Appendix L – Brine Discharge Modelling Report

Hunter Water Corporation

Belmont Drought Response Desalination Plant
Brine Discharge Modelling Report

November 2019

Executive summary

A three-dimensional (3D) hydrodynamic model was established and applied to inform the impact assessment of brine discharge from the proposed Belmont Drought Response Desalination Plant (also referred to as the temporary desalination plant (TDP)) through the existing Belmont Wastewater Treatment Works (WWTW) diffuser through a comparative analysis between the baseline effluent and proposed comingled effluent-brine scenarios. The addition of the TDP brine to the WWTW effluent will impact its chemical composition and salinity with potential changes to the spatial extent of the mixing zone.

In addition to dynamic model inputs (i.e. meteorology; Hunter River flows; open ocean boundary inputs for temperature, salinity, water levels and currents; effluent flow, temperature and salinity) the model incorporates the current WWTW diffuser configuration and Lake Macquarie. The model was calibrated and validated through comparisons with measured current speeds near the Belmont WWTW diffuser.

The TDP will have an instantaneous treated water flow rate of 16.4 ML/day. Two discharge scenarios into the marine environment via the diffuser were evaluated:

- Existing baseline conditions of the WWTW effluent.
- Normal full operation of the proposed TDP with a design brine discharge of 28.2 ML/day that is comingled with WWTW effluent prior to marine discharge.

Areas of impact (or effect) were defined on the basis of water quality objectives (WQOs). WQOs were estimated from water quality measurements of the existing WWTW effluent and the proximal ambient marine waters, the anticipated design water quality of the TDP brine, and trigger values on the basis of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000).

The key conclusions in regards to water quality impacts (or effects) from the proposed discharge of comingled TDP brine-WWTW effluent into the marine environment via the existing diffuser include:

- The marine toxicity WQO is met within ~1 m of the diffuser.
- The spatial area to meet the human health WQO for primary contact is predicted to be similar between the existing and proposed cases. Exceedances of the human health WQO are greater than ~1 km from the nearest beach, and thereby do not pose a material risk to swimmers for either the baseline or proposed scenarios.
- Generally, the spatial area of impact of the ambient salinity WQO was less (dry season) or similar (wet season) during the baseline relative to the proposed scenario. For proposed effluent-brine outflows with high salinity during the dry season (maximum of ~48 psu), a dilution factor for the ambient salinity WQO of 14 over the seabed is readily met in the immediate vicinity of the diffusers.
- The spatial area to maintain the marine ecosystem WQO is similar across dry and wet season periods for the baseline and proposed scenarios.

The key finding from this investigation is that the proposed brine-effluent discharge through the existing diffuser is predicted to cause some relatively minor changes in the spatial extent of impact (or effect) in terms of the human health, ambient salinity and marine ecosystem WQOs. Therefore no material impacts to WQOs are predicted for the proposed discharge over existing conditions.

This report is subject to, and must be read in conjunction with, the limitations set out in the report and the assumptions and qualifications contained throughout the Report.

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1. Introduction

Hunter Water Corporation (Hunter Water) engaged GHD Pty Ltd (GHD) to predict the marine environmental impacts of the brine discharge for a Drought Response Desalination Plant (also referred to as the Temporary Desalination Plant (TDP)) at Belmont, NSW. This report outlines the predicted marine water quality environmental impacts of its future commissioning and operation.

1.1 Background

The Metropolitan Water Directorate, now part of the NSW Department of Primary Industries (DPI Water), led the development of the Lower Hunter Water Plan (LHWP) in consultation with Hunter Water, government agencies, the community and stakeholders. The plan (released in April 2014) aimed to ensure that the Lower Hunter has enough water to meet community needs for the medium term, including withstanding a more severe drought than previously recorded in the region.

The LHWP sets out a cost-effective portfolio of supply and demand measures. The drought response measures include demand management (including restrictions and enhanced efficiency programs) and water transfers from the Central Coast, along with potential new groundwater resources or recycling/stormwater schemes. A small scale TDP is included as a contingency measure for an extreme drought.

The TDP planned at Belmont is to have a nominal capacity of up to 15 mega litres per day (ML/day) of potable water during emergency drought conditions. There is potential for lower capacities to be considered, including 5, 7.5 and 10 ML/day. The desalination process produces brine discharges during operation, which needs to be discharged to the ocean. The Belmont Wastewater Treatment Works (WWTW) Ocean Outfall and Booster Pump Station system are proposed to be utilised for this purpose.

1.2 Scope of report

The scope of this report is to predict the potential water quality impacts from the discharge of brine during the operation of the TDP that is comingled with the WWTW treated wastewater (hereafter referred to as 'treated wastewater') as follows:

- Develop water quality objectives (WQOs) for key parameters of concern for the co-mingled brine-treated wastewater discharge.
- Confirm the existing Belmont WWTW outfall diffuser can accommodate the additional brine flow from the TDP (from a near-field dilution perspective) that will be comingled with the treated wastewater.
- Develop a calibrated and validated three-dimensional (3D) hydrodynamic model incorporating the South Pacific Ocean (in the vicinity of the site) and Belmont Bay (Lake Macquarie).
- Simulate dispersion of the comingled brine-treated wastewater discharge in the marine environment under a range of WWTW flow conditions and Normal Full Operation brine discharge from the TDP of 28.2 ML/day, and a range of receiving marine water conditions (i.e. tides, stratification).
- Recommend mitigation measures (if any) to address potential water quality impacts to the marine environment from the comingled brine-treated wastewater outflows.

1.3 Disclaimer

This report has been prepared by GHD for Hunter Water Corporation and may only be used and relied on by Hunter Water Corporation for the purpose agreed between GHD and the Hunter Water Corporation as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Hunter Water Corporation arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Hunter Water Corporation and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.4 Assumptions

The following assumptions have been applied in this assessment:

- Quantitative estimates of WQOs from monitoring data assume that:
  – The ambient marine water quality is characterised by the available monitoring data.
  – Available treated wastewater data is representative of the facility’s future water quality.
  – The design brine water quality will be representative of the operation of the TDP.
- A conservative numerical tracer of the discharge through the diffuser is utilised to predict the spatial extent of the area of impact (or effect) for each of the WQOs. Fate transformations of water quality analytes (e.g. NO_3 to NH_X) from a variety of potential mechanisms (e.g. volatilisation to the atmosphere, uptake by primary producers, increases from biological excretion-mineralisation-degradation) are not simulated. Similarly, any water quality analytes comprised of particulate matter are not simulated to undergo settling and resuspension. Rather, the spatial extent of the mixing zone is predicted on the volumetric proportion of discharged waters in the receiving marine environment (i.e. based on the numerical conservative tracer that tracks the proportion of outlet waters in the marine environment), relevant characteristic concentrations of the outlet and ambient marine waters, and appropriate WQO trigger values. This approach provides precautionary estimates of the area of impact (or effect) for a particular WQO in that physical and fate processes are not considered.

