BLUESCOPE STEEL LIMITED
STEELWORKS CO-GENERATION PLANT (SCP)
PROPOSED SALT WATER COOLING
NUMERICAL COOLING WATER STUDIES

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1 INTRODUCTION

BlueScope Steel Ltd has identified a need to modify aspects of the currently approved Illawarra Cogeneration Project (ICP), now known as the Steelworks Cogeneration Project (SCP). The project is located at the Pork Kembla Steelworks. Figure 1.1 provides a general locality plan of the site and its relationship to Port Kembla.

The approved ICP includes a closed circuit cooling water system using a cooling tower. However, the modification proposed by BlueScope Steel addressed in this report is a replacement of the re-circulated cooling system with a once-through salt water cooling system. Operation of the SCP would involve decommissioning of the No. 1 power house and cessation of the associated flows and temperature loads into Main Drain. Saltwater used for cooling of the steam turbine generator (STG) condensers of the SCP would be drawn from Port Kembla Outer Harbour via the existing saltwater lift pump and channel, used as cooling water for the SCP and then returned back to Port Kembla Inner Harbour at a location in Allans Creek approximately 170m downstream of the existing No. 2 blower station drain - see Figure 1.2.

As part of environmental investigations and planning activities for the proposed SCP, BlueScope Steel have engaged Cardno Lawson Treloar to undertake a range of 3D numerical cooling water studies. The purpose of these analyses was to simulate the temperature fields arising from the existing and post SCP heat-loads in order to describe any changes in heat field conditions. Apart from environmental effects, this information was to extend to a description of any changes in heat re-circulation to the saltwater intake at the lift-pump station.

This report describes the data available to this study, the numerical modelling simulations undertaken and the outcomes from this study. It forms part of the input to CH2M HILL's report.

2 DATA

A range of data items were required to set up and operate the numerical hydrodynamic/heat models applied to this study, and then to assess the impacts. Some of these inputs were prepared and adopted for the previous ICP modelling studies. The following section describes the inputs used in the modelling process and the sensitivity of the model to each of these inputs.

These inputs are:

- bathymetry;
- heat-load (discharge flow x ΔT);
- tidal forcing;
- meteorological factors (wind, solar radiation and relative humidity); and
- salinity.

With the exception of heat-load, each of these factors was constant for pre and post-SCP case models and did not affect the outcome of the model simulation differences. Consequently, all simulated temperature differences were determined on the basis of model to model comparison with only the new heat-loads causing any change in results.

2.1 PORT KEMBLA HARBOUR BATHYMETRIC DATA

Bathymetric data is required to describe the seabed of the harbour basins, Allans Creek and the shoreline perimeter of the waterways of Port Kembla. This detailed information was available from a previous 2D MIKE-21 model set up for Port Kembla Port Corporation. Indicative bathymetry is shown in Figure 4.2. The Mike 21 configuration included some data for the mouth region of Allans Creek. Additional depth information for the creek was included from previous studies undertaken by Lawson and Treloar (2004).

2.2 STEELWORKS PLANT DRAIN FLOW DATA

Daily drain flow data for each existing drain was provided by BlueScope Steel. Data sets for January-February 2004 and June-July 2005, summer and winter, respectively, were analysed, to provide model input for existing condition simulations (see Section 4.2).

Proposed design flows for the SCP were provided by BlueScope Steel and were the same for summer and winter.

Figures 1.2 and 2.1 indicate the locations of the principal drains. Under the post-SCP arrangement, cooling water flows from Main Drain will cease. The other principal cooling water flow from the No. 2 Blower Station drain will remain.

2.3 DISCHARGE WATER TEMPERATURE DATA

Weekly drain flow temperature data was available for the same drain flow periods as those described in Section 2.2.

BlueScope Steel provided cooling water discharge temperatures for the proposed SCP. The same temperature changes (ΔT) were advised for summer and winter because it was assumed that the same heat load would be imparted to the water by the SCP in both seasons. Together with the proposed discharges from other drains on the site, they formed the total discharged heat-loads.

Simulations were undertaken for the following heat-load cases:-

- Pre-SCP(Existing) summer average heat-loads.
- Pre-SCP(Existing) winter average heat-loads.
- Post-SCP summer and winter typical loads. Each period included two periods of maximum heat-load per day in the new SCP drain; one in the morning, the other in the evening. This typical SCP heat load is described in Figure 2.2. The modelling simulated the SCP generating at a rate of 145 MW per day for all times during the day, except for two one-hour bursts of peak generation (at a rate of 230 MW per day) - these times being 0600 to 0700 and 1800 to 1900.
- Post-SCP summer maximum heat-loads. Although this case would not be common, it could occur during extended periods of very high demand and be sustained for periods of up to a month.

This investigation continues from the earlier ICP heat-load simulations. The present investigations relating to the saltwater cooling alternative commenced in November 2004 and have continued to the present. The initial simulations investigated summer conditions that were based on the latest data available at that time – Jan/Feb 2004. Since this time, discussions between BlueScope Steel and DEC have led to the need to also investigate winter conditions and such simulations were based on plant operational data for Jun/Jul 2005. These cases were presented as appropriate reflections of summer and winter operating conditions at the Port Kembla Steelworks.

At the time of model simulation, post-SCP heat-loads were at design stage and given that it is not reasonably possible to predict differences between summer and winter operating conditions in the post-SCP case, a single set of post-SCP heat-load operating conditions was adopted to cover both summer and winter operations. Whilst this approach may not recognise any actual differences between how the steelworks is to be operated in summer and winter post-SCP, it does present a reasonable approach (from an ecological standpoint) as the greatest possible heat-load to Port Kembla Harbour is likely to occur in summer when ambient sea and air temperatures are elevated.

2.4 PORT KEMBLA HARBOUR WATER TEMPERATURE DATA

Water temperature data has been recorded at the locations shown on Figure 2.3 at two heights in the water column at irregular intervals (Phillips, 2002). Upper water column (near surface) temperatures are higher than those near the seabed as a result of existing cooling water flows from existing steelworks activities. Seasonal information from this data set recorded near the ocean entrance to the Outer Harbour (sites #11 -14 on Figure 2.3) was used to determine typical average background temperatures of 22.5^{o}C and 16.8^{o}C for summer and winter, respectively. This data was used for the heat model ocean boundary because it was measured at the entrance to the Outer Harbour. Whilst Appendix A indicates that the Phillips dataset is from the same sample population as that from the saltwater lift-pump station, it best represents the temperatures at the model boundary. Comparison between sites #11-14 and the lift-pump station indicates that the average temperatures at the lift-pump station are slightly higher (23.2^{o}C and 17^{o}C for summer and winter, respectively), evidence of heat circulation effects at the lift-pump station site. In addition to the derivation of the boundary temperatures, this data was used also to determine the temperature difference (ΔT - ^{o}C) of cooling water flows affected by steelworks activities.

The Phillips' data was compared with the more continuous temperature data available from the routine saltwater intake temperature monitoring undertaken by BlueScope Steel at the lift-pump station in the Outer Harbour. The data sets were statistically shown to be from the same population, see Appendix A. In accordance with the ANZECC (2000) guidelines and as requested by the DEC, summer and winter 80th percentile trigger values for surface temperatures were calculated. The 80th percentile trigger values were calculated to be 24ºC and 18ºC, for summer and winter, respectively. These statistical parameters, are required to assist the assessment of the potential SCP impact by comparison with the 50th percentile temperature values derived from the model output.

2.5 MET-OCEAN DATA

Generally, the flows within Port Kembla Harbour are controlled by the astronomical tide, with some effects from base flow in Allans Creek and wind.

Port Kembla Harbour is a Standard Port and tidal constants from Australian National Tide Tables (2004) were used to prepare predicted tidal levels for the open ocean boundary of the model. The so-called Canadian Method (Foreman, 1977) was used to calculate predicted tide levels at 3-minute intervals. Although other meteorological and oceanic processes can affect water levels within the harbour, such as coastal-trapped waves, those processes are not important to the general structure of the dominant flow within the study area.

A base flow for Allans Creek of $0.17m^3/s$ at the ambient temperature (summer and winter) was included in the modelling flows (BHP Steel advice, 1999) and had been used throughout the previous ICP modelling.

Furthermore, wind speed and direction, as recorded and provided by the Port Kembla Port Authority for both the summer and winter simulation periods (January-February, 2004 and June-July, 2005), were applied to the model - data available at hourly intervals. This permitted the inclusion of the effects of wind on both surface currents and cooling in the modelling undertaken.

Additionally, solar radiation data was obtained from the Bureau of Meteorology (pers. comm. CLT - Bureau of Meteorology) for these same two periods as hourly solar heating and relative humidity. However, recorded solar radiation, as distinct from calculated solar radiation, is available from only one location in NSW (Wagga Wagga). As cloud cover is an important influencing factor, it was necessary to compare the two data sets (calculated and recorded) at Wagga Wagga in order to estimate a realistic basis for adjusting the calculated solar input at Port Kembla to equivalent ‘recorded’ solar radiation.

The applicability of this adjusted solar radiation data was confirmed by undertaking simulations with no cooling water flows and determining that there was no water temperature bias – both summer and winter cases, in Port Kembla Harbour.

2.6 VERIFICATION DATA

Two aspects of model verification were undertaken. They were: -

- Confirmation of the Allans Creek tidal prism flow; and
- Confirmation that simulations of the existing power station operation provided temperatures within Port Kembla that were consistent with observation.

Additionally, some verification information is provided in terms of Delft3D model experience and application at three other sites, namely:-

- Cooling water modelling in Lake Macquarie for Eraring power station;
- Cooling water modelling in Lake Illawarra for re-development of the Tallawarra power station; and
- Cooling water modelling in the Richmond River for a co-generation plant related to sugar milling.

However, this additional information is only general in nature because information related to those projects is proprietary.

Section 4 further describes the outcomes of these verification processes.

3 MODEL SYSTEMS

3.1 DELFT 3D

Whilst the hydrodynamics required for this application could be modelled successfully by many models, it is our experienced opinion that no other package offers the same extensive cooling water modelling capabilities and backup experience as the WL|Delft Hydraulics modelling system Delft3D.

The Delft3D modelling system includes wind, pressure, tide and wave forcing, three-dimensional current, stratification, sediment transport, cooling water and water quality descriptions and is capable of using rectilinear or curvilinear coordinates.

Delft3D has been used recently by Cardno Lawson Treloar for cooling water re-circulation studies in Lake Macquarie, in Lake Illawarra for power station investigations and in the Hunter River to assess the impact of a heated nitric acid spill near Kooragang Island. During these projects, the model produced either good agreement between modelled output and observed temperature data or was readily accepted by regulators.

Section 4.4 provides details on previous successful applications of the Deflt3D model.

Delft3D is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file.

