WALSH BAY ARTS AND CULTURAL PRECINCT

STATE SIGNIFICANT DEVELOPMENT APPLICATION

SSDA 8671

APPENDIX 28:

HARBOUR HEAT REJECTION IMPACT ASSESSMENT

NSW GOVERNMENT

Harbour Heat Rejection Impact

Assessment report

Contents

1. Objectives of assessment

1.1 The Project

The NSW Government is committed to development of a public arts and cultural precinct at Walsh Bay. Infrastructure NSW is acting on behalf of the client, Arts, Screen and Culture Division in preparing this State Significant Development Application for the Walsh Bay project.

This SSDA will seek approval for the construction and operation of Pier 2/3 and Wharf 4/5 for arts and cultural uses with complementary commercial and retail offerings to activate the precinct.

The site generally comprises Pier 2/3, Wharf 4/5, and Wharf 4/5 Shore Sheds. The site has a street frontage to Hickson Road as shown in Figure 1. The site is part of the Walsh Bay area, which is located adjacent to Sydney Harbour within the suburb of Dawes Point.

Figure 1: The Site

The Scope of the Project is as follows:

Pier 2/3

- The adaptive re-use providing for new arts facilities including performance venues for the Australian Chamber Orchestra, Bell Shakespeare and Australian Theatre for Young People;
- Retaining a large heritage commercial events/art space for events such as Sydney Writers Festival, Biennale of Sydney and a wide range of commercial and artistic events;
- A series of stairs, external lift and balconies designed as a contemporary interpretation of the original gantries reflecting the precinct's former industrial heritage

- Modifications to the roof

Wharf 4/5 (including Shore Sheds)

- Refurbishment of the ground floor arts facilities and its associated Shore Sheds for Bangarra Dance Theatre, Sydney Dance Company, Sydney Philharmonia, Gondwana and Song Company;
- New commercial retail opportunities; and
- A series of stairs, external lifts and balconies designed as a contemporary interpretation of the original gantries reflecting the precinct's former industrial heritage
- Modifications to the roof

It is proposed that the new facilities will feature an air conditioning system that utilises a closed loop sea water cooling system to reject heat. The closed loop sea water cooling system will transfer heat to adjacent sea-water without discharging any effluent.

Jacobs was commissioned by Infrastructure NSW to undertake an assessment of the potential thermal impacts of the closed loop sea water cooling system on the receiving waters of Walsh Bay and Sydney Harbour. This report documents the outcomes of this assessment.

1.2 Purpose and scope

The purpose of this report is to assess the potential thermal impacts of the closed loop sea water cooling system associated with the proposed Walsh Bay project.

Task components of the scope included:

- Develop a numerical model that can simulate the key dispersion processes within Walsh Bay and Sydney Harbour;
- Model the likely maximum thermal impacts of the proposed closed loop sea water cooling system operations; and
- Assess the potential thermals impacts of the sea water cooling system on the receiving water environment.

1.3 Report structure

The heat rejection impact assessment involved a number of technical analyses and modelling investigations as detailed in the following section of the report:

- **Section 2** describes the hydrodynamic model used to simulate currents and heat exchange processes;
- **Section 3** details the results of the heat rejection scenario modelling; and
- **Section 4** discusses and summaries the key findings of the study.

1.4 Existing Conditions

1.4.1 The Site and surrounds

The site generally comprises Pier 2/3, Wharf 4/5, and Wharf 4/5 Shore Sheds. The site has a street frontage to Hickson Road as shown in Figure 1. The site is part of the Walsh Bay area, which is located adjacent to Sydney Harbour within the suburb of Dawes Point.

The site lies within the City of Sydney Local Government Area and is strategically located to the north of Sydney's CBD in the vicinity of major tourist destinations including the Sydney Harbour Bridge, the historic areas of Millers Point and The Rocks, Circular Quay and the Sydney Opera House. The Barangaroo redevelopment precinct is located immediately to the south-west.

The land owner of the site is the Roads and Maritime Services (RMS). Both Pier 2/3 and Wharf 4/5 are occupied under various lease arrangements with Create NSW, Department of Justice, primarily for arts and cultural uses.

Walsh Bay comprises ten berths constructed between 1908 and 1922 for international and interstate shipping. These are collectively known as the Walsh Bay Wharves. The Walsh Bay Wharves Precinct is listed as an item on the State Heritage Register.

Bathymetry within the bay is typically around -10.0mCD, with Chart Datum relative to the Lowest Astronomical Tide (Source: Navionics).

The Walsh Bay Wharves comprise the following:

- Pier One which contains the Sebel Pier One Sydney Hotel;
- Pier 2/3 the last remaining undeveloped pier (has previously received approval for cultural uses, temporary arts events and some commercial events);
- Wharf 4/5 which is occupied by the Sydney Theatre Company (STC), the Australian Theatre for Youth Program (ATYP), Sydney Dance Company (SDC), Bangarra Dance Theatre and the choirs comprising Gondwana, the Song Company and Sydney Philharmonia;
- Pier 6/7 which has been redeveloped for residential apartments and associated boat marina;
- Pier 8/9 which has been redeveloped for office uses; and,
- Shore sheds aligning Hickson Road which contain a range of commercial activities, including restaurants, bars, shops and offices.

1.4.2 Climate

The climate of Sydney is temperate, having warm sometimes hot summers and mild winter, with moderate extreme seasonal differences. The maximum and minimum air temperature varies from occasionally more than 40 °C in summer to just below 0°C in winter. The daily average temperature is typically in the high twenties during summer and low tens during winter (Refer to Figure 2).

Rainfall is fairly evenly spread through the year, with moderate to low variability. Precipitation is slightly higher during the first half of the year when easterly winds dominate (February–June), and lower in the second half (mainly July–September).

Figure 3 presents a wind rose for Sydney Airport, located approximately 11 km south-southwest of the site, derived from measurements spanning a 70-year period. The wind rose shows that the region is affected by three dominant wind directions, namely southerlies, westerlies and north easterlies. The strongest and most frequent winds are from the south. All wind speeds presented in this report are 10-minute average values.

These general wind characteristics are also evident in the wind data from the Sydney Observatory Hill station, located less than a kilometre south-southwest of the site (Figure 4). The wind data of this station shows that ambient winds around the site are typically below 6 m/s.

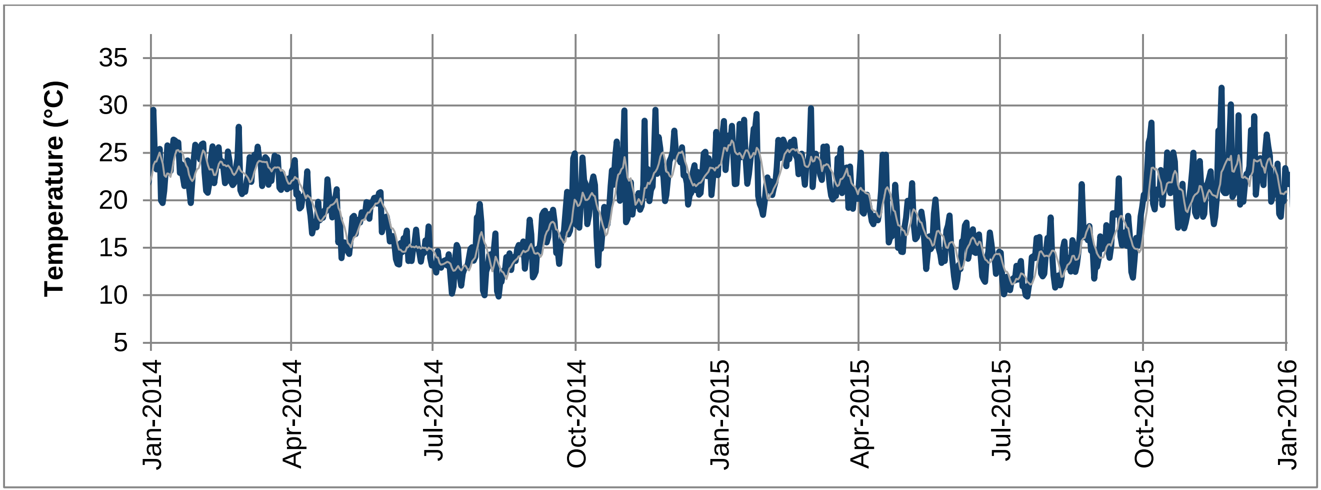

Figure 2: Daily Mean Air Temperature Observed at Sydney Observatory Hill Station

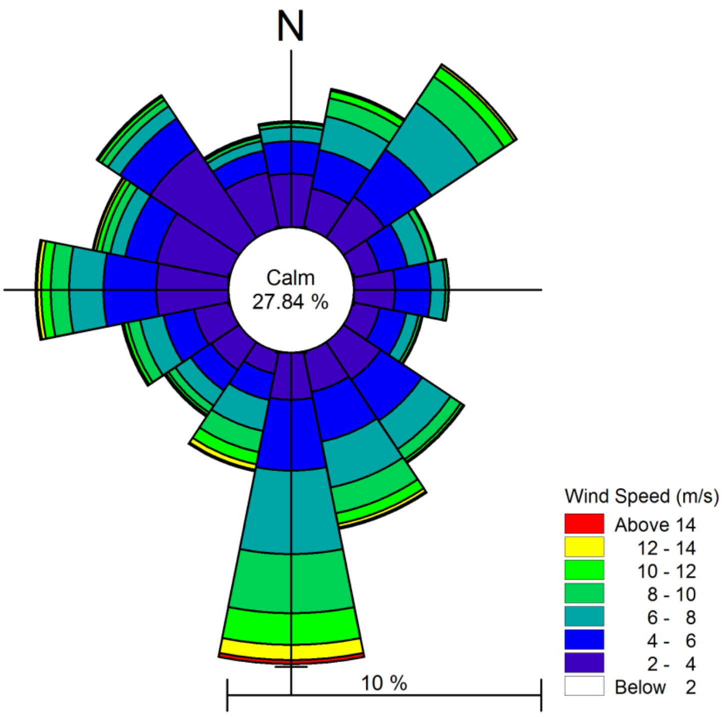

Figure 3:Sydney airport wind rose (1939 – 2009)

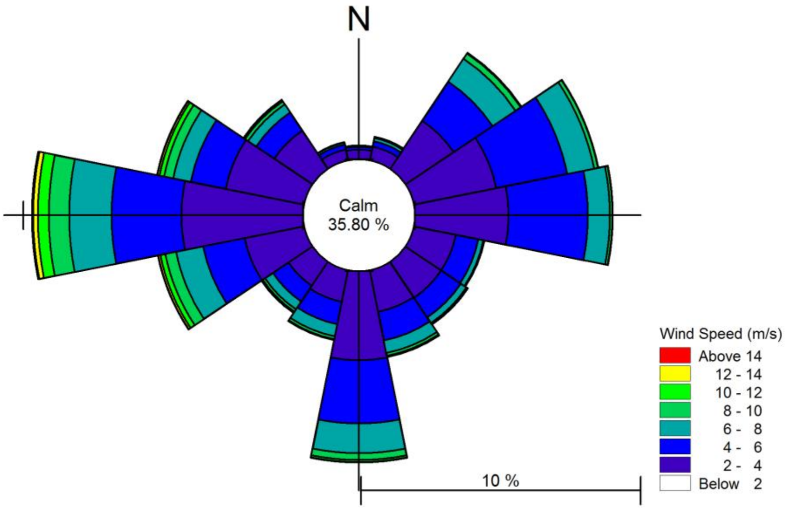

Figure 4:Sydney Observatory Hill wind rose (1997 – 2006)

1.4.3 Harbour hydrodynamics

Circulation within Sydney Harbour is dominated by the tides, with some influence from prevailing winds (Hedge *et al*. 2013). Tides within Sydney Harbour are semi-diurnal with a typical range of approximately two metres. Figure 5 presents tidal water level predictions for Sydney Harbour for the period February 2016 – March 2016. Tides propagate into the connected embayments and rivers, and their tidal tributaries. The speed of propagation of the tide up the estuary is primarily dependent on:

- Depth of the estuary; and
- Friction losses due to the roughness of the bed and banks and the non-uniformity of the cross section.