- Dry and wet weather conditions yield large variations in both WWTW effluent discharge and water quality due to stormwater. In this analysis the area of impact (or effect) of WWTW discharge on the marine environment during dry weather conditions was predicted for a combination of median dry weather effluent discharge and poor effluent water quality (90th percentile). For wet weather conditions, the area of impact (or effect) was predicted on the basis of the median wet weather effluent discharge and the 20th percentile effluent water quality. On the basis of Hunter Water's experience (Z. Rogers, pers. comm.), during wet weather conditions with elevated stormwater flows, effluent quality is reasonably characterised by the 10th to 20th percentile water quality. As a precautionary principle measure, the 20th percentile effluent quality was used to characterise the wet weather WWTW effluent quality in this assessment.
- Tides, winds and large scale oceanographic currents are the primary mechanisms that drive circulation patterns and mixing of the coastal waters in the vicinity of the diffuser with wave-induced currents a secondary mechanism. Wave-induced mixing likely causes greater mixing and dispersion in shallow waters in proximity to the shoreline (<10 m). In this study, hydrodynamic modelling simulates the currents due to large scale oceanographic circulation, tides and winds, but not waves as the outfall diffuser resides in relatively deep waters (>20 m).

2. Methodology

2.1 Define WQOs

The WQOs at the edge of the mixing zone for key parameters of concern of a future treated wastewater-brine mixture (Section 4.1) have been developed with reference to:

- The existing Environment Protection Licence (EPL) conditions for the treated wastewater
- ANZECC & ARMCANZ (2000) guideline and trigger values (Section 2.1.1)
- Available data of the treated wastewater discharge (Section 3.2.2)
- The ambient marine water quality (Section 3.2.4)
- The anticipated brine water quality from the TDP (Section 3.2.3)

These WQOs are expressed as a required dilution factor of the treated wastewater-brine mixture by the ambient marine waters to meet the relevant guideline or trigger values. These dilution factors are estimated in Section 4.1. The dilution factor of the treated wastewater (existing case) or treated wastewater-brine mixture (proposed case) with the ambient marine waters is simulated with a conservative tracer (Section 3.3.4) via three-dimensional (3D) hydrodynamic modelling (Section 2.3). The dilution factor is used to evaluate the spatial extent of the existing WWTW's treated wastewater mixing zone and to predict the spatial extent of the treated wastewater-brine mixing zone during operation of the TDP (Section 4.4).

The dilution factor to define the edge of the mixing zone is calculated as:

$$D = \frac{C_O - C_A}{C_V - C_A}$$

where:

D = Dilution factor of a water quality analyte (parameter) to meet a guideline or trigger value.

C_O = Outlet (diffuser) concentration. In this study, a precautionary principle approach is adopted with the use of the 90th and 20th percentile WWTW effluent concentrations for C_O for dry and wet weather cases for the baseline scenario and to estimate the comingled effluent-brine discharge for the proposed scenario.[1]

C_V = Guideline or trigger value.

C_A = Ambient seawater concentration. In this study, the median of the seawater reference sites date is used for C_A.

2.1.1 ANZECC & ARMCANZ (2000) guidelines and trigger values

The following water quality trigger and guideline values are summarised in Table 2-1:

- ANZECC & ARMCANZ (2000) default marine trigger values (DTV) for physical and chemical stressors of slightly disturbed marine ecosystems of south-east Australia (includes New South Wales coast)[2] for reduced inorganic nitrogen (NH_X), oxidised inorganic nitrogen (NO_X), total nitrogen (TN) and total phosphorus (TP).

[1] The 90th percentile WWTW effluent concentration is estimated as the characteristic high concentration during dry weather periods. The 20th percentile WWTW effluent concentration is estimated as the characteristic high concentration during wet weather periods whereby stormwater dilutes contaminant concentrations of the effluent. Refer to the assumptions in Section 1.4 and Section 4.1 for further explanation.

[2] Naturally occurring physical and chemical stressors can cause degradation of marine ecosystems when ambient values are too high and/or too low.

- Site specific trigger values (SSTV) for physical and chemical stressors (rather than DTVs above that are based on regional data sets) for nutrients and chlorophyll a (chl a) are defined as the 80th percentile of reference site monitoring data. The 80th percentile is applicable to define the SSTV for slightly- to moderately-disturbed ecosystems as per ANZECC & ARMCANZ (2000). The derived SSTVs meet the minimum number of samples (n) of 12 monthly measurements in ANZECC & ARMCANZ (2000). The SSTVs are based on measurement statistics reported in Section 3.2.4. These SSTVs are used primarily to assess the effects of elevated nutrients on stimulating primary production (i.e. eutrophication) or turbidity on reducing productivity (i.e. reduced underwater light, clogging of filter feeders), and is referred to hereafter as the marine ecosystem WQO.
- In this report, the maintenance of ambient salinity is defined by a salinity difference between the outlet plume and ambient seawater (ΔS). The following ΔS values have been used to define the mixing zone for desalination brine discharges in Australian marine waters (Jenkins et al 2012):
  - 1 psu for Sydney's desalination plant within 50-75 m of the diffuser.
  - 1.2 psu and 0.8 psu for Perth's desalination plant within 50 m and 1,000 m of the diffuser, respectively.

  A ΔS of 1 psu is adopted here for plume salinities that are above or below the ambient salinity. A ΔS of 1 psu is similar to criterion used to define the mixing zone for desalination brine discharges in Sydney and Perth. This adopted ΔS trigger value is used to quantify the potential effect of salinity variations on the local marine ecosystem, and is hereafter referred to as the ambient salinity WQO.
- Marine toxicant trigger values (MTTV) for a 95% species protection level for NH_X, copper (Cu), lead (Pb) and zinc (Zn) are evaluated. The specified three (3) metals-metalloids have been measured as part of the ambient seawater monitoring program, and therefore are evaluated along with ammonia. These MTTVs are used to assess the toxicity effects of ammonia and the three dissolved metals-metalloids on marine organisms, and is referred to hereafter as the marine toxicity WQO.
- Recreational primary contact (i.e. swimming) guideline values (RPCGV) is evaluated for the median of measurements of enterococci (E), which is also referred to as the human health WQO.

Table 2-1 provides the values used for C_V (guideline or trigger value) to calculate the dilution factor for each analyte with the equation in Section 2.1. The DTV values are only provided for context and are not utilised here. Ammonia is the only analyte that is evaluated for two (2) types of impacts, namely the WQOs of marine toxicity (i.e. MTTV) and marine ecosystem (i.e. SSTV).