3.1.1 Hydrodynamic Numerical Scheme

The Delft3D FLOW module is based on the robust numerical finite-difference scheme developed by G. S. Stellling (1984) of the Delft Technical University in The Netherlands. Since its inception, the Stelling Scheme has had considerable development and review by Stelling and others.

The Delft3D Stelling Scheme arranges modelled variables on a staggered Arakawa C-grid. The water level points (pressure points) are designated in the centre of a continuity cell and the velocity components are perpendicular to the grid cell faces. Finite difference staggered grids have several advantages including:

- Boundary conditions can be implemented in the scheme in a rather simple way;
- It is possible to use a smaller number of discrete state variables in comparison with discretisations on non-staggered grids to obtain the same accuracy; and
- Staggered grids minimise spatial oscillations in the water levels.

Delft3D can be operated in 2D (vertically averaged) or 3D mode. In 3D mode, the model uses the σ-coordinate system first introduced by N Phillips in 1957 for atmospheric models. The σ-coordinate system is a variable layer-thickness modelling system, meaning that over the entire computational area, irrespective of the local water depth, the number of layers is constant. As a result a smooth representation of the bathymetry is obtained. Also, as opposed to fixed vertical grid size 3D models, the full definition of the 3D layering system is maintained into the shallow waters and until the computational point is dried.

From a user point of view, the construction of a 3D model from a 2D model using the σ-coordinate system in Delft3D is effected by entering how many layers are required and the percentage of the depth for each layer. It is most common to define more resolution at the surface and at the bed where the largest vertical gradients occur. Boundary conditions can also be adjusted from depth averaged to specific discharges and concentrations per layer also.

Horizontal solution is undertaken using the Alternating Direction Implicit (ADI) method of Leendertse for shallow water equations. In the vertical direction (in 3D mode) a fully implicit time integration method is also applied.

Vertical turbulence closure in Delft3D is based on the eddy viscosity concept.

3.1.2 Wetting and Drying of Intertidal Flats

Many estuaries and embayments contain shallow intertidal areas; consequently Delft3D incorporates a robust and efficient wetting and drying algorithm for handling this sort of phenomenon.

Careful refinement in the intertidal areas and appropriate setting of drying depths to minimise discontinuous movement of the boundaries ensures oscillations in water levels and velocities are minimised and the characteristics of the intertidal effects are modelled accurately.

3.1.3 Conservation of Mass

Problems with conservation of mass, such as a ‘leaking mesh’, do not occur within the Delft3D system.

However, whilst the Delft3D scheme is unconditionally stable, inexperienced use of Delft3D, as with most modelling packages, can result in potential mass imbalances.

Potential causes of mass imbalance and other inaccuracies include: -

- Inappropriately large setting of the wet/dry algorithm and unrefined inter-tidal grid definition;
- Inappropriate bathymetric and boundary definition causing steep gradients; and
- Inappropriate timestep selection (i.e. lack of observation of the scheme’s allowable Courant Number condition) for simulation

3.1.4 Other Issues

Note that there were a number of processes not included in the modelling, such as currents caused by shipping and freshwater floods. Shipping would cause greater mixing and flooding would transport the surface plume further downstream. Both processes would be intermittent and transitory.

3.2 MODEL SET-UP

The model system was setup using the available bathymetric data and a general grid size of 30m, reducing in stages to be 7.5m in Allans Creek and the area of the creek entrance. A time step of 30 seconds was adopted to fulfil accuracy requirements based on the Courant Number.

3.3 NEARFIELD MODEL

3.3.1 CORMIX

CORMIX is a nearfield analytical model developed by Mixzon Inc. and is used by the U.S. E.P.A. for regulatory investigations. It describes the development of a buoyant jet(s) as it discharges into the receiving water environment. It includes single port, multi-port and surface channel discharges. The model is useful in describing the interaction in mixing zones – where a discharge is introduced to a receiving water. The model includes the effects of density difference, receiving water velocity, depth of the jet(s) below the surface, merging of jets, wind mixing, discharge port configuration and discharge rate.

Cardno Lawson Treloar has used this system for a number of outfall diffuser systems with success. CORMIX has been shown to suitably predict mixing effects. As part of investigations undertaken for Hunter Water for augmentation of the Belmont ocean outfall, Cardno Lawson Treloar undertook a field verification of the CORMIX model. That work entailed the measurement of salinity in the water column near the existing outfall in known discharge and receiving water conditions. Analyses of the results showed that CORMIX provided realistic results though it slightly under-estimated dilution. The 'map' of dilution above a discharge point is spatially and temporally very variable and this characteristic needs to be considered in analyses of this type by recognising this variability in any sampling that may be undertaken

For this assessment, CORMIX was selected from a suite of available near-field models and was used to assess the mixing zone effects in response to DEC concerns. The results of the CORMIX modelling are provided below.

However, it should noted that in the opinion of Cardno Lawson Treloar, the DEC's concerns relating to the definition of the mixing zone is more appropriately described by the Delft3D modelling results in this situation than a near-field model for the following reasons:

- the complex bathymetry cannot be described by the available near-field models;
- the presence of multiple cooling water discharges leads to cooling water field interaction that the available near-field models cannot handle;
- the reversing tide transports previously discharged cooling water backwards and forwards through the discharge points which is not handled in near-field models.

It should be noted that adopting a fine (7.5m) horizontal grid (and finer still in the vertical plane) as undertaken in Delft3D allows a reasonable description of these effects in the mixing zone.

3.3.2 CORMIX Results

Notwithstanding the limitations of near-field models identified above with relation to this site, the CORMIX modelling system has been used to examine the nearfield character of the new SCP Drain discharge to assess the mixing zone effects in response to DEC concerns.

The new SCP Drain would discharge to Allans Creek immediately upstream of the Inner Harbour. A channel depth of 2.5m has been assumed - based on available bathymetric chart and tidal information. Flow from Allans Creek was assumed to have a speed of 0.05m/s which represents a condition of least initial dilution. The new SCP Drain flow in average design conditions is 7.5m^3/s at a ΔT of about 6^{o}C. Due to the mixing effects, CORMIX indicates that the ΔT reduces to about 2^{o}C 60m downstream from the drain-creek junction, ignoring the effects of other discharges. At this stage the surface plume is about 2m deep and forms a surface plume about 40m wide.
In reality, this outcome is not meaningful for all the reasons cited in Section 3.3. A more realistic outcome is demonstrated by the Delft3D outputs described in Sections 5, 6 and 7.

4 VERIFICATION PROCEDURES

4.1 HYDRAULIC ISSUES

The principal concern here was to ensure that the extent of Allans Creek included in the numerical model reflected the actual tidal prism upstream of the Inner Harbour. A second matter was to compare recorded and modelled water temperature differences in the water column.

In order to provide field data for this task, BlueScope Steel engaged Cardno Lawson Treloar to undertake a series of Acoustic Doppler Current-meter Profiles (ADCP) across the line shown on Figure 2.3. This work was undertaken on 25 May, 2005 and also included intermittent temperature measurements at surface, mid and bottom layers along the transect using a NATA calibrated multi-probe. The temperatures collected at that time were used to describe the vertical temperature gradient at the transect site but could not be included in the measured background temperature dataset due to the time of year collected. ADCP transects of current speed across this line were taken at irregular time intervals. Current speed and direction through the water column were integrated to provide a time series of discharge over a period of flood-ebb tidal flow.

The Delft3D model was set and run for this period using Port Kembla tidal data and drain flow information provided by BlueScope Steel. Wind data was also included. A number of model simulations were undertaken, varying the extent of Allans Creek included in the model. This ranged from the confluence of Allans Creek and the Inner Harbour and extended upstream beyond the confluence with main Drain. The ocean temperature for May was estimated to be 20.5^{o}C from data provided by BlueScope Steel previously.

Figure 4.1 shows the outcome of the verification task in terms of Allans Creek tidal flow. It was necessary to reduce the extent of Allans Creek originally included in the model system to achieve realistic tidal flow in Allans Creek.

As an additional verification exercise, the model simulation demonstrated that a temperature difference of up to 2.5^{o}C occurred between the surface and creek bed near the mouth of Allans Creek. This is consistent with observations made in the field on 25 May.

4.2 TEMPERATURE VERIFICATION

A model simulation was undertaken for the January - February 2004 period on the basis of the average heat-load scenario - pre-SCP.

BlueScope Steel provided Cardno Lawson Treloar with operational data for the January - February 2004 period (see Section 2). This data contained daily flow rates and the discharge temperatures (recorded every 7 days) for the following drains: -

- 3500mm Plate Drain,
- No1 Flat Products East Drain,
- No2 Flat Products East Drain,
- Iron Making Drain,
- Main Drain,
- No5 Blast Furnace Drain,
- North Gate Drain,
- Plate Mill Cooling Tower Drain,
- Slab Mill Drain,
- Steel Haven West Drain, and

- 21 Area Drain.

Average daily heat-loads were determined by subtracting the modelled boundary temperature condition (22.5°C in the Outer Harbour for summer) from the discharged flow temperatures to determine the temperature difference between the discharge and the receiving water, and then multiplying by the daily flow rate. Hence model input described the heat-load reliably, but did not include all of the individual daily variations in heat-load since corresponding boundary temperatures were not available on a daily or weekly basis for the period modelled but within 1°C for the duration of the simulation based on variations in temperatures observed in the supplied data. Note that Bluescope have subsequently checked that the heat-load data provided for January-February 2004 is representative of typical summer heat-load data by investigating 5-years of heat-load data (BSL, 2006). The adopted period provides a very reliable description of longer term heat-load inputs.

The average heat-load scenario was then developed for the Delft3D model to represent the average heat loads for the existing BlueScope Steel operations. The formulation used to determine the temperature difference ΔT (°C) in each drain : -

$$\text{Average Heat Load Condition } \Delta T\ (^{o}C) = \Sigma \frac{\text{Daily Heat Load } (^{o}C.\ m^3/s)}{\text{Daily Flow Rate } (m^3/s)} \Big/ N$$

where N is the number of daily records of heat load

The calculated average temperature difference and average flow rate were applied as a constant condition for the whole simulation period. The limited amount of temperature data available in the various outlet drains limits the ability to develop an accurate time series of heat load for the modelled discharges. A discussion regarding the sensitivity of the model and harbour is provided in Section 4.3.1. Table 4.1 describes the heat loads applied for the January - February 2004 simulations. Note that in Table 4.1, where heat-loads such as that for Main Drain are applied, it is the temperature difference that is used for model input. This is to account for recirculation effects. On the other hand, the actual temperature is applied in the case of Allans Creek.

Salinity was maintained constant in all flows at 33.5ppt with an ocean seawater (model boundary) temperature of 22.5°C in the Outer Harbour.

