

Modelling of the impact of the Perth Seawater Desalination Plant discharge on dissolved oxygen in Cockburn Sound

Final

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Executive Summary

This report details the results of a numerical modelling project undertaken to investigate the potential impact of a hypersaline desalination plant discharge via an outfall into Cockburn Sound, Western Australia. The overall modelling study comprised of two key objectives:

1. Determine the impact of the desalination plant discharge on stratification in Cockburn Sound.
2. Determine the impact of the desalination plant discharge on dissolved oxygen conditions in the Cockburn Sound.

This report details the set-up and results of the ecological modelling study designed to address objective 2. Objective 1 is addressed in an accompanying report that details the results of a hydrodynamic modelling study completed as a precursor to the ecological modelling detailed herein.

The primary result of the hydrodynamic modelling was that stratification in the deep waters of Cockburn Sound (>15 metres) would not be impacted by the desalination plant discharge. As the strength and duration of natural stratification in the Sound is unlikely to be increased by the desalination discharge, it was expected that the effect of the discharge on dissolved oxygen will be negligible, however extensive simulations were conducted to confirm this.

The coupled three-dimensional hydrodynamics and water quality model ELCOM-CAEDYM was applied to Cockburn Sound. ELCOM was configured as outlined in an accompanying report describing an investigation into the hydrodynamics of the Sound. CAEDYM was configured to simulate the major processes controlling dissolved oxygen, which include transport into the Sound from the ocean boundary, atmospheric transfer, sediment consumption, seagrass production and respiration, algal production and respiration, and nitrification. Rates of sediment oxygen consumption were based upon laboratory analysis of cores from Cockburn Sound. Algal and seagrass biomass were simulated to ensure their impact on biological production and consumption of oxygen were considered. In order to capture the effect of microphytobenthos on the oxygen flux in the nearshore sediments, CAEDYM was modified to include a sediment photosynthetic rate calculated as a function of the amount of light reaching the sediment surface.

The results indicate that dissolved oxygen processes in the Sound are dominated by atmospheric transfer and sediment consumption. As dissolved oxygen drawdown due to sediment consumption is a strong function of stratification, which is unchanged by the desalination discharge, it was found that there would be no deleterious effect of the desalination plant discharge on dissolved oxygen conditions in Cockburn Sound.



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1 INTRODUCTION

Cockburn Sound is a coastal embayment to the south of Fremantle. It is bounded to the east by the mainland and to the west by Garden Island. The main basin is about 16 km long, 7 km wide, with a maximum depth of 22 m, the surface area is 80 km² and the volume 1.2 x 10⁹ m³. The southern end of the Sound is partially closed by a solid rock-fill causeway that connects the mainland to Garden Island, and has two openings of approximately 300 and 600 m wide.

The increase in industry along the coast of the Sound has led to increasing concerns about the ecological health of the embayment. The Water Corporation is currently constructing a seawater desalination plant along the eastern shore, which will produce 45GL of potable water per year via reverse osmosis. This process is approximately 45% efficient, which therefore requires extraction of 100GL per year (3.2 m³ s⁻¹) of water from the Sound, and the return of saline effluent of 55GL per year (1.75 m³ s⁻¹). This saline discharge is estimated to have a salinity of approximately 65 ppt, with the salinity of the ambient receiving waters approximately 37 ppt. The saline discharge enters the Sound via a diffuser which is designed to reduce the salinity to less than 1 ppt above ambient concentrations within 50 metres of the diffuser.

The Environmental Protection Authority is concerned that the desalination plant discharge will negatively impact the ecological health of the Sound. The indicator taken for this impact has been chosen to be dissolved oxygen concentrations, as measured nominally 0.5m from the seabed in three of the deepest locations in Cockburn Sound. Under the current licence arrangements (as issued October 2006) reduction of dissolved oxygen concentrations below a trigger level will potentially result in shut-down of the desalination plant; however it is felt that there has been no formal causal connection made between the dissolved oxygen concentrations at the measuring sites and the desalination plant operation. Vertical stratification is a large contributor to the decline of DO in the deeper waters of the sound due to the restriction that stable density gradients place on the rates of vertical mixing, and thus the replenishment of oxygen concentrations at depth. A companion report documents the application of the three-dimensional hydrodynamic Estuary, Lake and Coastal Ocean Model (ELCOM) to assess the impact of the desalination plant discharge on the stratification in the sound over seasonal time-scales. This report assesses the impact of the desalination plant on the dissolved oxygen in the Sound.

Historically, observations of dissolved oxygen in Cockburn Sound have been during the summer-autumn period, December to April (DEP 1996, DAL 2001). Vertical profiles of dissolved oxygen concentration have shown that the basin is generally well oxygenated (7-8 mg/L), although reduced oxygen concentrations have been observed in the deep bottom waters. Time series measurements close to the sediment surface (< 0.2 m) during April-May 1994 recorded episodes

of low dissolved oxygen concentrations (2-4 mg/L) associated with low wind conditions. The greatest variability and lowest concentrations were measured in Mangles Bay at the southern end of the Sound.

In order to determine the impact of the Perth Seawater Desalination Plant on dissolved oxygen conditions in the Sound, we conducted a coupled three-dimensional hydrodynamics and water quality modelling study. The study considered both summer and autumn periods, as well as scenarios to determine the likely maximum impact of the plant discharge. The model used was ELCOM-CAEDYM, developed by the Centre for Water Research at the University of Western Australia. The model is validated against field data from two periods (summer, autumn), in particular focusing on the ability of the model to reproduce bottom dissolved oxygen conditions.

2 THE COMPUTATIONAL AQUATIC ECOSYSTEM DYNAMICS MODEL (CAEDYM)

2.1 Model Requirements

The Computation Aquatic Ecological Dynamics Model (CAEDYM) was coupled with hydrodynamic driver Estuary Lake and Coastal Ocean Model (ELCOM) to simultaneously model the physical and ecological behaviour of Cockburn Sound over seasonal time-scales. The features of ELCOM are described in an accompanying report focussed on hydrodynamic modelling of the Sound (Part 1). Based on the marine biology of Cockburn Sound summarized above, the requirements for a coupled physical and ecological numerical model to simulate the dissolved oxygen dynamics of the Sound are:

- Advection of water containing dissolved oxygen from the ocean (computed by ELCOM)
- Atmospheric transfer of oxygen
- Sediment Oxygen Demand
- Phytoplankton production and respiration
- Uptake due to nitrification in the water column
- Consumption by bacterial breakdown of organic matter
- Seagrass photosynthesis and respiration
- Oxygen production by microphytobenthos

The models were developed by the Centre for Water Research, University of Western Australia (Hodges et al. 2000, Robson & Hamilton 2004) and have been successfully applied to more than 50 systems worldwide, including similar systems to Cockburn Sound such as the Venice and Barbamarco Lagoons, Northern Adriatic Sea (Spillman et al. in press) and Marmion Marine Park (Hillmer & Imberger, in press).

2.2 Model Description

CAEDYM is an aquatic ecological model designed to be readily linked to three-dimensional hydrodynamic model ELCOM. The coupling between CAEDYM and the hydrodynamic driver is dynamic; in particular, the thermal structure of the water body is dependent on the water quality concentrations by feeding back through water clarity. One of the objectives during CAEDYM development was to allow flexible ecological configuration that could be tailored for specific applications, though major elemental cycling and at least one algal group is compulsory. Hence, the model includes comprehensive process representation of the C, N, P, Si and DO cycles, several size classes of inorganic suspended solids, and phytoplankton dynamics. Numerous optional biological and other state variables can also be configured. Hence, CAEDYM is more

advanced than traditional N-P-Z models, as it is a general biogeochemical model that can resolve species- or group-specific ecological interactions. CAEDYM operates on any sub-daily time step to resolve algal processes (diurnal photosynthesis and nocturnal respiration), and is run at the same time interval as the hydrodynamic model. Algorithms for salinity dependence are included so that a diverse range of aquatic settings can be simulated. The user can prescribe whether the simulation is for freshwater, estuaries or coastal waters, since many of the algorithms have been developed to include a salinity dependence. With specification of the nature of the waterbody (i.e. fresh, estuarine or marine), internal checks in the model are then activated to ensure that salinity dependence is maintained (for an estuarine case) or removed (for a freshwater or marine water case).

The major biogeochemical state variables in CAEDYM are given in Figure 2.1. The computed ecological variables include:

- Light
- Inorganic Particles
- Sediments and Resuspension
- Dissolved Oxygen
- Carbon, Nitrogen, Phosphorus and Silica
- Phytoplankton Dynamics
- Bacteria
- Zooplankton
- Higher Biology (including seagrass)
- Pathogens and Microbial Indicator Organisms
- Metals

2.3 Suitability for application to Cockburn Sound

The aquatic ecological model CAEDYM contains all the features required as outlined in Section 2.1. Coupling CAEDYM with ELCOM gives three-dimensional capability to the modelling, in particular allowing for fluxes with the boundary and spatially varying biogeochemical rates. For example, the sediment oxygen consumption algorithm in CAEDYM consists of a maximum consumption rate which is modulated by the water temperature and the overlying redox condition of the bottom waters. Therefore regions that are consistently warmer than other regions as predicted by the hydrodynamics model ELCOM (for the same dissolved oxygen concentration) will have greater sediment oxygen demand. In addition to the simulated water column processes, ELCOM-CAEDYM is particularly suited to Cockburn Sound due to

- spatially heterogenous sediment oxygen demand that includes photosynthetic oxygen production due to microphytobenthos

- spatial heterogeneity of DO production/consumption in the water column due to patches of seagrass.

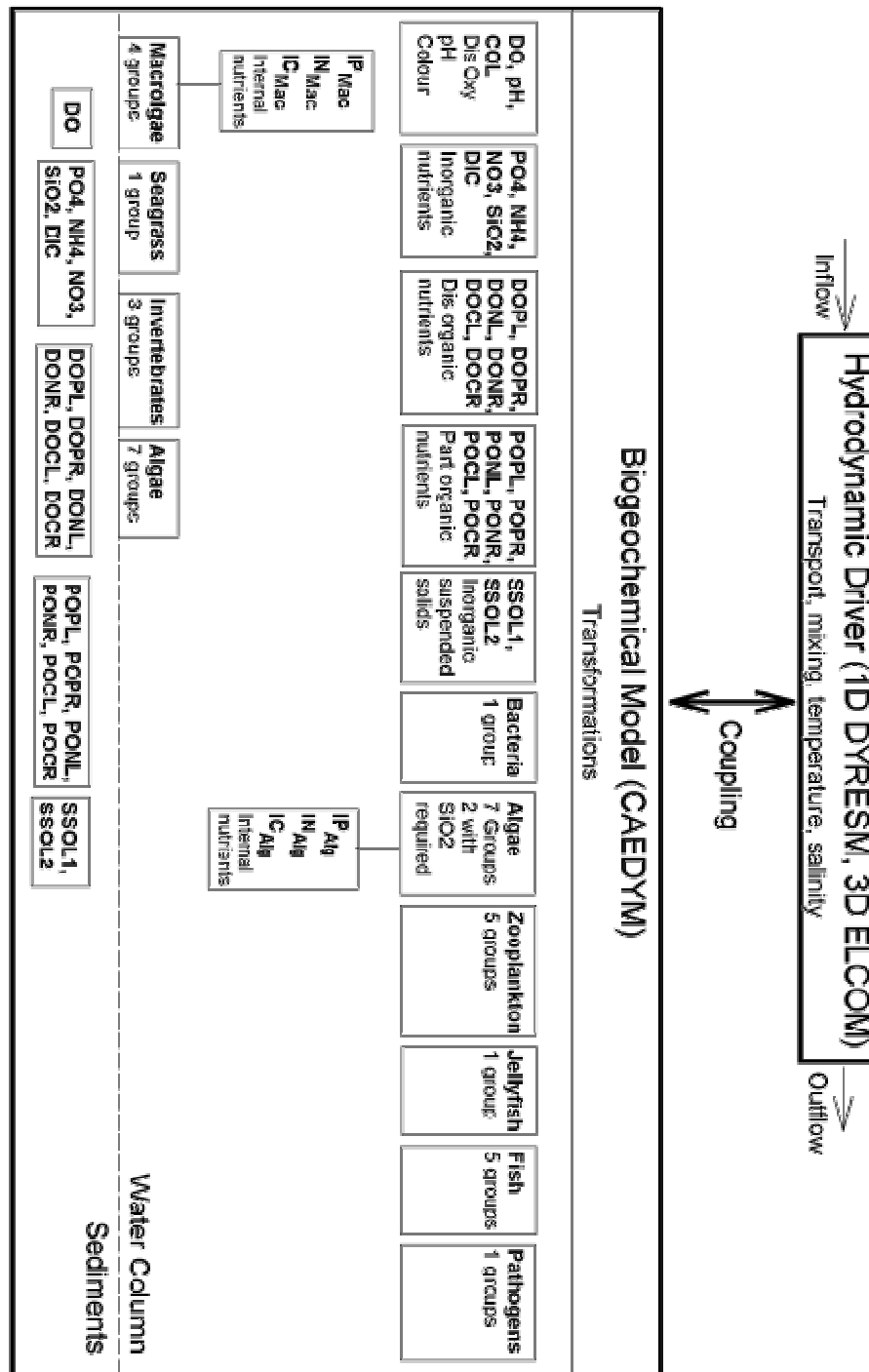


Figure 2.1. CAEDYM state variables. Application for Cockburn Sound does not include the bacteria, zooplankton, jellyfish, fish, pathogen, benthic macroalgae, benthic invertebrates or benthic algae.