Table 2-1 Summary of guideline and trigger values

Parameter	ΔS (psu)	NH_X (mg/L)	NO_X (mg/L)	TN (mg/L)	TP (mg/L)	E (CFU/ 100mL)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Turbidity (NTU)
MTTV (marine toxicity)		0.91					0.001 3	0.004 4	0.015	
DTV		0.015	0.025	0.120	0.025					~0.5
SSTV (marine ecosystem)	1.0[3]	0.009	0.049	0.334	0.012					2..7
RPCGV (human health)						35				

[3] ΔS value has been based on literature values in Section 2.1.1.

2.2 Near-field modelling

The near-field region refers to the immediate area around the diffuser where the outlet (diffuser) discharge undergoes momentum-driven or buoyancy-driven transport and enhanced mixing along its trajectory through the water column (i.e. prior to reaching the surface, impinging on the seafloor, or achieving neutral buoyancy). The highest rates of mixing and dilution occur through these near-field mixing processes relative to natural background levels of mixing and resultant dilution. Near-field modelling was carried out with the industry standard Updated Merge 3 (UM3) model of the Visual Plumes software suite by the United States Environmental Protection Agency (US EPA) (Frick et al. 2001). The near-field simulation with UM3 terminates when the buoyant plume intersects the sea surface. At this point, the near-field jet and/or plume mixing processes are no longer simulated with UM3.

The purpose of the near-field modelling is to confirm the existing WWTW outfall diffuser can accommodate additional flow from the TDP from a near field dilution perspective (Section 4.2). To meet this purpose, near-field modelling considered:

- Well-mixed marine waters. As illustrated in Section 3.2.5, thermal stratification in the vicinity of the WWTW diffuser is generally well-mixed or weakly stratified.
- High and low estimates of ambient marine current speeds.
- High and low estimates of discharge and salinity for treated wastewater and brine-treated wastewater mixture. As salinity has a greater effect on water (and plume) density than temperature, variations in temperature were not considered.

The results of the near-field modelling are presented as both the average and centreline dilutions with horizontal distance from the diffuser. The centreline dilution at the centre of the plume is much lower than the average plume dilution at a particular distance from the diffuser port because of less entrainment and mixing of ambient marine waters. Though the centreline dilution is presented, the focus of the description of the near-field results is on the average plume dilution.

2.2.1 Near-field dilution capacity of ambient marine waters

The near-field dilution capacity of the outlet was evaluated with a mass balance approach to determine the minimum ambient current speeds that provide sufficient volumetric flow to achieve the required dilution at the edge of the mixing zone within the near-field region (Section 4.2.3). The maximum dilution that can be achieved in the near-field is dependent on the following conditions:

- The total effluent discharge rate through the diffuser
- The cross-current length of the diffuser
- The depth of the diffuser
- The ambient current speeds at the diffuser location

The volumetric 'flow rate' transported past the diffuser is estimated as the water depth, multiplied by the horizontal diffuser length (in the cross-current direction), multiplied by the ambient current speed. This ambient water flow rate is divided by the discharge through the diffuser to estimate the maximum (near-field) dilution capacity for a particular current speed. This mass balance approach assumes that the outlet discharge through each port mixes vertically throughout the full water depth and horizontally between each port of the diffuser. As such, it is likely to over-estimate the near-field dilution capacity of the diffuser in deeper waters such as here, but nonetheless provides an upper limit.

The minimum current speed to achieve the target dilution is estimated and the proportion of time this value is met or exceeded at the site was determined from available current measurements. A high percentage of current speeds above this threshold indicates the target dilution has the potential be met in close proximity to the diffuser. This dilution capacity assessment confirms the veracity of the near-field modelling predictions, as UM3 does not simulate the mass balance of outlet waters with the mean ambient flow of the receiving environment, but rather assumes an infinite supply of ambient waters.

2.3 3D Far-field modelling

The far-field region beyond the near-field is where mixing and dilution of the outlet (diffuser) waters is driven by ambient mixing and transport processes associated with tides, winds, surface heat fluxes and waves. Three-dimensional (3D) far-field modelling was undertaken with the industry standard Danish Hydraulic Institute's (DHI) MIKE 3 FM (Flexible Mesh)[4].

The model domain in MIKE 3 FM is defined horizontally by an irregular network of triangles (the model 'cells') that are split into vertical 'layers' by either a z-level (defined layer thicknesses), sigma coordinate (fixed number of vertical layers equally spaced for each model cell) or a combined sigma and z-level configuration. For each model cell, at each vertical layer, MIKE 3 FM calculates a range of hydrodynamic properties including, but not limited to, current speed, current direction, water level, salinity and temperature.

MIKE 3 FM is driven by user-defined environmental inputs including, but not limited to, sea level variations and currents at the model's open boundaries, river inflows, wind speeds and directions over the surface, surface heat exchange at the surface, and point-source inputs from the diffuser ports or other outlet arrangements.

MIKE 3 FM was used to simulate the currents, temperature, salinity and dilution of outlet (diffuser) waters (via a conservative numerical tracer) in the following manner:

- The bathymetry (including Lake Macquarie), and the horizontal and vertical model grid were prepared from available data (Section 3.1).
- Model inputs included meteorology at the sea surface (Section 3.3.1), open model boundary forcing (i.e. water levels, currents, temperature, salinity) (Section 3.3.2) and Hunter River inflows (Section 3.2.8).
- The use of industry standard values for key hydrodynamic modelling parameters, namely:
  – Bed roughness height of 0.1 m.
  – Wind friction value of 0.00126 m/s.
- The 1992 original diffuser and 2004 diffuser augmentation were incorporated into the model (Section 3.3.3).
- A numerical conservative tracer was used to track the proportion of outlet (diffuser) waters in the receiving marine waters (Section 3.3.4).
- A model spin-up duration of one (1) week was run prior to simulation analysis.

2.3.1 Model calibration and validation

Current speed, current direction and water level measurements were available near the diffuser site (Belmont) from 14 February to 24 March 2018 and 24 April to 27 June 2018, and in proximity to Burwood Beach (Burwood) from 24 October 2017 to 11 April 2018 (Section 3.2.6). The Belmont site data was utilised for model calibration and validation (Section 4.2.3).

[4] The use of a 3D model rather than a vertically averaged two-dimensional (2D) model is necessary to simulate the vertical variations that are caused by the plume dynamics of the effluent-brine mixture discharge that is discharged into marine waters.