4.3 RESULTS

Figure 4.2 describes the locations of selected time-series output grid points in the Delft3D model. Figures 4.3 and 4.4 present the time series of modelled temperature between 01/01/04 and 29/02/04 at these locations in the Inner and Outer Harbour areas for the average heat-load summer conditions, respectively. The results show that Inner Harbour locations (Figure 4.3) have larger diurnal variations and vertical temperature differences than the Outer Harbour locations (Figure 4.4). Each plot includes air temperature at Port Kembla (dashed lines). Variations in water temperature are caused only by the tides, solar radiation (day/night) and meteorological variations. There is no apparent neap/spring tide cycle influence and there is no evidence of rapidly increasing temperatures that might be caused by recirculation and experienced at the lift-pump station.

Figures 4.5 and 4.6 present probability of exceedance plots for this average heat load (solid lines) scenario for the Inner and Outer harbour areas, respectively. The plots include also results for the post-SCP summer typical simulation (dashed lines), which are introduced and discussed in Section 5. Results are shown for the top (Layer 1), middle (Layer 5) and bottom (Layer 10) layers of the water column. The second vertical axis (right hand side) shows the vertical temperature gradient (Layer 1 - Layer 10 – black lines). They demonstrate the range of temperatures that occur at each output location.

Measured temperature data at a number of sites on 14/01/04 and 14/03/04 were provided by BlueScope Steel, see Figure 2.3. This data was collected as part of a water-quality monitoring programme at Port Kembla, AMOG (1995). Table 4.2 shows the modelled and measured results at two sites. It is important to note that the actual ocean water temperature at the harbour entrance (model boundary) was 21.6°C, rather than the 22.5°C adopted for this general summer simulation - a difference of 0.9°C. The average of the model result temperatures is about 0.8°C greater than the average of the measured temperatures on 14/01/2004; hence, adjusting for the boundary temperature difference, there is a 0.1°C difference between the measured and modelled average temperatures on 14/01/2004. Although not precisely correct, the temperatures throughout the harbour are generally linearly dependent upon the boundary temperature. Thus any incremental change in seawater temperature at the model boundary/harbour entrance is reflected in a similar incremental change throughout the harbour. Hence the approach above, which accounts for spatial and temporal variation inherent in the data and model, is appropriate for verification.

The verification of the model to the measured data shows average variability of less than 0.1°C, which is good given the available model input data (and is also considered good for larger data sets). The model had a constant heat-load applied throughout the simulation period because of the limited available drain and harbour entrance water temperature data. However, the available daily discharge data indicated that due to significant daily flow variations there was also variation in the heat-load from the steelworks into Port Kembla from day-to-day. Due to production variability of the varying steelworks activities that discharge into the drain network, the actual heat-load discharged into Port Kembla on 14/01/04 and preceding days could have been somewhat different from the modelled average heat load condition. Note also that there is no record of the time-of-day at which the field data was recorded and water temperatures vary during the day as air temperature and tide changes occur.

Moreover, the changes between post-SCP and existing temperatures because they are based on model-to-model-comparisons and any uncertainty between model results and reality will be the same for both sets of model results

Overall, the model verification, in terms of the tidal prism in Allans Creek and temperatures in Port Kembla Harbour, is good even though the sample size is limited to basic statistical analysis.

4.3.1 Sensitivity Analysis

If the ΔT in the discharge cooling water were in error (either due to drain temperature or boundary temperature or both), then the corresponding error in receiving water temperatures, other than at the immediate point of discharge, would cause temperatures generally in the harbour of much less than 1°C. This outcome is due to the relative volume of flow compared to harbour volume and the tidal flow versus the cooling water flows. In summary, it can be said that the model (as a reflection of the harbour) is relatively insensitive to temperature differences of this order. It can be reasonably stated that the harbour boundary temperatures do not vary by more than 1°C per month on average over the simulation period based on observations in the Phillips data, hence weekly fluctuations can be expected to be smaller. In reality on a weekly basis is it reasonable to assume negligible variation in temperature at the model boundary.

In order to assess the effect of errors in drain heat-loads, a simulation could be undertaken with a temperature change in one drain (leaving all other heat-loads unchanged). However, an alternative approach could be to examine the likely maximum difference from the average heat load case by undertaking a simulation based on maximum heat-loads. This simulation is described in Section 7. For example, a comparison between modelled existing surface temperatures at locations (22, 67) and (80, 34) shows a difference of 1.41 ^{o}C and 0.15^{o}C between average and maximum heat load cases, respectively. In the latter, it was assumed that maximum heat loads could occur in all drains simultaneously and persist for two months which would be unlikely in the context of the operational activities at the steelworks. Consequently any change in a single variable such as an error in ΔT of say 1^{o}C would cause much smaller changes to propagate through the model.

4.4 OTHER SITES

4.4.1 Lake Macquarie - Eraring Energy

The Delft3D model has been applied in Lake Macquarie for cooling-water studies related to Eraring power station upgrade planning. The model was verified using infra-red satellite imagery of the lake surface which showed the cooling water plume extending over some kilometres across the lake.

Heat-load and environmental data, though not complete, was used to drive the model and comparisons were made with the satellite observations. Reasonable agreement was achieved. Similar thermal imagery was not available at Port Kembla Harbour for the corresponding modelling period of this study.

4.4.2 Port River – South Australian EPA

Cardno Lawson Treloar has used the Delft3D model in a joint initiative with the Environment Protection Authority, South Australia to set up, calibrate and implement the Delft3D model for use by SA EPA staff. This was based on a study of the Port River northwest of Adelaide, SA. A full reproduction of the results of this study are provided in Appendix B. The outcomes of this study showed that the model achieved a good level of calibration with the data collected and modelled temperature and hydrodynamics showed good agreement with observed data.

4.4.3 Hong Kong Government

Delft3D has been selected by the Hong Kong government as their preferred model because of its superior performance in an international calibration ‘competition’. It has also been applied to water quality studies in the Venice lagoon, where other systems have been less successful.

5 POST SCP MODELLING – TYPICAL SUMMER HEAT LOAD CONDITIONS

5.1 GENERAL

The discharge and temperature conditions for the post-SCP case were provided by BlueScope Steel, as shown in Table 5.1. Following the construction of the SCP, heat-loads discharging to Allans Creek and the harbour will change. As described in Section 2 and Tables 4.1 and 5.1, there will be no process flow from Main Drain, which previously discharged a significant heat-load (1.17m^3/s, 7.1^{o}C ΔT) to Allans Creek about 700m upstream from the entrance to the Inner Harbour. Discharge and ΔT from No. 2 Blower Station will change from (7.95m^3/s, 6.44^{o}C) to (7.04m^3/s, 5.94^{o}C). Typical daily average heat-load from the new SCP drain would be (7.5m^3/s, 5.9^{o}C ΔT). Discharge rates and temperature differences at all other drains remain unchanged from the existing case. Note that the typical heat-load from the new SCP plant includes the two daily heat-load peaks in the new SCP drain, one in the morning, the other in the evening as shown on Figure 2.2. A maximum heat load case is also considered and this is described in Section 7.

5.2 SCP HEAT-LOAD DISCHARGE DEVICE

Preliminary simulations of the maximum summer heat-load conditions demonstrated that there would be an increase in average temperature of more than 3^{o}C in the bottom layer at Location (22, 67), see Figure 4.2. BlueScope were advised that ecological concerns might arise should increases of average temperature greater than 3^{o}C occur. Operational demands of the SCP could mean that the SCP would occasionally be required to generate maximum heat loads for periods of up to one month. Hence a range of discharge structure options were considered. It was believed that it would be best for the new SCP drain to discharge laterally into the upper/surface layers of the water column, rather than mixing through the full depth, in order to minimise vertical mixing and maximise cooling by atmospheric processes.

Such discharge is possible by constructing an engineered device. This could take a range of forms including, but not necessarily limited to:-

- a ‘launder’ that allows discharges to flow laterally into the surface layers of the receiving water body; or
- a multi-port discharge arrangement
- some other form of structure that provides an equivalent effect;

constructed along the bank of Allans Creek.

A review of structures of different lengths showed that a 30m long structure would provide a satisfactory outcome in terms of satisfying the ecological requirements described above.

Drain flow in the model was set-up to emulate a flow structure consistent with either of these arrangements and was applied to all post-SCP simulations.

5.3 RESULTS

Salinity has been maintained constant everywhere at 33.5ppt with an ocean seawater temperature of 22.5°C in the Outer Harbour. A small flow rate in Allans Creek is included. Time series output locations are indicated in Figure 4.2. This model setup is consistent with the existing-case average summer simulation reported in Section 4.

Figures 5.1 and 5.2 present the time series of modelled temperature for the period between 01/01/04 and 29/02/04 in the Inner and Outer Harbour areas, respectively, for the typical summer post-SCP conditions. The plots show that Inner Harbour locations (Figure 5.1) have larger diurnal variations and vertical temperature differences than Outer Harbour locations (Figure 5.2). Each plot includes air temperature at Port Kembla (dashed lines). Variations in water temperature are caused only by the tides, solar radiation (day/night) and meteorological changes. There is no apparent neap/spring tide cycle influence, in common with the results for existing average summer case described in Figures 4.3 and 4.4.

Figures 4.5 and 4.6 include the probability of exceedance plots for the average existing heat-load (solid lines) and typical post-SCP summer heat-load (dashed lines) cases. Results are shown for the top (Layer 1), middle (Layer 5) and bottom (Layer 10) layers of the water column. The second vertical axis (right-hand side) shows the vertical temperature gradient (Layer 1 - Layer 10). Inner Harbour locations (Figure 4.5) show greater variation between the exceedance curves than do the Outer Harbour locations shown in Figure 4.6. These figures present the composite summer temperature change results; that is, medians and ranges of temperatures.

Tables 5.2 (Harbour areas) and 5.3 (Allans Creek) present average temperatures and standard deviations of temperatures for both the existing and typical post-SCP summer cases. Locations in Table 5.3 are in terms of distance upstream from the No. 2 Blower Station discharge, which can be seen clearly in Figure 1.2. These results show that there have been some increases and some reductions in water temperatures throughout the water column. Generally, both existing and post-SCP average temperatures exceed the summer trigger value of 24°C at the three Inner Harbour locations - (22, 67; 45, 68 and 60, 62) and at all locations within Allans Creek. All increases in average temperatures were less than 0.8°C at the six selected Harbour output locations. As a result of the cessation of heat-load from the Main Drain, surface temperatures would be reduced by about 0.5°C at 300m to 500m upstream of No. 2 Blower Station in Allans Creek. Surface water temperatures are up to 0.72°C lower (Location 22, 67), middle layer is up to 0.23 C higher Location (45, 68) and bottom layer water temperature up to 0.72°C higher (Location 22, 67) for the post-SCP simulation. Note that temperature gradients have been computed as the average gradient rather than the gradient of the average temperatures. Note also that where surface temperatures are lower than those below the surface, then that condition arises as a result of cooling to the atmosphere.

Note that locations (81, 40) and (80, 34) relate to the lift-pump location. The results indicate a small increase in temperature at this site, the difference depending upon position in the water column. The average increase in each case is less than 0.5°C at the lift-pump site.

