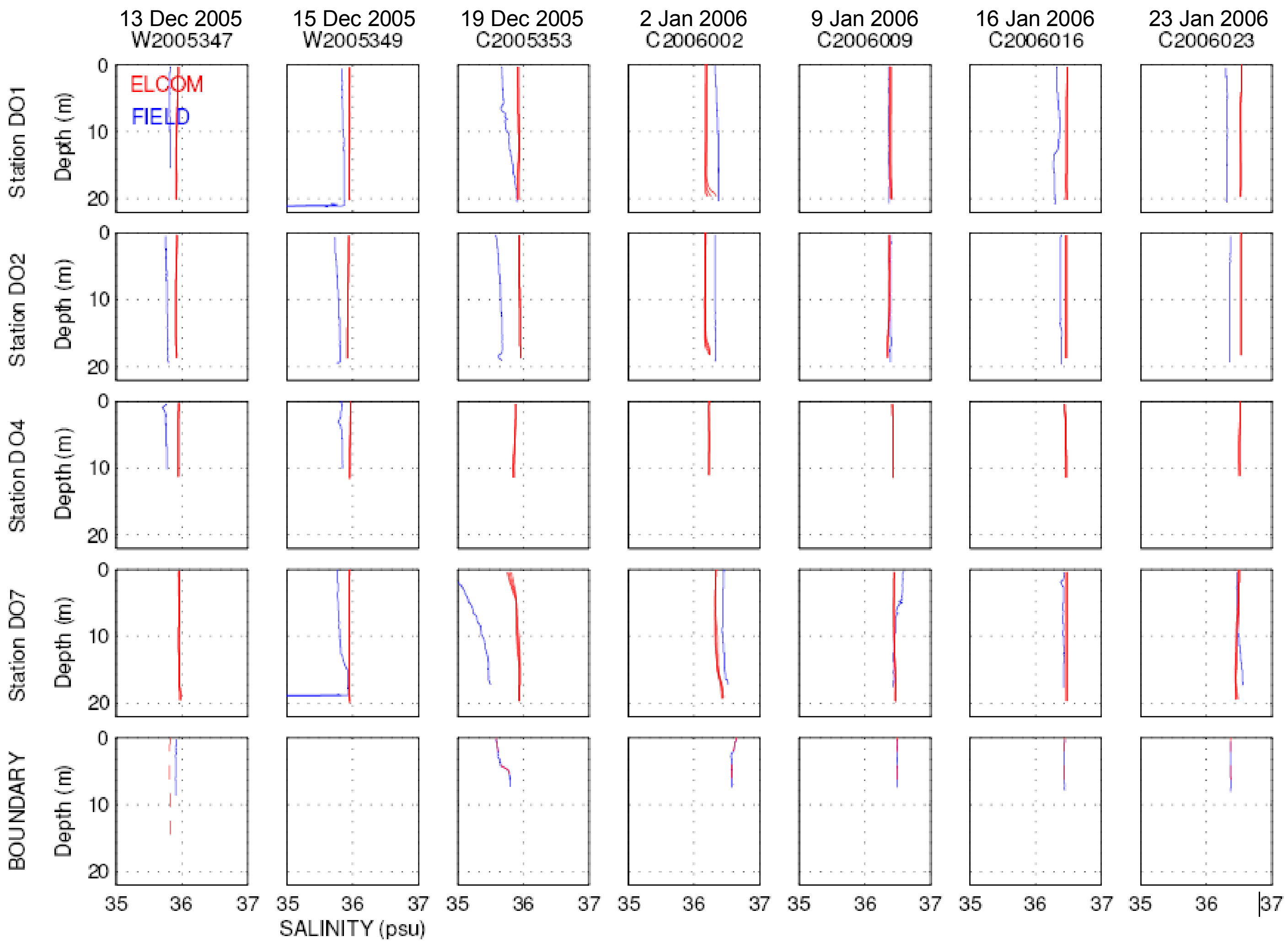


Figure 11, continued. [CWR Appendix 6, Figure 5.9]

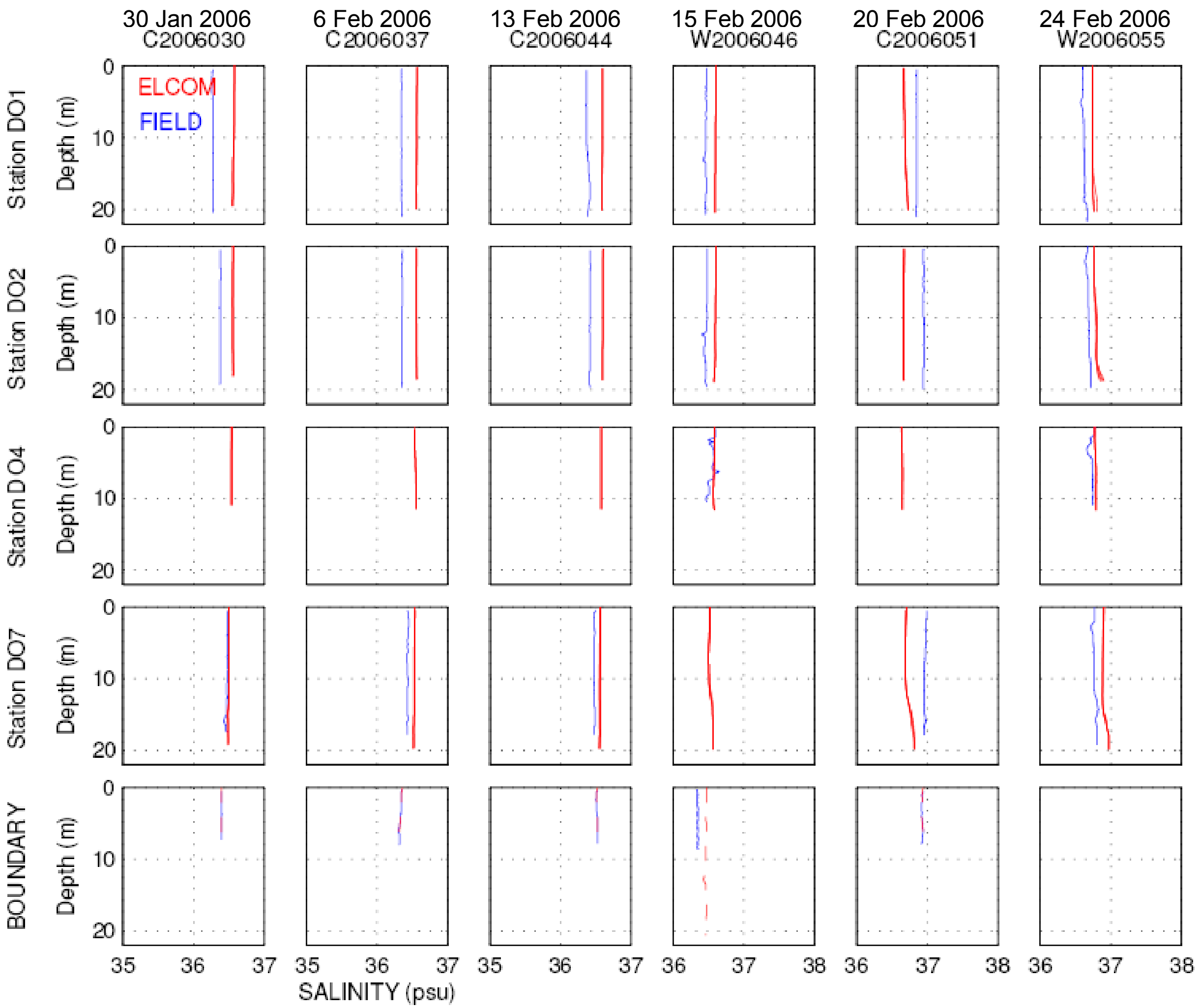


Figure 11, continued. [CWR Appendix 6, Figure 5.11]