The tidal prism at a particular location is the volume of water that passes this location during the rise or fall of a tide. Therefore the tidal prism decreases from a maximum at the mouth of the embayment to zero at the limit of tidal influence.

Das *et al*. (2000) estimated discharge volumes to be up to 6,000 m^3/s across the Heads at the peak of the ebb tide, with more than 4,000 m^3/s coming from the main branch of Port Jackson and less than 1,500 m^3/s coming from Middle Harbour (Hedge *et al*. 2013).

Tidal currents within Port Jackson flow in a general east-to-west direction during flood tide and a general west-to-east direction during ebb tide. Tidal flow velocity between Clyne Reserve (approximately 500m west of Pier 2/3) and the Sydney Harbour Bridge is typically less than 0.5 m/s. Locally, tidal currents within Port Jackson are influenced by the coves and points along the coast, resulting in the generation of weak eddies (National Geospatial Intelligence Agency, 2014).

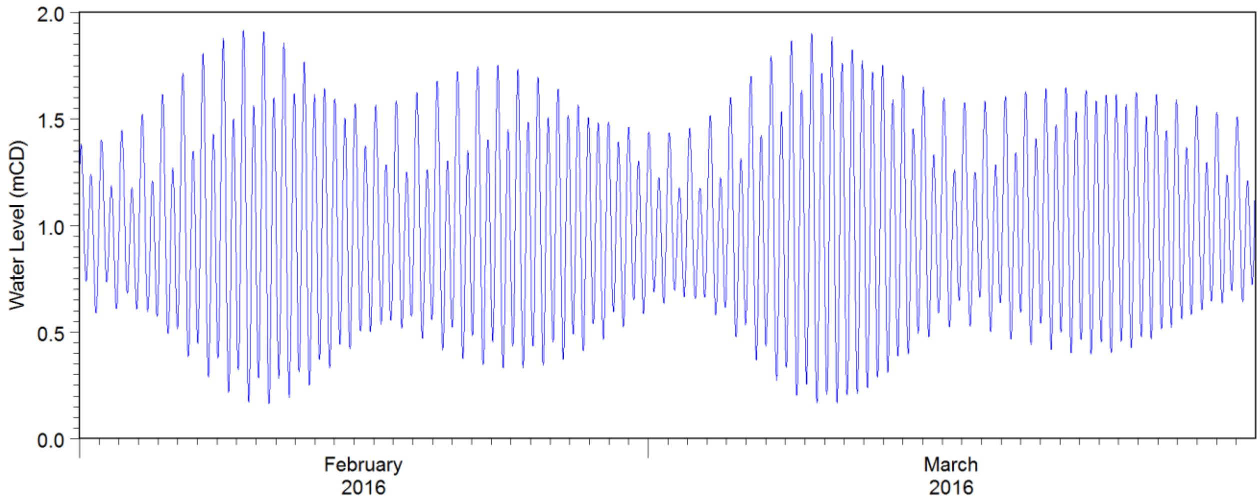

Figure 5: Tidal water level predictions for Feb/Mar 2016 at Sydney Harbour (Source: Australian Hydrographic Office, 2012)

1.4.4 Waves

The waves affecting Walsh Bay are dominated by waves generated within Sydney Harbour by local winds. Ocean swell entering Sydney Harbour through the Heads is considered to have no significant influence on coastal processes at the western part of the Harbour (Cardno, 2015).

Waves at Walsh Bay are generally of low height and relatively short period (generally less than four seconds) although occasionally larger waves associated with strong wind events may occur.

1.4.5 Ambient air and water temperature

Water temperature measurements taken at the mouth of the Parramatta River have been obtained from the Hornsby Shire Council. In addition, data has been extracted from the HYCOM global dataset, at an ocean location close to the mouth of the Sydney Harbour. These are provided in Figure 6.

Water temperature measurements taken at the mouth of the Parramatta River show a greater annual variation than re-analysis predictions from the HYCOM dataset.

Daily mean air temperature measurements obtained from the Bureau of Meteorology show that there is a strong correlation between ambient air and water temperature measurements taken inside the harbour. The 5th and 95th percentile water temperature values were derived from the Parramatta River dataset as a proxy of the typical annual ambient water temperature variation within Walsh Bay. The 5th and 95th percentile temperatures are 13.2°C and 26.8°C respectively.

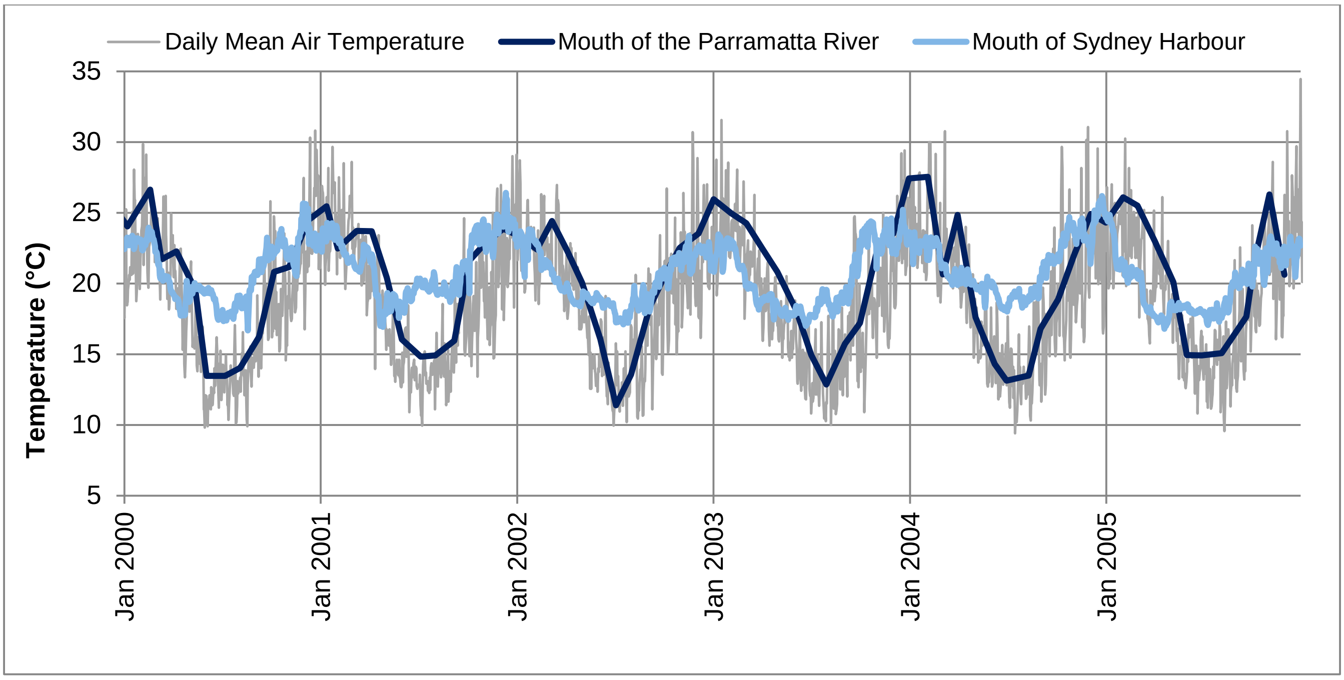

Figure 6: Ambient temperature measurements inside the Sydney Harbour estuary at the mouth of the Parramatta River (Hornsby Shire Council) and at the mouth of Sydney Harbour (HYCOM)

1.4.6 Proposed sea-water cooling system

The Walsh Bay Arts Precinct will feature an air conditioning system that utilises a closed loop sea water cooling system to reject heat. The heat rejection system will transfer heat to adjacent sea-water via a network of submerged coiled chillers.

At the time of writing, the design of the heat rejection system was not yet finalised, however preliminary details have been provided to Jacobs.

The heat rejection system will consist of a network of PEX Piping, coiled and mounted underneath the southern end of Pier 2/3, approximately 2m below low water mark. The system will have a capacity of approximately 1.2MW, and operate with cooling liquid at approximately 30-35°C. An example of a similar closed-loop Heat Rejection System being installed in Sydney Harbour is presented in Figure 7.

Figure 7: Photograph taken during installation of closed loop geoexchange system at Woolloomoolloo Wharves, Sydney Harbour (Source: GEOEXCHANGE Australia)

2. Walsh Bay Heat Dispersion Model

2.1 Introduction

A numerical modelling system was used to simulate the key dispersion processes operating within the Sydney Harbour estuary and to assess the potential thermal impacts of the Walsh Bay Heat Rejection System.

The numerical modelling system was developed using DHI's MIKE hydrodynamic modelling software, and comprises of a three-dimensional (3D) model of Sydney Harbour (Refer to Figure 8).

MIKE hydrodynamic modelling software is a commonly used tool to simulate hydrodynamic (water level variation and flow) and heat exchange processes in oceanic, coastal and estuarine environments. MIKE3 HD solves the 2D/3D Non-Linear-Shallow-Water-Equations (NLSWE) on a flexible mesh using a finite-volume numerical scheme. The model is based on the numerical solution of the 3D incompressible Reynolds averaged Navier-Stokes equations subject to the assumptions of Boussinesq and hydrostatic pressure (DHI, 2011).