Model calibration and validation utilised the following quantitative indices to compare simulated and measured currents:

- **Mean Absolute Error (MAE).** A quantitative measure of the absolute differences between the simulation and measurements. Low values of MAE represent good model performance. This metric is easily interpretable and a more natural measure than the commonly used root-mean-squared error, as it is less influenced by extreme values (i.e. outliers or 'noise' in the measured data) (Willmott 1982). The MAE is calculated as:

$$\boldsymbol{MAE} = \frac{\sum_{i=1}^{n} |P_i - O_i|}{n}$$

where:

– P_i = Predicted value at comparison time i

– O_i = Observed value at comparison time i

– n = Number of comparison measurements

- **Index of Agreement (IOA).** IOA is a quantitative measure of the average differences between predicted and observed values relative to the range of values in the observation data (Willmott 1982). It is bounded between the values of 0 and 1, with values close to 0 describing large relative differences (i.e. poor validation) and values close to 1 describing small relative differences (i.e. good validation). Willmott et al. (1985) suggests that IOA values meaningfully >0.5 represent good model validation, with values approaching 1 representing excellent validation. Here, IOA values greater than 0.6 and 0.5 are deemed to represent good and satisfactory model agreement, respectively. The IOA is calculated as:

$$\boldsymbol{IOA} = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (|P_i - \bar{O}| + |O_i - \bar{O}|)^2}$$

where, further to the definitions for MAE:

– $\bar{O}$ = Mean of the observations during the comparison period.

Current directions are excluded from the MAE and IOA calculations in this study. Directions are measured with a polar coordinate system (where 0° and 360° both represent north), whereas the equations to calculate MAE and IOA are for a Cartesian coordinate system. As such, MAE and IOA values are presented for the u (eastward) and v (northward) velocity components, which provides a manner to evaluate the model's skill in simulating current directions.

2.3.2 Overview of simulations and scenarios

An overview of the diffuser discharge (Q), salinity (S) and temperature (T) for the two scenarios is provided in Table 2-2. The simulations for the baseline effluent and proposed comingled effluent-brine scenarios were run over the duration of 15 February to 29 June 2018, which spans summer, autumn and winter conditions. The simulation period includes weakly stratified to non-stratified conditions from May-June 2018 and a period with stronger thermal stratification events from mid-February to mid-April (Section 3.2.5). WWTW outflow measurements were used rather than an average volumetric discharge to simulate the large sub-daily and wet versus dry weather variations (see Section 3.2.1). However, for the TDP, the volumetric discharge, temperature and salinity were estimated average values.

Table 2-2 Overview of data for outlet (diffuser) volumetric discharge, salinity and temperature

<table>
<tr><th>Scenario</th><th>Start</th><th>End</th><th>WWTW Q (m^3/s)</th><th>Potable Water Supply Q (ML/day)</th><th>Outlet (Diffuser) Q (m^3/s)</th><th>WWTW S (g/kg)</th><th>Brine-WWTW S (g/kg)</th><th>WWTW T (°C)</th><th>Brine-WWTW T (°C)</th></tr>
<tr><td>Baseline</td><td rowspan="2">15 February 2018</td><td rowspan="2">30 June 2018</td><td rowspan="2">WWTW SCADA</td><td>-</td><td>WWTW SCADA</td><td rowspan="2">4.3 (Median SCADA S, see Section 3.2.1)</td><td>-</td><td rowspan="2">Daily average air T (see Section 3.2.1)</td><td>-</td></tr>
<tr><td>Normal Full Operation</td><td>16.4</td><td>WWTW SCADA + Desal Estimate (see Section 3.3.5)</td><td>WWTW-Brine Mixture Estimate (see Section 3.3.5)</td><td>Estimated WWTW-Brine Mixture (see Section 3.3.5)</td></tr>
</table>

These simulations were evaluated over two (2) assessment periods (i.e. dry and wet weather) to meet various modelling objectives as summarised in Table 2-3. The entire simulation period (15 February -29 June 2018) also included large (22-30 March 2018, peak discharge of 800 m^3/s), moderate (18 - 24 June 2018, peak discharge of ~120 m^3/s) and small (6-10 April 2018, peak discharge of ~40 m^3/s) Hunter River inflow events. However, as noted in Table 2-3, no inflow events occurred during the dry weather analysis period, and the moderate-sized inflow event occurred at the end of the wet weather analysis period and did not materially affect the salinity at the Belmont site.

Table 2-3 Overview of report objectives, scenarios and assessment periods

<table>
<tr><th>Objective</th><th>Scenario</th><th>Start Date of Analysis</th><th>End Date of Analysis</th></tr>
<tr><td>Model Calibration</td><td>Baseline
Large inflow event at end of analysis period that does not affect Belmont site</td><td>21 February 2018</td><td>24 March 2018</td></tr>
<tr><td>Model Validation</td><td>Baseline
Moderate-sized inflow event at end of analysis period</td><td>24 April 2018</td><td>27 June 2018</td></tr>
<tr><td>Existing – Dry Weather</td><td rowspan="2">Baseline & Normal Full Operation
No inflow events</td><td rowspan="2">21 April 2018</td><td rowspan="2">18 May 2018</td></tr>
<tr><td>Normal Full Operation – Dry Weather</td></tr>
<tr><td>Existing – Wet Weather</td><td rowspan="2">Baseline & Normal Full Operation
Moderate-sized inflow event at end of analysis period</td><td rowspan="2">2 June 2018</td><td rowspan="2">29 June 2018</td></tr>
<tr><td>Normal Full Operation – Wet Weather</td></tr>
</table>

As described previously in Sections 1.4 and 2.1 and subsequently in Section 3.3.4, a numerical conservative tracer of the outlet (diffuser) waters serves to track dilution with the ambient waters.

3. Model data and analysis

3.1 Model domain and bathymetry

The model domain, bathymetry and mesh are shown in Figure 3-1, and were prepared with the following data sources:

- DHI's C-Map database of digitised nautical charts
- EOMAP 10 m horizontal resolution satellite derived data primarily for nearshore coastal ocean waters <10 m depth and throughout the connection of Belmont Bay (Lake Macquarie) with the coastal waters
- GHD digitised contours of NSW OEH data of Belmont Bay (Lake Macquarie)

The model's spatial domain is bounded by northern, eastern and southern offshore open boundaries at distances of ~30 km, ~70 km and ~40 km from the Belmont outlet (diffuser) site, respectively. The offshore boundaries have coarse spatial resolution (~2-3 km) that are driven by tidal (water levels and depth-averaged currents) and oceanographic (vertically varying) currents, and vertically varying temperature and salinity through the water column (Section 3.3.2). Finer model resolution (~30 m) is configured in the immediate region around the diffuser, the channel between Lake Macquarie and the ocean, and the Newcastle Harbour and lower Hunter River region. Lake Macquarie is included because estuarine discharge during ebb tides can potentially influence currents in the vicinity of the diffuser's location. Similarly, Newcastle Harbour and the lower Hunter River were included to simulate the potential effect of large river flows on the salinity dynamics of the local ocean waters. The model bathymetry and mesh structure in the vicinity of the outlet (diffuser) are shown in Figure 3-2.