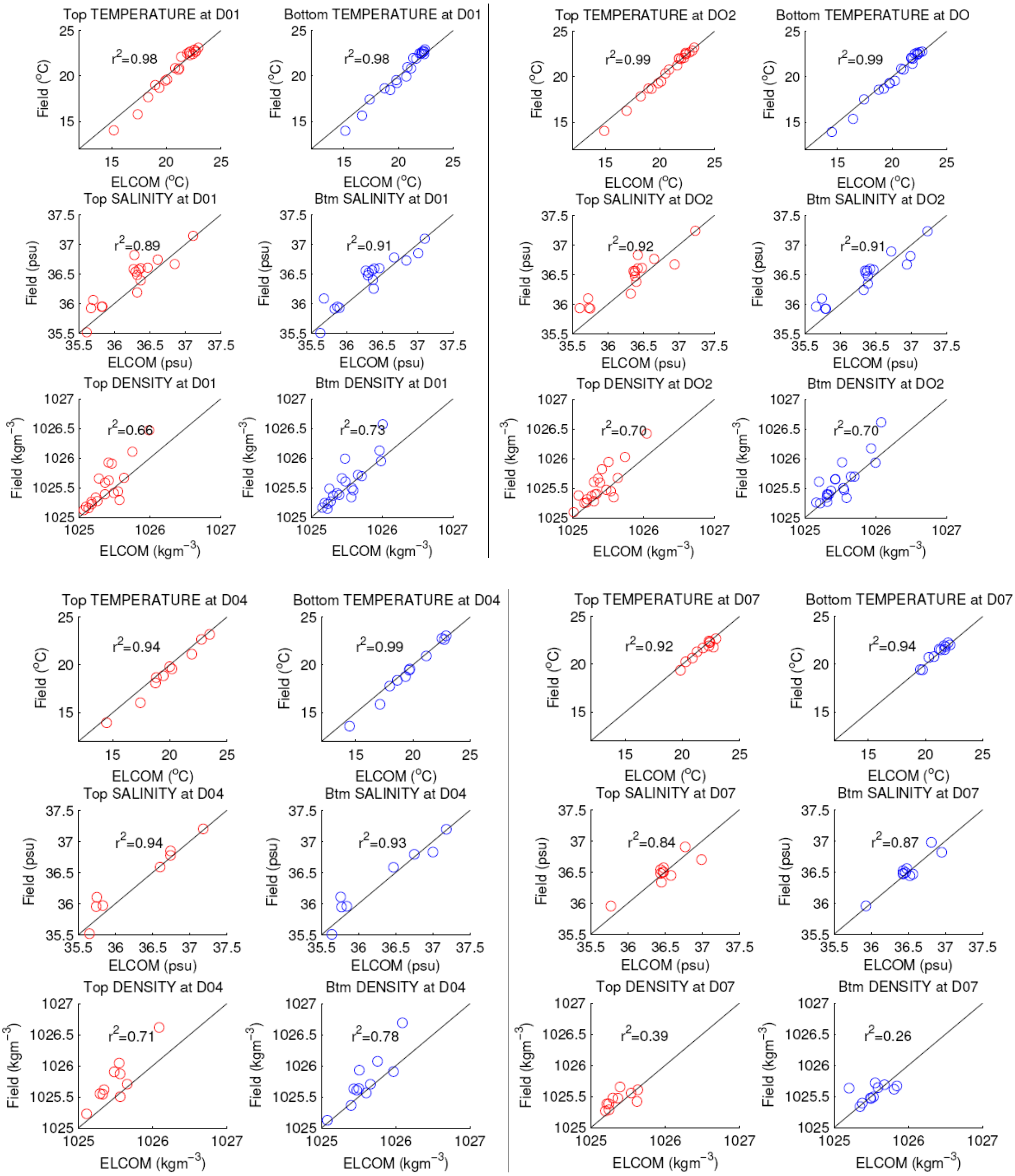


Figure 12: Scatter plots showing correlation between measured vs. modeled temperatures, salinities and densities at sites DO1, DO2, DO4 and DO7 in Cockburn Sound. DO1, DO2, and DO7 are near the RTMS sites in north, central and south Cockburn Sound, respectively; DO4 is near the PSDP diffuser on the eastern shelf of Cockburn Sound. [CWR Appendix 6, Figure 5.19, 5.20, 5.21 and 5.22]

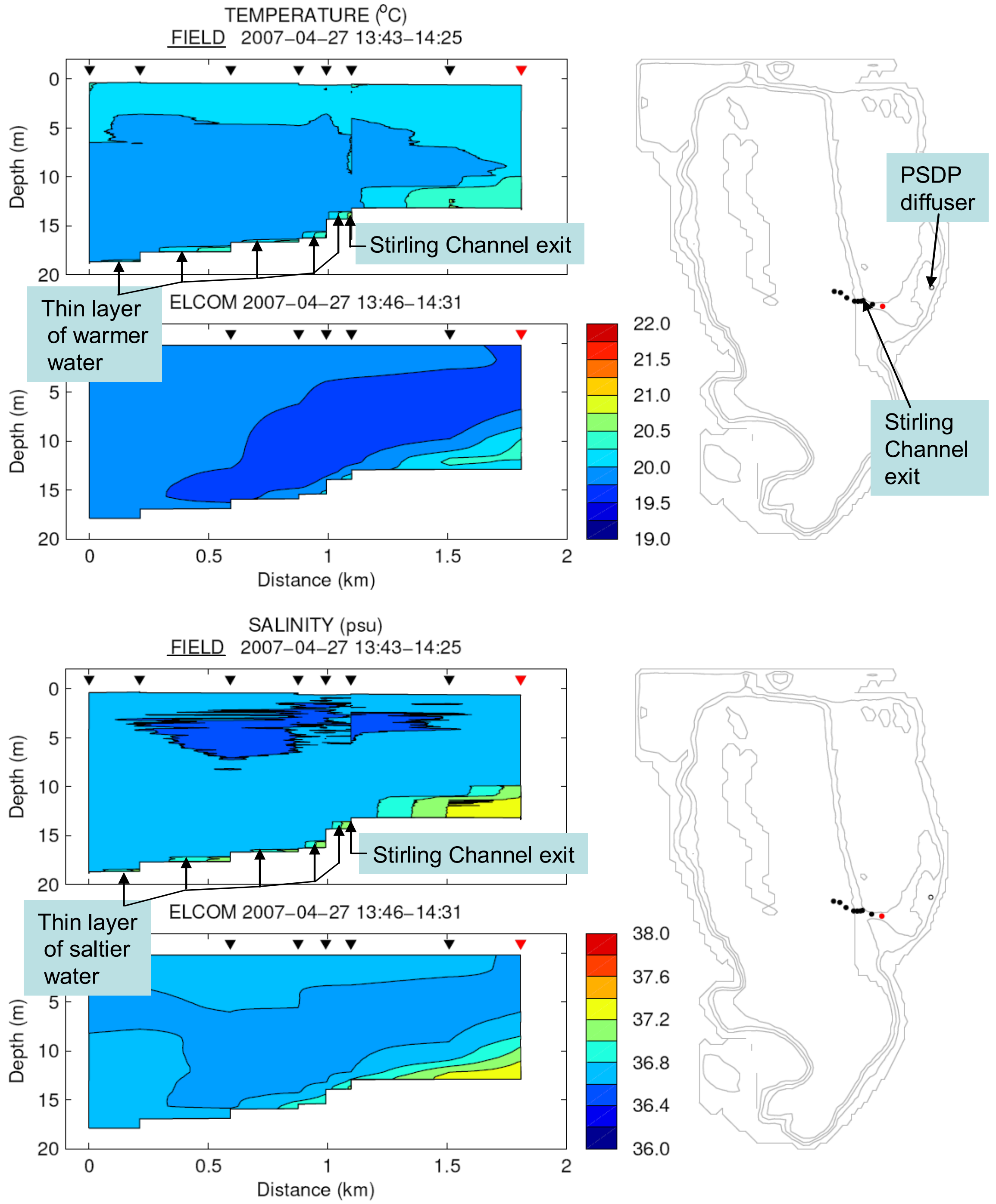


Figure 13: Temperature (top panels) and salinity (bottom panels) transects that extend into the main basin of Cockburn Sound, measured during the April 2007 field campaign in the early afternoon of 27 April 2007, that appear to show evidence of the desalination plume at a distance of approximately 1 km from the exit of Stirling Channel. [CWR Appendix 7, Figure 3.19 and 3.31; notes and arrows have been added].