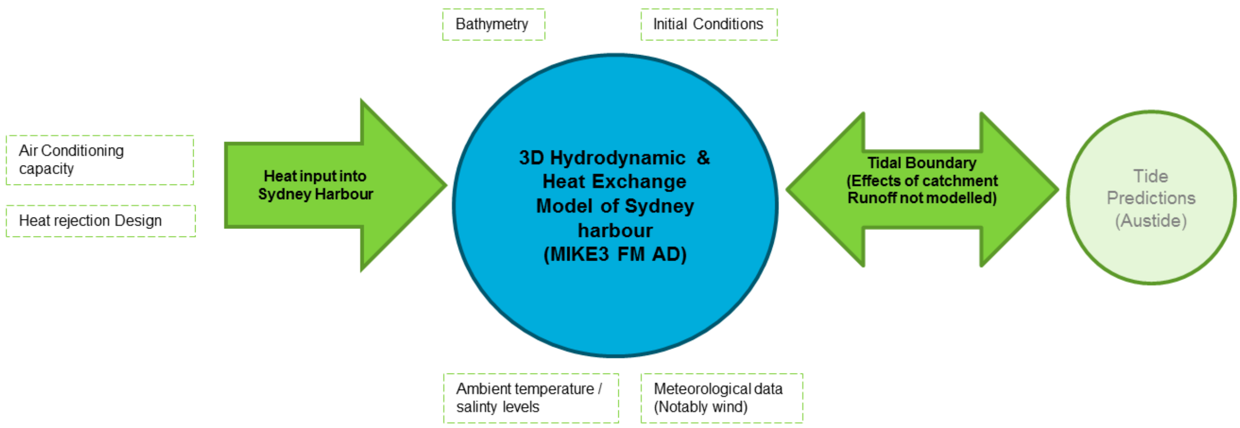

Figure 8: Structure of the Walsh Bay Modelling System

2.2 Walsh Bay MIKE3 FM Model

2.2.1 Model Mesh and Bathymetry

The model domain covers the entire estuarine section of Sydney Harbour and extends from the tidal limits of the Parramatta River to its outflow location, the Pacific Ocean. A layered flexible mesh approach was adopted to resolve the model in the vertical and horizontal domain (see also Figure 9). In the horizontal domain an unstructured mesh was adopted as shown below in Figure 10 and Figure 11 (all figures are displayed in MGA Zone 56 projection). In the vertical domain, the model uses a combined sigma / z-layer formulation with up to 10 discrete layers. The thickness of the z-layers varies over the depth, as shown in Table 1.

The model resolution was varied from approximately 1.0km element lengths around the offshore boundaries to approximately 20m by 20m in the vicinity of Walsh Bay.

A Digital Elevation Model (DEM) was developed by interpolating data extracted from Jeppesen Norway's C-MAP Professional+ electronic navigation database. Model bathymetry levels relative to chart datum were defined by sampling the digital elevation model at mesh nodes throughout the domain.

Table 1: Vertical mesh definition of the Sydney Harbour MIKE3 FM Model

Layer Type	Layer	Layer Thickness (m)	Location
Sigma	1 & 2	Varying: 2 equidistance layers	Surface to -2.0m
Z-Layer	3	2	-2.0m to -4.0m
	4	2	-4.0m to -6.0m
	5	2	-6.0m to -8.0m
	6	2	-8.0m to -10.0m
	7	5	-10.0m to -15.0m
	8	5	-15.0m to -20.0m
	9	10	-20.0m to -30.0m
	10	50	-30.0m to -80.0m

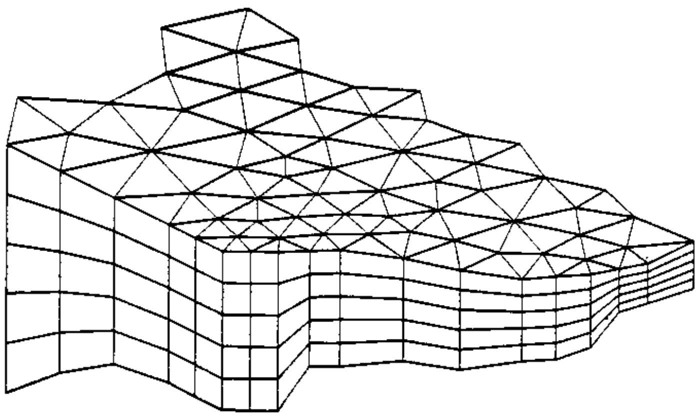

Figure 9: Principle of a 3D Flexible Mesh solution technique (Source: DHI, 2013)

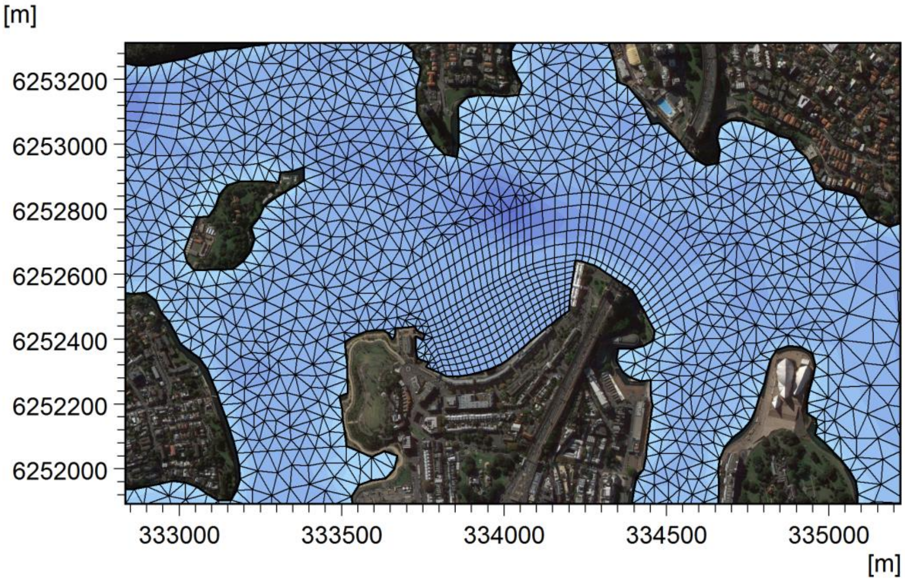

Figure 10: Model mesh adopted at Walsh Bay (MGA 56 projection)

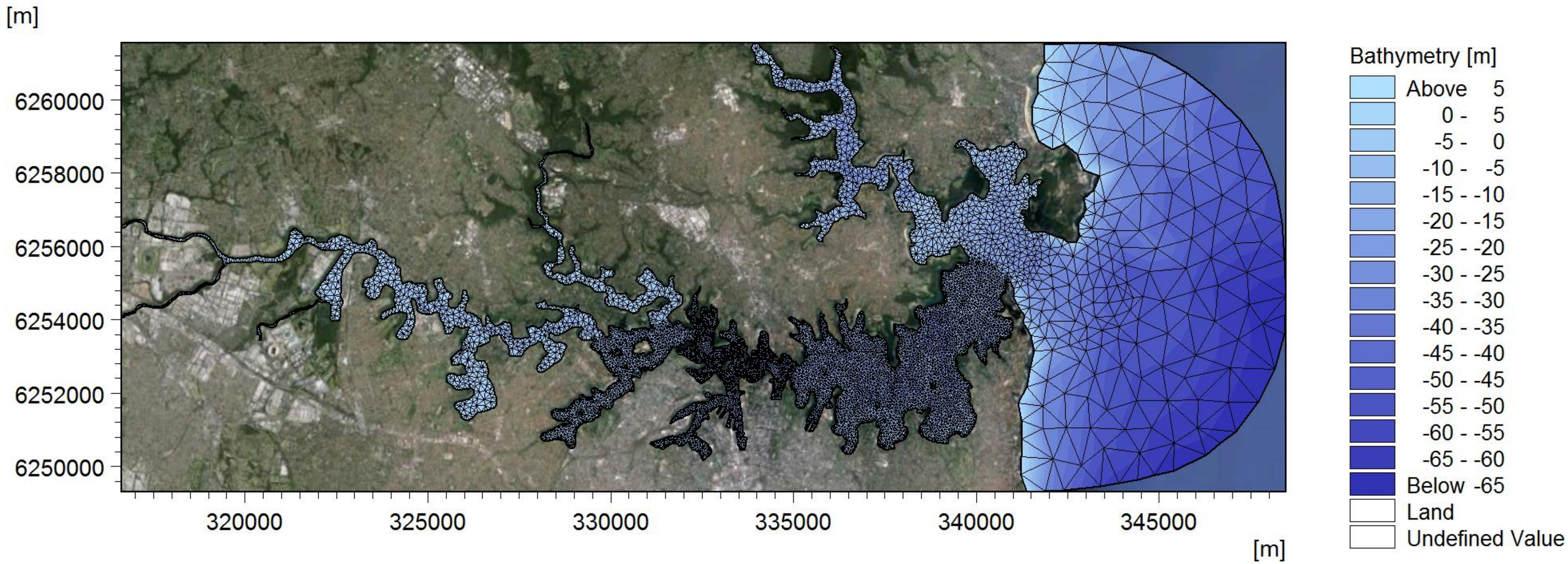

Figure 11: Model mesh and bathymetry of the Sydney Harbour model (MGA56 projection

2.2.2 Boundary Conditions

Tidal constituents for Sydney (Fort Denison) were obtained from the Australian Hydrographic Service AusTide software (2012) and used to generate tidal height prediction levels for Sydney Harbour. These tidal levels were applied along the model's open boundary to drive tidal flows across the model domain.

2.2.3 Bottom Friction

Hydraulic bed friction was applied in the model as effective bed roughness length. A constant value of 0.066m was adopted throughout the wet domain with the exception of Walsh Bay. A value of 0.25m was adopted at the elements that intersect with the piled foundations of the piers at Walsh Bay.

2.2.4 Eddy Viscosity

A scaled eddy viscosity formulation was used to simulate dispersion processes in the model. The Smagorinsky model has been used to represent horizontal eddy-viscosity and a log-law formulation for vertical eddy-viscosity.

In lieu of site specific data, horizontal and vertical scaling factors of 1.0 have been adopted and a horizontal eddy viscosity coefficient of 0.28.

2.2.5 Heat Exchange

The seawater heated by the Heat Rejection unit will experience heat loss to the atmosphere where the heated water contacts the water surface.