Figures 5.3 and 5.4 present the temperature difference (ΔT) probability of exceedence distributions between the average existing condition summer simulation, and the typical heat-load for the post-SCP simulation at Location (81,40) (Figure 5.3) and Location (80,34) (Figure 5.4). At Location (81,40) (Figure 5.3), the middle and bottom layers show a significantly smaller temperature increase compared with the top layer. The median increase in temperature for the typical post-SCP - average heat load cases is less than 0.10°C in the mid and bottom layers of the water column and between 0.3 and 0.4°C in the upper layers of the water column. At Location (80,34) (Figure 5.4), the variation in temperature increase between the surface and bottom layers of the water column is approximately 0.05°C.

At the intake pump channel, the difference in water temperature between the existing configuration and the post-SCP configuration is likely to be in-between the results at Location (81,40) and Location (80,34) presented in Figures 5.3 to 5.4. Based on the bathymetric chart AUS195 (see Figure 4.2), the depth at the intake channel is approximately 5m Chart Datum.

Figures 5.5 and 5.6 provide comparisons between surface water temperatures and the summer trigger temperature of 24°C, as well as surface temperatures themselves, at two separate times for the existing and post-SCP summer cases for the typical heat-load discharge scenario. The selection of the times was based on peak temperature conditions at Location (45, 68). The results show that the trigger value may be exceeded up to 500m further from the entrance to Allans Creek along the western berth-line of the Inner Harbour near high tide in the post-SCP case - Figure 5.6. Note that the trigger temperature is applicable to surface temperature only because it was determined from surface data. The difference between these results, in terms of extent of the region where exceedance of the trigger value occurs, arises from different tidal phases and meteorological conditions at the selected times.

- 1600 2004/01/28 near low tide; 4m/s wind from 58° TN
- 1600 2004/02/14 near high tide; 4m/s wind from 17° TN

Hence, in these low wind speed conditions, the stage of the tide dominates the extent of the cooling water field. Figure 5.5 shows no significant change in the extent of the 1°C above trigger value contours between the existing and post-SCP cases.

Figures 5.7 and 5.8 present temperature difference information at two selected times between the post-SCP and existing summer cases at three layers in the water column. Figure 5.8 describes the cooling water field at the time of the highest temperature difference over the simulation period. Both results are based on times near high water and with low wind speeds from the north-east sector. Nevertheless, the outcome in Figure 5.7 relates to a time about 1 hour after high water and that in Figure 5.8 relates to a time about 1 hour before high water; the latter being a time when the cooling water plume flowing from Allans Creek is held back, as shown in the plots. There are noticeable differences between temperature changes at each level in the water column. Generally, the highest temperatures occur in the surface layer, but the largest changes in temperature from existing conditions may occur at the surface or in the mid-water column and be as much as 2°C.

Figure 5.9 describes the average post-SCP 1°C temperature increase contour for this scenario. The areas are small and occur in the bottom and mid layers only. This result, which is presented in terms of the average temperature, shows that although there may be periods of time when temperature increases are greater than 3°C, generally the area over which average temperatures increase over 1°C is small and confined to the mid to lower water column. Average temperature increases were all less than 1°C so illustration against the ecologically important 3°C was not possible since this condition does not occur.

These examples demonstrate that the cooling water fields can take many forms and that any analyses of the effects of the proposed SCP should be based on the statistical descriptions described in Figures 4.5 and 4.6 and those in Tables 5.2 and 5.3.

The good agreement between modelled and measured data discussed in Section 4 advises that these results are realistic. This is especially so in terms of the changes between post-SCP and existing temperatures because they are based on model-to-model-comparisons and any uncertainty between model results and reality will be the same for both sets of model results.

6 POST SCP MODELLING – TYPICAL WINTER HEAT LOAD CONDITIONS

Heat-load data for existing winter conditions were determined from the drain flow and temperature data described in Sections 2.2 and 2.3 and Outer Harbour water temperatures and analysed following procedures the same as those described in Section 4.2. This data was provided by BlueScope Steel for the period of June-July 2005. The derived model input parameters are presented in Table 6.1. Average water temperature in the Outer Harbour was estimated to be 16.8°C. On advice from BlueScope Steel (see Section 2.3), post-SCP heat-load inputs were adopted to be the same as those for the summer cases, but with the temperature of the base flow in Allans Creek being set at 16.8°C. Again, salinity was maintained at 33.5ppt and Figure 4.2 describes the selected time series output locations.

Figures 6.1 and 6.2 present the time series of modelled water temperature between 01/06/2004 to 31/07/2004 in the Inner and Outer Harbour areas for the average winter heat-load existing conditions. Figures 6.3 and 6.4 present the equivalent typical winter heat-load case results for post-SCP conditions.

Figures 6.5 and 6.6 present the data in terms of probability of temperature exceedance. Results are presented for existing (solid lines) and post-SCP heat-load conditions (dashed lines). They are presented for the top (Layer 1), middle (Layer 5) and bottom (Layer 10) layers of the water column. The second (right hand) vertical axis shows the vertical temperature gradient (Layer 1 - Layer 10). Inner Harbour locations show the greatest variation in the exceedance curves.

Tables 6.2 (Harbour) and 6.3 (Allans Creek), present comparisons for average water temperatures and standard deviations between the winter existing and post-SCP simulations at the selected locations. Locations in Table 6.3 are in terms of distance upstream from the No. 2 Blower Station discharge, which can be seen clearly in Figure 1.2. These results show that there have been some increases and some reductions in water temperatures throughout the water column. Generally, both existing and post-SCP temperatures exceed the winter trigger value of 18°C at Location (22, 67) only in the Inner Harbour and at all locations in Allans Creek. All increases in average temperatures were less than 0.7°C at the six selected Harbour output locations. As a result of the cessation of heat-load from the Main Drain, surface temperatures would be reduced by about 0.5°C at 300m to 500m upstream of No. 2 Blower Station in Allans Creek. Surface water temperatures are up to 0.47°C lower (Location 45, 68), middle layer is up to 0.32°C higher Location (45, 68) and bottom layer water temperature up to 0.65°C higher (Location 22, 67) for the post-SCP simulation. Note that temperature gradients have been computed as the average gradient rather than the gradient of the average temperatures. Note also that where surface temperatures are lower than those below the surface, then that condition arises as a result of cooling to the atmosphere.

Figures 6.7 and 6.8 present temperature difference statistics at Locations (80, 34) and (81, 40) for typical winter conditions. Near mid-depth there will be a temperature increase of about 0.2°C at both locations.

Figures 6.9 and 6.10 provide comparisons between surface water temperatures and the winter trigger temperature of 18°C, as well as surface temperatures themselves, at two separate times for the existing and post-SCP winter cases. The selection of the times was based on peak temperature conditions at Location (45, 68). The results show that the trigger value may be exceeded up to 250m further from the entrance to Allans Creek along the western berth-line of the Inner Harbour near high tide in the post-SCP case - Figure 6.9. Note that the trigger temperature is applicable to surface temperature only because it was determined from surface data. The difference between these results, in terms of extent of the region where exceedance of the trigger value occurs, arises from different tidal phases and meteorological conditions at the selected times. The average temperature increases at the lift-pump station intake are smaller than 0.4°C, indicating a small increase in recirculation from the existing case.

- 1800 2004/06/09 near low tide; 6m/s wind from 7° TN
- 1600 2004/06/08 near mid tide; 3m/s wind from 13° TN

Hence, in these wind conditions, and when the tide is ebbing in both cases, the relatively stronger (four times stronger in terms of surface shear), northerly wind on 09/06/2004 holds the surface plume closer to Allans Creek than is the case on 08/06/2004. Both Figures 6.9 and 6.10 show that that 18°C trigger value contour has a greater extent in the post-SCP scenario.

Figures 6.11 and 6.12 present temperature difference information at two selected times between the post-SCP and existing winter cases at three layers in the water column. Figure 6.12 describes the cooling water field at the time of the highest temperature difference over the simulation period. Figure 6.11 is based on a time about 1.5 hours before low tide with a wind of 6m/s from the north. Figure 6.12 is at high water with a weak westerly wind of 2m/s. Hence Figure 6.12 relates to a time when the incoming tide (high spring tide) has pushed most of the cooling water plume into the western harbour with little cooling by the wind; but leaving some residual warm water patches throughout the harbour. On the other hand in Figure 6.11, although the cooling water plume can move out with the tide, it is held back and cooled to some extent by the wind. There are noticeable differences between temperature changes at each level in the water column. Generally, the highest temperatures occur in the surface layer, but the largest changes in temperature from existing conditions may occur at the surface or in the mid-water column and be as much as 2°C.

These examples demonstrate that the cooling water fields can take many forms and that any analyses of the effects of the proposed SCP should be based on the statistical descriptions described in Figures 4.5 and 4.6 and those in Tables 6.2 and 6.3.

Figure 6.13 describes the average post-SCP 1°C temperature increase contour for this scenario. The areas are small and occur in the bottom and mid layers only. This result, which is presented in terms of the average temperature, shows that although there may be periods of time when temperature increases are greater than 3°C, generally the area over which average temperatures increase over 1°C is small and confined to the mid to lower water column. Average temperature increases were all less than 1°C so illustration against the ecologically important 3°C was not possible since this condition does not occur.

The good agreement between modelled and measured data discussed in Section 4 advises that these results are realistic. This is especially so in terms of the changes between post-SCP and existing temperatures because they are based on model-to-model-comparisons and any uncertainty between model results and reality will be the same for both sets of model results

These changes are caused also to some extent by the non-linear relationship between density and water temperature. Moreover, the heat-load discharged from No.2 Blower Station drain is greater for existing winter conditions than for post-SCP conditions.

7 POST SCP MODELLING – MAXIMUM SUMMER HEAT LOAD CONDITIONS

Although not likely to be common, there may be a future requirement to operate the new SCP at maximum heat-load during the summer. Consequently a maximum existing heat-load and a maximum post-SCP heat load simulation were undertaken. Heat-load parameters are described in Table 5.2 and all tide and meteorological conditions were the same as those adopted for the existing average and post-SCP typical simulations. Whilst using maximum heat-loads in all drains may overstate real operating conditions and therefore could be considered unrealistic, it is conservative and conditions generating a greater heat-load are unlikely. The same assumption was made for both pre and post simulations and is therefore consistent between cases. Moreover, the dominant heat loads come from the No.2 Blower Station drain and the Main Drain/new SCP drain and these two would normally occur together.

Table 7.1 presents comparisons for average water temperatures and standard deviations between the summer existing and post-SCP simulations at the selected harbour locations. These results show that there have been some increases and some reductions in water temperatures throughout the water column and harbour. Generally, both existing and post-SCP temperatures exceed the summer trigger value of 24°C (surface temperature only) at Locations (22, 67; 45, 68 and 60, 62) in the Inner Harbour. However, in the post-SCP scenario, two more locations have average temperatures exceeding this trigger value; namely, Locations (77, 46 and 81, 40). The largest increase occurs in the bottom layer at Location (22, 67) - 2.4°C. This is compensated to some extent by the smaller range of temperatures likely at this location in the post-SCP state. Generally, temperature increases were less than 0.7°C. Note that temperature gradients have been computed as the average gradient rather than the gradient of the average temperatures. Note also that where surface temperatures are lower than those below the surface, then that condition arises, to some extent, as a result of cooling to the atmosphere.