3 CAEDYM CONFIGURATION

3.1 Introduction

The ELCOM-CAEDYM simulations were conducted to determine the major controls on dissolved oxygen, and so all simulation results and discussion focus on this variable alone. Other variables (eg nutrients, phytoplankton, seagrasses) were included in the simulations, and efforts were made to ensure the approximate magnitude of these pools were simulated correctly in order to determine their impacts on dissolved oxygen. However, they were not the intended focus of this analysis.

3.2 Hydrodynamics

The hydrodynamics of the Sound were determined by the physical model ELCOM, which was dynamically coupled with CAEDYM to run in an integrated fashion. The details of the ELCOM simulations and validation are contained in an accompanying report. The main feedback between CAEDYM and ELCOM is through the light extinction coefficient, which is computed in CAEDYM as the sum of the background extinction coefficient and contributions due to inorganic and organic particulate matter. The role of Chl-a on light extinction was configured according to data collected within the Sound (SMCWS 1996). Note that biogeochemical parameters in CAEDYM are transported by ELCOM, and the two models communicate at each time step.

3.3 Nutrients and Phytoplankton

Organic and inorganic phosphorus and nitrogen cycles were simulated, where each pool consists of organic and inorganic particulate and dissolved components. Based on phytoplankton composition and abundance in Cockburn Sound from SMCWS (1996) and Oceanica Consulting Pty Ltd, species from the diatom group dominate the phytoplankton assemblage. Therefore, CAEDYM was configured to model one phytoplankton group that represents marine diatoms. Parameters for this group were taken from Hillmer & Imberger (In Press), who applied ELCOM-CAEDYM to the Marmion Marine Park, which has a similar phytoplankton assemblage.

3.4 Dissolved Oxygen

The major processes impacting dissolved oxygen in ELCOM-CAEDYM are:

- Phytoplankton production and respiration
- Seagrass production and respiration
- Sediment oxygen demand
- Atmospheric and oceanic exchange
- Nitrification

Sediment oxygen demand (SOD) as a function of overlying concentration of dissolved oxygen was based on the parameterisations of Van Senden and Miller (2005), who use $SOD = 0.035 * DO$. This equation was based on SOD measurements from sediment cores taken in the Cockburn Sound in 1992 (SMCWS 1996) and 2005 (Read and Oldham 2005). CAEDYM uses a Michaelis-Menton function for sediment oxygen consumption, given by $SOD = SOD_{MAX} DO / (K_{DO} + DO)$. In order to replicate the same functional shape of the Van Senden and Miller (2005) equation, SOD_{MAX} should be set to $0.8 \text{ g O m}^{-2} \text{ d}^{-1}$ with K_{DO} set to 15 mg O L^{-1} . To replicate the field measurements of dissolved oxygen, however, SOD_{MAX} was increased to $1.6 \text{ g O m}^{-2} \text{ d}^{-1}$. Note that the maximum measured rate of sediment oxygen consumption in Cockburn Sound is $0.41 \text{ g O m}^{-2} \text{ d}^{-1}$ (DAL 2005), and for 8 mg O L^{-1} the CAEDYM formulation results in $0.56 \text{ g O m}^{-2} \text{ d}^{-1}$. Thus, the CAEDYM formulation is conservative as it results in *greater* sediment oxygen consumption than in previous modelling studies.

Microphytobenthos in the shallow regions of the Sound produce oxygen, and so effectively decrease the rate of sediment oxygen consumption. This was accounted for by an additional term in the sediment oxygen demand equation, which becomes $SOD = SOD_{MAX} (DO / K_{DO} + DO) - MPB_{MAX} (1 - \exp(-I / I_K))$, where MPB_{MAX} is the maximum microphytobenthos oxygen production rate (set to $0.17 \text{ g m}^{-2} \text{ d}^{-1}$ based on Masini and McComb 2001), I is the light at a particular point in the domain and is computed by CAEDYM, and I_K is the light saturation parameter (set to $100 \text{ } \mu\text{E m}^{-2} \text{ s}^{-1}$ based on Masini and McComb 2001). This has the effect that in shallow regions where the light is high, the sediment oxygen consumption is reduced due to microphytobenthos oxygen production.

3.5 Seagrasses

One seagrass group was configured for the ELCOM-CAEDYM simulations. Initial spatial distribution and biomass from surveys of the Southern Metropolitan Coastal Waters Study (SMCWS) (1996), Cambridge and Hocking (1997) and Kendrick et al. (2002) (Figure 3.1). As they are rooted in the sediment, they were assumed to not form part of the nutrient budget. This assumes seagrass wrack (i.e. sloughing of seagrass material from the bottom) to be negligible. Seagrasses interact with the dissolved oxygen through photosynthesis and respiration, where the parameters were based on Masini and Manning (1997). This study of seagrass species found in Western Australia included *Posidonia sinuosa*, the dominant species in Cockburn Sound. The light saturation parameter (I_K) was set to $55 \text{ } \mu\text{E m}^{-2} \text{ s}^{-1}$. The maximum growth rate (μ) was set to 0.05 day^{-1} , and the respiration rate coefficient (k_R) set to 0.023 day^{-1} , based on maximum gross and net photosynthetic rates of $2 \text{ mgO}_2 \text{ (g leaf)}^{-1} \text{ h}^{-1}$ and $1.2 \text{ mgO}_2 \text{ (g leaf)}^{-1} \text{ h}^{-1}$ reported by Masini and

Manning (1997) respectively, and using a leaf biomass to carbon ratio of 0.35 for *Posidonia* species (Atkinson and Smith, 1983).

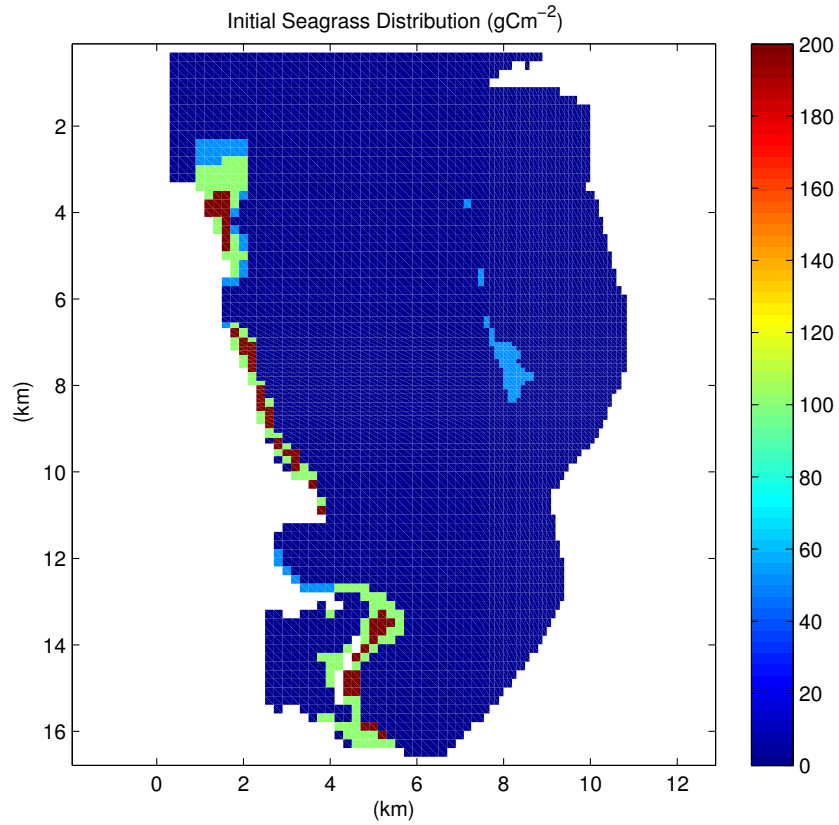


Figure 3.1. Initial seagrass distribution and biomass.

4 DATA REVIEW

4.1 Water Column Data

Water column data were sourced for Cockburn Sound by the Water Corporation. The data included water column profiles of temperature, salinity and dissolved oxygen at stations DO1, DO2 and DO4, plus a station 2 km north of Garden Island (WC8), collected on 11 occasions during the period Feb 2005 to Apr 2006: 23 Feb, 6 Apr, 25 May, 11 Jul, 10 Aug, 28 Oct, 14 Nov, 13 Dec in 2005; 15 Feb, 14 Mar, 4 Apr in 2006. Water quality data was available for each sampling event and location, providing light attenuation and surface and bottom values of NO₃-NO₂, NH₄, PO₄ and chlorophyll *a*. Profile data of temperature, salinity and dissolved oxygen was available for station DO7 for 15 Dec 2005, 24 Feb, 10 Mar, 11 Apr, 12 Apr in 2006; stations DO1, DO2 and DO4 were also profiled on these dates. More intensive profile data for the summer months (Dec-Mar) was available from the Cockburn Sound Management Council (provided by Oceanica Consulting Pty Ltd). This data included weekly water column profiles of temperature, salinity and dissolved oxygen at stations close to DO1 (CS04) and DO2 (CS08), a station 2km west of DO7 near the Causeway and Mangles Bay (CS11), and a station 1km south of the Garden Island (CSSC).

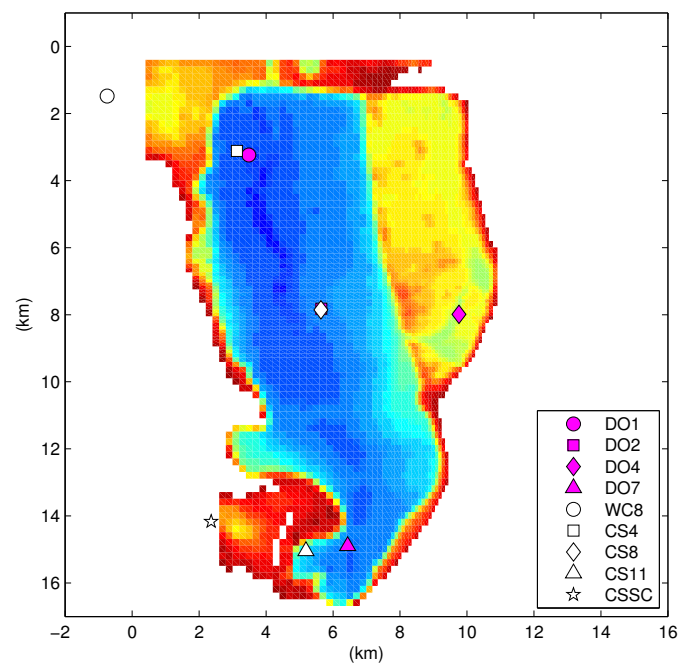


Figure 4.1. Location of sampling stations in Cockburn Sound.

4.2 Automated logger data

Dissolved oxygen data was also available from automated loggers at stations DO1, DO2 and DO7 and from the Real-Time Management System (RTMS) stations from the Water Corporation. These data have proved to have significant problems with measurement drift, and are therefore unreliable for periods longer than a few days since calibration. Comparisons between the logger measurements of dissolved oxygen and those of the profiler at the same depths have shown great disparity (Figure 4.2), with the loggers generally measuring lower values than the profiler, in some cases by up to 2 mg L^{-1} . Note that independent assessment of these sensors has demonstrated significant problems with drift after deployment (ACT 2004), and similar problems appeared to have occurred in Cockburn Sound as the comparison at deployment (solid symbols) is relatively good, however at other times the comparison is poor. As the profiler was calibrated prior to every deployment, we use these data for model validation.

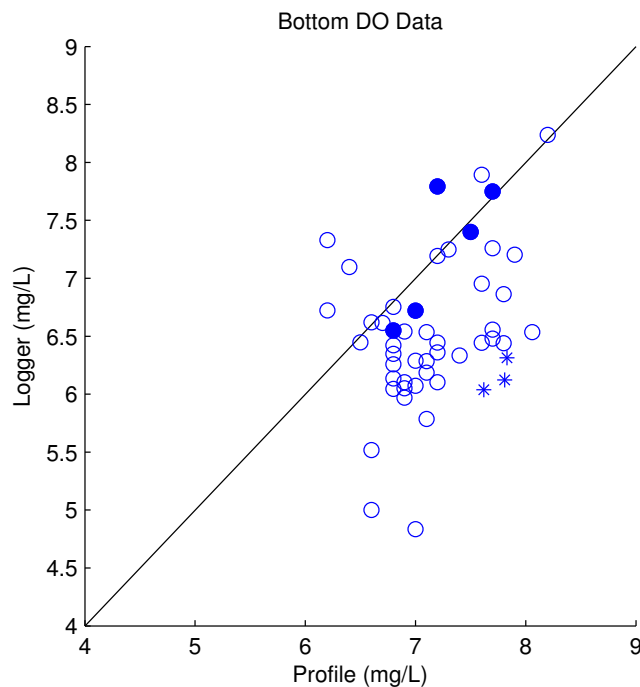


Figure 4.2. Comparison of dissolved oxygen measured by profiler and logger at the bottom of Cockburn Sound. Circles indicate logger data, stars indicate RTMS data. Filled symbols indicate dates on which calibration of the loggers took place. Solid line shows the 1:1 fit.

4.3 Ocean Boundaries

Forcing of the oceanic boundaries in the simulations for temperature, salinity and dissolved oxygen came from profiles collected at boundary stations WC8 and CSSC. For nutrients, concentrations were set to a constant average value based on measurements during water quality sampling events (Figure 4.3).