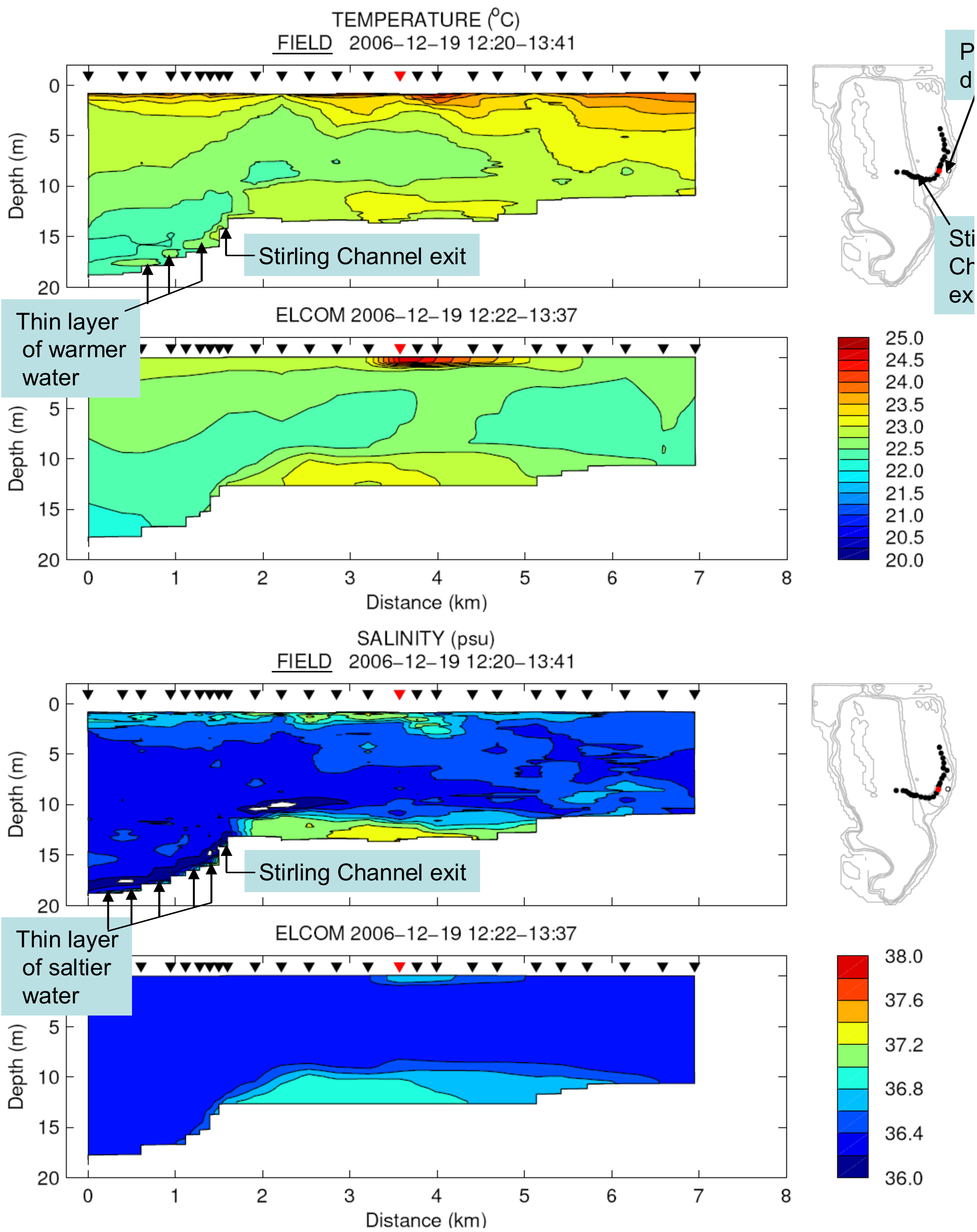


Figure 14: Temperature (top panels) and salinity (bottom panels) transects that extend into the main basin of Cockburn Sound, measured during the December 2006 field campaign in the early afternoon of 19 December 2006, that appear to show evidence of the desalination plume at a distance of approximately 1 km from the exit of Stirling Channel. [CWR Appendix 7, Figure 4.19 and 4.28; notes and arrows have been added].

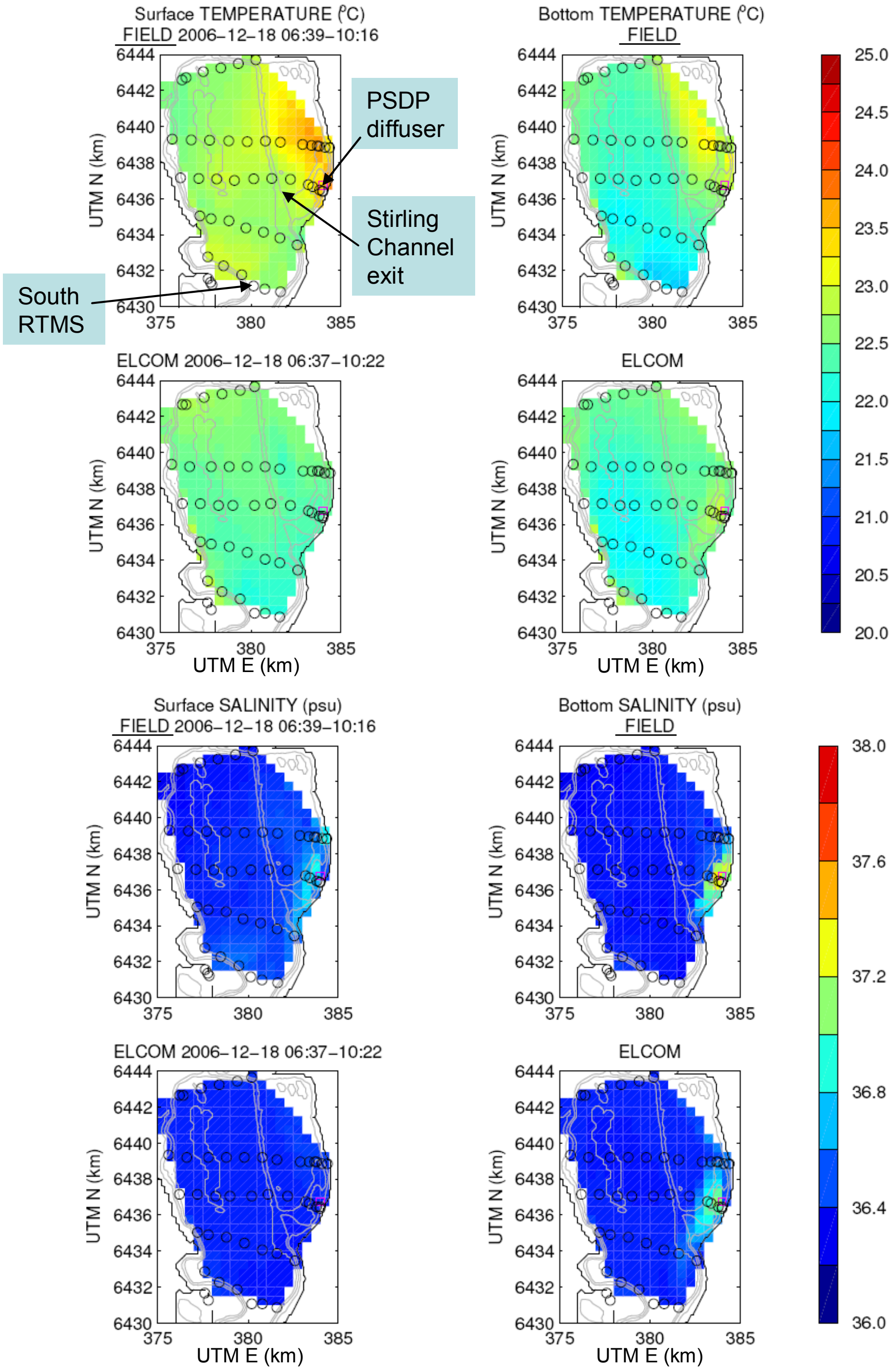


Figure 15: Maps of surface and bottom temperature (top panels) and salinity (bottom panels) in Cockburn Sound, measured during the December 2006 field campaign on the morning of 18 December 2006, that show no evidence of the desalination plume spreading into the main basin from the exit of Stirling Channel. Stratification appears to be dominated by temperature, with warmer surface temperatures and cooler bottom temperatures, while there is little difference between surface and bottom salinities. [CWR Appendix 7, parts of Figure 4.13 and 4.23; notes and arrows have been added].

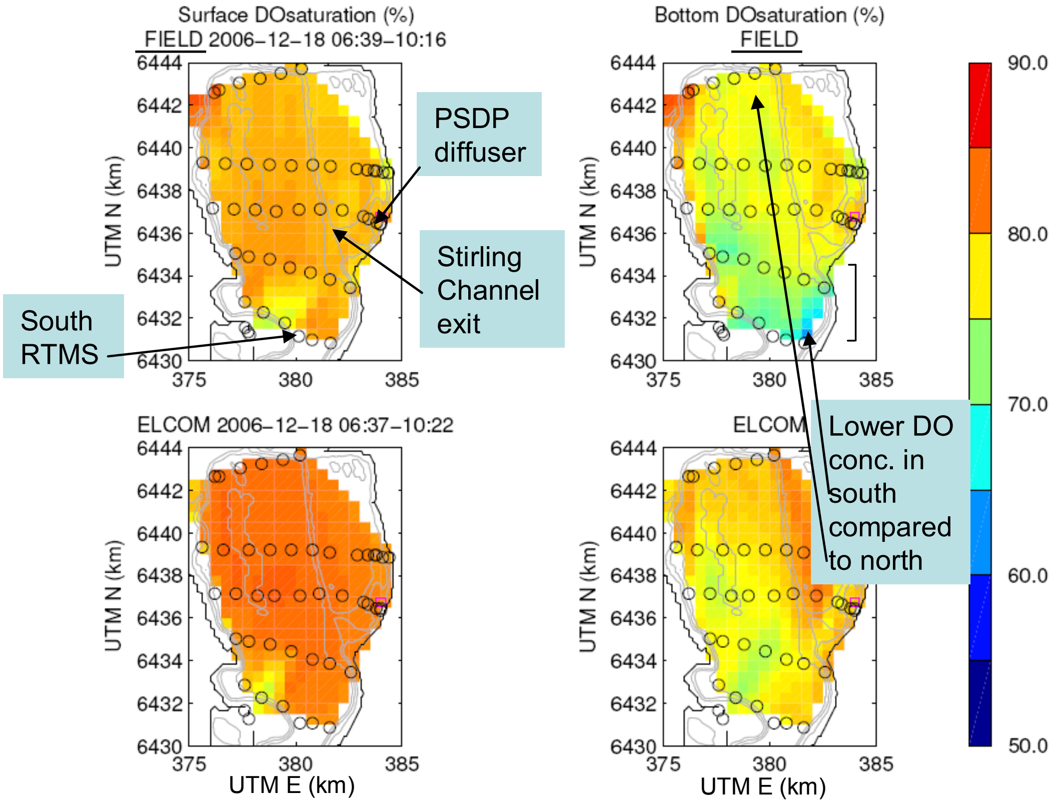


Figure 16: Maps of surface and bottom dissolved oxygen in Cockburn Sound, measured during the December 2006 field campaign on the morning of 18 December 2006, that illustrate the south – north gradient in oxygen depletion in bottom waters, with higher depletion in the south. [CWR Appendix 7, part of Figure 4.39; notes and arrows have been added].