The average temperature increases at the lift-pump station intake are smaller than 0.4°C, indicating a small increase in recirculation from the existing case.

Figures 7.1 and 7.2 provide comparisons between surface water temperatures and the summer trigger temperature of 24°C, as well as surface temperatures themselves, at two separate times for the existing and post-SCP summer maximum heat-load cases. The selection of the times was based on peak temperature conditions at Location (45, 68). Note that the trigger temperature is applicable to surface temperature only because it was determined from surface data. The difference between these results, in terms of extent of the region where exceedance of the trigger value occurs, arises from different tidal phases and meteorological conditions at the selected times.

- 1600 2004/01/28 near low tide; 4m/s wind from 58° TN
- 1600 2004/02/14 near high tide; 4m/s wind from 17° TN

Hence, in these similarly low wind speed conditions, the stage of the tide dominates the extent of the cooling water field. Both results show some change in the extent of the 1° above trigger value contours between the existing and post-SCP cases.

Figures 7.3 and 7.4 present temperature difference information at two selected times between the post-SCP and existing maximum-summer heat-load cases at three layers in the water column. Figure 7.3 describes the cooling water field at the time of the highest temperature difference over the simulation period. Both results are based on times near high water and with low wind speeds from the north-east sector. Nevertheless, the outcome in Figure 7.3 relates to a time about 1 hour after high water and that in Figure 7.4 relates to a time about 1 hour before high water; the latter being a time when the cooling water plume flowing from Allans Creek is held back, as shown in the plots. There are noticeable differences between temperature changes at each level in the water column. Generally, the highest temperatures occur in the surface layer, but the largest changes in temperature from existing conditions may occur at the surface or in the mid-water column and be as much as 2°C.

Figure 7.5 describes the average post-SCP 3°C temperature increase contour for this scenario. The areas are small and occur in the surface and mid layers only. This result, in terms of the average temperature, shows that although there may be periods of time when temperature increases are greater than 3°C, generally the area is small and confined to the mid to upper water column.

These examples demonstrate that the cooling water fields can take many forms and that any analyses of the effects of the proposed SCP should be based on the statistical descriptions described in Tables 7.2.

The good agreement between modelled and measured data discussed in Section 4 advises that these results are realistic. This is especially so in terms of the changes between post-SCP and existing temperatures because they are based on model-to-model-comparisons and any uncertainty between model results and reality will be the same for both sets of model results.

8 CONCLUDING REMARKS

This report describes, for both the existing and proposed post-SCP (Steelworks Co-generation Plant) systems, the set up, verification and operation of a 3D numerical hydrodynamic and heat model system of the Port Kembla Steelworks that includes both steelmaking activities and power generation.

The model system was based on Delft3D and used a basic 30m horizontal grid, but with grid sizes reducing to 7.5m near the mouth of Allans Creek in order to provide better spatial resolution there. This fine grid arrangement provided a good basis for describing the spatial and temporal variation of the cooling water fields Ten vertical layers were applied in the vertical direction to ensure that physically realistic vertical gradients of temperature and current speed were described by the model.

Model verification included ensuring that the tidal prism within Allans Creek was represented realistically by the model, based on ADCP transects across the mouth of the creek.

A second phase of model verification involved comparing model results with temperature data recorded in the harbour. The recorded data was of limited extent, and although the actual record times were unknown, there was good agreement between the two – in the order of 0.1°C difference on an average temperature basis.

Moreover, the report describes other locations where the model has been successfully verified and applied.

Overall there can be good confidence that the results are statistically reliable.

Existing operations heat-loads were developed from drain flow and temperature data provided by BlueScope Steel. Periods of two months, (January-February) and (June-July), summer and winter respectively, were analysed to provide average and maximum heat-load cases.

Heat-load information for post-SCP operations was provided by BlueScope Steel.

Model simulations were undertaken for: -

- Existing average and post-SCP typical summer operations heat-loads;
- Existing average and post-SCP typical winter operations heat-loads; and
- Existing and post-SCP maximum summer operations heat-loads.

In order to reduce increases in lower water column temperatures near the mouth of Allans Creek, discharge from the new SCP drain would be via some form of structure that provides horizontal discharge of cooling water into the creek along approximately 30m of the creek bank.

The overall purpose of these analyses has been to prepare data for ecological impact assessment. Results have been presented in tabular and graphical form and analysed in terms of average temperatures and standard deviations at nine locations: -

- Outer Harbour – 3
- Inner Harbour – 3
- Allans Creek – 3

These analyses have been based on output at three levels in the water column, namely:- surface, mid-depth and bottom.

Generally, apart from locations near the post-SCP drain discharge, to be located near the mouth of Allans Creek, average temperature increases in the post-SCP conditions would be less than 0.8^{o}C and 0.7^{o}C for typical summer and winter conditions, respectively. The largest increase in average temperature occurs near location (22, 67) at the seabed in maximum summer conditions; about 2.4^{o}C.

9 REFERENCES

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Table 4.1: Existing Operations – Simulation Heat-Loads (Summer)

Modelled Drain Flows – Existing January-February 2004 Conditions					
Model Source No	**Drain**	**Average Condition**		**Maximum Conditions**	
		Q (m^3/s)	**ΔT (°C)**	**Q (m^3/s)**	**ΔT (°C)**
1	Main Drain	1.174	7.1	1.431	9.5
2	No.2 Blower Station	7.953	6.44	8.233	8.5
3	Iron Making East	0.208	4.05	0.232	7.5
4	3500mm Plate Mill Drain	0.395	2.84	0.43	3.5
5	Slab Mill Drain	0.013	31.41*	0.013	32.68*
6	No.1 Flat Products East Drain	0.112	4.64	0.112	10.5
7	Allan's Creek Flow	0.17	22.5*	0.17	22.5*
8	North Gate Drain	0.077	28.06*	0.13	30.22*

*This is not a power station source, absolute temperature (°C)

Table 4.2: Model Verification – January-February 2004

Model Location	**Date**	**Measured Results (°C)**			**Model Results (°C)**		
		Surface	**Bottom**	**Vertical Profile**	**Surface**	**Bottom**	**Vertical Profile**
45, 68	14/1/04	**24.7**	**21.9**	2.9	**24.3**	**22.8**	1.5
45, 68	14/3/04	26.8	22.5	4.3			
77, 46	14/1/04	**22.6**	**21.4**	1.2	**23.9**	**22.7**	1.2
77, 46	14/3/04	23	22.1	0.9			
Average	14/1/04	**22.65**			**23.43**		

Table 5.1: Post-SCP – Simulation Heat-Loads (Summer)

Modelled Drain Flows – Post SCP January-February 2004 Conditions					
Model Source No	**Drain**	**Average Condition**		**Maximum Conditions**	
		Q (m^3/s)	**ΔT (°C)**	**Q (m^3/s)**	**ΔT (°C)**
1	Main Drain	0	0	0	0
2	No.2 Blower Station	7.04	5.94	7.32	8.0
3	Iron Making East	0.208	4.05	0.232	7.5
4	3500mm Plate Mill Drain	0.395	2.84	0.43	3.5
5	Slab Mill Drain	0.013	31.41*	0.013	32.68*
6	No.1 Flat Products East Drain	0.112	4.64	0.112	10.5
7	Allan's Creek Flow	0.17	22.5*	0.17	22.5*
8	North Gate Drain	0.077	28.06*	0.13	30.22*
9	New SCP Drain	7.5	5.9	7.5	9.4

* This is not a power station source, absolute temperature (°C)

Table 5.2(a): Existing and Post-SCP Average Water Temperatures (^{o}C) - Average/Typical Heat-Load Conditions - Summer

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient* (1-10)	
Harbour Location	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP
22,67	27.21	26.94	28.20	28.17	27.57	28.29	-0.37	-1.37
45,68	24.42	24.93	23.32	23.55	22.92	23.02	1.50	1.90
60,62	23.85	24.28	23.23	23.45	22.81	22.89	1.04	1.39
77,46	23.54	23.89	22.99	23.14	22.64	22.68	0.91	1.21
81,40	23.38	23.68	22.83	22.92	22.67	22.72	0.71	0.96
80,34	23.01	23.18	23.03	23.19	22.93	23.05	0.08	0.13

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 5.2(b): Existing and Post-SCP Water Temperature Standard Deviations (^{o}C) - Average/Typical Heat-Load Conditions - Summer

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Harbour Location	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP
22, 67	1.46	1.80	1.12	1.27	1.08	1.05	1.42	1.82
45, 68	0.73	0.72	0.28	0.30	0.20	0.19	0.69	0.69
60, 62	0.65	0.70	0.26	0.26	0.20	0.19	0.62	0.69
77, 46	0.60	0.66	0.25	0.25	0.20	0.19	0.58	0.67
81, 40	0.59	0.65	0.29	0.30	0.22	0.22	0.54	0.63
80, 34	0.51	0.53	0.47	0.49	0.41	0.43	0.22	0.26

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 5.3(a): Existing and Post-SCP Average Water Temperatures (^{o}C) - Average/Typical Heat-Load Conditions - Allans Creek - Summer

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Creek Location	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP
100m U/S	27.30	27.03	28.25	28.23	27.64	28.33	-0.34	-1.30
300m U/S	26.94	26.53	27.99	27.85	27.56	28.15	-0.62	-1.62
500m U/S	26.79	26.11	27.83	27.27	28.08	27.83	-1.29	-1.72

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 5.3(b): Existing and Post-SCP Water Temperature Standard Deviations (^{o}C) - Average/Typical Heat-Load Conditions - Allans Creek - Summer

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Creek Location	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**
100m U/S	1.49	1.83	1.11	1.24	1.11	1.05	1.47	1.85
300m U/S	1.44	1.79	1.22	1.47	1.10	1.24	1.24	1.75
500m U/S	1.52	1.70	1.27	1.59	1.19	1.54	1.37	1.66

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 6.1: Existing Operations – Simulation Heat-Loads (Winter)

Modelled Drain Flows – Existing June-July 2005 Conditions					
Model Source No	**Drain**	**Average Condition**		**Maximum Conditions**	
		Q (m^3/s)	**ΔT (°C)**	**Q (m^3/s)**	**ΔT (°C)**
1	Main Drain	1.517	6.28	2.993	6.20
2	No.2 Blower Station	8.211	7.11	8.413	13.20
3	Iron Making East	0.100	3.06	0.127	4.20
4	3500mm Plate Mill Drain	0.408	2.41	0.405	4.21
5	Slab Mill Drain	0.016	21.37*	0.081	22.00*
6	No.1 Flat Products East Drain	0.196	4.35	0.189	9.21
7	Allan's Creek Flow	0.170	16.80*	0.170	16.80*
8	North Gate Drain	0.102	17.98*	0.172	17.00*