The vertical and horizontal resolution of all grid cells in the vicinity of the outlet (~30 m horizontal, 2 m thick) was configured so that the WWTW effluent or the comingled WWTW effluent - TDP brine volumetric discharge fills a substantial proportion of the model cell in which the outflow is inserted over a single model time step. The 3D hydrodynamic model uses a simplified near-field model (Jirka 2004) to determine the depth in which to insert the outflows from the diffuser (refer to Section 3.3.3 for further explanation). This reduces the potential for numerical dilution (i.e. a small volumetric discharge into a large model cell that will be immediately diluted to an unrealistically high degree) to materially influence the simulated dilution of outlet waters by the marine environment. The vertical resolution of the model domain was configured as follows:

- Three (3) sigma layers over the upper 5 m with varying proportional thickness of 10% for the surface layer and 45% each for the next two layers
- Ten (10) fixed layers below the three surface sigma layers of 2 m thickness that extends to depths greater than the diffuser
- Thereafter fixed layers of 5, 20, 20, 30, 100, 500, 500 and 800 m thickness

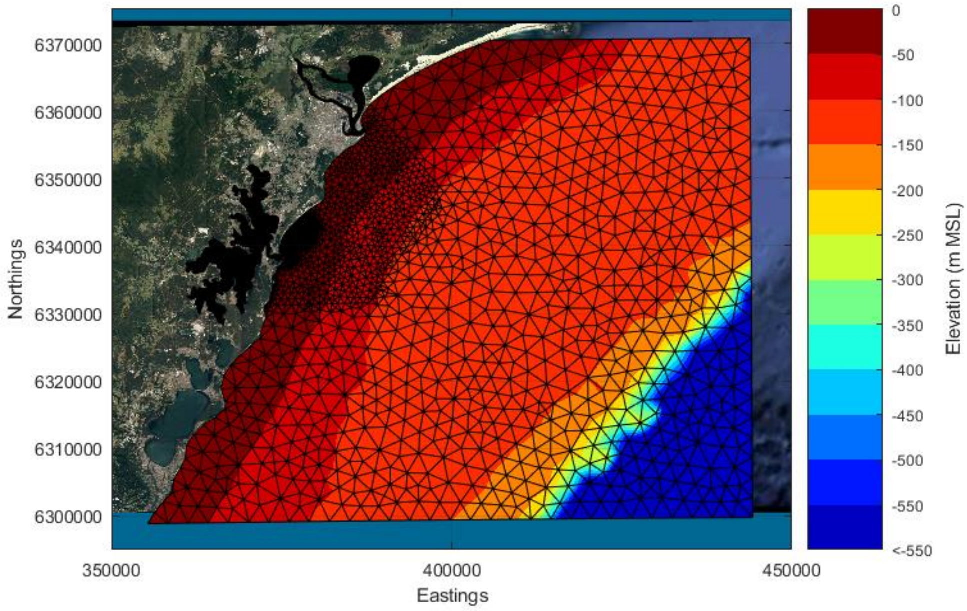


Figure 3-1 Model domain, mesh and bathymetry

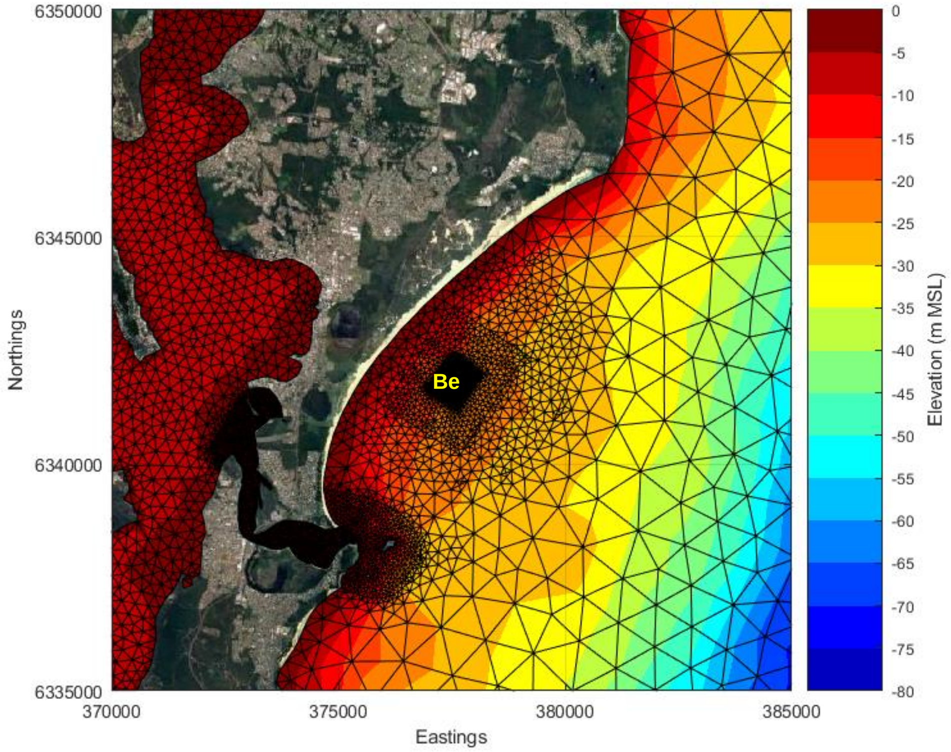


Figure 3-2 Model bathymetry and mesh in the vicinity of the diffuser with diffuser location and the Belmont ADCP/thermistor chain location (Be)

3.2 Available data and information

3.2.1 WWTW discharge, salinity and temperature

Discharge

Thirty minute averages of 1 minute measurements of the WWTW outlet (diffuser) discharge from 1 July 2017 to 30 June 2018 are illustrated in the top panel of Figure 3-3, which shows that:

- Extended periods of dry weather outlet discharge occurred from 1 July to 19 October 2017, 13 November 2017 to 18 February 2018 and 5 April to 2 June 2018. *Here, one representative dry weather period is evaluated over two tidal cycles (28 days, 4 weeks) from 21 April-18 May 2018.*
- Wet weather discharge periods occurred from 20 October to 12 November 2017, 26 February to 4 March 2018, 21 March to 4 April 2018 and 1 to 30 June 2018. *Here, one representative wet weather period is evaluated over two tidal cycles (28 days, 4 weeks) from 2-29 June 2018.*

The selected analysis periods, which are summarised in Table 2-3, correspond to a range of meteorological (Section 3.2.7) and thermal stratification (Section 3.2.5) conditions.