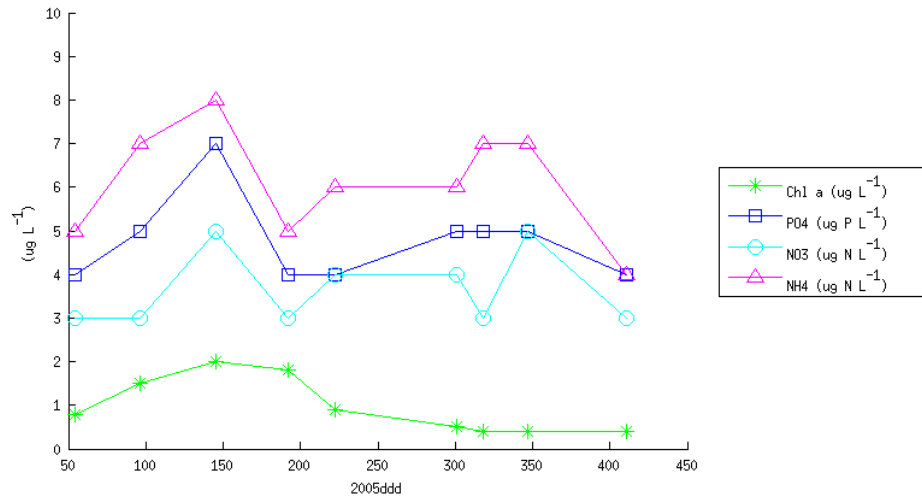


Figure 4.3. Nutrient and chlorophyll data at the boundaries of Cockburn Sound.

5 MODEL VALIDATION (CONTROL SIMULATION)

Two control simulations were undertaken for validation, corresponding to periods of greatest concern regarding dissolved oxygen and most data for available for validation and boundary forcing.

1. Summer 2005/06: 13 Dec 2005 (Day 2005347) – 24 Feb 2006 (Day 2005420)
2. Early Autumn 2006: 6 Mar 2006 (Day 2005430) – 3 May 2006 (Day 2005488)

5.1 Ecological Parameters

The major focus of the investigation was dissolved oxygen, however in order to capture the dominant processes it is important to ensure other water quality variables are also accurately simulated. Results for the simulation of algae, nutrients and seagrass are presented in Figure 5.1. Although the data is extremely sparse for the period of simulation (with generally only one data point available), the results show that the concentrations of these variables are approximately constant throughout the simulation. Note that the nutrient drawdown in the summer simulation is captured, along with the seasonal variability in algal concentrations. Also note that the seagrass biomass was approximately constant during the simulations. These results indicate that basic ecological dynamics of the system are captured in the ELCOM-CAEDYM parameterisation. Note that no re-calibration of ELCOM-CAEDYM was required to reproduce these results. Parameter values were taken from simulations conducted in Marmion Marine Park by Hillmer and Imberger (in press).

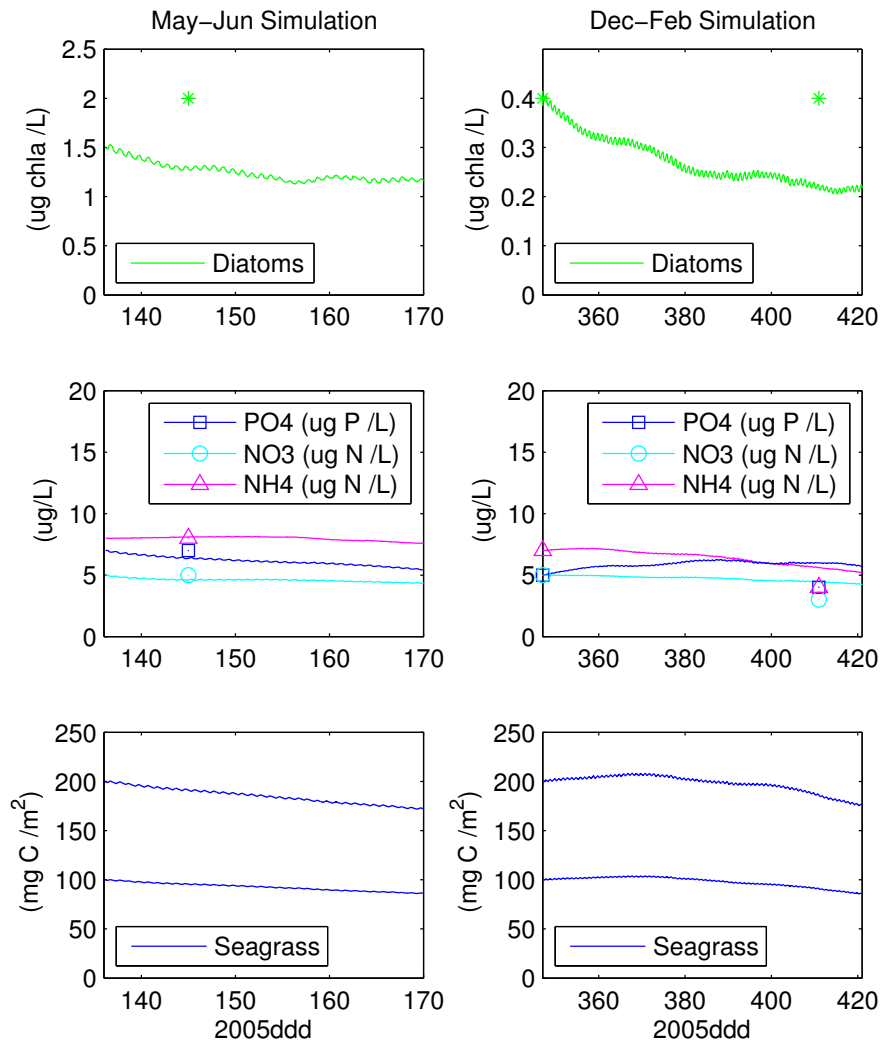


Figure 5.1. Time series of spatial average simulated concentration of diatoms and nutrient species during simulations (lines) and average field measurements (symbols), and a time series of simulated seagrass biomass at two locations.

5.2 Dissolved Oxygen

5.2.1 Summer 2005/06 Validation Simulation

Results from the Summer 2005/06 validation simulation are presented in Figure 5.2 to Figure 5.6. The impact of all processes impacting dissolved oxygen in Cockburn Sound is presented in Figure 5.2, where for each timestep the processes in the domain are integrated. This clearly shows that over the duration of the simulation, the dominant source of dissolved oxygen is oceanic (during the early part of the simulation) and atmospheric exchange (during the latter part of the simulation), and the dominant sink of dissolved oxygen is the sediment oxygen demand. The dominance of the oceanic exchange during the early part of the simulation is due to the higher dissolved oxygen

concentrations at the boundaries of the domain during this time (Figure 5.4). While seagrasses show a large diurnal production/respiration diurnal signal, there is little net effect. The impact of phytoplankton production/respiration and nitrification are negligible. At a single point in the domain, chosen here to be at station DO7 at 20.5 metres depth, a similar pattern emerges (Figure 5.3) where mixing and advection is the major source of dissolved oxygen and sediment consumption is the major sink. No seagrass is present at this location, hence there is no local direct impact, however an indirect impact is possible on local oxygen conditions through advection from nearby seagrass beds.

Comparisons of the dissolved oxygen profiles produced by ELCOM-CAEDYM and those measured in the field are presented in Figure 5.4 and Figure 5.5. These generally show good correlation between the measured and simulated results at all sites, with the absolute values and nature of the vertical stratification captured. There are some cases where the measured data and simulated data diverge (eg DO1, DO2 and DO7 on 2005353), however the measurements are questionable on at least some of these occasions. For example, the measurements on 2005349, four days earlier, at DO1 and DO2 were 0.5 mg L^{-1} lower, indicating a massive input of dissolved oxygen into the system over a very short period which does not seem to be physically or biologically reasonable.

Further validation of the simulated dissolved oxygen is presented in Figure 5.6, which focuses on the bottom data point from the profiles presented in Figure 5.4 and Figure 5.5. This shows that ELCOM-CAEDYM reproduces the summer drawdown in the bottom dissolved oxygen measured by the profiler in the three deep water locations (DO1, DO2, DO7). Note that the lowest dissolved oxygen concentrations are simulated at DO7, the same location as the lowest measured concentrations with values approaching 6 mg L^{-1} . The values and trends in surface dissolved oxygen is also captured (Figure 5.7).

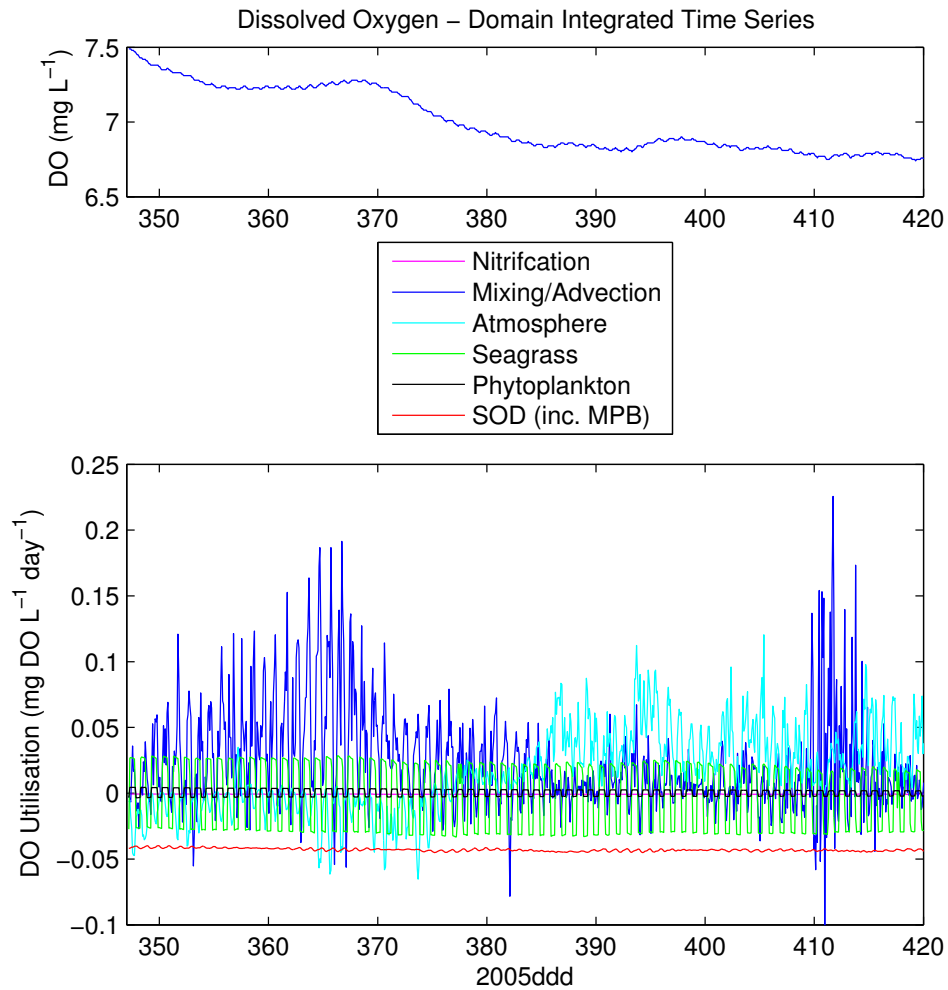


Figure 5.2. Time series of spatial and depth average simulated DO concentration (top panel) and DO utilisation (bottom panel, positive/negative values correspond to production/consumption of DO).

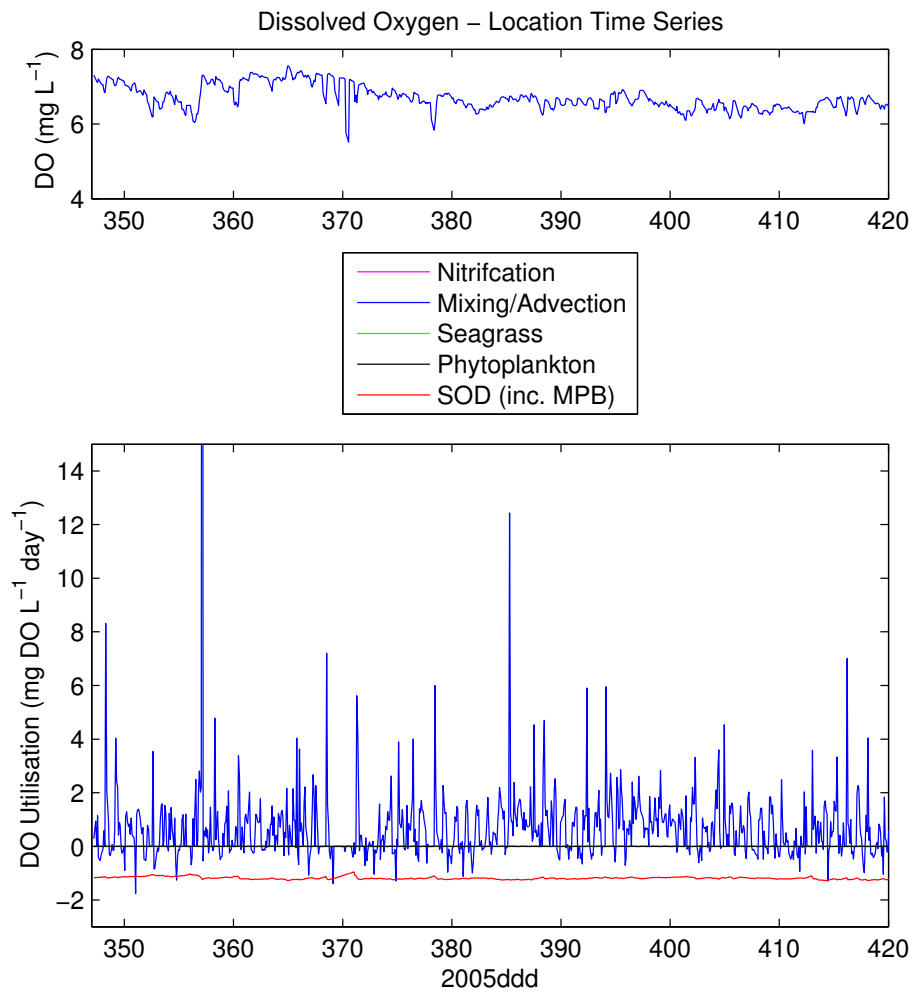


Figure 5.3. As for Figure 5.2, simulated DO concentration and DO Utilisation at 20.5 m depth at station DO7.