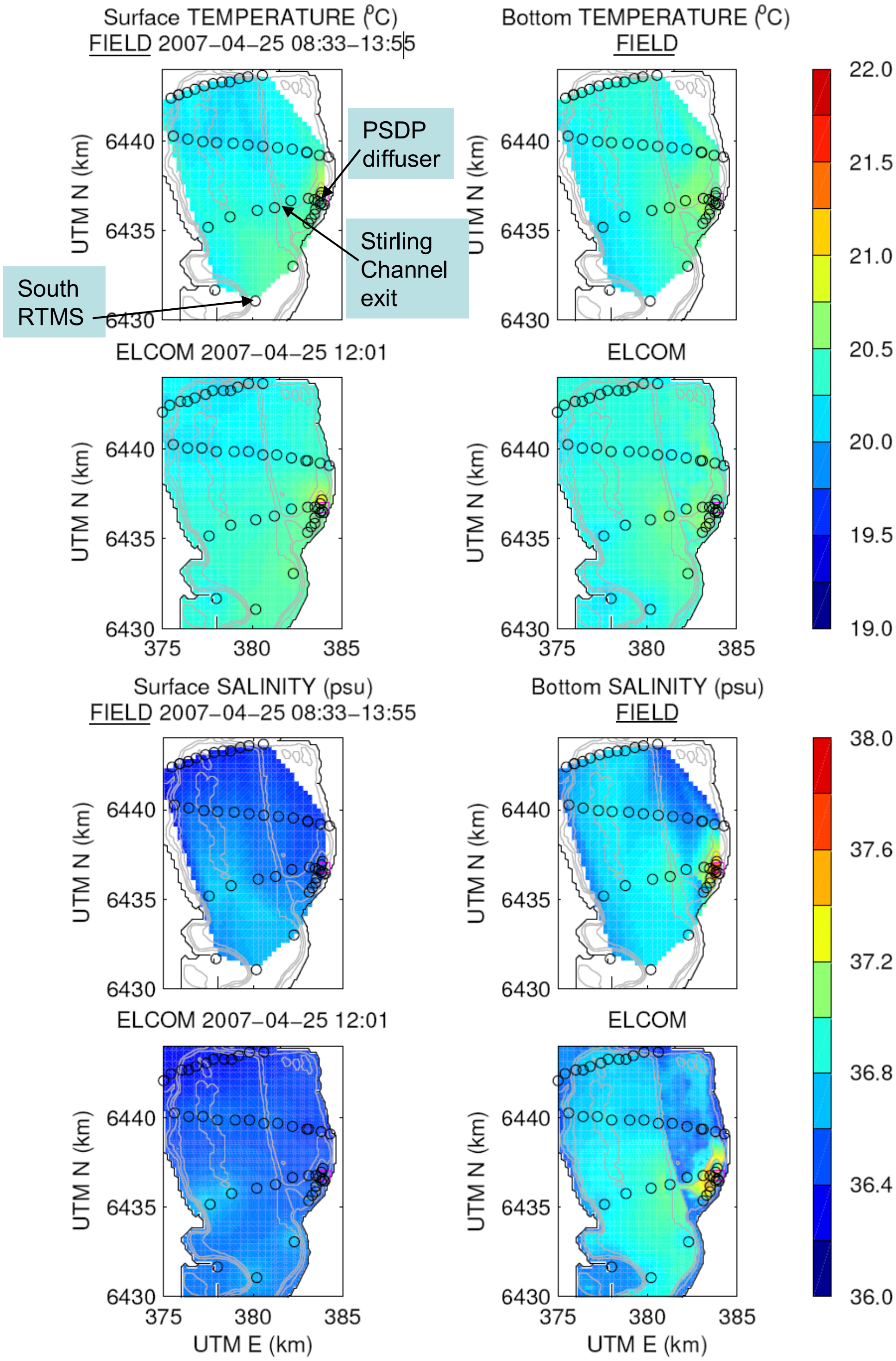


Figure 17: Maps of surface and bottom temperature (top panels) and salinity (bottom panels) in Cockburn Sound, measured during the April 2007 field campaign on the morning of 25 April 2007, that appear to show evidence of the desalination plume spreading into the main basin from the exit of Stirling Channel. [CWR Appendix 7, Figure 3.5 and 3.6; notes and arrows have been added].

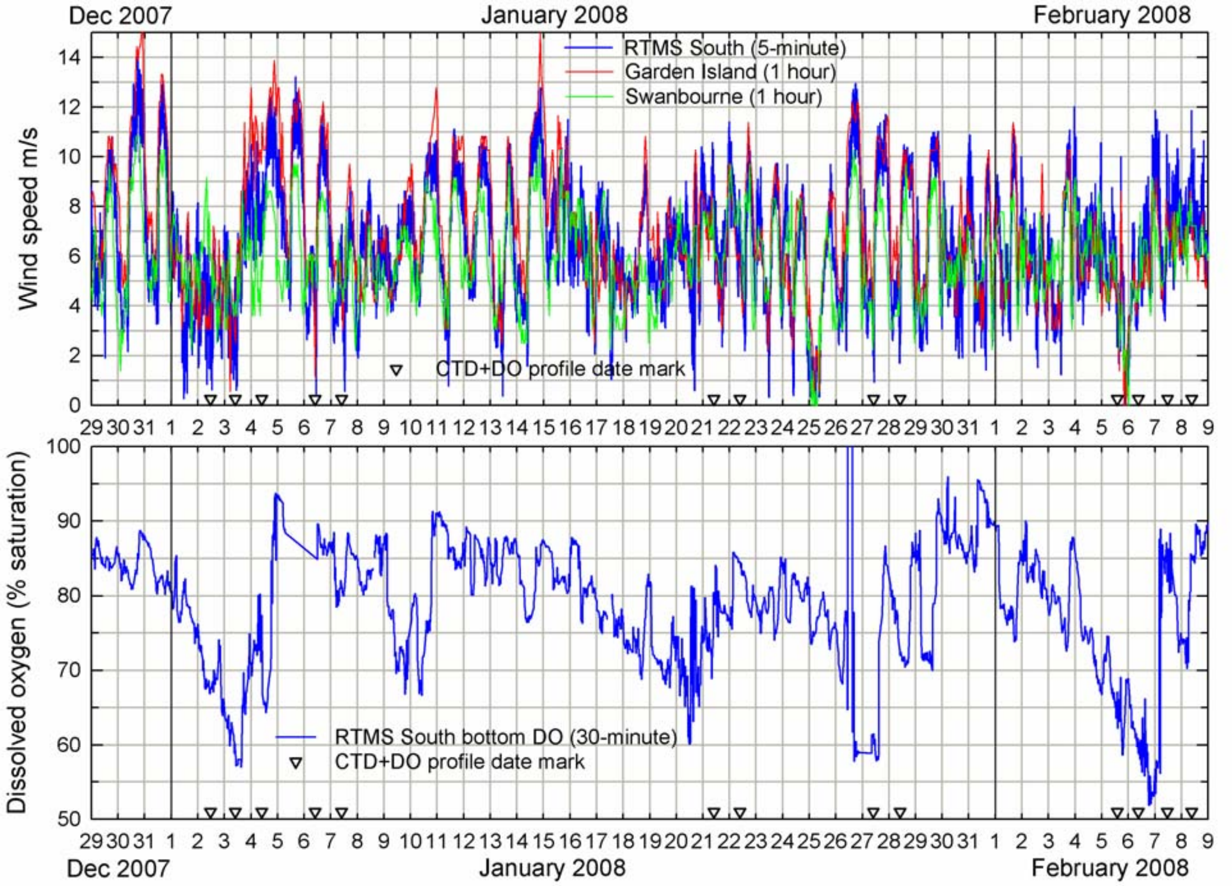


Figure 18: Time series of wind speeds (5-minute samples from south RTMS mooring; hourly values, as means over the 10 minutes preceding the end of the hour, from Garden Island and Swanbourne) and dissolved oxygen concentrations 0.5 m above the bottom (30-minute samples). RTMS data were supplied by the Water Corporation upon request; Swanbourne and Garden Island data are from BOM.

Appendix A: Recommendations and conclusions from Water Corporation's S46 report to the Minister for Environment (Water Corporation 2008, Section 3.6, p. 17):

3.6 Recommendation

Monitoring, studies and modelling have clearly demonstrated that the discharge of seawater concentrate does not affect dissolved oxygen levels in the deep basin of Cockburn Sound. Further, the waters of Cockburn Sound are generally well oxygenated with dissolved oxygen criteria and triggers being met virtually all of the time with or without seawater concentrate being discharged from the PSDP.