* This is not a power Station source, absolute temperature (°C)

Table 6.2(a): Existing and Post-SCP Average Water Temperatures (°C) - Average/Typical Heat-Load Conditions - Winter

	Layer 1 (Surface)		**Layer 5 (Middle)**		**Layer 10 (Bottom)**		**Vertical Gradient (1-10)**	
Harbour Location	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**
22,67	20.14	19.80	21.08	21.06	21.05	21.70	-0.92	-1.90
45,68	17.42	17.89	16.44	16.76	16.29	16.54	1.13	1.35
60,62	16.84	17.29	16.40	16.72	16.25	16.46	0.59	0.83
77,46	16.51	16.91	16.30	16.54	16.21	16.35	0.30	0.56
81,40	16.40	16.74	16.26	16.41	16.22	16.35	0.18	0.39
80,34	16.14	16.32	16.22	16.40	16.21	16.36	-0.07	-0.05

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 6.2(b): Existing and Post-SCP Water Temperature Standard Deviations (°C) - Average/Typical Heat-Load Conditions - Winter

	Layer 1 (Surface)		**Layer 5 (Middle)**		**Layer 10 (Bottom)**		**Vertical Gradient (1-10)**	
Harbour Location	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**
22,67	1.60	1.72	1.47	1.45	1.10	1.00	1.64	1.80
45,68	0.81	0.79	0.44	0.39	0.41	0.35	0.62	0.63
60,62	0.67	0.67	0.43	0.37	0.40	0.34	0.43	0.49
77,46	0.61	0.61	0.40	0.36	0.37	0.34	0.34	0.39
81,40	0.56	0.58	0.37	0.35	0.36	0.34	0.29	0.35
80,34	0.47	0.49	0.44	0.46	0.41	0.41	0.10	0.14

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 6.3(a): Existing and Post-SCP Average Water Temperatures (°C) - Average/Typical Heat-Load Conditions - Allans Creek - Winter

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Creek Location	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP
100m U/S	20.32	19.96	21.20	21.13	21.14	21.76	-0.82	-1.80
300m U/S	19.71	19.32	20.77	20.75	21.02	21.54	-1.31	-2.22
500m U/S	19.36	18.81	20.52	20.13	21.30	21.16	-1.94	-2.35

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 6.3(b): Existing and Post-SCP Water Temperature Standard Deviations (°C) - Average/Typical Heat-Load Conditions – Allans Creek - Winter

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Creek Location	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP	Existing	Post-SCP
100m U/S	1.64	1.72	1.47	1.41	1.12	0.95	1.76	1.86
300m U/S	1.48	1.68	1.46	1.58	1.18	1.24	1.44	1.66
500m U/S	1.53	1.67	1.38	1.68	1.13	1.45	1.60	1.70

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 7.1(a): Existing and Post-SCP Average Water Temperatures (°C) -Maximum Heat-Load Conditions - Summer

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Harbour Location	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**
22,67	28.62	27.58	28.04	28.38	23.92	26.36	4.72	1.21
45,68	25.08	25.92	23.38	23.68	22.94	23.08	2.13	2.84
60,62	24.30	25.01	23.30	23.59	22.84	22.94	1.47	2.06
77,46	23.86	24.43	23.06	23.28	22.66	22.71	1.20	1.72
81,40	23.63	24.13	22.89	23.02	22.70	22.77	0.94	1.36
80,34	23.16	23.43	23.15	23.39	23.01	23.19	0.22	0.24

* Note: - Gradient result is average gradient, not gradient of the average temperatures

Table 7.1(b): Existing and Post-SCP Water Temperature Standard Deviations (°C) - Maximum Heat-Load Conditions - Summer

	Layer 1 (Surface)		Layer 5 (Middle)		Layer 10 (Bottom)		Vertical Gradient (1-10)	
Harbour Location	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**	**Existing**	**Post-SCP**
22,67	1.93	2.04	1.65	1.42	1.46	1.09	2.48	1.91
45,68	0.92	0.89	0.30	0.35	0.19	0.19	0.89	0.87
60,62	0.84	0.93	0.26	0.27	0.19	0.19	0.82	0.94
77,46	0.75	0.86	0.25	0.26	0.19	0.18	0.74	0.89
81,40	0.72	0.83	0.30	0.31	0.22	0.22	0.68	0.83
80,34	0.58	0.62	0.51	0.54	0.43	0.46	0.26	0.38

* Note: - Gradient result is average gradient, not gradient of the average temperatures

APPENDIX A

Determining Temperature Guidelines for SCP Cooling Water Analysis

The ANZECC & ARMCANZ guidelines (2000), Volume 2, Section 8.2-.3.4 p 8.2-66 as referenced by the DEC provide guidance for "Unnatural change in temperature". The reference states:

"Hot water discharges should not be permitted to increase the temperature of the aquatic ecosystem above the 80%ile temperature value obtained from the seasonal distribution of temperature data from the reference system."

These guidelines have been used for the SCP as follows:

1. Phillips (2002) provided sampling of surface water temperatures at 14 locations at the mouth of Allans Creek (2), Port Kembla Harbour Inner (6), Port Kembla Harbour Outer (4) and the Pacific Ocean (2) beyond the harbour between 1992 and 1999. A total of 22 data points relevant to the project and covering all seasons were collected. Given the absence of a similarly disturbed system, the use of this data from the various parts of Port Kembla Harbour and the Pacific Ocean are deemed to be suitable as a reference system;

2. BlueScope Steel (2006) collect temperature data on a daily basis at the intake structure for the saltwater channel that takes seawater from the outer harbour and provides cooling water for the PKSW. Data between January 2000 and March 2005 was used;

3. Statistical assessments were made between the Phillips and BlueScope Steel data sets to determine if they could be considered to be derived from the same population:

Table A9.1 Statistical comparison of Port Kembla Harbour Water Temperature data

Parameter	Phillips (2002)	BlueScope Steel (2006)
N	22	237
min. (° C)	15.5	12
max. (° C)	26	27
mean (° C)	19.9	19.9
Standard Deviation	3.2	2.9
variance	10.34997835	8.160087249
Pooled variance	8.339027767	
t-Test: Two-Sample Assuming Equal Variances [1] Alpha = 0.05 Alpha = 0.01	 t critical = 1.9692, P (two tail): 0.9706, P>0.05 t critical = 2.5950, P (two tail): 0.9706,	
t-Test: Two-Sample Assuming Unequal Variances [1] Alpha = 0.05 Alpha = 0.01	 t critical = 2.0639, P (two tail): 0.9736 t critical = 2.7969, P (two tail): 0.9736	

[1] Hypothesized Mean Difference of 0 (zero) used. Indicates that the sample means are hypothesized to be equal. Two-tailed test adopted in all cases – this test looks for any change in the parameter (which can be an increase or decrease)

The assessments identified the two data sets as not being significantly different and hence can be considered to be derived from the same population – that is, the larger BlueScope Steel data set is representative of water temperatures across Port Kembla Harbour (inner and outer).

4. Given the larger number of data points taken for BlueScope Steel's saltwater intake channel, it was possible to generate meaningful data sets of winter (June/July) and summer (January/February) seasonal data from which it was possible to determine an appropriate 80th percentile temperature value for each season.

5. The 80th percentile values for winter and summer were then derived from the verified data set as shown in Table A9.2.

Table A9.2 80th percentile temperature values for summer and winter in Port Kembla Harbour

Parameter	Winter (June/July)	Summer (January/February)
n	37	44
min. (° C)	13	20
max. (° C)	19	27
Mean (° C)	17	23.2
S.D	1.3	1.5
80th percentile temperature (° C)	18	24

APPENDIX B

Port River Model

Port River Delft3D Water Quality Model – Setup and Calibration

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Abstract
The Port River Water Quality Improvement Plan is a joint initiative of the State and Commonwealth governments to improve the water quality in the Port River and Barker Inlet, South Australia. The objective of the plan is to reduce nutrient pollutant loads and consequent algal blooms in the Port River waterways. Part of this project involved the setup and calibration of a high-level water quality model to assist in the future planning for licensed discharges in the estuary.

Cardno Lawson Treloar were commissioned by the Environment Protection Authority, South Australia (EPA) to setup, calibrate and implement a Delft3D water quality model to be used by EPA staff. The model was firstly setup as a hydrodynamic model and calibrated to available data. The model was then expanded into a high-level Delft3D-WAQ water quality model and calibrated using an extensive dataset from June 2004. The water quality calibration process utilised expertise from Cardno Lawson Treloar, EPA and Delft Hydraulics. This paper discusses the model setup and calibration process. Model results from the calibration process are also presented.

1 Introduction

The Port River is an estuary located northwest of Adelaide. The estuary has come under pressure from the effects of industrial, commercial and residential development. The Port River estuary consists of two main branches. One of these is the Port River itself, which has a predominantly industrial catchment and features a uniform shipping channel along most of its length. The other branch is Barker Inlet, which is relatively shallow with intertidal regions covering 75% of the area. The North Arm channel links the Port River with the Barker Inlet in the south. The Port River and Barker Inlet discharge into the Gulf of St Vincent a short distance apart.

The Port River Water Quality Improvement Plan is a joint initiative of the State and Commonwealth governments. The objective of the plan is to reduce nutrient pollutant loads and consequent algal blooms in the Port River waterways. The development of a numerical model to simulate the hydrodynamic behaviour and the nutrient and sediment dynamics of the estuary is one component of the task. The modelling will be used for scenario testing by the Environment Protection Authority (EPA) and will become a decision support tool for the project managers. Figure 1 shows the Port River Water Quality Improvement Plan study area.

The modelling system applied to this project is the Delft3D system developed by Delft Hydraulics, The Netherlands. The Delft3D system includes hydrodynamic, wave, sediment transport and water quality modules. In the first instance the model was set up and hydrodynamically calibrated using data provided predominantly by EPA. Following successful hydrodynamic calibration, water quality processes were defined in the model. The water quality processes description and water quality model calibration were jointly developed by Cardno Lawson Treloar, EPA and Delft Hydraulics. A feature of this process was to directly use the site specific expertise of the EPA staff in the water quality model development process.

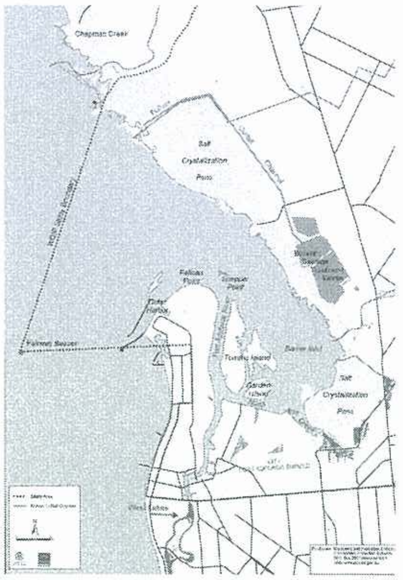

Figure 1 Port River Water Quality Improvement Plan study area.