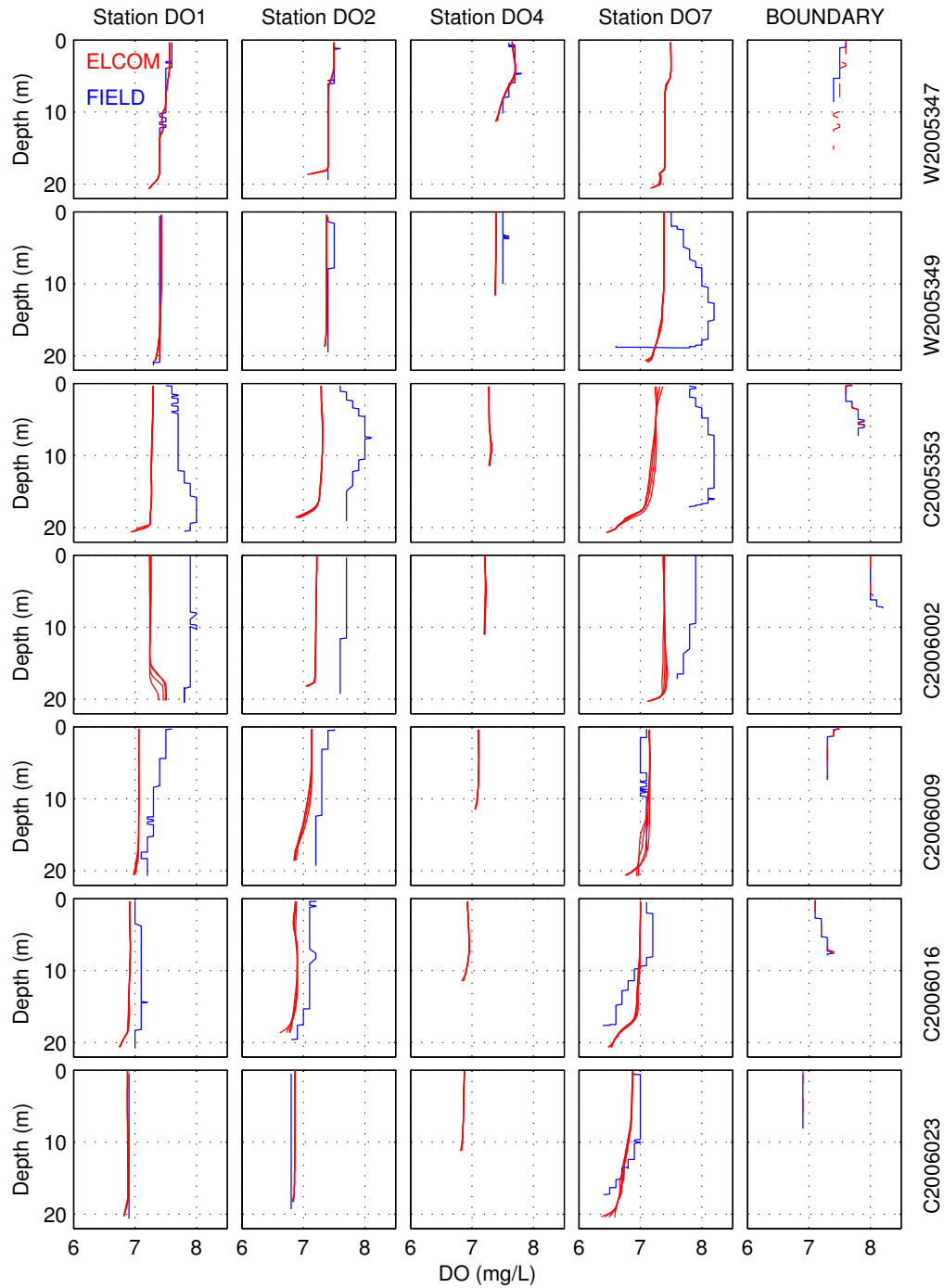


Figure 5.4. Comparison of measured (blue) and simulated (red) dissolved oxygen profiles for four locations (DO1, DO2, DO4, DO7) in the Sound. The day of collection is shown on the right (as yyyyddd), with each row representing a sampling day and each column representing a sampling location. The letter 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 monitoring (C, CS stations).

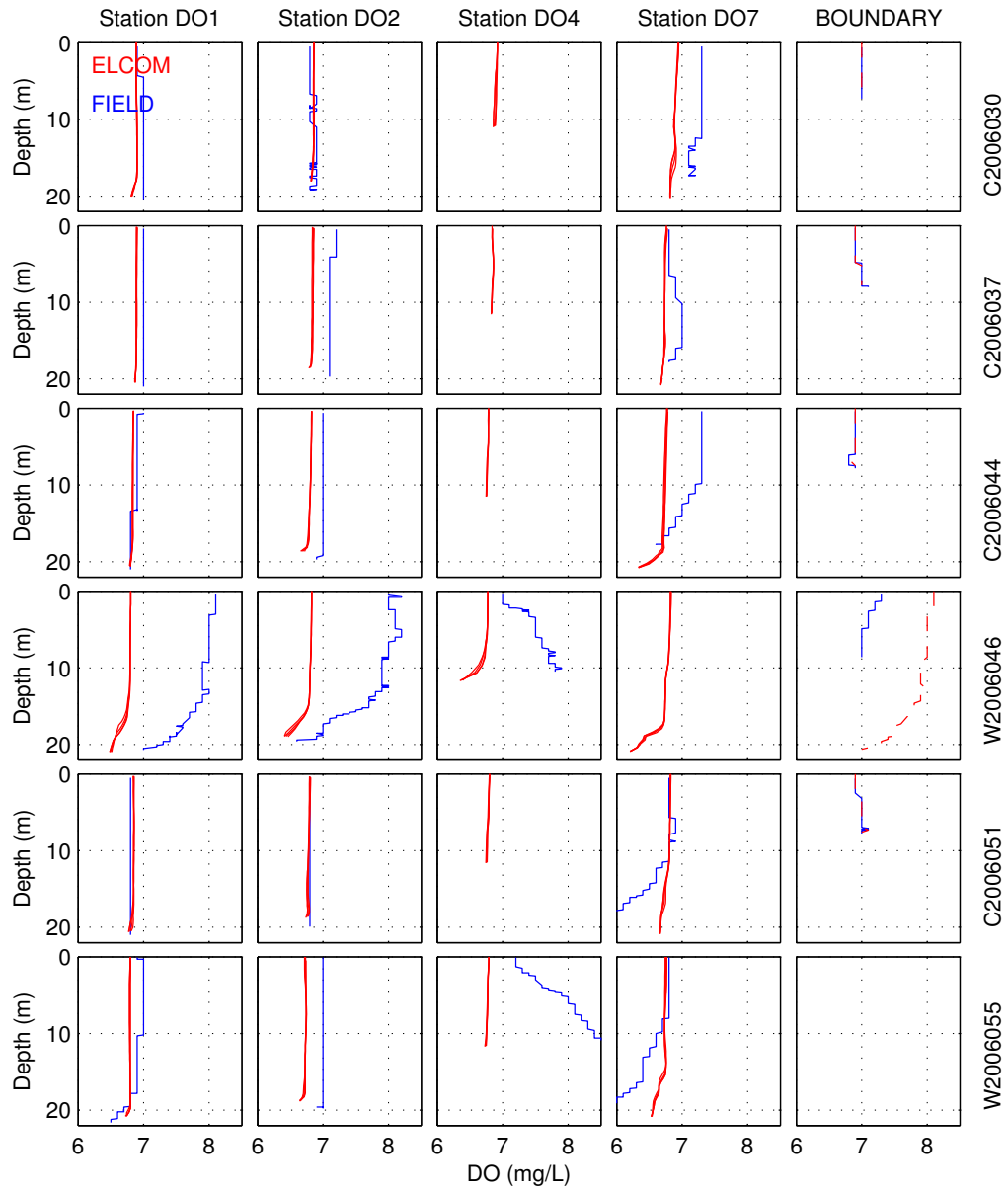


Figure 5.5. As for Figure 5.4, but for Jan-Feb 2006.

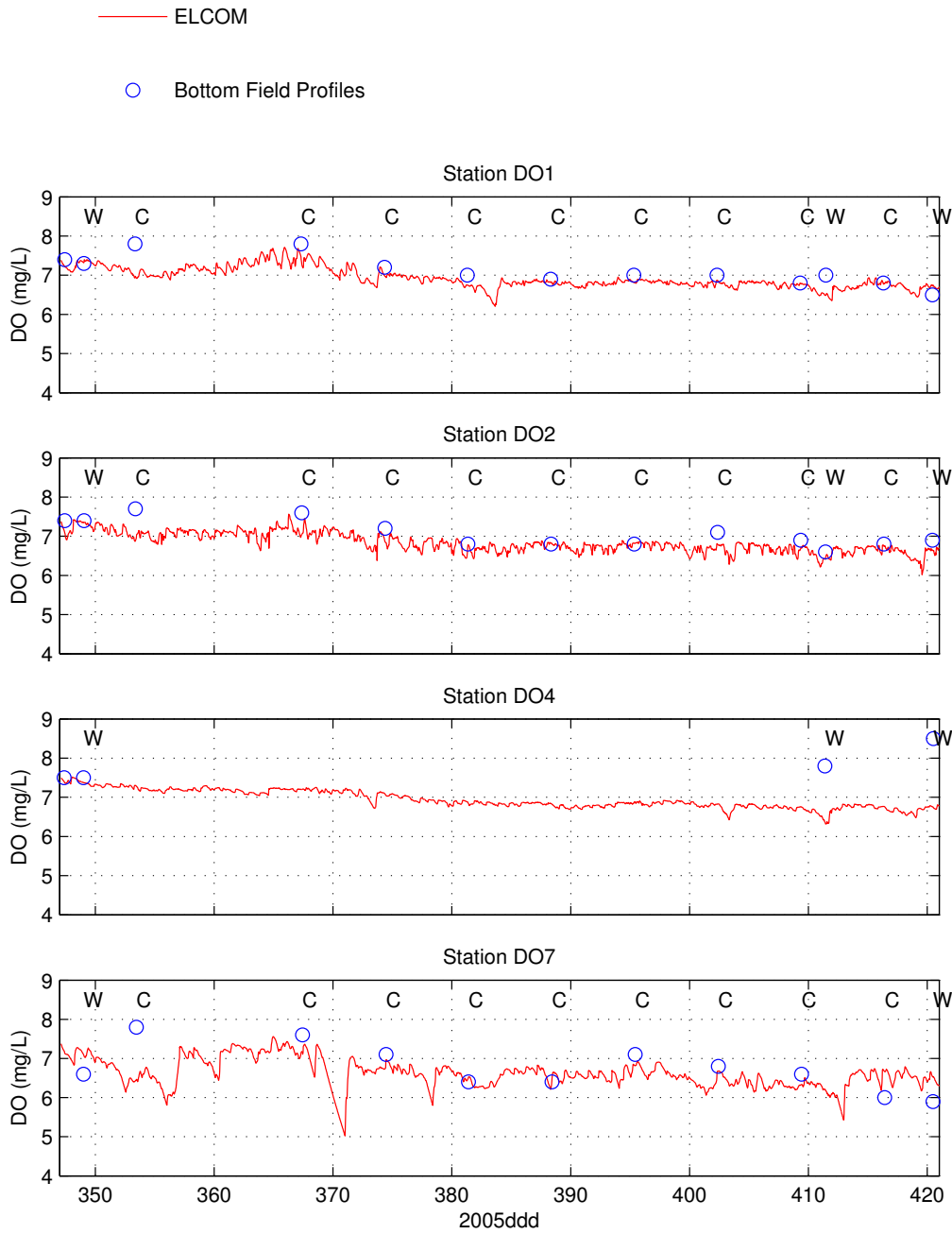


Figure 5.6. Time series of simulated bottom (deepest grid cell in water column) DO concentration (red line) and bottom measurements from profiles (blue circles), at stations DO1, DO2, DO4 and DO7 (Letters above second panel indicate sampling program, see Figure 5.4 caption.)