In the model, atmospheric heat exchange has been simulated using the sensible heat flux module. The heat loss coefficient is a representation of the rate of heat loss per area for a given temperature differential between the surface water temperature and the air temperature. The value of the heat loss coefficient depends on the ambient water temperature and wind speed.

The heat loss coefficients recommended by Adams et al. (1981) have been adopted in this study. The adopted coefficient for each model scenario is presented in Table 2 in Section 3.2.

2.2.6 Walsh Bay Heat Rejection System

As aforementioned, the design of the Heat Rejection System is yet to be finalised, however the principles of this report will guide the detailed design.

In the modelling, it is assumed that the Heat Rejection System will have a length of less than 20m and the heat emission of the Heat Rejection System can be represented by a point source. At the location presented in Figure 12, at an elevation of -3mCD, a flow discharge was applied with a temperature of 35°C to represent the heat influx of each scenario (1.2 or 0.96MW depending on the season, refer to Table 2 in Section 3.2).

Figure 12: Modelled heat influx location

2.3 Model Verification

No current measurements were available in the vicinity of Walsh Bay, hence the model was verified using tidal survey data measured on 19 March 1992, as reported in the Manly Hydraulics Laboratory Report MHL 1988 (2010). This survey data consisted of tidal discharge and water level measurements taken across 10 transects within Sydney Harbour. The location of these transects are shown in Figure 13.

Calibration plots of predicted and modelled water levels and tidal flow discharges during the measurement period are presented in Figure 14 to Figure 15 for each of the transects. These plots show good agreement between the model results and the measured water levels and flows. The performance of the model was verified by simulating the period 28 February to 2 March 2016 and comparing model predictions against current measurements from a bottom mounted ADCP installed near Balls Head. Figure 16 compares the model predictions of the current magnitude and direction against ADCP measurements averaged over the top 12m. This plots shows that the model predicts current speed and direction with a high correlation against measurements made at the Balls Head ADCP.

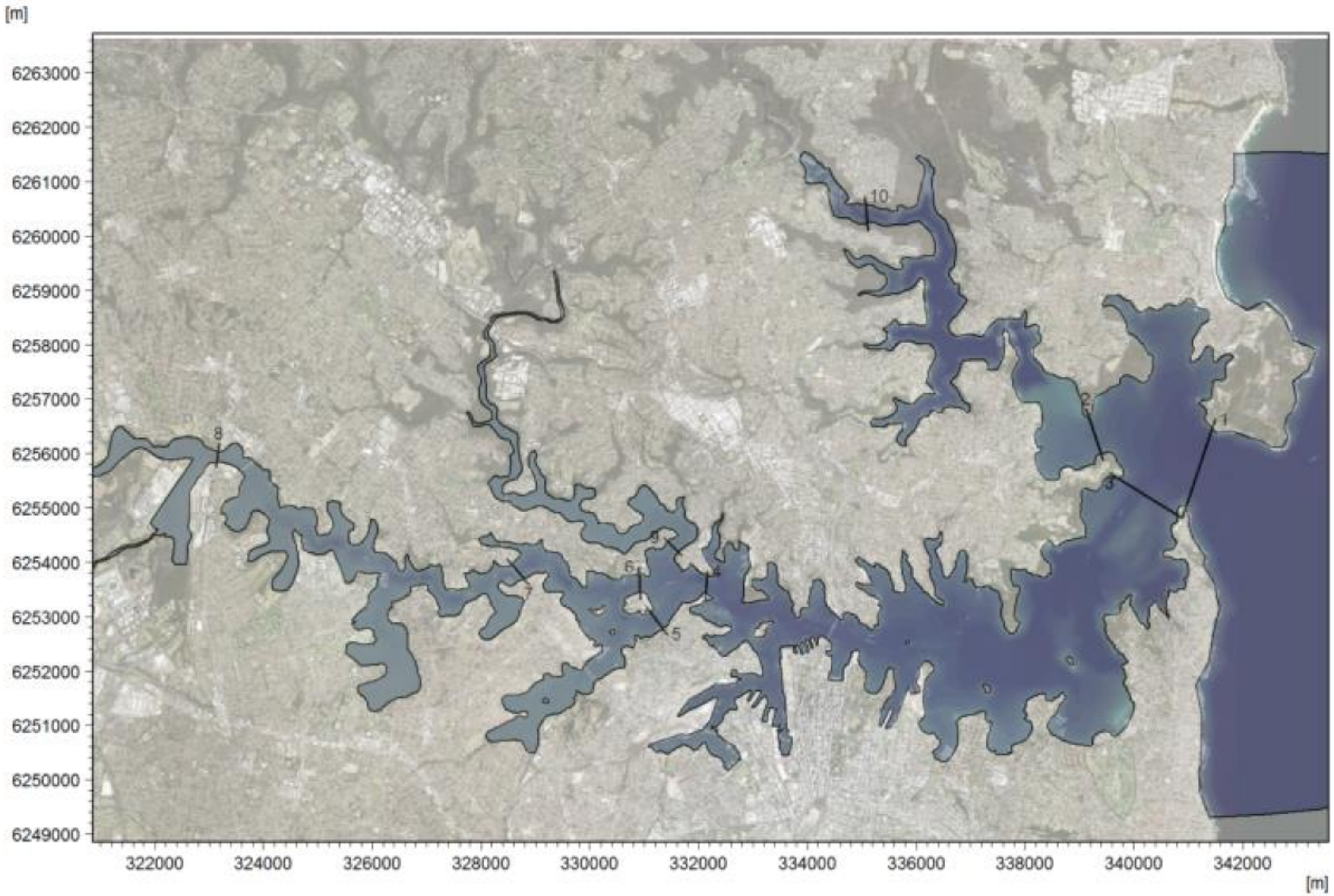

Figure 13: Location of tidal survey transects for 19 March 1992 (MHL, 2010)