The Port River Delft3D model has been used by the EPA to investigate a range of different point source discharge scenarios. The model has the potential to be used as a planning tool into the future.

2 Study Approach

The investigation stages undertaken by Cardno Lawson Treloar in this project have been to:-

- Compile a range of data sets and develop model parameters including, a Digital Terrain Model of the Port River,

- Develop and verify (hydrodynamically) the model using available data from 1995 investigations (Lord, 1996),
- Develop and calibrate a Delft3D hydrodynamic model using data collected in May-June 2004,
- Develop a water quality process description for the system, and
- Calibrate a Delft3D-WAQ water quality model using this water quality process description.

3 Data

A range of data items were required to set up and validate the model system applied to this investigation.

3.1 Bathymetric Data

Bathymetric data was compiled from a number of surveys (some data in digital form) and bathymetric charts. The EPA provided a range of survey data, including:-

- Survey of Port River Channel conducted in 1995,
- Survey data of the Barker Inlet tidal channels undertaken in 2003 and 2004,
- North Arm survey, and
- Upper Port River survey undertaken in 2004.

In addition to the survey data, Cardno Lawson Treloar obtained bathymetric data from AUS Charts 137 and 781 to define the model domain.

3.2 Tidal Data

Tidal plane data for the Port River is provided by the Australian Hydrographic Service. The tidal planes for the Outer Harbour tide gauge are: -

Highest Astronomical Tide	2.8m
Mean High Water Springs	2.3m
Mean High Water Neaps	1.3m
Mean Low Water Neaps	1.3m
Mean Low Water Springs	0.3m

all to Chart Datum, with mean sea level (MSL) being about 1.3m above Chart Datum. The tidal character at the site can be described generally as semi-diurnal, that is, two high tides and two low tides each day. However, there are periods of time when the tide is diurnal, or a dodge tide occurs.

Tidal constants enabling the prediction of tide levels were obtained from the Australian National Tide Tables (Australian Hydrographic Service, 2003).

3.3 Estuary and Lakes Hydraulic Flushing Model Study

A flushing investigation of the Port River and Barker Inlet was undertaken for the proposed Multi-Function Polis development in 1995 (Lord, 1996). This project involved the development of a hydraulic model and extensive field data collection exercises. The EPA provided a range of data from the February to March 1995 period to assist in the initial calibration of the model.

3.4 May to June 2004 Field Data

During the May to June period in 2004, the EPA collected a range of data from the Port River and Barker Inlet. This included:-

- ADCP discharge data at 3 sites,
- Salinity, density and temperature data from a number of locations over a period of thirty days and
- A wide range of water quality data collected between 25 May and 21 June 2004 including DO, TP, NH_4^+, TN and Chl-a.

In addition to the data collected by the EPA, a range of other data was supplied to Cardno Lawson Treloar including:-

- Meteorological data (temperature, rainfall, humidity, wind and solar radiation) from a number of sites near the study area, and
- Discharge data or the Port Adelaide WWTP, Bolivar WWTP, Penrice Soda Ash Plant, West Lakes, Barker Wetlands (via North Arm Creek), Torrens Island Power Station and Pelican Point Power Station.

4 Model System

The model system that has been supplied to the EPA is based on Delft3D. This is a world leading hydraulic and water quality modelling package developed by Delft Hydraulics in The Netherlands. The EPA version of Delft3D is capable of investigating a range of processes, including:-

- Hydrodynamic phenomena, including 3D processes (Delft3D-FLOW),
- Water quality processes including algal processes and sediment/water nutrient exchange (Delft3D-WAQ),
- Sediment transport and morphology(Delft3D-MOR), and
- Wave processes (Delft3D-WAVE), based on SWAN.

The Delft3D modelling system has been applied to water quality investigations at many international locations, as well as within Australia by Cardno Lawson Treloar, other consultants and universities.

Delft3D has been selected by the Hong Kong government as its preferred model because of its superior performance in an international calibration 'competition'. It has also been applied to water quality studies in the Venice lagoon, where other systems have been less successful.

The Delft3D modelling system includes wind, pressure, tide and wave forcing, three-dimensional currents, stratification, sediment transport and water quality descriptions and is capable of using rectilinear or curvilinear coordinates.

Delft3D is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file.

The water quality process capabilities of the Delft3D-WAQ module are extensive. There are well over 200 processes. The package is fully capable of meeting the requirements of the Port River Water Quality Improvement Plan.

Model substances included in the WAQ module include:-

- Conservative substances (salinity, chloride and up to five tracers)
- Decayable substances
- Suspended sediment
- Temperature
- Nutrients (ammonia, nitrate, phosphate, silicate)
- Organic matter (subdivided into fractions of carbon, nitrogen, phosphorus and silicon
- Oxygen
- BOD and COD
- Algae
- Bacteria
- Heavy metals
- Organic micro-pollutants.

5 Hydrodynamic Model

5.1 Model Processes

The following processes and parameters are incorporated in the Delft3D hydrodynamic model of the Port River:-

- Tides
- Salinity,
- Temperature,
- Wind,
- Discharges from Port Adelaide WWTP, Bolivar WWTP, Penrice Soda Ash Plant, bitterns (hypersaline) from the Penrice salt production ponds, West Lakes and Barker Wetlands,
- Intake and discharge of cooling water from the power stations at Pelican Point and Torrens Island,
- Solar radiation,
- Evaporation and rainfall
- Some wetlands flow, and
- Exchange with gulf waters.

At the time of this study, insufficient data was available to include all creek discharges into the system.

5.2 Model Domain

Figure 2 shows the domain of the Port River model. It features a single water level boundary along the western side. The model resolution varies between 10m x 10m inside the Port River and Barker Inlet regions to approximately 100m x 100m in the offshore regions. The model can be run in 2D or 3D sigma layer mode. The May-June 2004 simulation period used 10 vertical sigma layers with percentages of the depth for each layer (top to bottom) of 2%, 5%, 9%, 14%, 20%, 20%, 14%, 9%, 5% and 2%. The layers are thin at the top and bottom where process and parameter gradients are typically steep; for example, bed shear stress near the bottom and temperature near the surface, as well as wind shear.

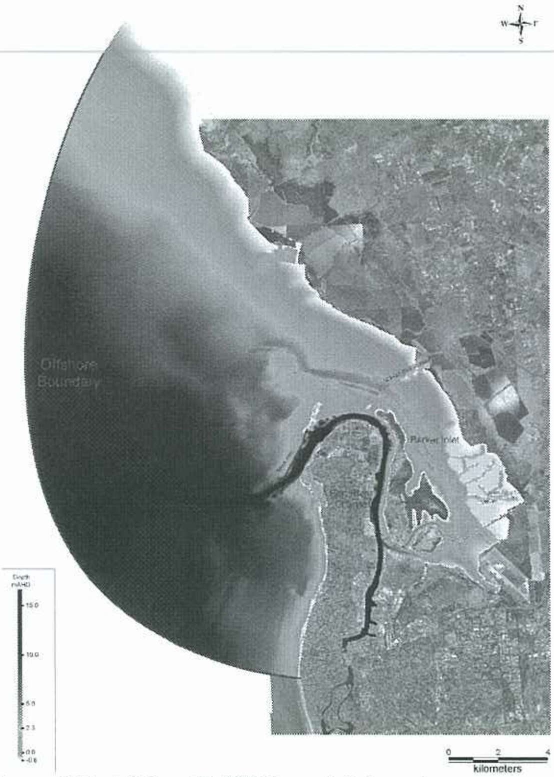

Figure 2 Port River Delft3D model domain.

The model features a variable Manning's 'n' bed roughness description. It was initially developed with a constant Manning's 'n' of 0.03. During the calibration process a spatial roughness map was developed. Three broad areas were defined:-

- General roughness, including the Port River Channel with a Manning's 'n' of 0.03,
- Barker Inlet with a Manning's 'n' of 0.035, and
- Mangrove areas with a Manning's 'n' of 0.05.

The roughness in Barker Inlet was set higher than in the Port River Channel to reflect the irregular nature of Barker Inlet compared to the uniform shipping channel in the Port River.

The Murakami heat flux model has been applied to the hydrodynamic model. This model has been calibrated for Japanese waters; however, parameters such as secchi depth can be adjusted to reflect local conditions

(Murakami et al, 1985). The Murakami heat model was selected because of its applicability to 3D modelling. The incoming solar radiation is absorbed as a function of depth which prevents unrealistically high water temperatures when the surface layer is very thin. The input parameters for the Murakami model are:-

- Net solar radiation,
- Relative humidity,
- Air temperature and
- Wind speed

These parameters were applied to the model as time series data with an interval of 30 minutes. Heat loss due to evaporation is calculated within the model using the temperature and relative humidity, as well as wind speed.

Note also that the source/sink model processes enable the heat exchange of the power stations to be modelled. The excess heat of the power station cooling water is added to the intake heat flux in order to describe the discharge temperature.

5.3 Model Calibration: May-June 2004

Model boundary and input conditions for the Port River model were developed for the period from 1 May to 30 June 2004. Data was obtained from a range of sources and supplied to Cardno Lawson Treloar by the EPA.

Figure 3 shows time series plots of the measured and modelled discharges at the three ADCP transects. The general locations of the transects were; upper Port River (PR1), North Arm (PR2) and lower Port River (PR3). Modelled results are presented as the solid lines and measured data are presented as characters. Generally, the model results are a good match to the field data. The results at PTR1 are a very good match, reflecting the detailed bathymetry data which exists upstream of this site in the Port River. The calibration at PTR2, whilst being good, also reflects the limited survey data in the mangrove areas in North Arm and Barker Inlet. The variable roughness map was developed during the calibration process to improve the model result.

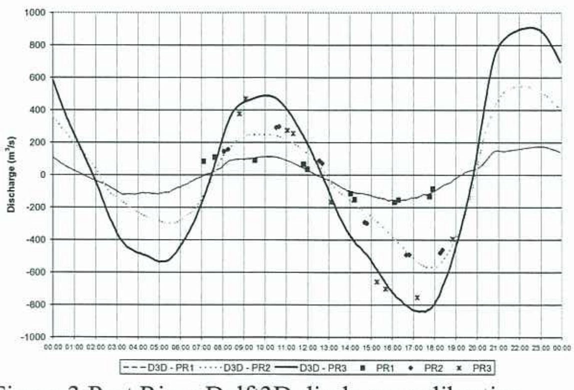

Figure 3 Port River Delft3D discharge calibration.