Closer inspection of the time series of 30 minute averages from 21 April to 29 June 2018 (bottom left panel of Figure 3-3) that encompass the representative dry and wet weather WWTW flows show that:

- Dry weather outlet discharge varies on a daily basis from minimums of ~0.2-0.3 m^3/s to maximums of ~0.7-0.95 m^3/s.
- Though the daily variations in outlet discharge also occurs during the representative wet weather period, it is predominantly the non-sewage component of the outlet discharge (associated with wet weather) that has the greatest influence. Flows during the wet weather period (see Figure 3-3) had brief minimums of ~0.5 m^3/s and peak discharge in excess of 3 m^3/s.

Percentile distributions of the time series of 30 minute averages over the 1 year and the representative dry and wet weather periods in the middle and bottom right panels of Figure 3-3, respectively, shows that:

- Over the dry weather periods a large increase (rather than gradual) in discharge occurs between the 55^{th} and 60^{th} percentiles, which represents the large variation in sewage inputs between night (low) and day (high).
- Over the representative wet weather periods this daily variation in sewage inputs does not materially affect the percentile distributions of the outlet volumetric discharges because of the greater relative importance of non-sewage inputs ‘throughout’ the entire 24 hour period. Clearly, the wet weather conditions have substantially greater discharge than the dry weather conditions.

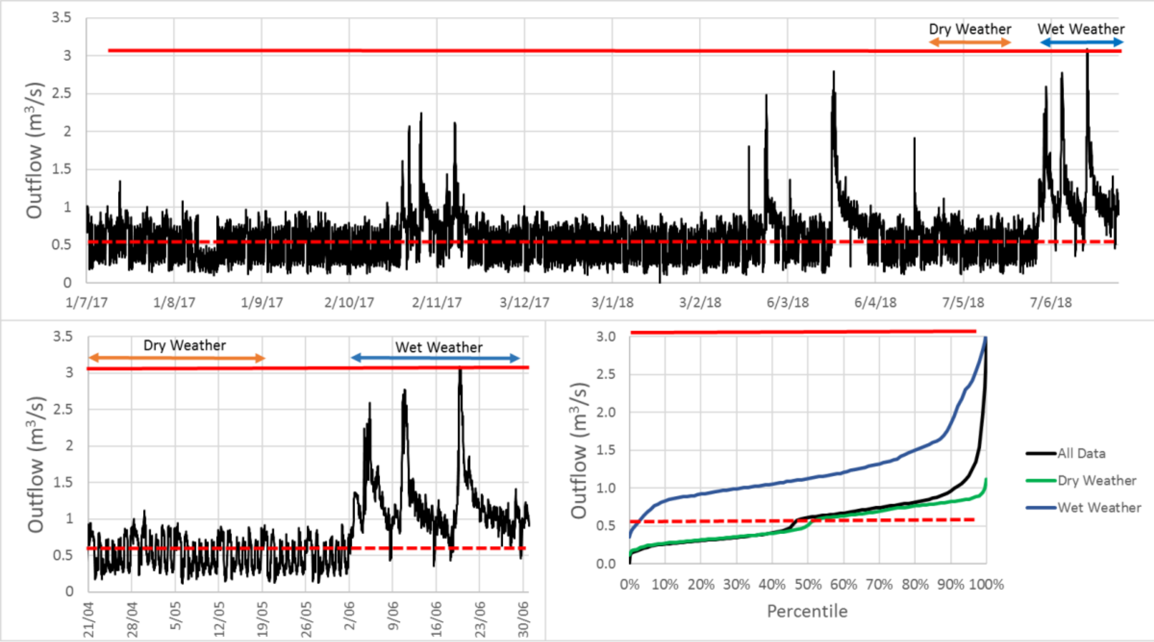


Figure 3-3 WWTW outlet discharge (30 minute averages, black) with average (red dashes) and maximum (red solid) from 1 July 2017 to 30 June 2018 (top) with zoom of 21 April to 29 June 2018 (bottom left) with percentiles for all data, representative dry weather and representative wet weather conditions (bottom right)

Salinity

WWTW measurements of conductivity (µS/cm) and total dissolved solids (TDS) of the 'secondary effluent' and 'raw effluent' from the Belmont facility are highly correlated with a linear zero-intercept regression that explains 98% of the variability (Figure 3-4). This relation was used to estimate the TDS of conductivity measurements of the 'final combined effluent' if TDS or salinity measurements were not available. Salinity (psu) was estimated as TDS (mg/L) divided by thousand if salinity measurements were not available. Table 3-1 summarises the statistics of the salinity measurements and estimates of the 'final combined effluent'. The average salinity of 3.9 psu is similar to the median of 4.3 psu.

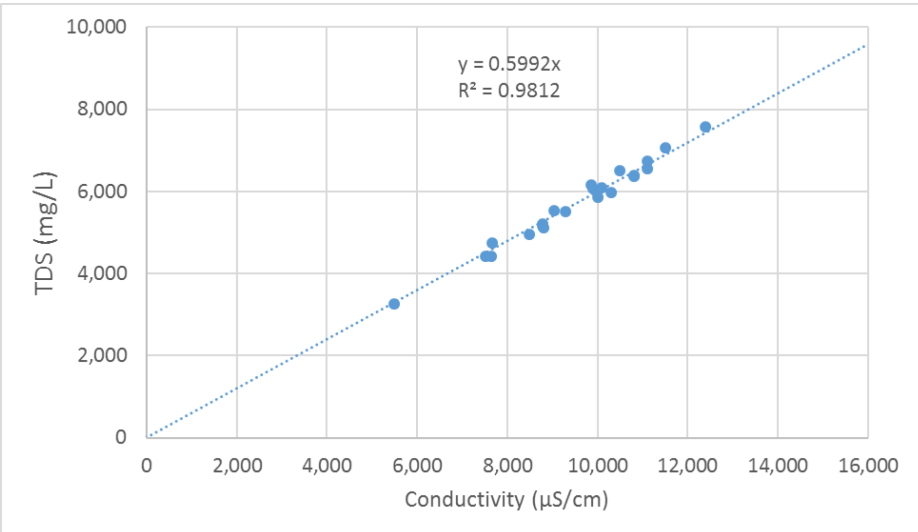


Figure 3-4 Linear relation between conductivity and TDS of secondary effluent and raw effluent

Table 3-1 Descriptive statistics of WWTW final combined effluent salinity

Statistic	S (psu)
Average	3.9
Standard Deviation	1.6
5th Percentile	1.7
10th Percentile	1.7
20th Percentile	2.6
Median	4.3
80th Percentile	5.2
90th Percentile	5.6
95th Percentile	6.2

Temperature

No WWTW effluent temperature data is available. The effluent temperature was estimated as the daily average air temperature from the Bureau of Meteorology (BoM) Nobby Head station (station number 61055) as illustrated in Figure 3-5.