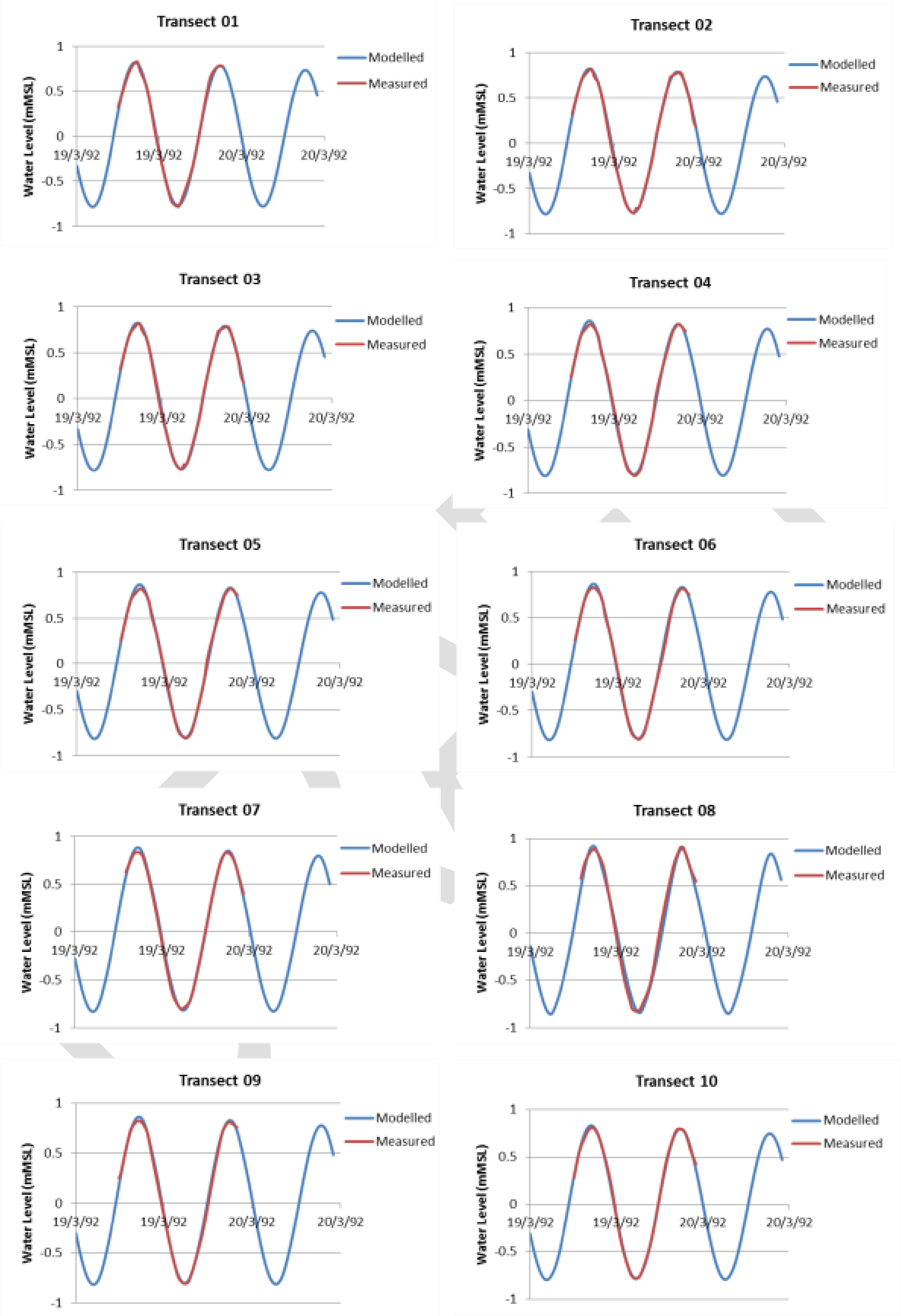

Figure 14: Hydrodynamic model water level calibration

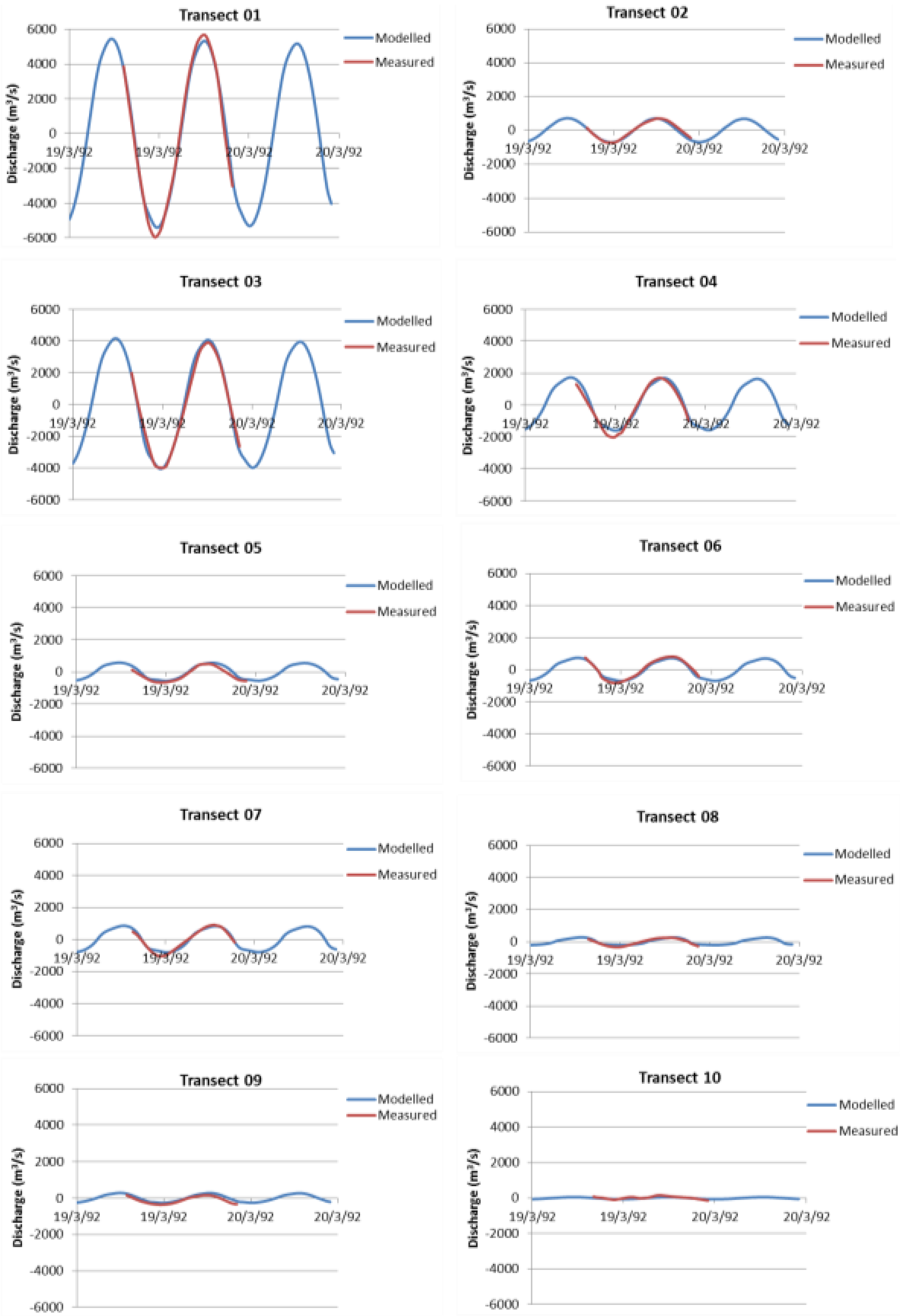

Figure 15: Hydrodynamic tidal discharge calibration

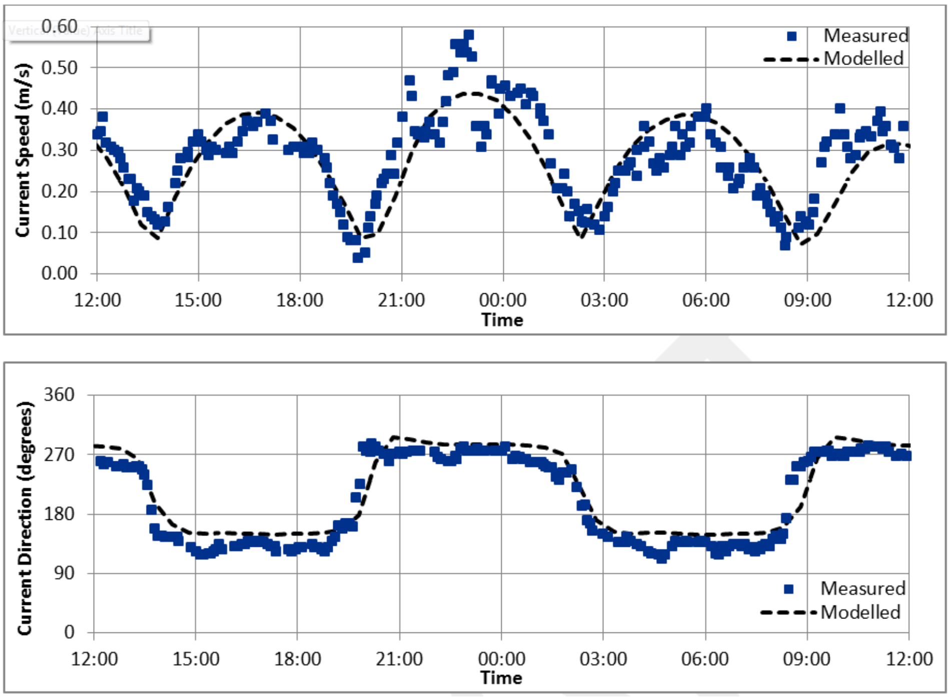

Figure 16: Model verification against Balls Head ADCP over period February 29th to March 1st, 2016

3. Thermal Plume Scenario Modelling

3.1 Assessment Criteria

Aquatic ecosystem functioning is closely regulated by temperature with aquatic organisms, and water quality sensitive to temperature changes (ANZECC/ARMCANZ 2000). An organism's growth metabolism, reproduction mobility and migration patterns may all be altered by changes in ambient water temperature.

There is limited data available on the thermal responses of Australian organisms to enable meaningful predictions of the effects of thermal alterations on Australian aquatic ecosystems and the provision of guidelines (ANZECC/ARMCANZ 2000). However for the purposes of this assessment, a temperature increase limit of 2◦C has been adopted, based upon the Marine Water Quality Objectives for NSW Ocean Waters (1999).

3.2 Modelled Scenarios

The size and impact of a thermal plume is dependent on a number of factors. The most important factors that influence these are the hydrodynamics of the estuary, ambient air and water temperature, as well as wind magnitude and direction.

A number of model simulations were performed to simulate the thermal plume behaviour under a range of ambient conditions. The scenarios modelled are summarised in Table 2. These scenarios were chosen to represent the likely maximum variability at the site (excluding extreme conditions) in terms of heat emission and meteorological conditions, and represent expected worst case scenarios in terms of consequence from heat rejection:

Three ambient air and water temperature scenarios have been adopted to correspond to a typical summer, winter and yearly average temperature (Refer to Section 3.4). Wind forcing has been included in four directional bands with a constant wind speed of 5m/s, as well as a scenario without wind. Magnitudes of greater than 5m/s have not been modelled as such wind conditions will provide significantly enhanced atmospheric cooling and therefore results in a smaller thermal plume, compared to lower wind conditions.

The Heat Rejection System (described in Section 4.2.6) will provide up to 1.2MW of energy into the water during summer. During winter, it is unlikely that the air conditioning system will operate at capacity, hence a heat emission of 80% of the installed capacity (0.96MW) was adopted in the modelled winter scenarios.

In all model scenarios, the heat emission was assumed to be present during the entire simulation period (i.e. a constant source energy input was applied 24/7), which is considered to be a conservative representation of the system.

Table 2: Thermal Plume Modelling Scenarios

Scenario Name	Ambient Conditions	Heat Emission from Heat Rejection System	Heat loss coefficient (W/m2/ºC)
Summer No Wind	Water temperature: 26.8°C Air Temperature 26.8°C Wind Condition: 0 m/s	1.2MW	17
Summer Wind	Water temperature: 26.8°C Air Temperature 26.8°C Wind Condition: 5m/s Directions: NN, EE, SS, WW	1.2MW	85
Winter No Wind	Water temperature: 13.2°C Air Temperature 13.2°C Wind Condition: 0 m/s	0.96MW	11
Winter Wind	Water temperature: 13.2°C Air Temperature 13.2°C Wind Condition: 5m/s Directions: NN, EE, SS, WW	0.96MW	55

3.3 Model Results

The MIKE3 HD model was run for a two week period during the transition from a spring tidal cycle into a neap cycle. Thermal plume impacts have been assessed by creating percentile maps (95th percentiles) of the temperature impacts relative to ambient water temperature. The spatial maps depict the levels of increased temperature above ambient water temperature that are exceeded only 5% of the time.

Figure 17 and Figure 18 present the 95^{th} Percentile Maps for the winter and summer - no wind scenarios respectively, which were found to be the model scenarios resulting in the largest thermal impacts. Percentile maps for the complete range of scenarios are presented in **Appendix A.**

The highest 95^{th} percentile temperature impact is modelled to occur during the “winter - no wind” scenario, where a temperature impact of up to approximately 0.8°C is predicted in the vicinity of the heat rejection system.

The addition of wind significantly decreases the thermal impact and size of plume for all wind directions, due to an increased rate of heat transfer from the water to the atmosphere. The maps demonstrate that the footprint of the thermal plume is small for all scenarios modelled, with the thermal impacts of up to 0.1°C confined to an area within approximately 50m from the source on Pier 2/3.

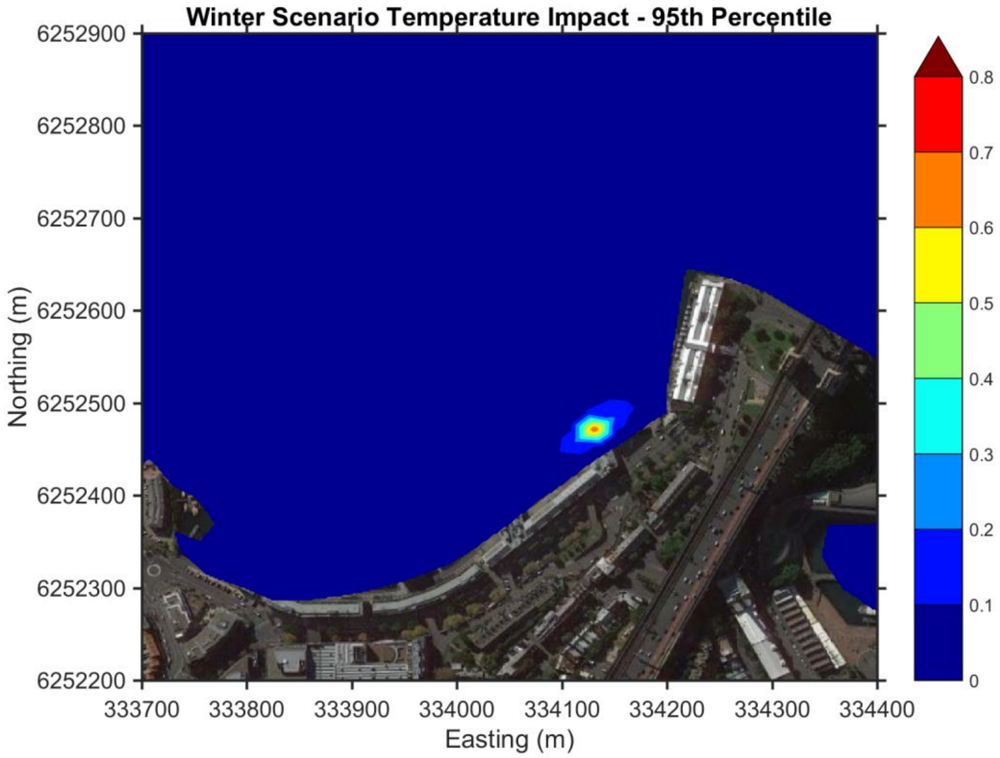

Figure 17: Modelled 95th Percentile Temperature Impact - Winter, No Wind Scenario