Accordingly, it is recommended that:

- No further investigations into stratification and/or dissolved oxygen levels be conducted;

- Dissolved oxygen criteria do not need to be applied to the PSDP discharge to protect the deep basin of Cockburn Sound;

- The dissolved oxygen monitoring being conducted under the Water Quality Monitoring Plan (WQMP) cease as of April 2008;

- Any further monitoring of dissolved oxygen should be undertaken as part of the regular Cockburn Sound Management Council's monitoring programme. This will ensure an integrated monitoring programme that is focussed on the requirements of the Council; and

- The Water Corporation make a one-off donation of $10,000 to the Cockburn Sound Management Council's monitoring programme.

Appendix B: Modelling calibration dates.

	Sampling authority	Sites sampled	Year	Day no. year	Day no. 2005	Date
Hydrodynamic modelling (ELCOM)						
1	W	DO1, DO2, DO4	2005	54	54	23-Feb05
2	W	DO1, DO2, DO4	2005	96	6	06-Apr-05
3	W	DO1, DO2, DO4	2005	145	145	25-May-05
4	W	DO1, DO2, DO4	2005	192	192	11-Jul-05
5	W	DO1, DO2, DO4	2005	222	222	10-Aug-05
6	W	DO1, DO2, DO4	2005	301	301	28-Oct-05
7	W	DO1, DO2, DO4	2005	318	318	14-Nov-05
8	W	DO1, DO2, DO4, DO7	2005	347	347	13-Dec-05
9	W	DO1, DO2, DO4, DO7	2005	349	349	15-Dec-05
10	C	DO1, DO2, DO4, DO7	2005	353	353	19-Dec-05
11	C	DO1, DO2, DO4, DO7	2006	2	367	02-Jan-06
12	C	DO1, DO2, DO4, DO7	2006	9	374	09-Jan-06
13	C	DO1, DO2, DO4, DO7	2006	23	388	23-Jan-06
14	C	DO1, DO2, DO4, DO7	2006	30	395	40-Jan-06
15	C	DO1, DO2, DO4, DO7	2006	37	402	06-Feb-06
16	C	DO1, DO2, DO4, DO7	2006	44	409	13-Feb-06
17	W	DO1, DO2, DO4, DO7	2006	46	411	15-Feb-06
18	C	DO1, DO2, DO4, DO7	2006	51	416	20-Feb-06
19	W	DO1, DO2, DO4, DO7	2006	55	420	24-Feb-06
Oxygen modelling (ELCOM-CAEDYM)						
1	W	DO1, DO2, DO4, DO7	2005	347	347	13-Dec-05
2	W	DO1, DO2, DO4, DO7	2005	349	349	15-Dec-05
3	C	DO1, DO2, DO4, DO7	2005	353	353	19-Dec-05
4	C	DO1, DO2, DO4, DO7	2006	2	367	02-Jan-06
5	C	DO1, DO2, DO4, DO7	2006	9	374	09-Jan-06
6	C	DO1, DO2, DO4, DO7	2006	16	381	16-Jan-06
7	C	DO1, DO2, DO4, DO7	2006	23	388	23-Jan-06
8	C	DO1, DO2, DO4, DO7	2006	30	395	30-Jan-06
9	C	DO1, DO2, DO4, DO7	2006	37	402	06-Feb-06
10	C	DO1, DO2, DO4, DO7	2006	44	409	13-Feb-06
11	W	DO1, DO2, DO4, DO7	2006	46	411	15-Feb-06
12	W	DO1, DO2, DO4, DO7	2006	51	416	20-Feb-06
13	W	DO1, DO2, DO4, DO7	2006	55	420	24-Feb-06
14	C	DO1, DO2, DO4, DO7	2006	65	430	06-Mar-06
15	W	DO1, DO2, DO4, DO7	2006	69	434	10-Mar-06
16	C	DO1, DO2, DO4, DO7	2006	72	437	13-Mar-06
17	W	DO1, DO2, DO4, DO7	2006	73	438	14-Mar-06
18	C	DO1, DO2, DO4, DO7	2006	79	444	20-Mar-06
19	C	DO1, DO2, DO4, DO7	2006	86	451	27-Mar-06
20	W	DO1, DO2, DO4, DO7	2006	94	459	04-Apr-06
21	W	DO1, DO2, DO4, DO7	2006	101	466	11-Apr-06
22	W	DO1, DO2, DO4, DO7	2006	102	467	12-Apr-06

C = Cockburn Sound Management Council, by Oceanica Consulting Pty Ltd

W = Water Corporation

DO1, DO2, DO7 are near the RTMS sites in north, central and south Cockburn Sound

DO4 is near the PSPD diffuser on the eastern shelf of Cockburn Sound

Appendix C: Wind mixing calculations

Results are presented in the Table C-1 below of calculations to estimate the magnitude of wind speed acting for a duration of Δt = 6 hours required to mix a layer of higher salinity of thickness Δh = 0.5 m with an overlying layer lower salinity and thickness h = 19.5 m. A water current velocity difference between the two layers of ΔU = 0.05 m/s is assumed, based on current meter data presented in Steedman and Craig (1983) during periods of low wind speeds. An ambient salinity for the upper mixed layer (UML) of 36.2 psu has been used, and wind speeds required for mixing lower layers with salinity increments of 0.1 psu have been computed. A uniform temperature of 20°C has been assumed.

The formulation used for the calculations is based on Equations 15, 16, 23 and 24 in Hodges et al. (2000), which describes applications of ELCOM to Lake Kinneret. The formulation neglects any potential energy effects introduced by either surface heating or surface cooling. Surface heating would increase the required wind given in the table, while surface cooling would reduce it. It also neglects any increase in mean current speed difference ΔU that would occur at higher wind speeds. Higher values of ΔU would reduce the wind speed below the values given in the table.

The basic formulation for computing the wind speed is:

$$\left(\frac{\Delta\rho g h}{2} - \frac{C_S \Delta U^2}{2} \right) \frac{\Delta h}{\Delta t} = \frac{\rho C_N{}^3 u_*{}^3}{2}$$

where $\Delta\rho$ is the density difference due to the salinity difference, g is acceleration of gravity (9.81 m/s^2), ρ is the density of the upper mixed layer, and C_N and C_S are coefficients whose values are given in Hodges et al. (2000). Values for all parameters as used in the calculations are listed beneath the table below. The above equation can be solved for the shear velocity u_* and then the wind speed U_{wind} can be calculated by solving:

$$u_*{}^2 = \frac{\rho_{air}}{\rho} C_D U_{wind}{}^2$$

for U_{wind}. Results of the calculations are summarized in Table C-1.

Only the values in the table at lower wind speeds have been used to give an indication of awind speed threshold to specify the upper limit of "calm" conditions.

Based on the results in the table and on visual inspection of the time series for wind speeds and dissolved oxygen concentrations at the south RTMS before and during the 5 February 2008 event that triggered compliance monitoring (Figure 18 of main report), a value of 5 m s^{-1} was chosen for use in estimating the maximum annual durations of summer-autumn "calm" conditions, as described in Section 5 of the main report.

Table C-1: Wind-mixing calculations

Salinity	Density ($kg\ m^{-3}$)	Density difference from UML ($kg\ m^{-3}$)	gprime ms^{-2})	gprime * h (m^2s^{-2})	u_star^3 to mix $(ms^{-1})^{-3}$	u_star to mix (ms^{-1})	**Wind speed (ms^{-1})**	Diff in wind speed (ms^{-1})
36.2	1025.6787	0.0	0.0	0.0				
36.3	1025.7550	0.0763	7.298E-04	1.423E-02	1.351E-07	0.005131	**4.16**	4.16
36.4	1025.8314	0.1527	1.460E-03	2.848E-02	2.753E-07	0.006505	**5.27**	1.11
36.5	1025.9077	0.2290	2.190E-03	4.271E-02	4.153E-07	0.007461	**6.05**	0.77
36.6	1025.9841	0.3054	2.921E-03	5.696E-02	5.555E-07	0.00822	**6.67**	0.62
36.7	1026.0604	0.3817	3.651E-03	7.119E-02	6.955E-07	0.00886	**7.18**	0.52
36.8	1026.1368	0.4581	4.381E-03	8.544E-02	8.357E-07	0.009419	**7.64**	0.45
36.9	1026.2131	0.5344	5.111E-03	9.967E-02	9.757E-07	0.009918	**8.04**	0.40
37.0	1026.2895	0.6108	5.842E-03	1.139E-01	1.116E-06	0.010372	**8.41**	0.37
37.1	1026.3659	0.6872	6.573E-03	1.282E-01	1.256E-06	0.01079	**8.75**	0.34
37.2	1026.4223	0.7636	7.303E-03	1.424E-01	1.396E-06	0.011177	**9.06**	0.31