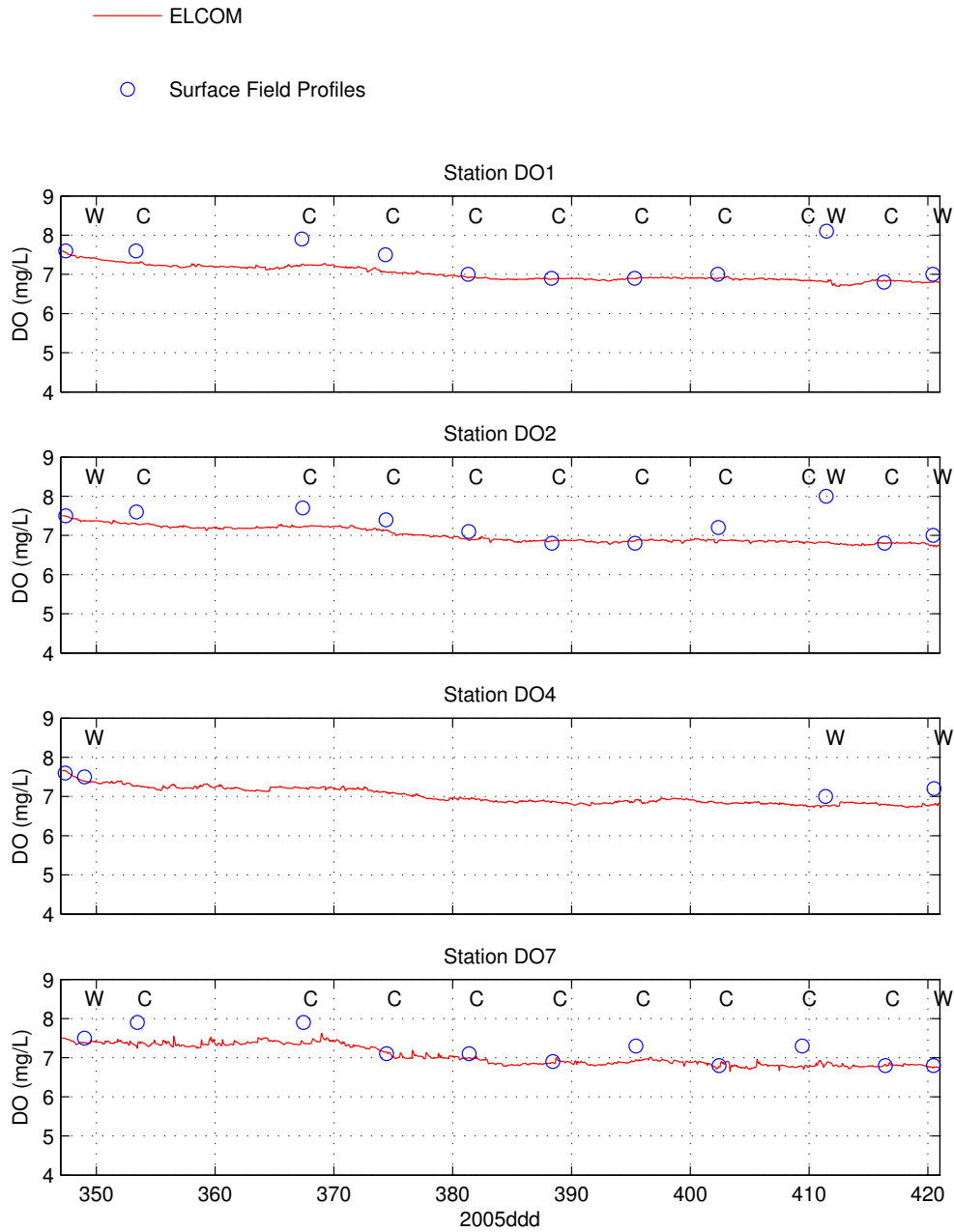


Figure 5.7. As for Figure 5.6, but for surface measurements.

5.2.2 Early Autumn 2006 Validation Simulation

Results for the autumn 2006 simulation are presented in Figure 5.8 to Figure 5.10. The simulation results show excellent comparison with the field data. In particular, the oxygen drawdown at depth on days 2006065 and 2006069 (Figure 5.8) is reproduced, and is followed by the simulation of vertically near-homogenous dissolved oxygen concentrations. This is also evident in the

comparison of the bottom measurements (Figure 5.10), which shows ELCOM-CAEDYM replicates the jump in dissolved oxygen concentrations from less than 6 mg L⁻¹ to approximately 7 mg L⁻¹.

The dominant processes impacting oxygen are presented in Figure 5.12 and Figure 5.13. Dissolved oxygen concentrations actually increase during this time as sediment oxygen consumption is reduced due to lower water temperatures.

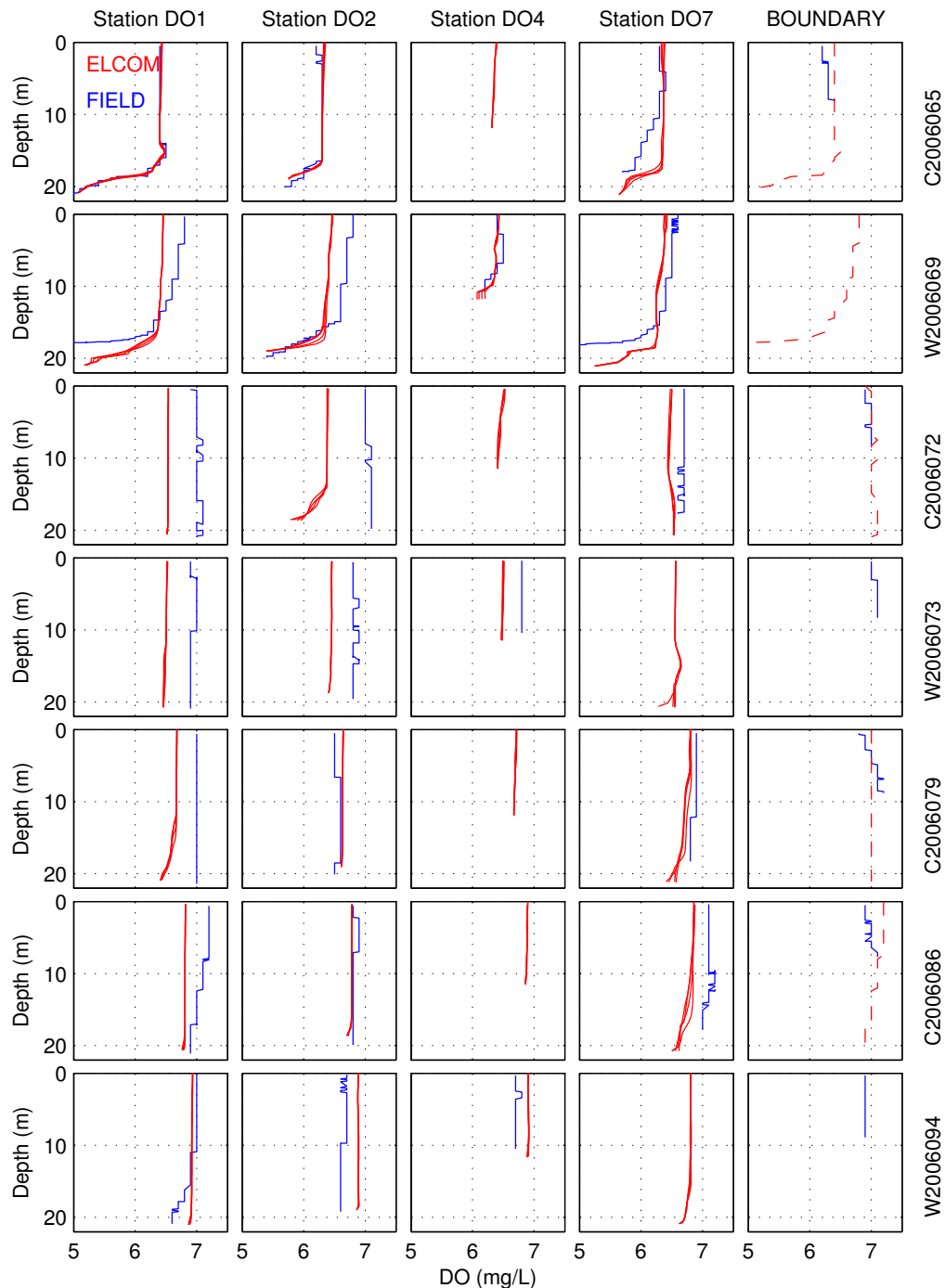


Figure 5.8. As for Figure 5.4, but for Mar 2006.

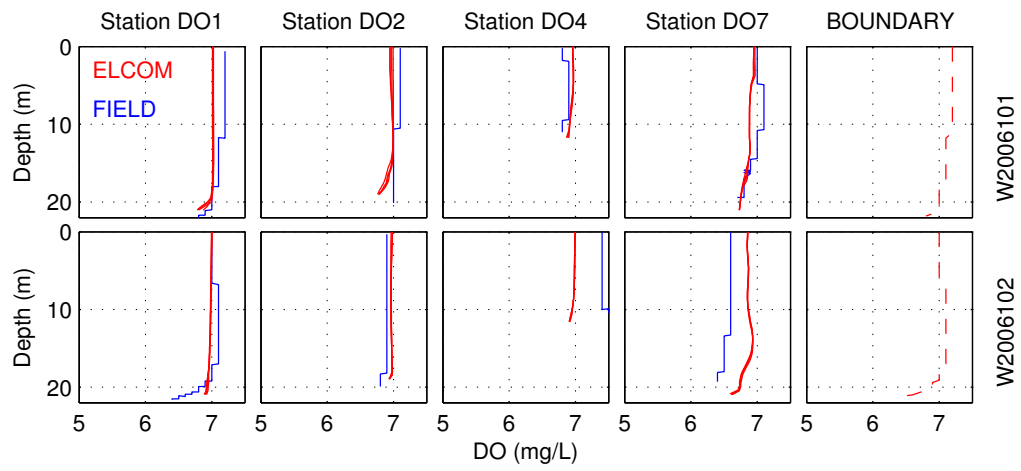


Figure 5.9. As for Figure 5.4, but for Apr 2006.

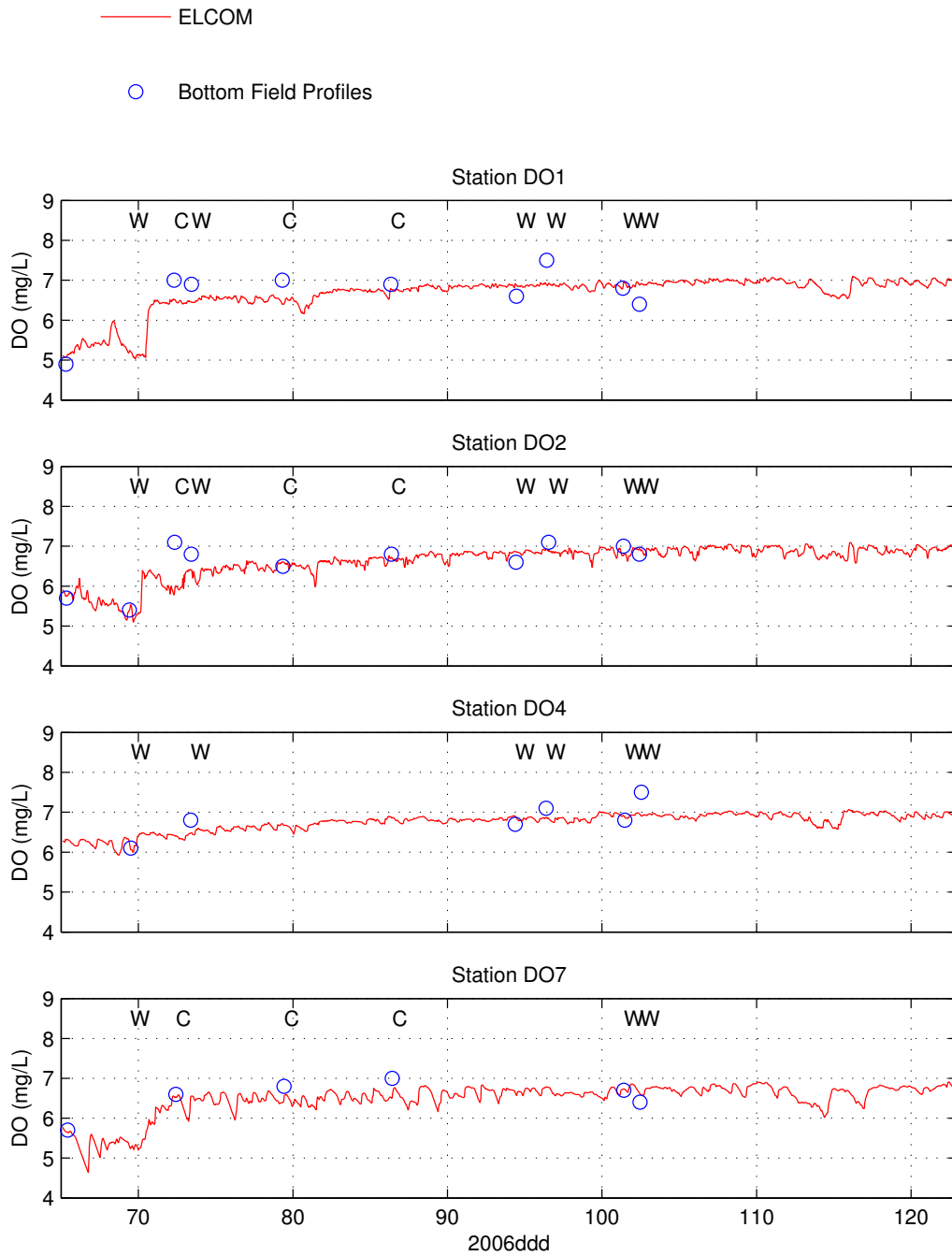


Figure 5.10. As for Figure 5.6, but for Mar-Apr 2006 in the bottom waters.