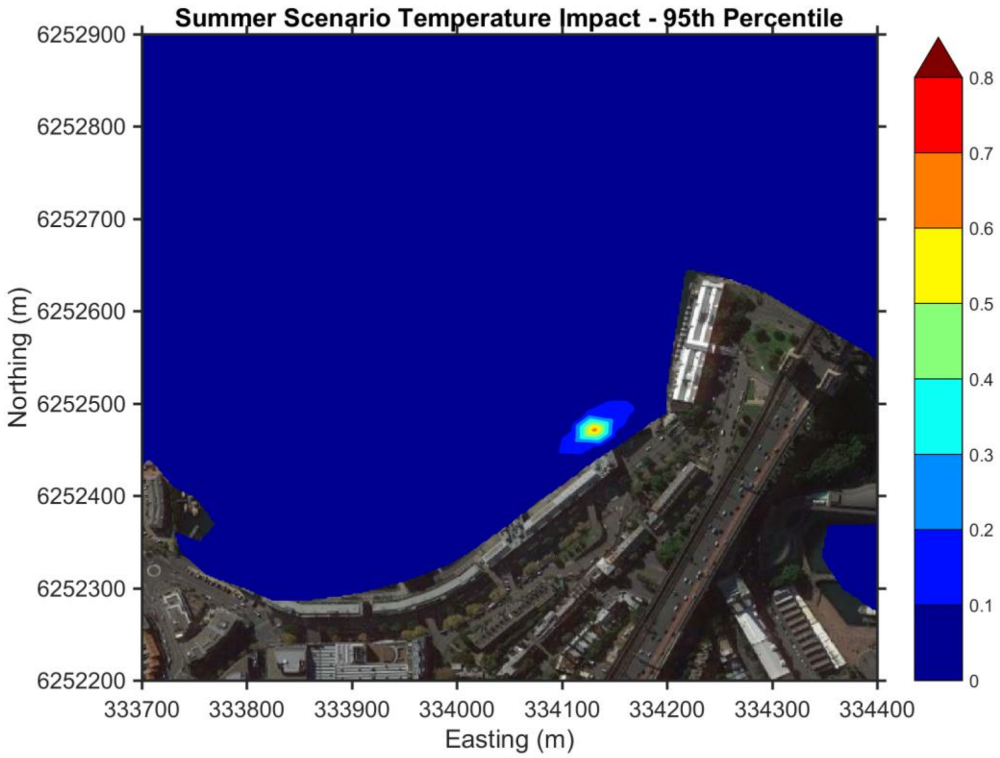

Figure 18: Modelled 95th Percentile Temperature Impact – Summer, No Wind Scenario

4. Conclusions

Modelling has been undertaken to investigate the likely maximum thermal impact of the installation of a Heat Rejection System at Pier 2/3 in Walsh Bay. The likely maximum thermal impacts of the proposed system were determined by simulating the thermal plume behaviour under a range of model scenarios. The model scenarios adopted for assessment are considered to be conservative; it is more likely that less extreme conditions will prevail and as such thermal impacts are likely to be less than that shown in the model results.

The model results demonstrate that the footprint of the thermal plume will be small, with a temperature impact of greater than 0.1°C confined to an area of approximately 50m from the Heat Rejection System. The highest 95th percentile impact (approximately 0.8°C) is significantly below the temperature increase limit of 2°C.

Based on the assessment undertaken, the environmental risks associated with operating the proposed heat rejection system at the Walsh Bay development are considered insignificant.

5. References

Adams, E, D. Harleman, G. Jirka and K. Stolzenbach, Heat Disposal in the Water Environment, Course Notes, R.M. Parsons Laboratory, MIT, 1981

Cardno (2015). Gun Wharf Design Criteria, Ref 59915092/L002, 27 August 2015

Das, P., Marchesiello, P., Middleton, J. (2000) Numerical Modelling Of Tide-Induced Residual Circulation In Sydney Harbour, Marine And Freshwater Research 51: 97-112

DHI (2011), MIKE 21 & MIKE 3 FLOW MODEL FM Hydrodynamic Module Short Description, DHI, Denmark.

DHI (2013), MIKE 3 FLOW MODEL FM – Mud Transport Module User Guide, MIKE by DHI 2014, September 2013

DHI (2013), MIKE 21 & MIKE 3 FLOW MODULE FM – Hydrodynamic and Transport Module Scientific Documentation, MIKE by DHI 2014, October 2013

DHI (2013), MIKE 21 FLOW MODULE FM – Mud Transport Module User Guide, MIKE by DHI 2014, September 2013

Hedge L.H., Johnston E.L., Ayoung S.T., Birch G.F., Booth D.J., Creese R.G., Doblin M.A., Figueira W.F., Gribben P.E., Hutchings P.A., Mayer Pinto M, Marzinelli E.M., Pritchard T.R., Roughan M., Steinberg P.D. (2013), Sydney Harbour: A systematic review of the science, Sydney Institute of Marine Science, Sydney, Australia.

National Geospatial Intelligence Agency (2014), Sailing Directions (Enroute) – East Coast of Australia and New Zealand, Publication 127, United States Government, Virginia.

Appendix A. Temperature Impact Maps

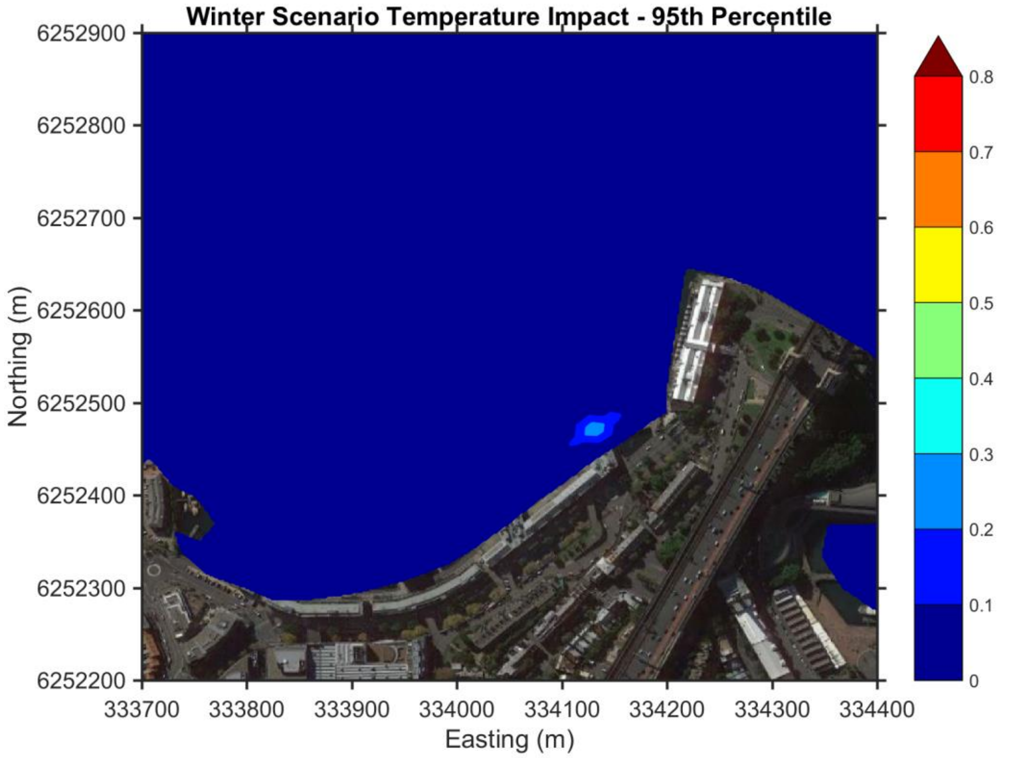

Figure A- 1 Modelled 95th Temperature Impact – Winter, 5m/s Easterly Wind Scenario

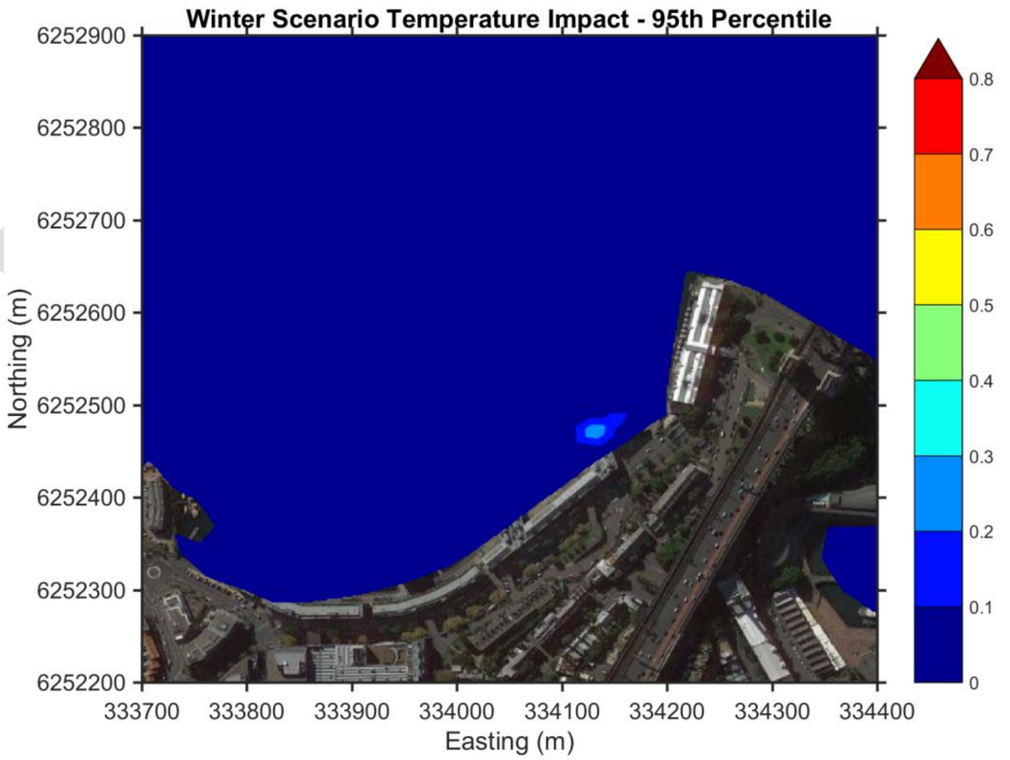

Figure A- 2 Modelled 95th Temperature Impact – Winter, 5m/s Northerly Wind Scenario