Temperature (deg C)	=	20.0
h (m)	=	19.5
Δh (m)	=	0.5
Δt (hours)	=	6
Δt (s)	=	21600
Δh/Δt (m/s)	=	2.315E-05
ΔU (m/s)	=	0.05
CD	=	0.2
CD * $\Delta U^2 (m/s)^{-2}$	=	5.000E-04
CN	=	1.33
CNM^3	=	2.35
CD	=	1.30E-03
dens air ($kg\ m^{-3}$)	=	1.2
CD*dens_air/dens_water	=	1.52E-06

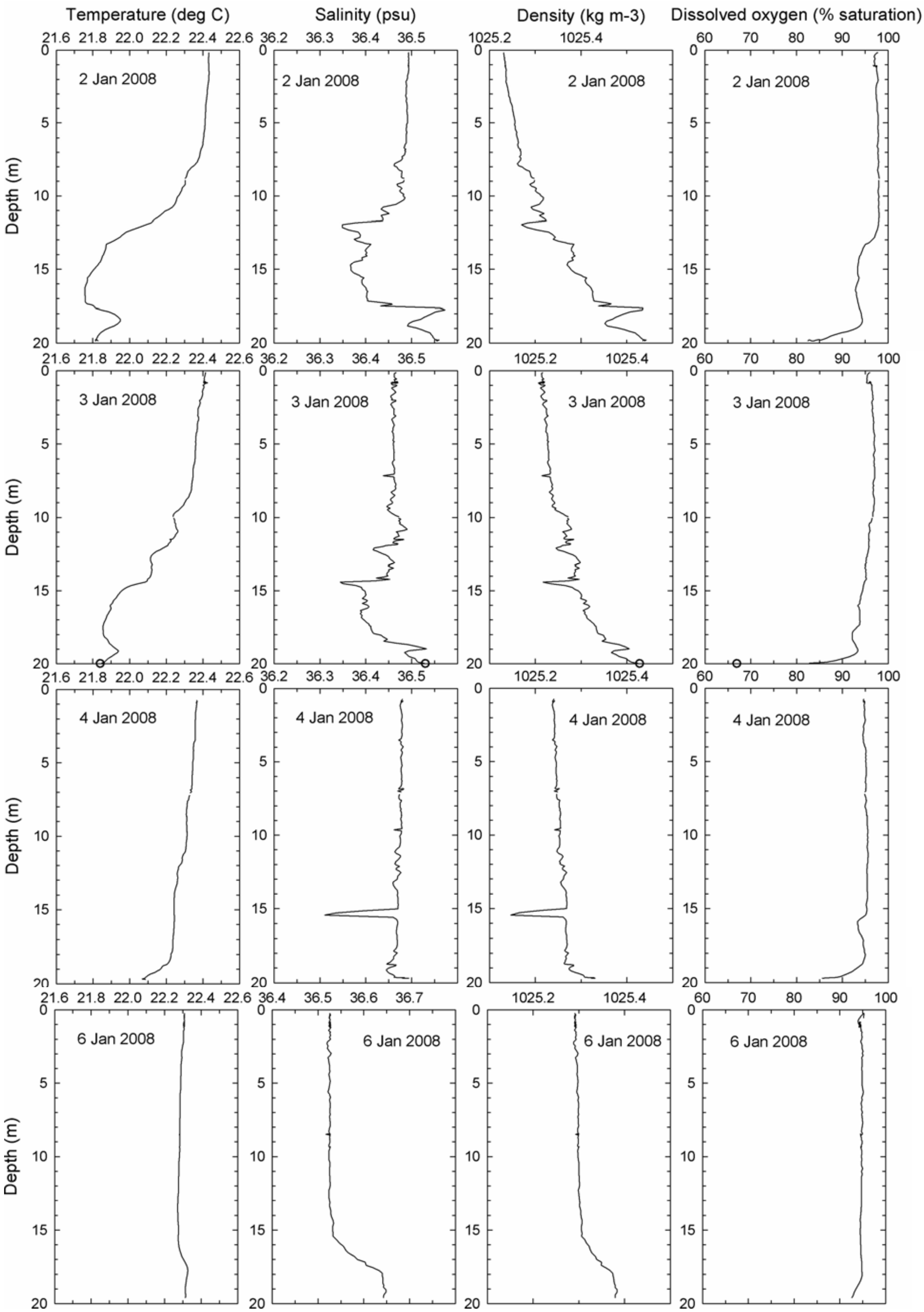
Appendix D: Profiles of temperature, salinity, density and dissolved oxygen measured at the south RTMS mooring, 2 January – 8 February.

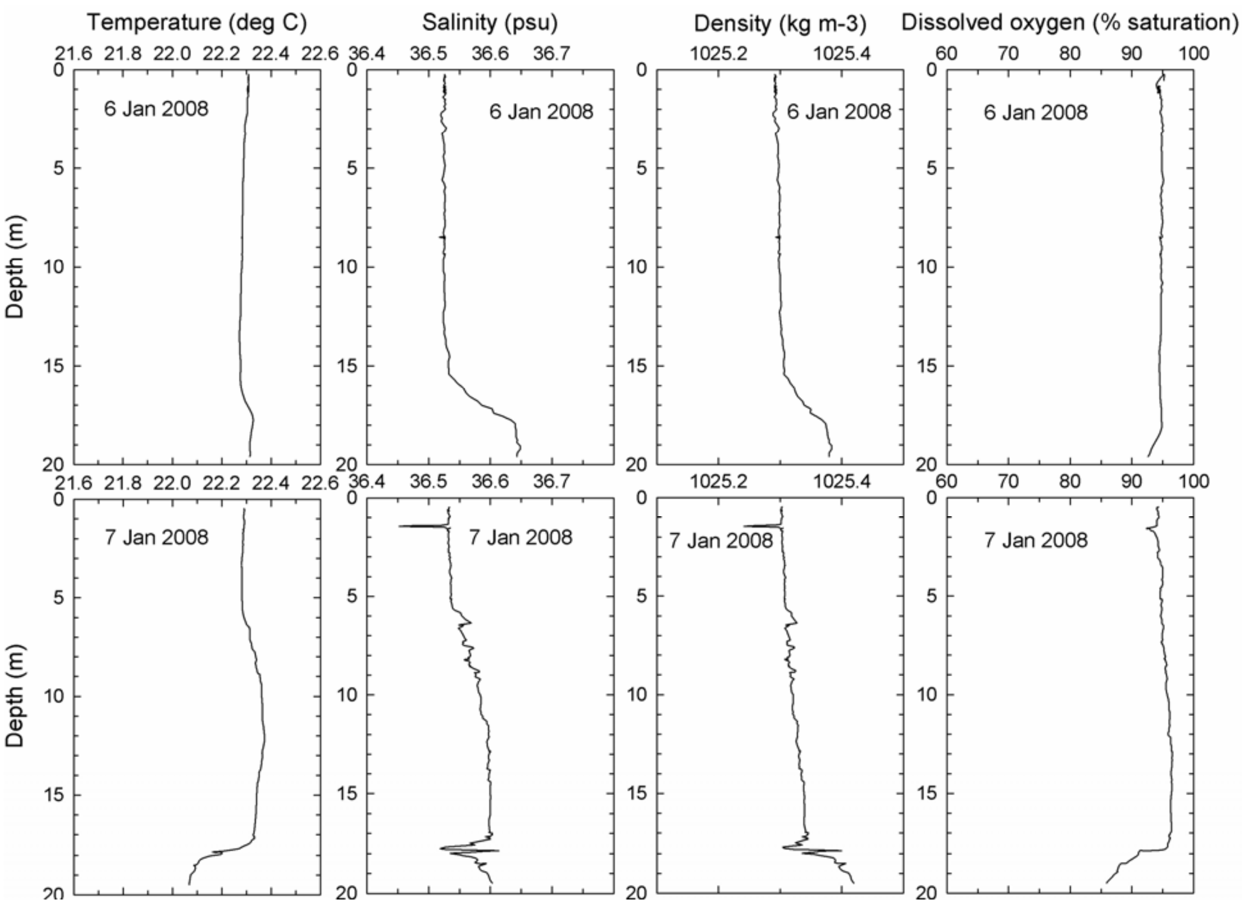
These data were supplied by the Water Corporation upon request.