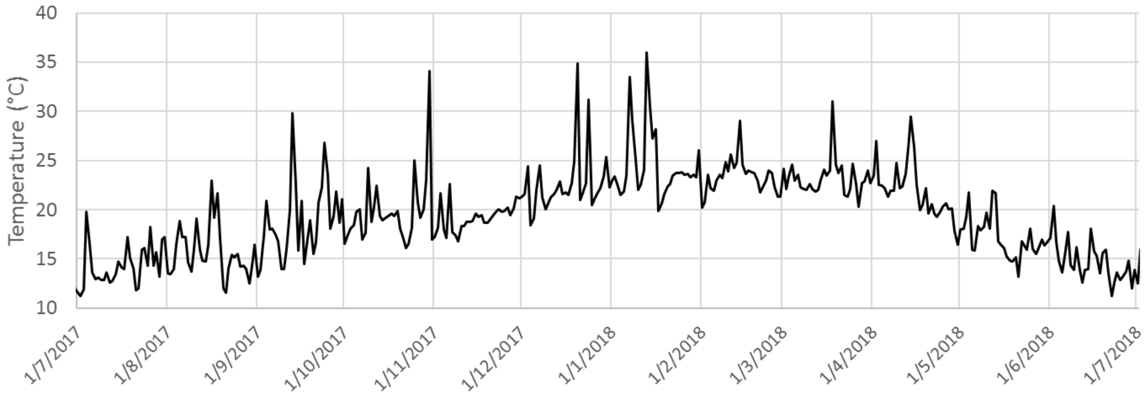


Figure 3-5 Daily average air temperature at BoM station number 61055 at Nobby Head used as an estimate of the final combined effluent water temperatures

3.2.2 WWTW outlet water quality

The WWTW outlet water quality was used to define the required dilution factor at the edge of the mixing zone around the diffuser and at proximal beaches (e.g. Redhead Beach, Blacksmith Beach) in Section 4.1. Regular measurements (~weekly) of total reduced inorganic nitrogen (ammonia+ammonium or $NH_X=NH_4+NH_3$), total suspended solids (TSS), total phosphorus (TP), total oxidised inorganic nitrogen (nitrate+nitrite or $NO_x=NO_3+NO_2$), enterococci (E), copper (Cu), lead (Pb) and Zinc (Zn) are collected of the WWTW effluent data. TN is estimated as the sum of TKN (total kjeldhal nitrogen or TKN) and NO_x. Time series of these data from 1 January 2014-30 November 2018 are illustrated in Figure 3-6 for NH_x, NO_x, TSS, TP and TN with a descriptive statistical summary in Table 3-2 of these parameters along with E, Cu, Pb and Zn[5]. Observations of the WWTW effluent quality include:

- NH_X is generally low (<1 mg/L up to 90th percentile) though elevated levels occurred for a prolonged period from January-February 2018, which resulted in a substantially greater average of 0.29 mg/L than the median of 0.05 mg/L.
- NO_X generally ranged from 5-10.5 mg/L (10th-90th percentiles) with an average and median of 8.0 mg/L and 8.1 mg/L, respectively.
- TN generally ranged from 6.5-13.5 mg/L (10th-90th percentiles) with an average and median of 10.0 and 9.8 mg/L, respectively.
- TP generally ranged from 1.5-3.5 mg/L (10th-90th percentiles) with an average and median of 2.6 mg/L.
- TSS generally ranged from 2-21 mg/L (10th-90th percentiles) with an average and median of 11.6 mg/L and 10.0 mg/L, respectively.
- E generally ranged from 594-1,622 MPN/100 ml (10th-90th percentiles) with an average and median of 1,065 MPN/100 ml and 938 MPN/100 ml, respectively.
- Cu generally ranged from 0.9-4 mg/L (10th-90th percentiles) with an average and median of 2.4 mg/L and 2.2 mg/L, respectively.
- Pb generally ranged from 0.1-0.59 mg/L (10th-90th percentiles) with an average and median of 0.25 mg/L and 0.1 mg/L, respectively.
- Zn generally ranged from 2-21 mg/L (10th-90th percentiles) with an average and median of 38.2 mg/L and 29.5 mg/L, respectively.

Table 3-2 WWTW combined final effluent water quality descriptive statistics

Statistic	NH_X (mg/L)	NO_X (mg/L)	TN (mg/L)	TP (mg/L)	E (MPN[6]/ 100 mL)[7]	Cu (mg/L)[8]	Pb (mg/L)	Zn (mg/L)	TSS (mg/L)
Count (n)	227	276	244	246	13	24	22	24	280
Average	0.29	8.0	10.0	2.62	1,065	2.4	0.25	38.2	11.6
Standard Deviation	0.72	2.2	2.6	0.88	466	1.4	0.22	21.7	8.2
1st Percentile	0.00	3.0	5.6	1.00	428	0.7	0.10	19.2	1.0
5th Percentile	0.00	4.2	6.1	1.40	500	0.8	0.10	20.6	1.0
10th Percentile	0.01	5.0	6.7	1.60	594	0.9	0.10	24.6	2.0
20th Percentile	0.02	6.3	7.8	1.90	761	1.2	0.10	27.6	5.0
Median	0.05	8.1	9.8	2.60	938	2.2	0.10	29.5	10.0

[5] E, Cu, Pb and Zn have a substantially smaller dataset and hence are not shown in Figure 3-6.

[6] Most probable number.

[7] Enterococci data from 17-19 December 2001, 16-17 January 2002, 25-26 February 2002, and 6 & 11 May 2019.

[8] Metals and metalloids data from 2 January 2017 to 29 December 2018.