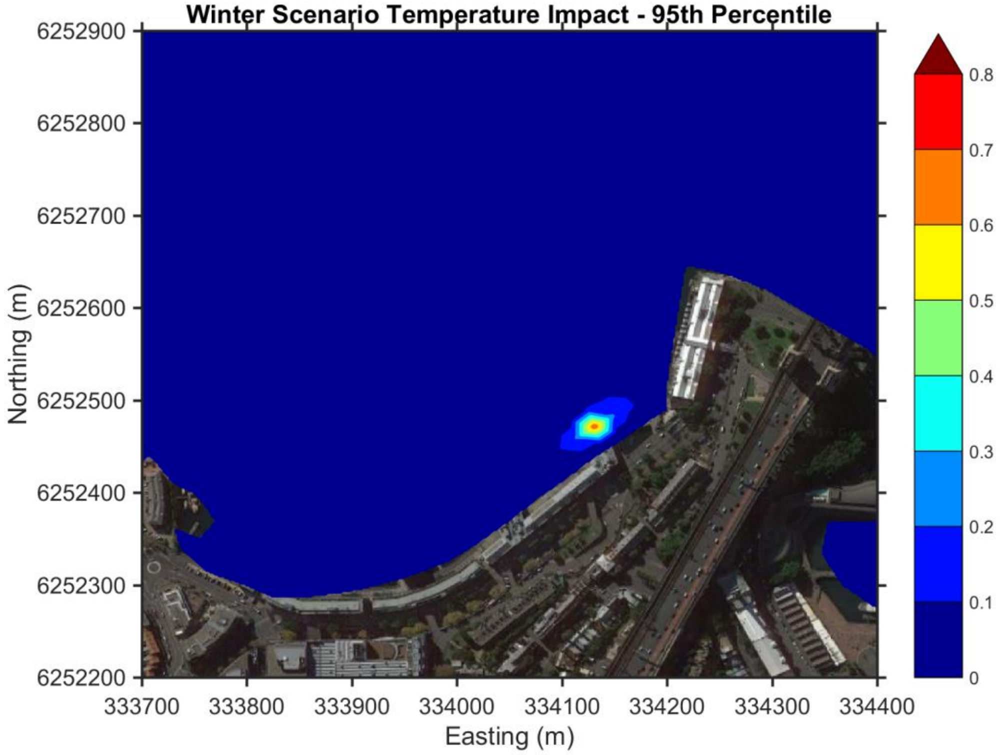

Figure A- 3 Modelled 95th Temperature Impact – Winter, No Wind Scenario

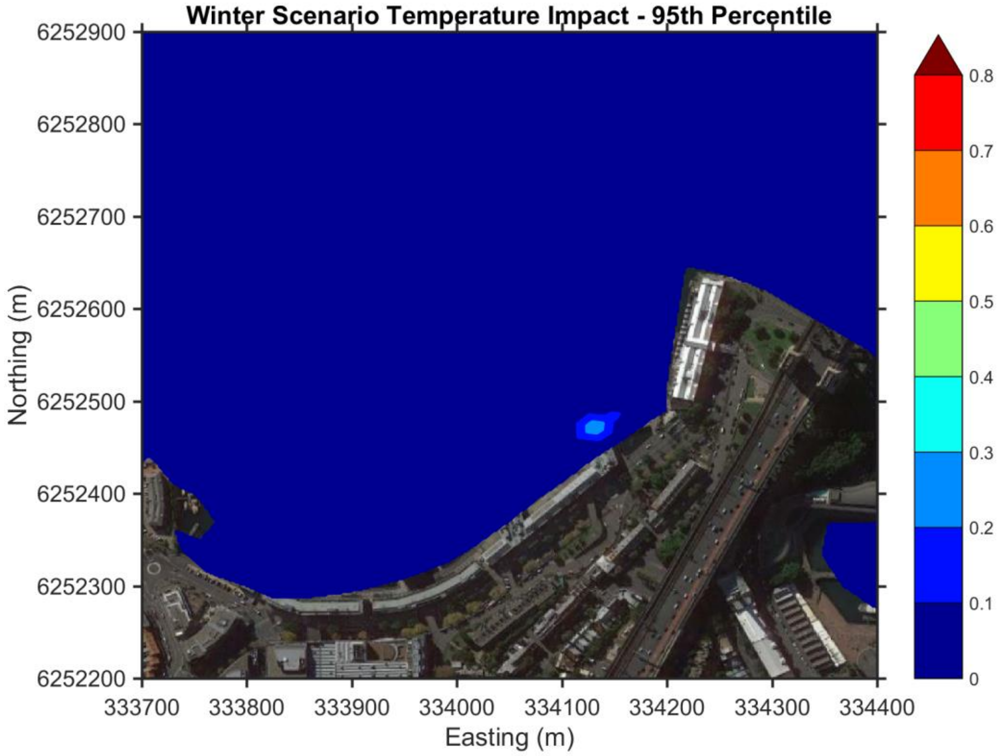

Figure A- 4 Modelled 95th Temperature Impact – Winter, 5m/s Southerly Wind Scenario

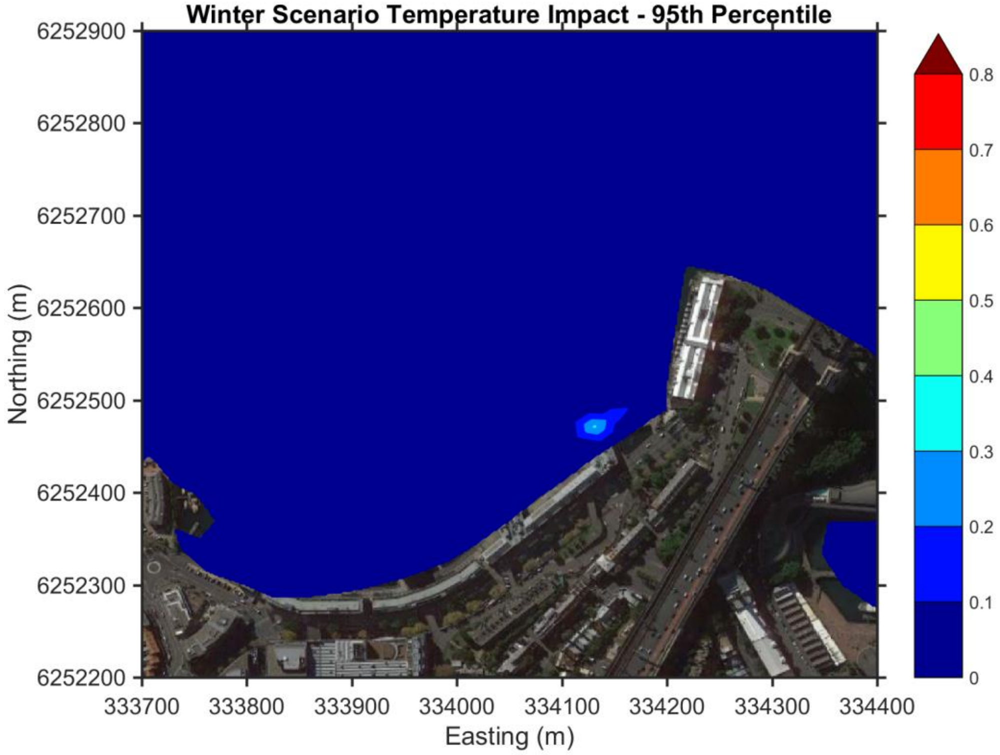

Figure A- 5 Modelled 95th Temperature Impact – Winter, 5m/s Westerly Wind Scenario

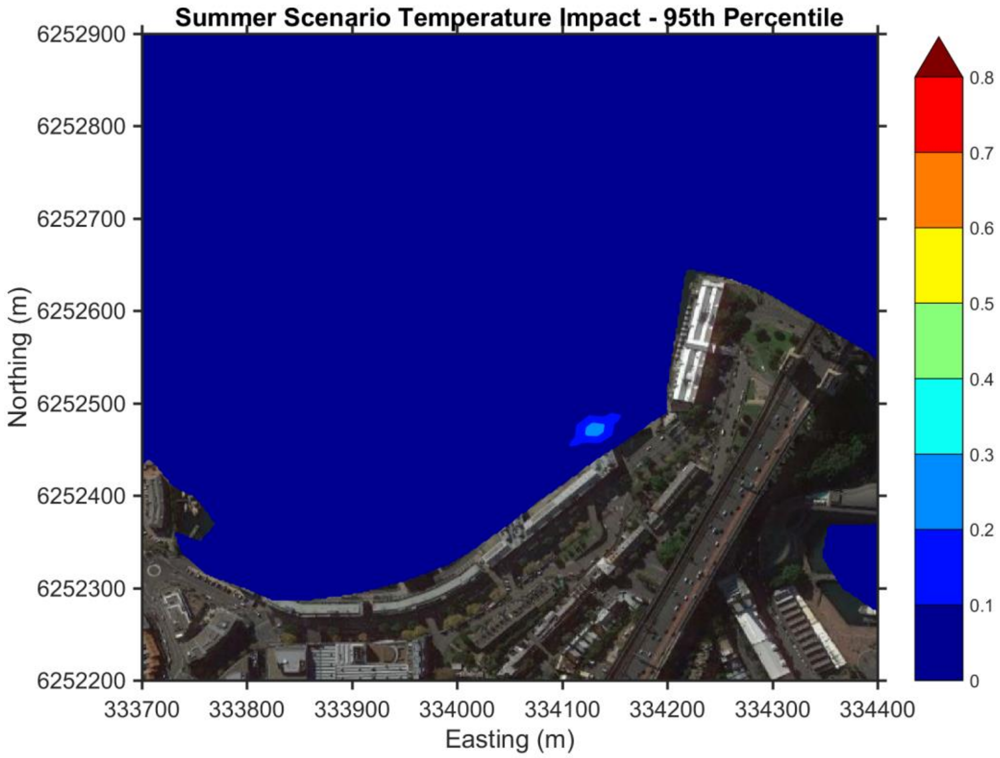

Figure A- 6 Modelled 95th Temperature Impact – Summer, 5m/s Easterly Wind Scenario