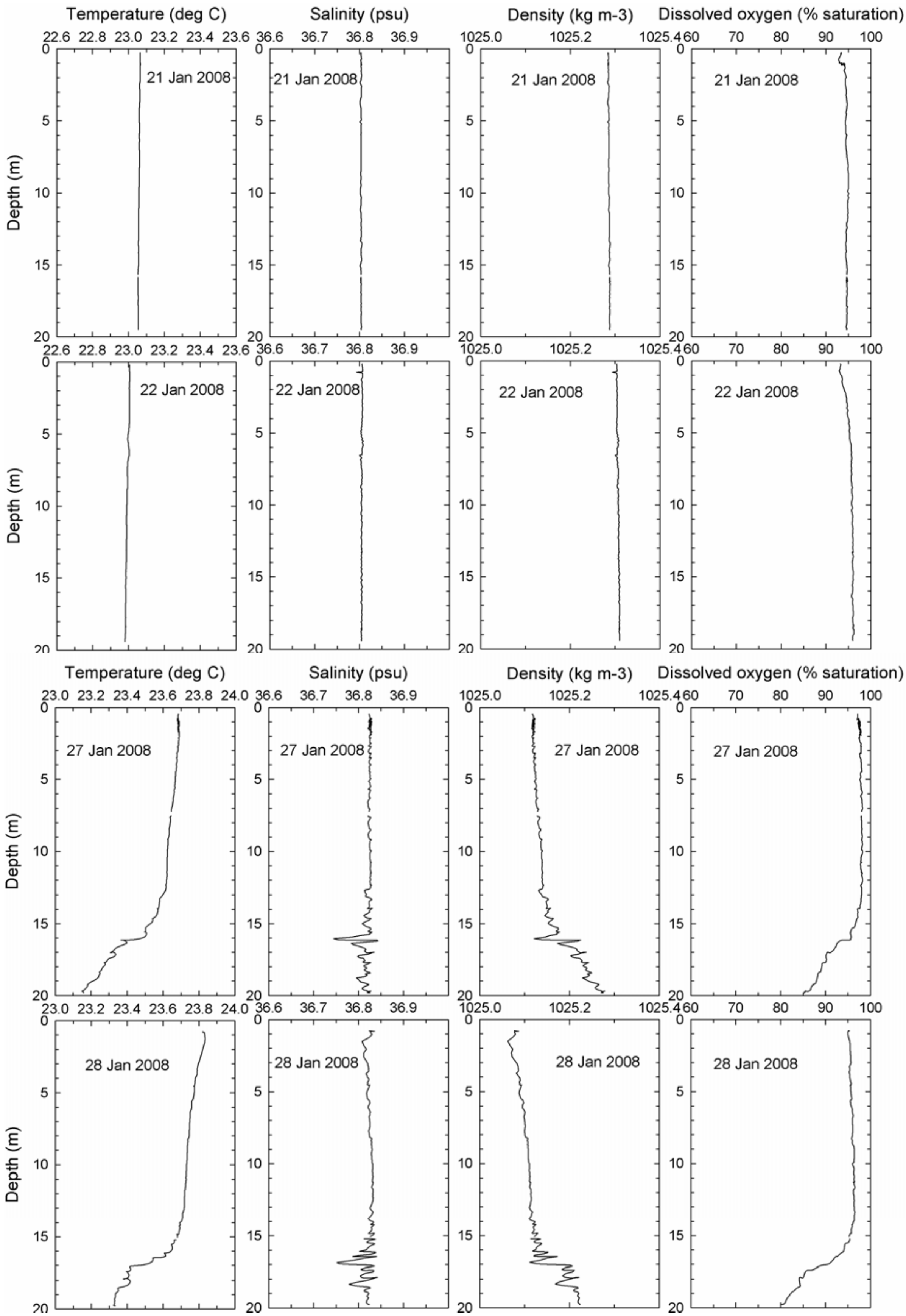
For wind speeds and dissolved oxygen concentrations measured at the mooring, see Figure 18 of the main report.

The profiles were measured at the RTMS mooring for the Water Corporation by the Marine and Freshwater Research Laboratory, Murdoch University (MAFRL) using a Seabird SBE19 CTD with an auxiliary SBE43 dissolved oxygen sensor attached. The CTD is fitted with a cage that is intended to keep the sensors 0.5 m above the bed, in accordance with the PSDP license requirements. (Steve Christie, personal communication).

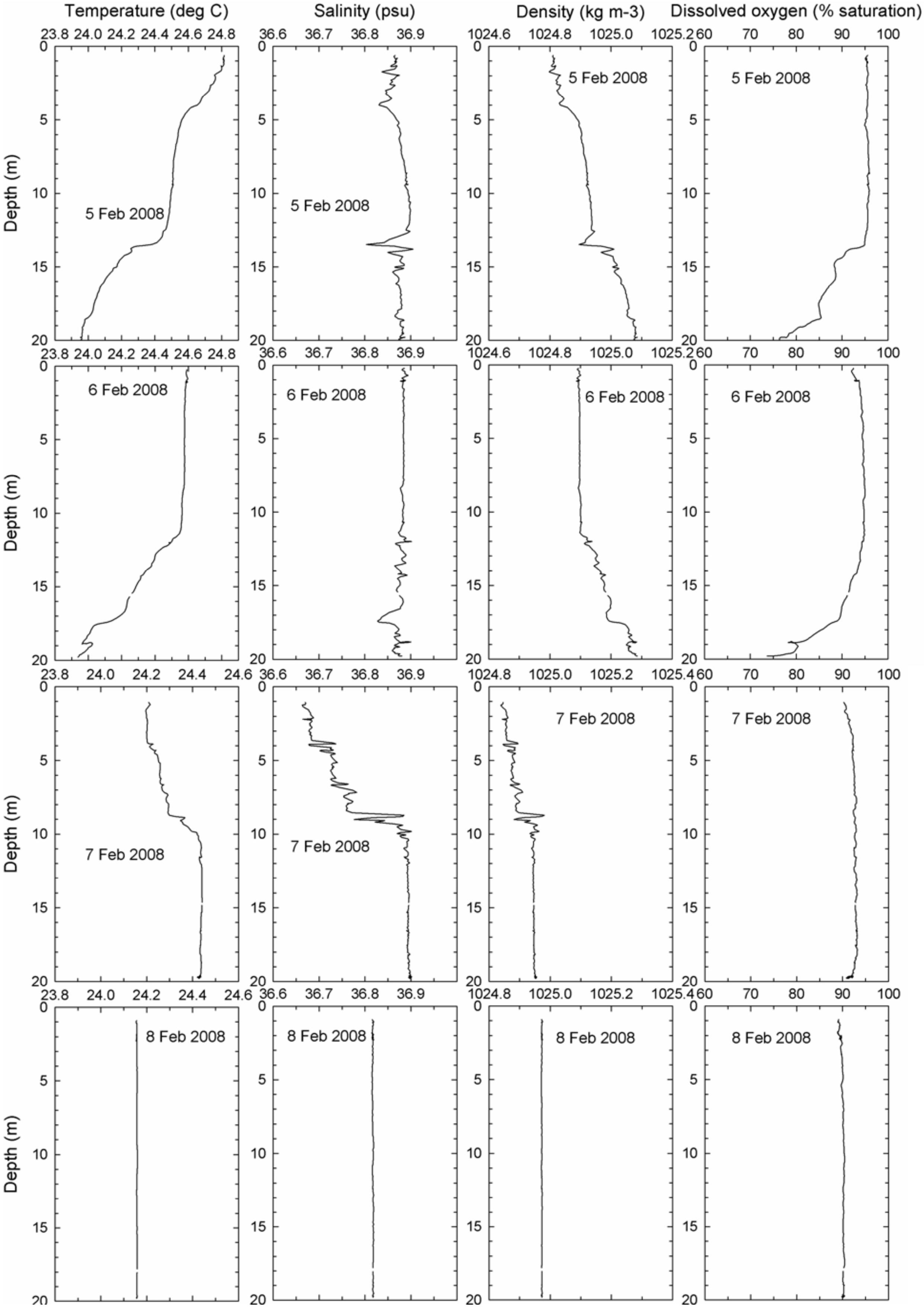
Extra values recorded with the CTD resting at maximum depth have been deleted. For most profiles there may be > 100 such values that are virtually identical to the bottom value shown in the plots. However, in the profile of 3 January 2008, dissolved oxygen concentrations dropped from around 80% saturation to 67% percent saturation over time, and a typical data point is shown by the open circle on the graphs at just above 20 m.


Temperature (deg C)
Salinity (psu)
Density (kg m-3)
Dissolved oxygen (% saturation)
Depth (m)
2 Jan 2008
3 Jan 2008
4 Jan 2008
6 Jan 2008


Temperature (deg C)
Salinity (psu)
Density (kg m-3)
Dissolved oxygen (% saturation)
21.6 21.8 22.0 22.2 22.4 22.6
36.4 36.5 36.6 36.7
1025.2 1025.4
60 70 80 90 100
Depth (m)
0 5 10 15 20
6 Jan 2008
7 Jan 2008



Temperature (deg C)
Salinity (psu)
Density (kg m-3)
Dissolved oxygen (% saturation)
Depth (m)
21 Jan 2008
22 Jan 2008
27 Jan 2008
28 Jan 2008


Temperature (deg C)
Salinity (psu)
Density (kg m-3)
Dissolved oxygen (% saturation)
Depth (m)
5 Feb 2008
6 Feb 2008
7 Feb 2008
8 Feb 2008

Appendix E: Advice relating to the Water Corporation's response to this review

The Water Corporation has provided a response to this review in the form of a memo from CWR (Dr Jason Antenucci) to the Water Corporation dated 11 June 2008. In this appendix I will summarise the main points of the CWR memo and present my response to them. The memo includes information collected by the Water Corporation after the end of February 2008, when the S46 report was submitted. The information consists of salinity profiles measured by the Water Corporation in the Stirling Channel and at distances up to 1 km from the Stirling Channel exit on two further occasions (12 April and 4 May 2008) that low oxygen levels triggered compliance monitoring. Because the Water Corporation was advised by the Chairman of the EPA that information collected after the end of February 2008 would not be considered, I will restrict my presentation to information available prior to the end of February 2008. I have examined the additional information, however, and my initial assessment is that the additional information is unlikely to change the main conclusions of the review or of this Appendix.