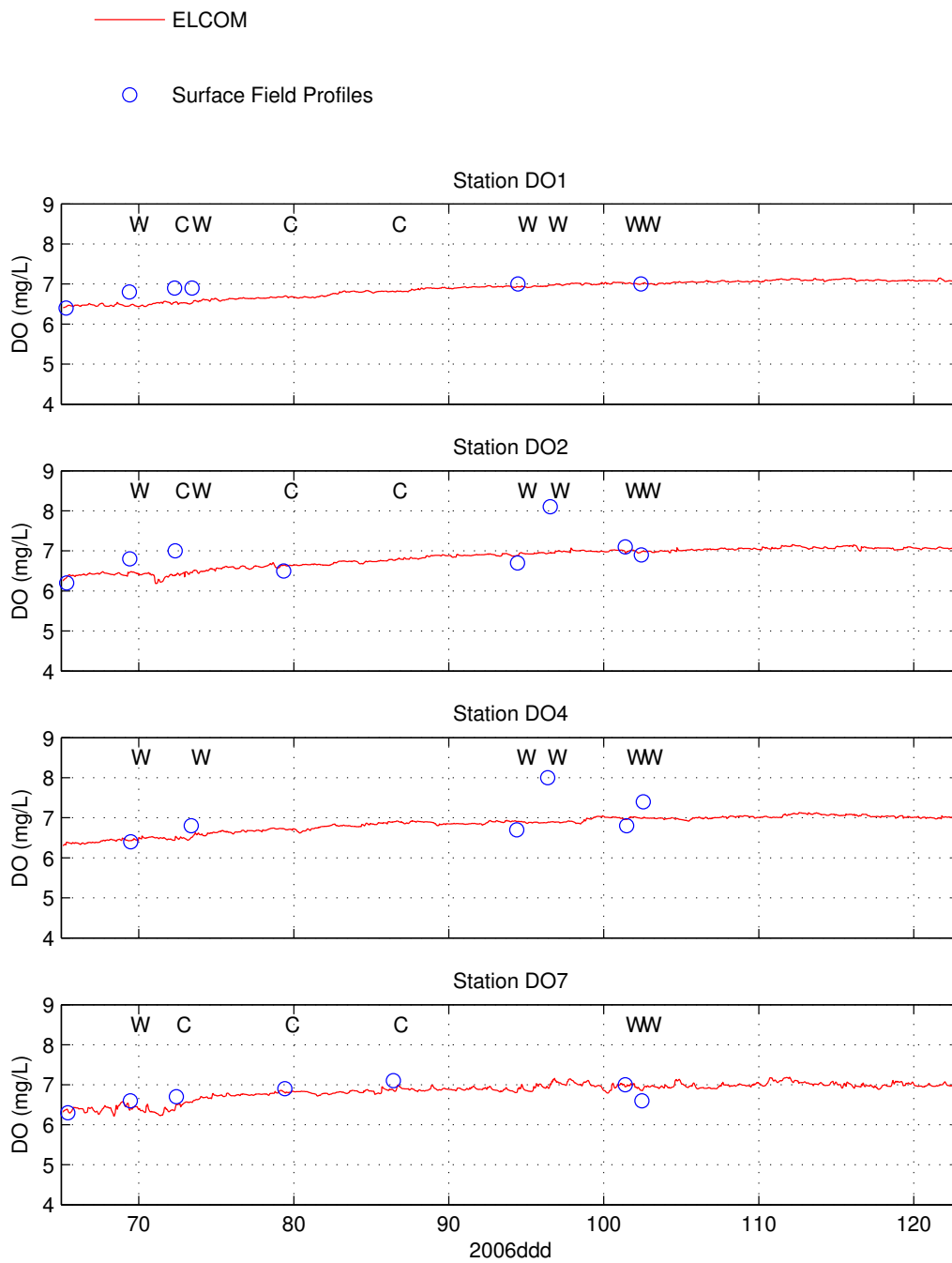


Figure 5.11. As for Figure 5.6, but for Mar-Apr 2006 in the surface layer.

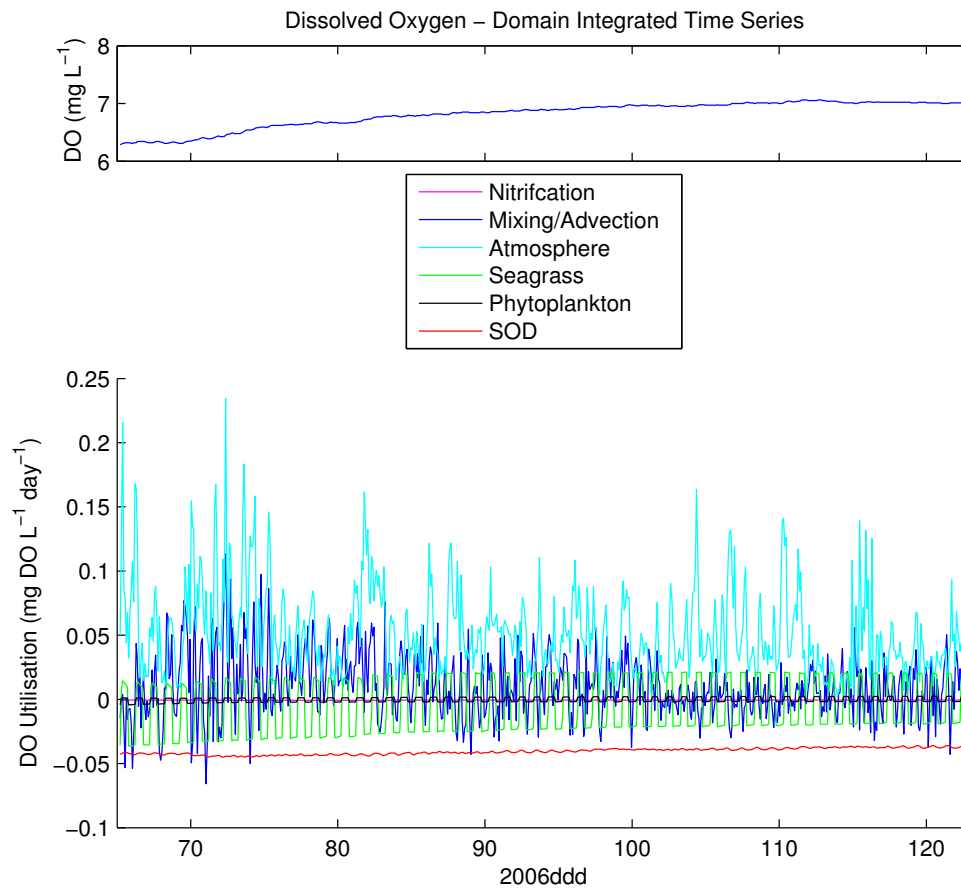


Figure 5.12. Time series of spatial and depth average simulated DO concentration (top panel) and DO Utilisation (bottom panel, positive/negative values correspond to production/consumption of DO).

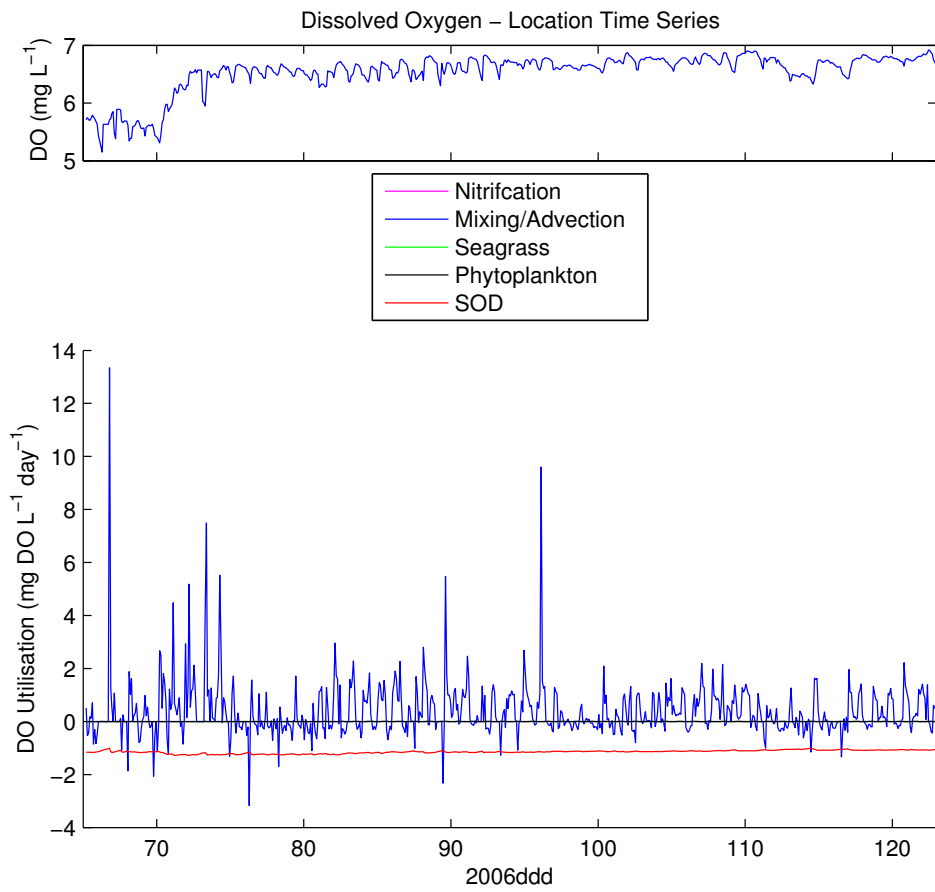


Figure 5.13. As for Figure 5.12, simulated DO concentration and DO Utilisation at 20.5 m depth at station DO7.

6 DESALINATION DISCHARGE SIMULATIONS

6.1 Summer 2005/06 Desalination Simulation

The desalination discharge was configured as outlined in the accompanying hydrodynamic report. The concentration of dissolved oxygen in the water leaving the diffuser was set to the ambient concentration in the vicinity of the diffuser. Results are presented in Figure 6.1 for the dissolved oxygen at the bottom for four stations in the Sound and compared with the control simulation. It is clear that there is no significant difference in dissolved oxygen conditions for stations DO1, DO2 and DO7 in the deep basin of Cockburn Sound. For station DO4, near the discharge point, the dissolved oxygen is slightly lower than the control simulation ($< 0.5 \text{ mg L}^{-1}$).

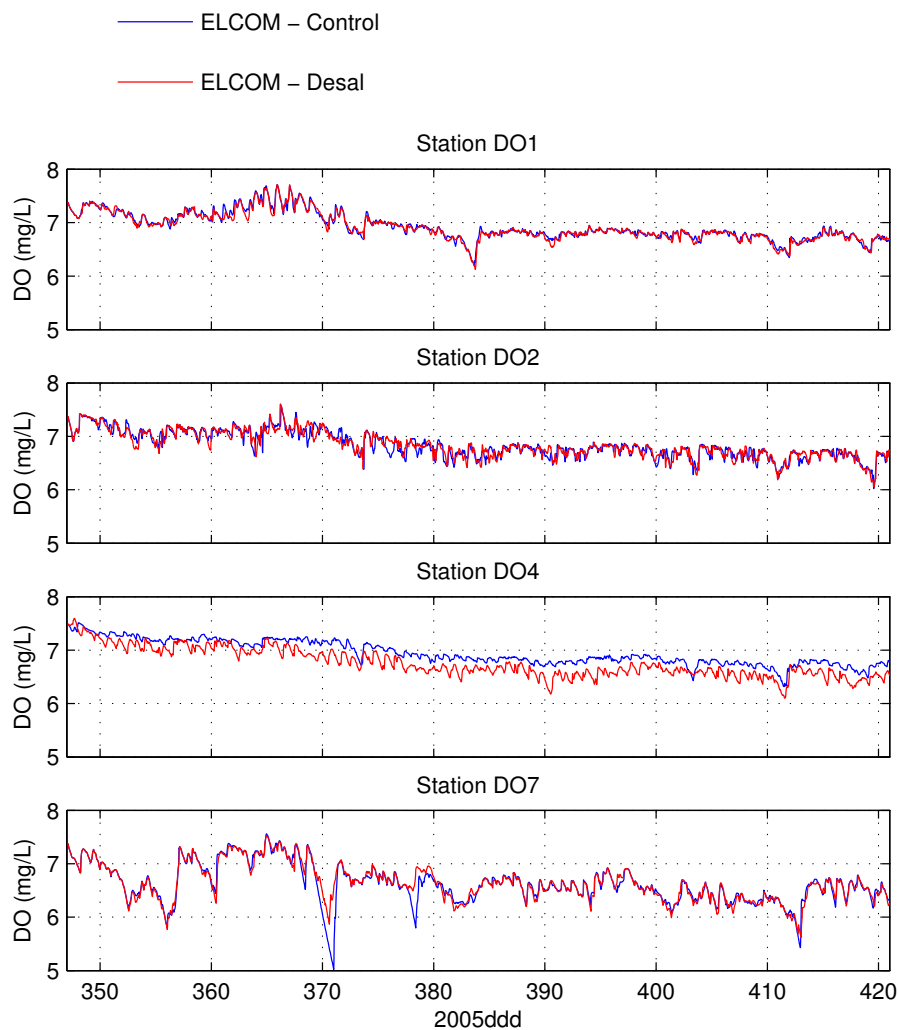


Figure 6.1. Time series of simulated bottom DO concentration for control (blue) and desalination (red line) simulations at stations DO1, DO2, DO4 and DO7.

6.2 Early Autumn 2006 Desalination Simulation

Results for the desalination plant discharge during autumn 2006 are presented in

Figure 6.2. As for the summer simulation, these results show no impact of the desalination plant on dissolved oxygen in the deep basin of Cockburn Sound, and only minor differences on the eastern shelf of $< 0.5 \text{ mg L}^{-1}$ close to the discharge point.