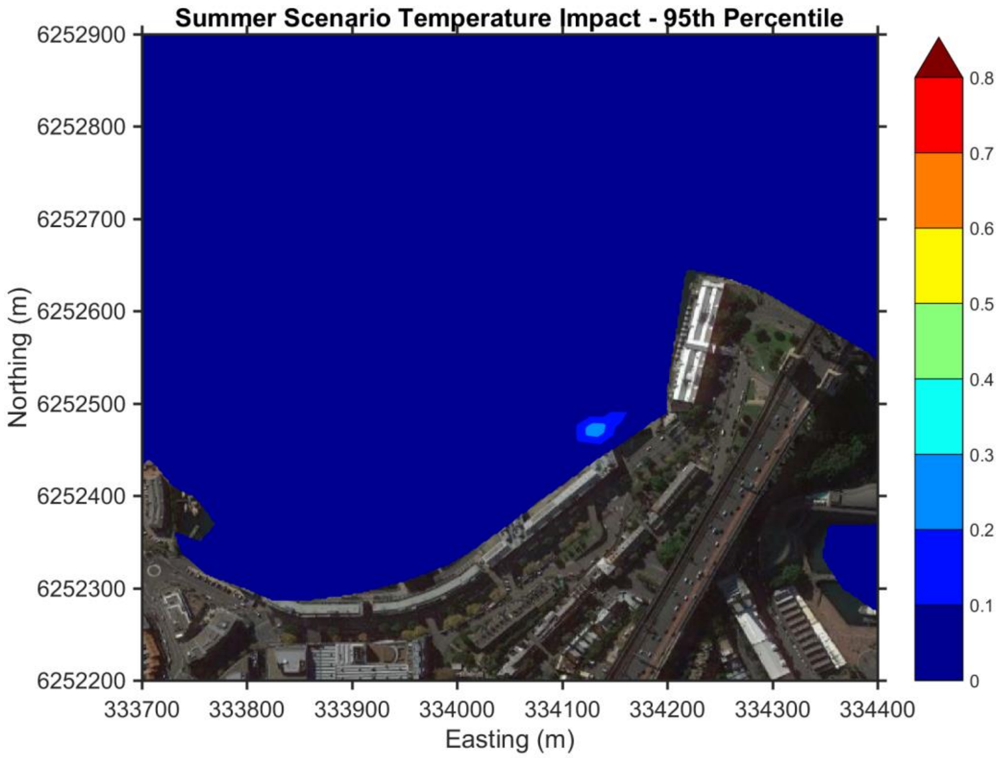

Figure A- 7 Modelled 95th Temperature Impact – Summer, 5m/s Northerly Wind Scenario

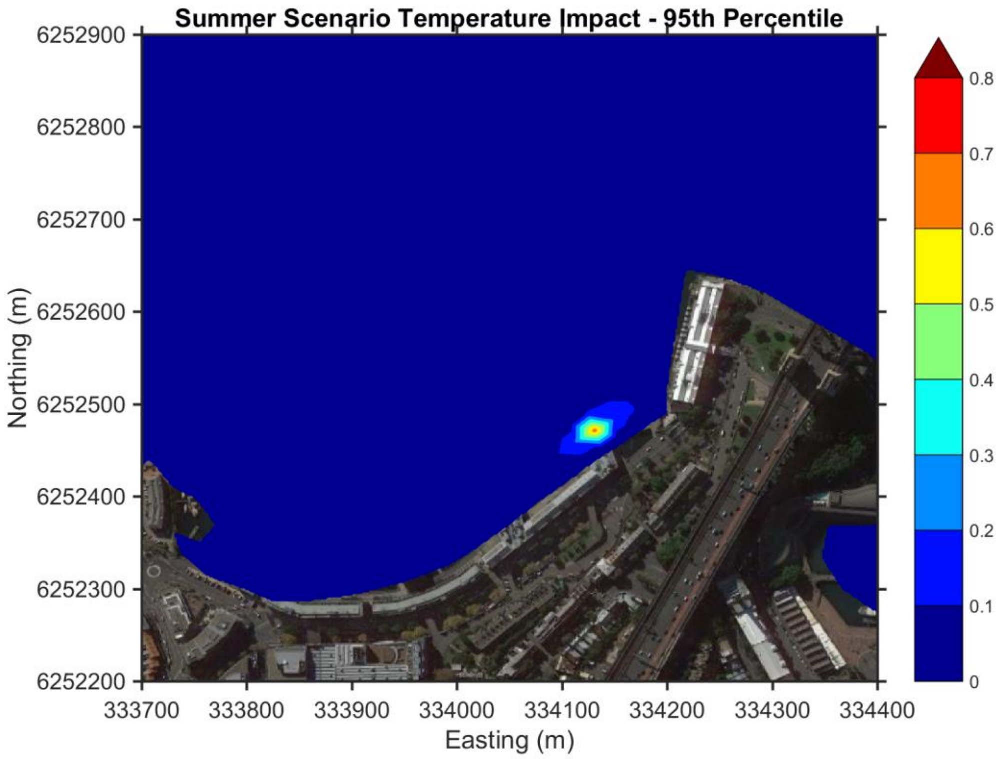

Figure A- 8 Modelled 95th Temperature Impact – Summer, No Wind Scenario

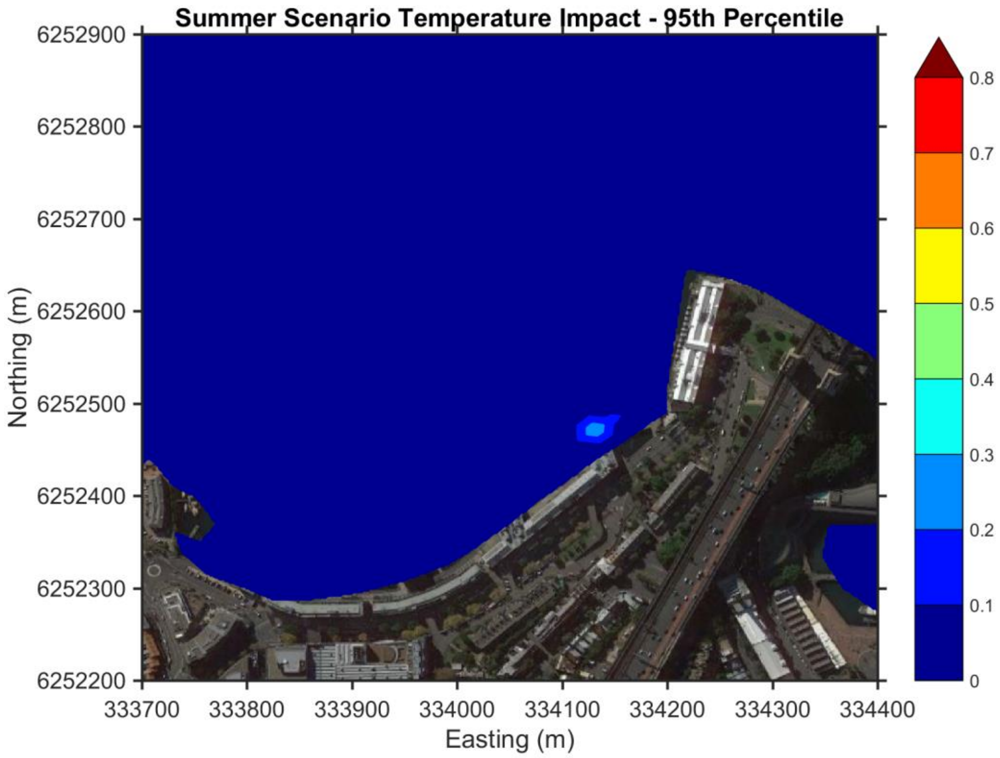

Figure A- 9 Modelled 95th Temperature Impact – Summer, 5m/s Southerly Wind Scenario

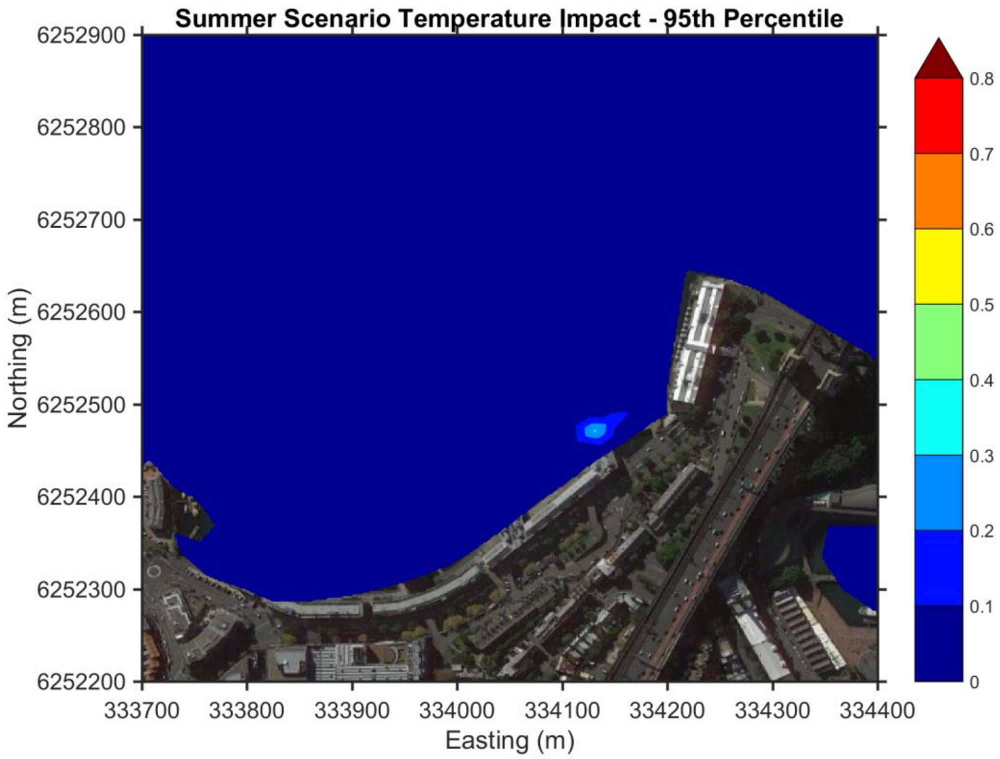

Figure A- 10 Modelled 95th Temperature Impact – Summer, 5m/s Westerly Wind Scenario