Figure 4 presents the modelled (solid line) and measured (dashed Line) water levels at the Osborne and Outer Harbour tide gauges for the period from 25 May to 25 June, 2004. The calibration at both sites is good in terms of amplitude and phasing.

Overall the Delft3D-FLOW model achieved a good level of calibration. The hydrodynamic calibration is very good, with water levels and discharges through the major branches showing good agreement. The 1995 initial calibration process also indicated that the current speed distribution in different areas of the model matched the measured data well. The uncertainties in bathymetric data in the Barker Inlet/North Arm intertidal areas do not appear to greatly reduce the model performance. Figure 3 shows that the discharge through North Arm is well represented in the model.

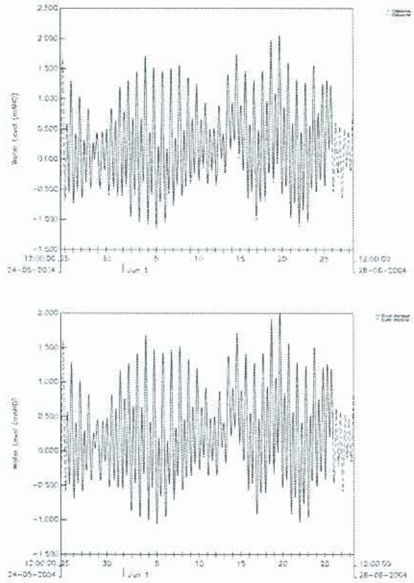

Figure 4 Port River Delft3D water level calibration at Osborne (upper) and Outer Harbour (lower).

The heat model also produced a good calibration. Figure 5 shows a map plot of the depth averaged water temperature showing the impact of the Torrens Island power stations on water temperature throughout the system. In Barker Inlet and North Arm the agreement between the model and measured data is good. The model results indicate that there has been too much nearfield dilution/cooling of the discharge from the power station in the Angus Inlet region. This dilution has reduced the vertical temperature profile in the model. The modelled water temperature through the North Arm channel and Barker Inlet was a good match to the available data. In the Port River, the modelled temperature does not reflect the measured data as well as it does in the North Arm and Barker Inlet. The measured and modelled bottom layer temperatures show reasonable agreement, but, the modelled surface layer temperatures are lower than the measured data. Vertical stratification is generally well described in the model. However, the temperature gradient is not as steep as observed. This indicates that the heat load from West Lakes and Port Adelaide WWTP is most likely higher than was specified in the model input.

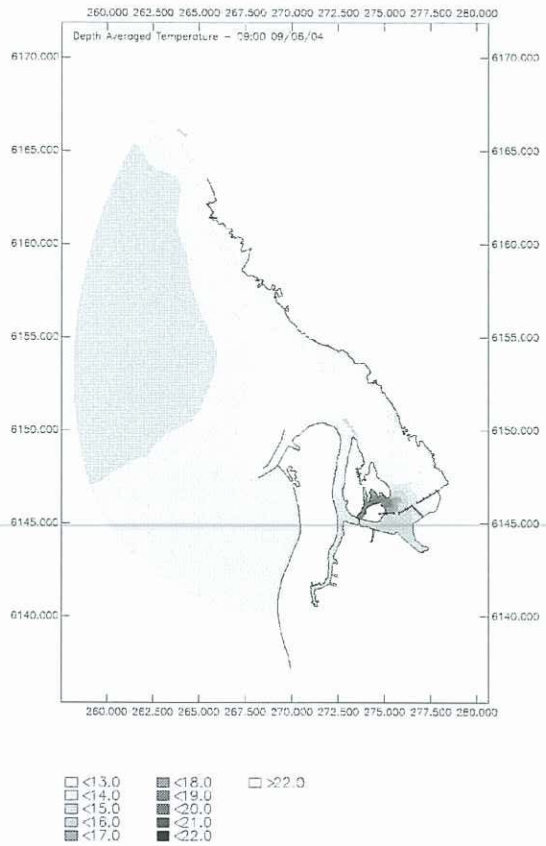

Figure 5 Modelled thermal plume (°C) from Torrens Island Power Station.

6 Water Quality Model

6.1 Initial Conditions

The Delft3D-WAQ model domain is based on the Delft3D-FLOW domain. The hydrodynamic grid was aggregated using DIDO to improve the computational performance of the water quality model. The aggregated grid has 5326 computational elements compared to the 67884 cells in the hydrodynamic model. The WAQ model has 10 vertical layers with the same vertical structure as the hydrodynamic model.

The initial values of the various water quality constituents were firstly specified as the average of all of the data collected at sites in the middle reaches of the Port River and Barker Inlet branches. Water quality simulations were undertaken a number of times, restarting from the final results of the previous run. This process allows a stable dynamic equilibrium initial condition to be established. Offshore boundary conditions were developed from data collected by the EPA in July 2004.

A range of data was utilised to describe the loads from various point source discharges, such as the Penrice soda ash plant.

6.2 Model Processes

The following processes are included in the Port River Delft3D-WAQ model:-

- Temperature and humidity
- Nitrogen, phosphorus, silicon and carbon cycling,
- Sediment uptake and release of nutrients,
- Nitrification/de-nitrification,
- Dissolved oxygen (including re-aeration/de-aeration),
- Light extinction,
- Nutrient fluxes through the power station cooling water system , and
- Algal processes.

6.3 Calibration Process

The transport and dispersion capability of the water quality model was calibrated initially using salinity, and then by investigating Total P and Total N. An initial aggregated WAQ grid, which featured 1100 computational elements, was created. The salinity gradient produced by the WAQ model was compared with the salinity gradient in the high-resolution hydrodynamic model. This initial aggregation indicated that the WAQ grid was too coarse and that a finer horizontal grid was needed to match the spatial gradients in the hydrodynamic model. A second aggregated WAQ model with 5326 computational elements was developed.

Initially the model produced an under-estimation of ammonia and an over-estimation of nitrate in the Port River channel. This gave reason to decrease the nitrification coefficient by half as compared to the DELFT3D default value. Overall, the Port River region of the model, with only the Port River point source loads, showed a lower level of nitrogen than was observed in the field data. Data available to the EPA indicated that the nitrogen load from bed sediment in the shipping channel (Port River) was significantly higher than other areas in the system, at least, during the winter. A zero-order nitrogen flux was added to the Port River shipping channel to increase the nitrogen load flux from the sediment.

During the calibration process it became evident that there was significant variation between the algal dynamics of the Port River channel and Barker Inlet. The upper Port River features significant stratification, high silica loads from the Port Adelaide WWTP and is generally dominated by diatoms. In the Barker Inlet silica is also relatively abundant, but diatom levels are generally low. The higher grazing rates of diatoms in Barker Inlet compared to the Port River is thought to be due to the higher abundance of bivalve filter feeders such as razorfish (Pinna bicolor). To account for the greater abundance of grazing organisms in Barker Inlet, compared to the Port River and outer waters, a spatially varying mortality rate for diatoms was imposed on the model.

Ulva growth is widespread throughout Barker Inlet. The biomass of this green macroalga has not been measured, but is obviously very significant ecologically. Although Ulva is not explicitly modelled in WAQ, it has been incorporated into the 'Green' algae fraction. The Ulva chlorophyll contribution was not included in the field measurement analyses, but the

EPA estimated that the average chlorophyll-a contribution of Ulva in Barker Inlet was approximately 1.5-2µg/L.

6.4 Model Calibration: May-June 2004

This section briefly describes the results from the 3-Dimensional Delft3D-WAQ model for the May to June 2004 calibration period. The results relate to the following parameters:-

- Total phosphorus (TP),
- Total nitrogen (TN), and
- Chlorophyll-a (Chl-a).

Overall the model achieved good calibration for total phosphorus and total nitrogen. In the Barker Inlet and outer Port River the match between modelled and measured results was very good. In the mid-section of the Port River the model produced slightly lower total nitrogen concentrations than were observed. This result indicates that an additional source that was not represented in the model contributed nitrogen to the system during the calibration period. Figure 6 presents a spatial plot of modelled surface layer total nitrogen at 13:00 13 June 2004, and measured total nitrogen collected as surface samples between 10:00-15:00 13 June 2004 - shown as circles. The modelled and observed results are generally a good match. In the upper Port River the modelled values suggest that the model is allowing slightly too much dispersion. However, this region is strongly influenced by the tidal cycle and West Lakes discharge, with significant uncertainties in the latter.

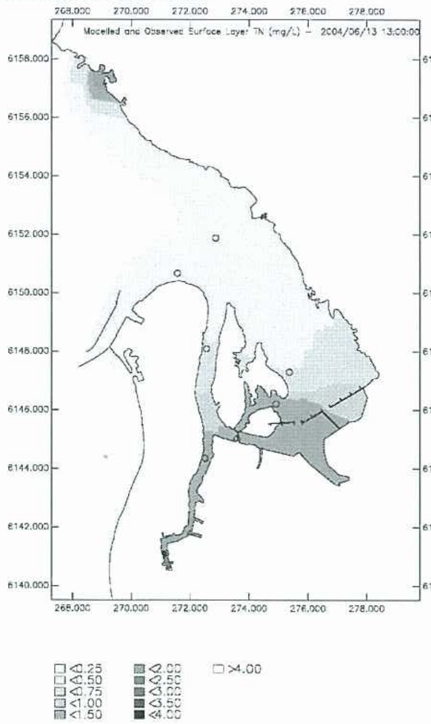

Figure 6 Modelled and measured total nitrogen (mg/L) at the surface of the water column 13:00 13 June 2004.

The chlorophyll-a calibration result is more difficult to analyse than these results for nitrogen and phosphorus because of the limited reliable data. Furthermore, the measured data does not account for the chlorophyll-a in Ulva whereas this is represented in the Delft3D-WAQ model (although not explicitly). Overall the chlorophyll-a calibration is generally good, however the available field data for chlorophyll-a was limited compared to the available total nitrogen and total phosphorus data. The model indicated that Barker Inlet is dominated by the "green algae" including Ulva rather than diatoms, and the upper Port River is dominated by diatoms.

7 Conclusions

Overall, the Port River hydrodynamic and water quality Delft3D models have achieved a good level of calibration with the data collected during the May-June 2004 simulation period. The modelled temperatures and hydrodynamics showed good agreement with the observed data. The modelled salinity and temperature in the upper (inner) Port River was lower than the observed data. The uncertainty with the salinity, temperature and discharge data for the West Lakes outlet limits the ability for a numerical model to replicate the observed data in this area. Although the modelled salinity and temperature in the upper Port River was lower than observed, the vertical salinity and temperature gradients near the West Lakes / Port Adelaide WWTP and Penrice soda ash discharges are well described in the model.

The water quality model has also achieved a suitable level of calibration. Due to the different algal dynamics between the Port River and Barker Inlet, spatial variation in some parameter values was required. The Delft3D-WAQ model of the Port River is a highly advanced tool available to the EPA to assist in the future planning and redevelopment of the Port River and Barker Inlet.

8 Acknowledgements

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