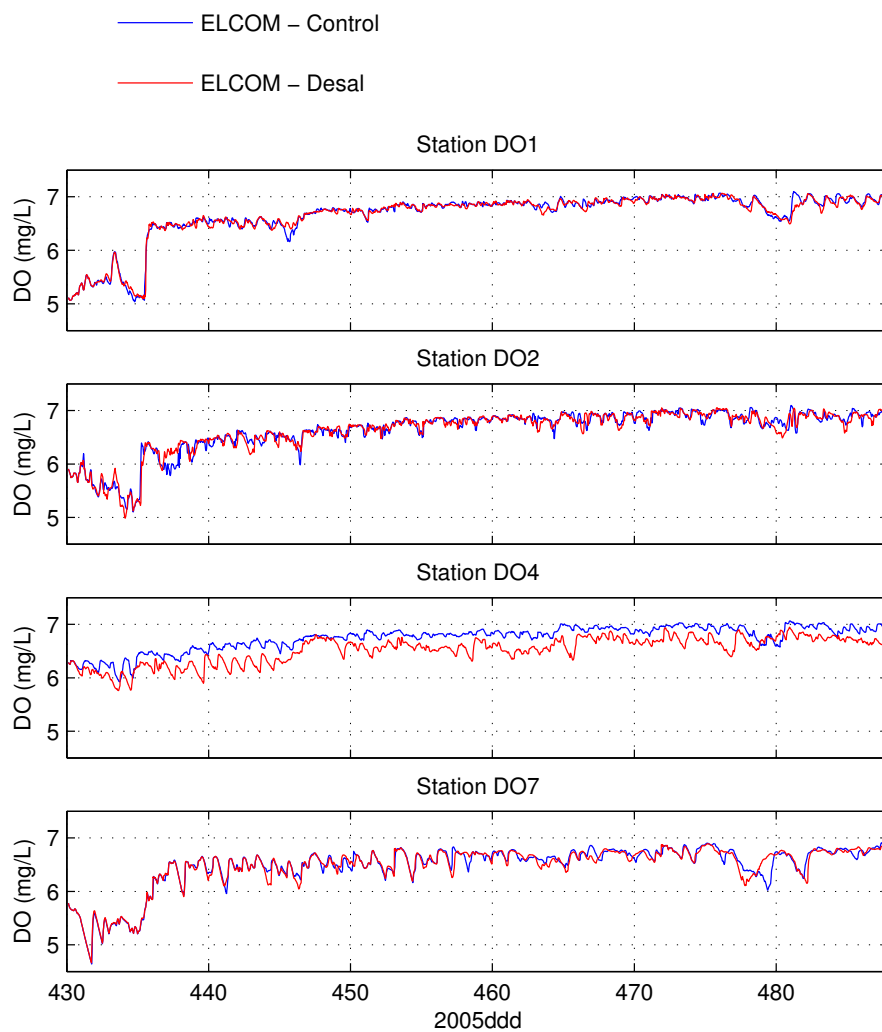


Figure 6.2. As for Figure 6.1, but for Mar-Apr 2006.

7 Additional scenarios

Four additional scenarios were investigated using the following simulations:

1. Late Autumn 2005 control simulation: 16 May 2005 (Day 2005136) – 19 Jun 2005 (Day 2005170)
2. Late Autumn 2005 desalination simulation: 16 May 2005 (Day 2005136) – 19 Jun 2005 (Day 2005170)
3. Artificial Low Wind Event: 16 May 2005 (Day 2005136) – 19 Jun 2005 (Day 2005170); as for Late Autumn 2005, except wind speed was reduced to 1 m/s for 11 days between 23 May 2005 (Day 2005143) – 2 Jun 2005 (Day 2005153).
4. James Point Port Construction: as for Artificial Low Wind simulation, except bathymetry was modified to include expected changes to bathymetry due to future James Point port construction (Stage 1).

The autumn 2005 simulations were conducted to complement the autumn 2006 simulations presented above, as this period of the year is considered to have a higher risk of low oxygen conditions. The low wind simulation was conducted to determine how quickly this would impact dissolved oxygen conditions, and the James Point port simulation was conducted to determine the cumulative impact of development in the Sound.

7.1 Late Autumn 2005 Control Simulation

Comparison between simulated and field measurements are presented in Figure 7.1 and Figure 7.2. Only one field data point (at three locations) is available during this period, however the simulations indicate the dissolved oxygen remains relatively constant during this time.

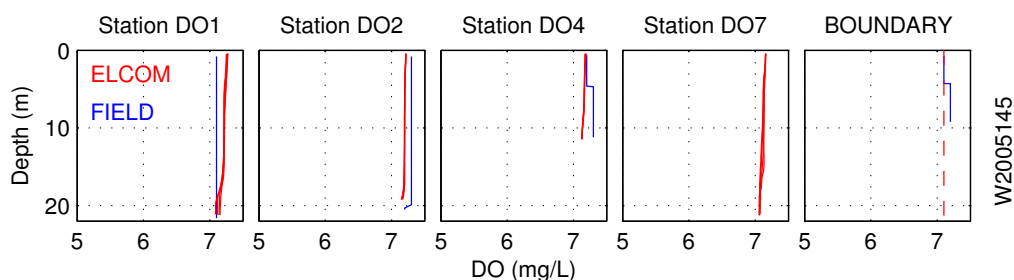


Figure 7.1. Simulated (red) and field (red) profiles of dissolved oxygen concentration at stations D01, D02, D04 and D07 on day 2005145 during May-Jun 2005 simulation period.

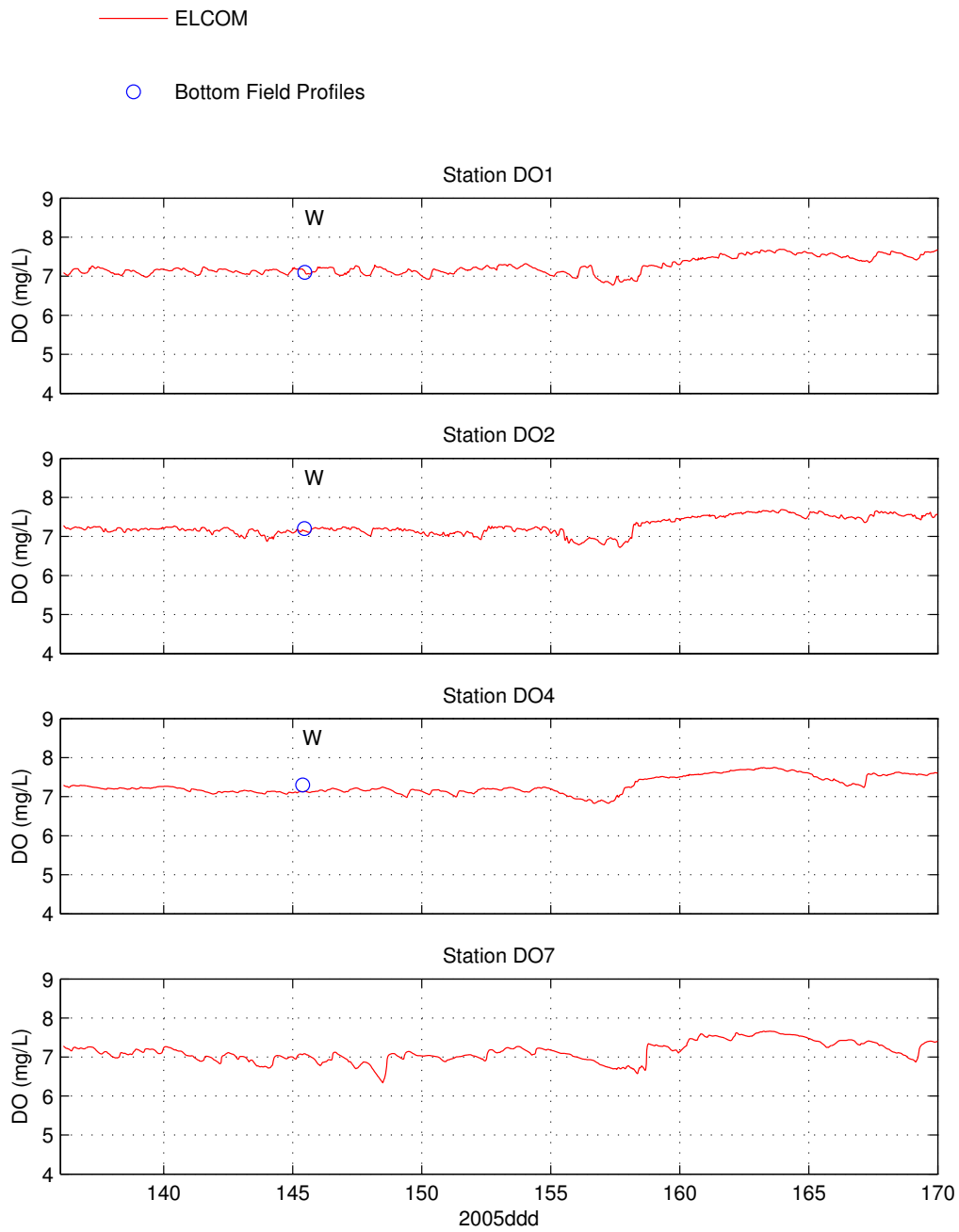


Figure 7.2. Time series of simulated bottom DO concentration (red line), and bottom measurement from field profile (blue circle) on day 2005145, at stations DO1, DO2, DO4 and DO7.

7.2 Late Autumn 2005 Desalination Simulation

Results for the desalination discharge are compared with the base case shown above in Figure 7.3. This shows negligible impact of the desalination plant discharge on dissolved oxygen conditions at the bottom in the deep waters of Cockburn Sound, and only minor differences ($< 0.5 \text{ mg L}^{-1}$) in the shallow waters of the eastern shelf in the vicinity of the diffuser as with previous simulations presented for summer 2005/2006 and autumn 2006.

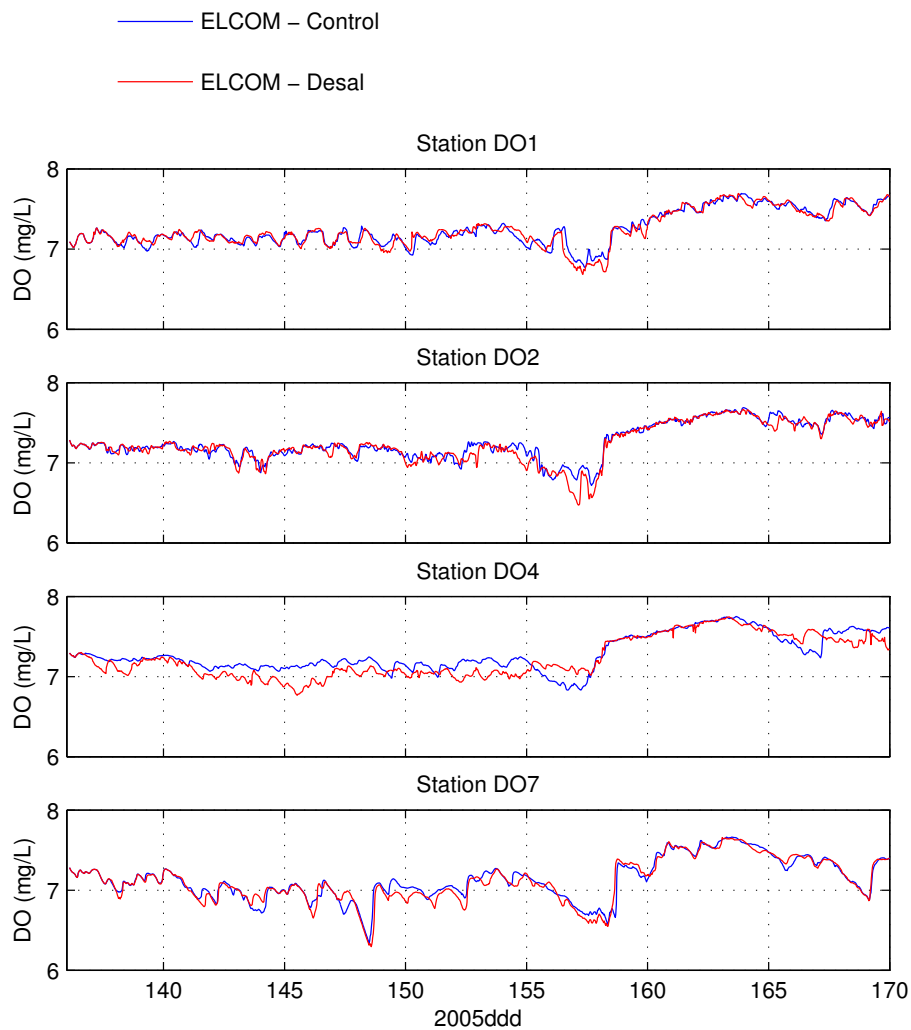


Figure 7.3. Time series of simulated bottom DO concentration for control (blue) and desalination (red line) simulations at stations DO1, DO2, DO4 and DO7.

7.3 Artificial Low Wind Event

To determine the impact of an extended period of low wind, a simulation was conducted in May whereby the wind was reduced to artificially low levels (Figure 7.4) for a period of 11 days. The control simulation showed the oxygen drawdown was approximately 1 mg L^{-1} in the bottom water over this period, reaching a minimum concentration of approximately 5.5 mg L^{-1} at station DO2 in the central part of the Sound.

Inclusion of the desalination plant discharge into the low wind simulation (Figure 7.5) shows little impact of the desalination discharge on oxygen concentrations in the bottom waters, even under low wind conditions for 11 days, with a similar minimum concentration of 5.5 mg L^{-1} observed for approximately an extra day compared to the base case low wind simulation.