CWR memo

1. In the memo summary, CWR reiterate the basic conclusion of their original report, "that the desalination plant discharge does not impact on stratification (and therefore dissolved oxygen) in the deep basin of Cockburn Sound…" As in the original reports, the memo points to the lack of any evidence from field data or modeling results that would lead them to conclude otherwise. The field data include salinity and temperature profiles and the measurements from two dye releases.

2. CWR point out that no measurements, either by CWR during their two field campaigns of 13-21 December 2006 and 25-28 April 2007, or by the Water Corporation made during their compliance monitoring survey in response to the low oxygen event of February 2008, found evidence of a bottom plume from the desalination discharge at a distance further than 1.5 km from the Stirling Channel exit to the main basin of Cockburn Sound. The memo argues against the possibility that thin bottom density currents could persist in the Sound, because "the physics of the entrainment process dictates that the plume should increase in thickness, and decrease in density, until it inserts at the level of neutral buoyancy."

3. The memo presents calculations based on salinity profiles measured by the Water Corporation at the Stirling Channel exit during compliance monitoring, that give an order-of-magnitude estimate for plume discharge into the main basin from the Stirling Channel of 1 – 10 $m^3\ s^{-1}$, with a salinity excess of approximately 0.5 psu. The memo shows that this represents only 0.7% – 7% of the total plant discharge.

4. The memo acknowledges that there may be some limitations to the numerical modeling, in terms of its ability to accurately model the fate of thin bottom density currents. However, the memo indicates that this is not important because of the small amount of salt entering the basin from the plant discharge. The memo concludes that it is highly unlikely that any underestimation by the model of plume penetration into the main basin would cause significant errors in the model predictions of stratification and dissolved oxygen. In response to the review's concerns surrounding model validation and lack of a quantifiable measure for uncertainty, the memo reiterates results for correlation coefficients for measured versus predicted temperatures, salinities and densities.

5. The memo finds that there is little to recommend the suggestion made in the review that measurements be made closer than 0.5 m to the bed, and points out that while Water Corporation measurements do not extend closer to the bed than 0.5 m, the CWR profiles were made to 0.12 m from the bed. The memo concludes that any monitoring closer than 0.5 m to the bed would be wasteful of resources.

6. Finally, the memo concludes that any plumes from the desalination plant "**do not** form spatially coherent underflows of any significant size."

Reviewer's response to CWR's memo

In the main body of this review I have given several reasons why I think the conclusion "that the desalination plant discharge does not impact on stratification (and therefore dissolved oxygen) in the deep basin of Cockburn Sound…" needs to be qualified. In spite of the points presented in CWR's memo, I still think there needs to be some acknowledgment that the desalination discharge does have an influence, as yet undetermined, on stratification and dissolved oxygen in the Sound. I think the following comment, made in the Introduction of the review, is still a valid one: "The effect may be small or even negligible much of the time; it may become significant only infrequently; and it may be so localised geographically that affected areas are recolonised over time. But it undoubtedly adds a further increment to existing stress on the Cockburn Sound ecosystem." I also reiterate two points made in the review and noted in the Conclusions section. The first is that any salt stratification may cause oxygen drawdown, either by itself or by reinforcing the effects of thermal stratification. I think that inspection of even a small selection of profiles measured at the south RTMS shows this to be the case. Second, the length of observations has not been long given year-to-year variability in climate and in coastal ocean conditions, and it is likely that more extreme conditions than those observed over the time span of the modelling or since the start of monitoring will occur in the future.

Below I give a more detailed response to the points raised in CWR's memo.

Points 1 and 2

I agree with CWR that a bottom layer associated with the desalination plant discharge is not likely to form a widespread, coherent layer extending over a large area. For this reason more intensive profiling is required to either locate it or to be able to rule out its occurrence with a reasonable degree of confidence (see also the response below to point 6). This is also relevant for the dye studies, which released dye over a period of approximately 20 minutes. The spatial extent of resulting bottom dye patches were therefore limited, and would be easy to miss once they entered the main basin of the Sound. The same is true for higher salinity bottom layers, although the period of release is much longer, corresponding to that for which calm conditions persist. Hence the spatial extent is much larger than for the experimental dye patches, but still much smaller than the area covered by the main basin of the Sound. To date, neither dye nor salinity profile data measured further than 1.5 km from the Stirling Channel exit have indicated the presence of a bottom layer that can be associated with the desalination plant discharge. However, this does not preclude the possibility that such bottom layers do occur but have gone undetected, given the coarse resolution of sampling in both time and space in the main basin of the Sound.

I disagree that the physics of the entrainment process dictates that the plume should increase in thickness, and decrease in density, as it flows down the slope at the exit to the Stirling Channel and enters the main basin of the Sound. This description aptly describes entrainment processes observed in experiments on steep slopes, but the behaviour observed on very mild, near-horizontal slopes is different. On slopes less than 3°, turbulent entrainment, dilution and thickening are much more limited (Nokes, personal communication; Maxworthy and Nokes 2007 and references contained therein). This applies even to the steepest reaches of the Stirling Channel (at least as indicated by available bathymetry). Ambient turbulence, generated directly by wind or by wind-driven currents, will be the main cause of mixing and dilution of any saline inflows on these near-horizontal slopes. Effects of wind were quantified in an approximate way in Section 5 of the review.

Point 3

The order-of-magnitude calculation for the flow is a valuable addition to the insights and results presented by CWR. A minor comment here is that, as with all such calculations, the actual values calculated depend on the values chosen for the scaling parameters, such as plume width and plume velocity, and are open to some subjective interpretation. My own interpretation of the Water Corporation's profiles measured at the Stirling Channel exit on 5 February 2008 was that the plume signature could be seen over a wider distance than that mentioned in the CWR memo. Also, in calculating plume velocities I used a formulation given by Simpson (1997, p. 176) that is essentially the same as that used in the CWR memo, but that has an additional factor that accounts for ratio of thickness of a gravity current to that of the total depth. The factors ranged from 1.4 to 1.9, resulting in higher estimated speeds. I would therefore tend to have more confidence in the higher estimate for plume flux presented by CWR (10 $m^3 s^{-1}$) than the smaller estimates (1 $m^3 s^{-1}$), although admittedly these are only approximations and subject to uncertainty.

Using the estimate of 10 $m^3 s^{-1}$ for plume flux, it is possible to estimate a time for a plume to fill the main basin below 18 m depth [for which D'Adamo (2000, p. 8) gives an area of 67 km^2] with a layer 0.5 m thick, as approximately 39 days. This is approximately 5 times longer than the maximum duration of 8 days observed for calm periods since 1994-1995, as given in Section 5 of the review (Table 1). This indicates that there is almost no chance of the plume filling the bottom of the entire basin with a layer 0.5 m thick. However, smaller, more localized areas could be affected within a few days, the time being in direct proportion to the total area covered.

Point 4

This point relates to possible limitations to the numerical modelling. I am still not convinced that the model has the capability to model thin bottom boundary layers accurately enough to be able to resolve the small effects of concern here. And while the correlation coefficients for observed versus modelled salinities and temperatures are very high, those for density are not so good. Finally, correlation coefficients alone do not allow uncertainty to be quantified in terms of limits for density.

Point 5

It is good to know that CWR's CTD profiles can be made to within a distance of 0.12 m of the bed, and this removes any questions of their CTD's ability to detect salinity effects close to the bed. I would not think that reducing the clearance of the cage fitted to the Water Corporation's CTD, so that it could measure to within, say, 0.2 m of the bed, would be wasteful of resources. I accept that extending Water Corporation monitoring capabilities to depths closer to the bed would require extra resources if it involved purchasing and installing expensive extra sensors at all three RTMS moorings. That is why I suggested the possibility of restricting this to one site. In any event, any additional expense needs to be weighed against the possible increase in information, and the chance that this information would allow better quantification of the possible effects of the plume on stratification and the extent of oxygen depletion. CWR does not think the additional expense worthwhile, while I would reserve judgment until seeing some further results.

Point 6

From my own experience in trying to track underflows in lakes, and from reading about similar efforts in coastal areas, I think that once any saline plume entered the main basin of Cockburn Sound under relatively calm conditions, that it would tend to meander, subject to any weak currents that exist, and would also follow any depressions caused by irregularities in topography. Tracking of such underflows can be tedious and difficult. I agree that it would be unlikely to form a "spatially coherent underflow", although the total area covered would depend on how long the calm conditions persisted, as noted under the response to point 4.

References

Maxworthy, T.; Nokes, R.I. (2007). Experiments on gravity currents propagating down slopes. Part 1. The release of a fixed volume of heavy fluid from an enclosed lock into a canal. *Journal of Fluid Mechanics 584*: 433-453.

Simpson, J.E. (1997). Gravity currents in the environment and the laboratory (2nd ed.). Cambridge, Cambridge University press. 244 p.