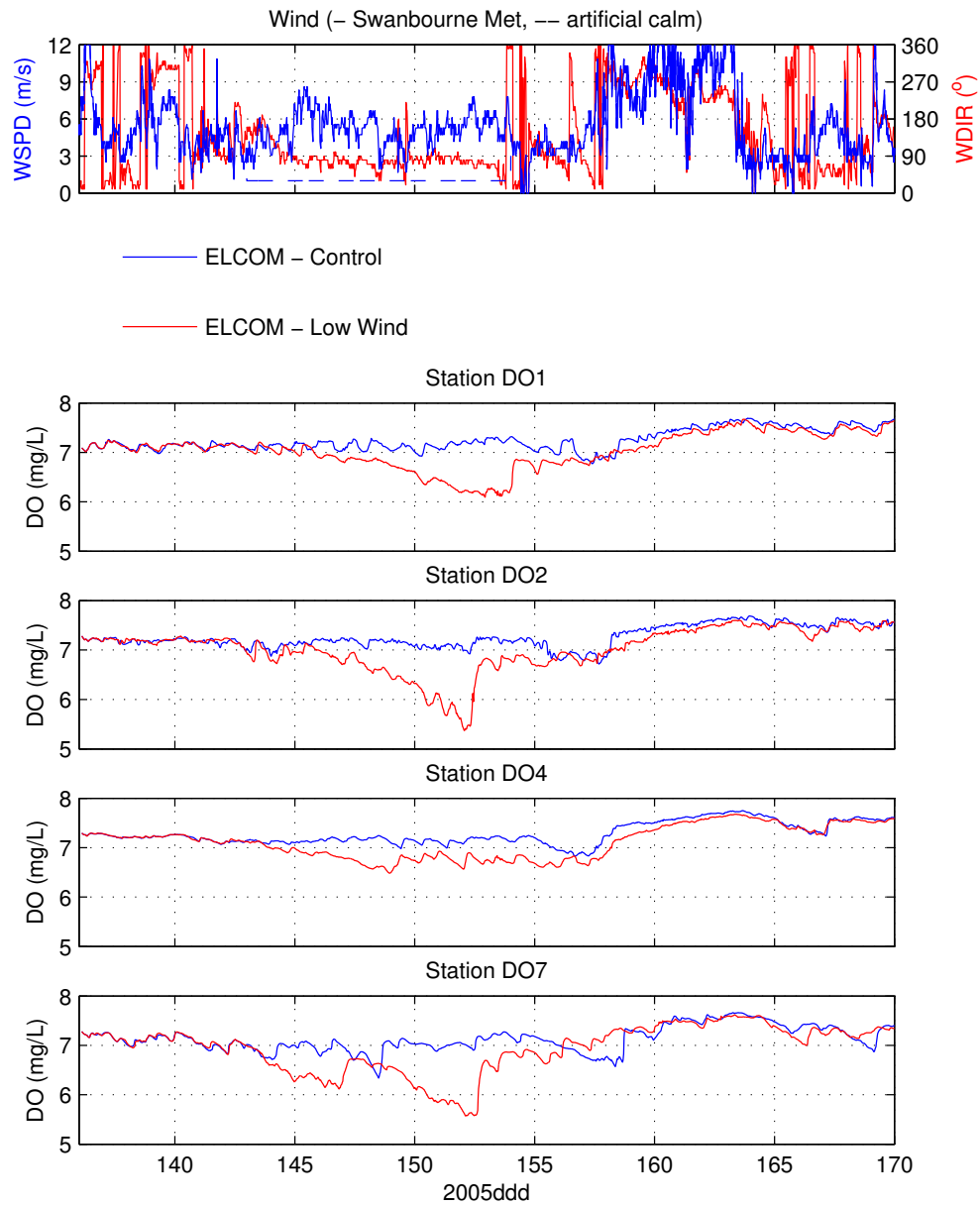


Figure 7.4. Time series of bottom DO concentration simulated using Swanbourne wind speed (blue) or including artificial low wind period (red), at stations DO1, DO2, DO4 and DO7; Swanbourne wind speed (blue), with and without artificial calm, and wind direction (red) (top panel).

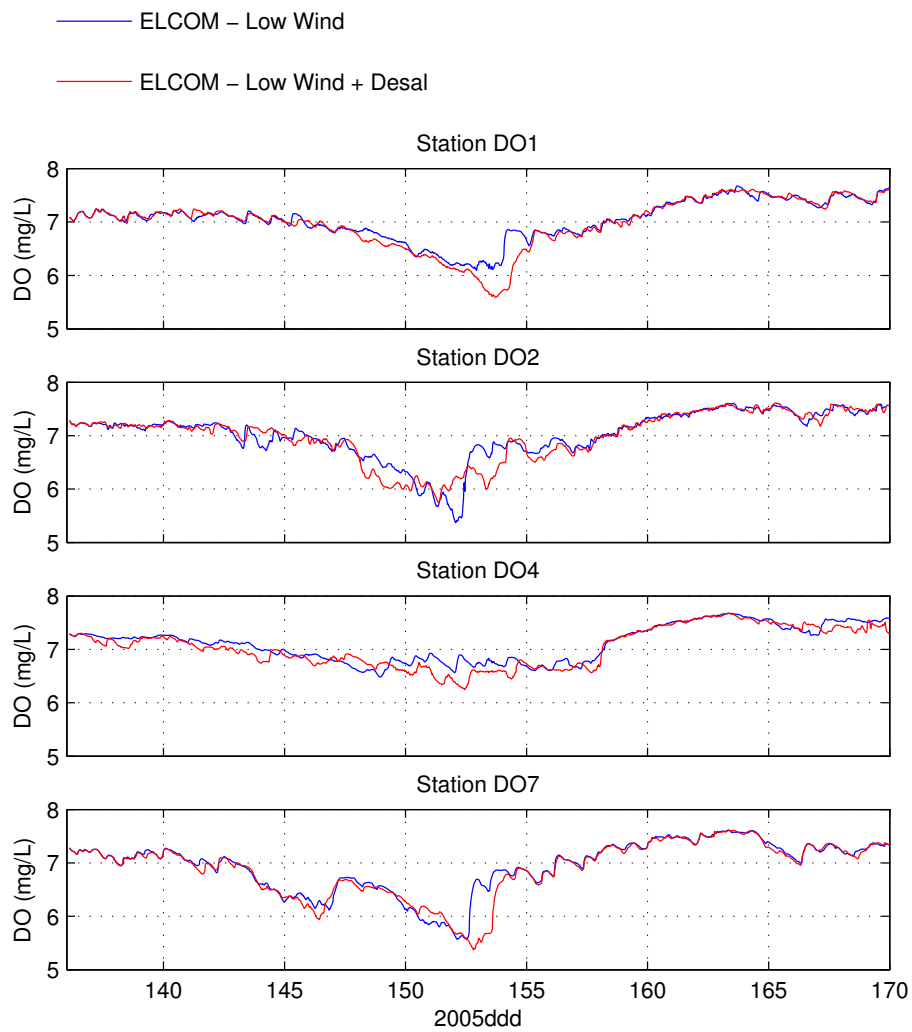


Figure 7.5. As for Figure 7.4, but compares the base low wind simulation (blue) and the low wind simulation that includes the desalination discharge (red).

7.4 James Point Port Construction

To determine the cumulative impacts of development in Cockburn Sound, a simulation was conducted with the James Point port development (Stage 1) included in the model. The hydrodynamic modelling showed no impact of the development on stratification in the Sound. Results for the dissolved oxygen are presented in Figure 7.6 for the comparison of the low wind case with and without the James Point development, and in Figure 7.7 for the comparison of the low wind case with the James Point development with and without the desalination discharge. The results demonstrate that for a worst case scenario of an 11 day period of extremely low wind speeds, the James Point development and the desalination discharge would only see oxygen concentrations drop to a minimum of approximately 5.5 mg L^{-1} at the base of the water column.

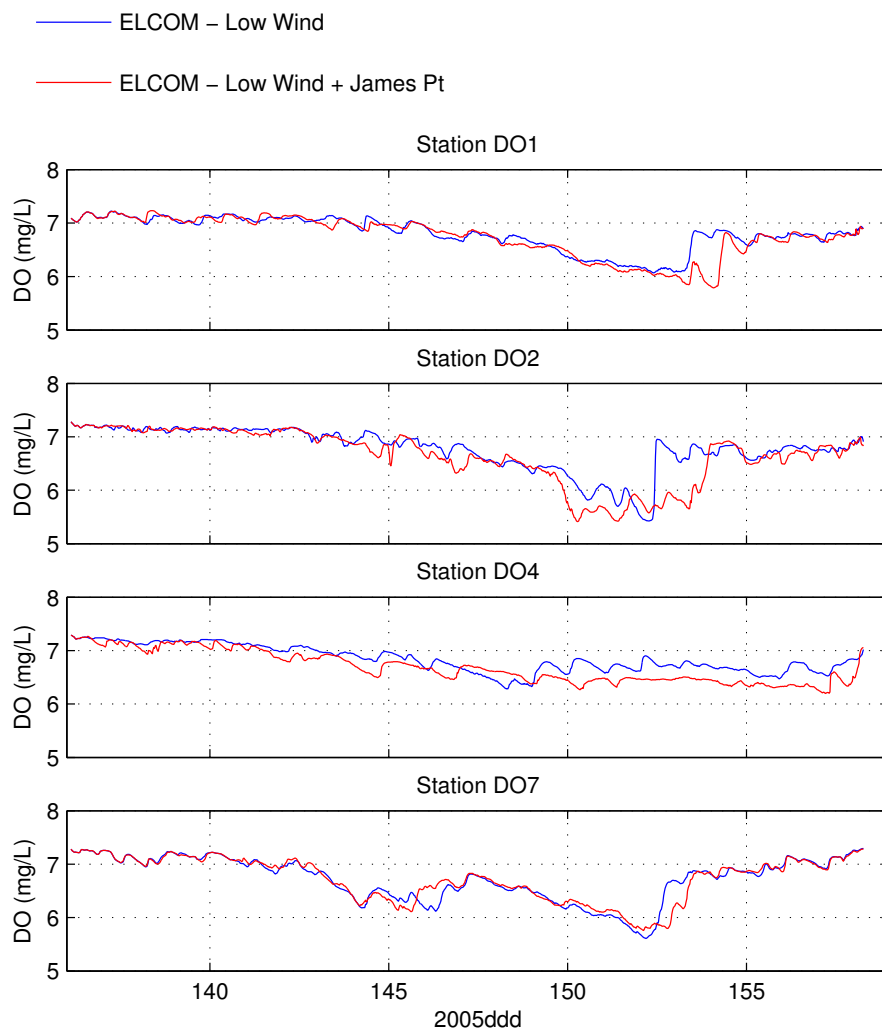


Figure 7.6. As for Figure 7.4, but compares the base low wind simulation (blue) and the low wind simulation that includes the James Point Port Construction (red).

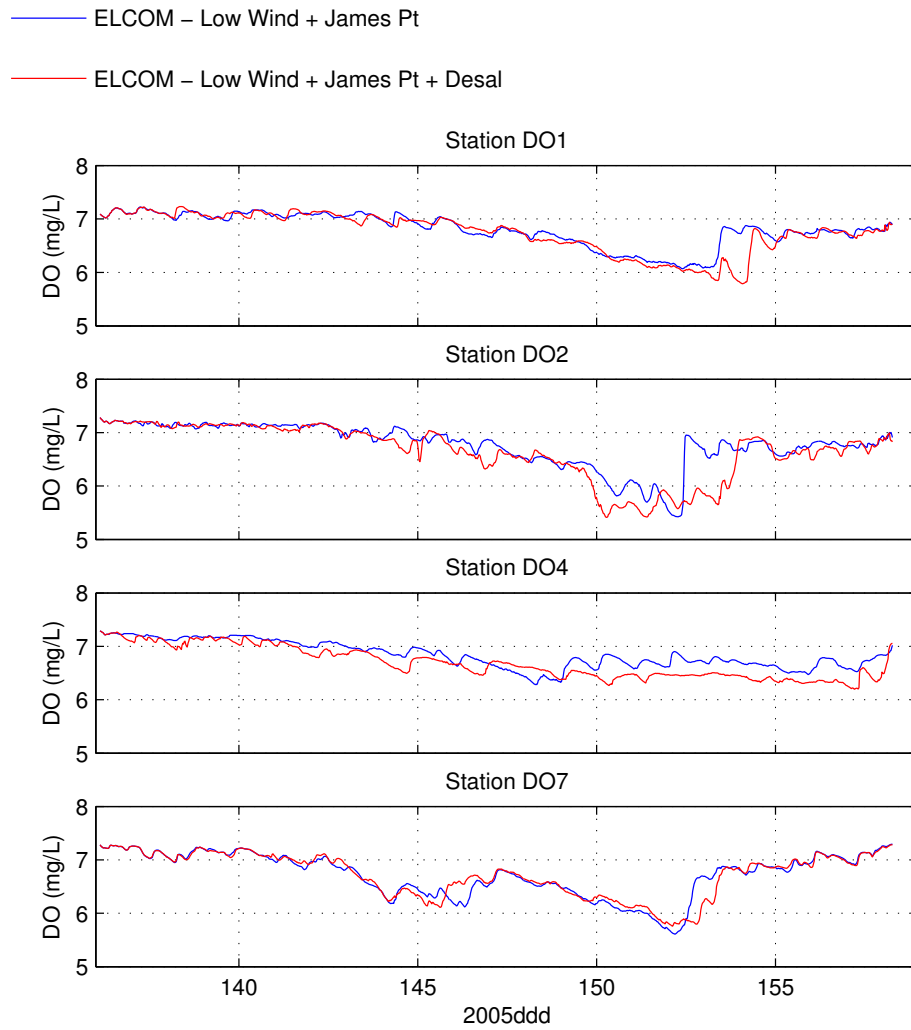


Figure 7.7. As for Figure 7.4, but compares the base low wind simulation that includes the James Pt Port Construction (blue) and the low wind simulation that includes the James Pt Port Construction and desalination discharge (red).

8 Conclusions

From the investigation conducted here, the following conclusions can be drawn:

- The dominant process responsible for oxygen drawdown in Cockburn Sound is sediment oxygen consumption. The dominant source of oxygen is atmospheric transfer.
- As sediment oxygen consumption is the primary sink, water needs to be isolated from the atmosphere for an extended period to result in oxygen depletion. 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. The modelling conducted here unambiguously indicates that this simply does not occur in Cockburn Sound, and that mixing and advection, even in deep waters (~20m), occurs very regularly (Figure 5.3).
- 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.
- On the eastern shelf, the desalination plant discharge will cause dissolved oxygen concentrations to drop by less than 0.5 mg DO L⁻¹ below current levels, however concentrations will still generally be greater than 5.5 mg DO L⁻¹.
- Consideration of extreme wind events and existing and approved shoreline development in the vicinity of the desalination discharge indicates no impact of the desalination plant discharge on dissolved oxygen under these scenarios.

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