Statistic	NH_X (mg/L)	NO_X (mg/L)	TN (mg/L)	TP (mg/L)	E (MPN[6]/ 100 mL)[7]	Cu (mg/L)[8]	Pb (mg/L)	Zn (mg/L)	TSS (mg/L)
80th Percentile	0.14	9.8	11.9	3.20	1,390	3.3	0.30	43.4	17.0
90th Percentile	0.76	10.4	13.3	3.50	1,622	4.0	0.59	57.2	21.0
95th Percentile	1.76	11.2	14.5	3.78	1,840	4.7	0.70	80.7	26.1
99th Percentile	3.74	12.5	17.0	5.64	2,048	6.3	0.78	108.6	40.0

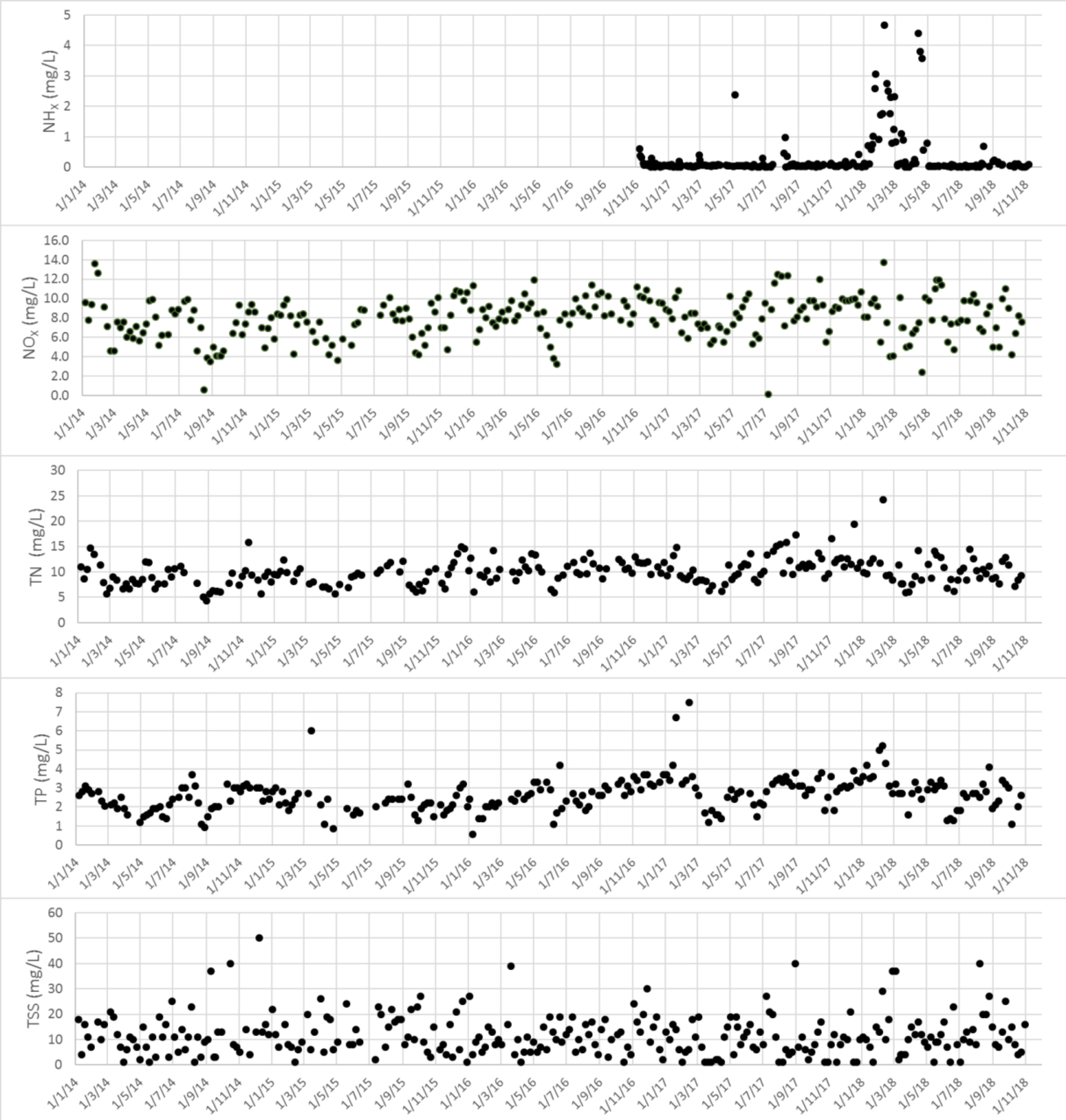


Figure 3-6 Effluent water quality (NH_X, NO_X, TN, TP and TSS) from January 2014-November 2018

3.2.3 Design brine water quality

A brine temperature of 20 °C and brine salinity of 65 psu were set for the purposes of the modelling here, where the salinity is considered conservative (i.e. during operations a lower brine salinity is likely). NH_X and NO_3 are projected to be 0.44 mg/L and 6.7 mg/L, respectively (GHD 2019).

3.2.4 Ambient seawater quality

Ambient seawater quality was characterised on the basis of quarterly measurements during July 2011-April 2013 and August 2017-July 2018 of surface and mid-water samples at four (4) reference sites. These reference sites are ~2 km from the WWTW outlet (diffuser) with a descriptive statistics summary in Table 3-3. These statistics are used in Section 4.1 to define the quantitative WQOs as outlined in Section 2.1 and to define the SSTVs for nutrients and chlorophyll a (chl a) in Section 2.1.1).

The following brief overview of the seawater monitoring data indicates low ambient concentrations of nutrients, chl a, metals and pathogens:

- Salinity variations are relatively large ranging from 32.7 to 36.4 psu for the 20^{th} to 80^{th} percentiles, respectively.
- The median (and 20^{th} percentile) of NH_X is below the Limit of Reporting (LoR, <0.005 mg/L), and the 80^{th} percentile is 0.009 mg/L.
- The median NO_X of 0.005 mg/L is approximately 10-fold lower than the 80^{th} percentile value of 0.049 mg/L.
- The median TN of 0.121 mg/L is approximately 3-fold lower than the 80^{th} percentile value of 0.334 mg/L.
- The median TP of 0.005 mg/L is approximately 2-fold lower than the 80^{th} percentile value of 0.012 mg/L.
- The medians of total Cu, Pb and Zn are lower than their respective LoRs.
- The median enterococci is lower than the LoR (<1 CFU/100 ml).
- The median turbidity of 0.5 NTU is approximately 5-fold lower than the 80^{th} percentile value of 2.7 NTU.

The medians of the ambient seawater analytes are used as the estimates for C_A (ambient seawater concentration) to calculate the required dilution factor (Section 2.1) for each analyte (Section 4.1). The 80^{th} percentiles of NH_x, NO_X, TN, TP and turbidity are used to define C_V (site specific trigger value or SSTV) as per Table 2-1 of Section 2.1.1 to calculate the required dilution factors (Section 2.1) for each analyte (Section 4.1). Salinity (S) utilises both the 20^{th} and 80^{th} percentile values to define C_V as per Table 2-1 of Section 2.1.1 depending on whether the outfall (diffuser) discharge has a lower or higher salinity than the ambient seawater, respectively. Enterococci (E) to define human health guideline values, and metals-metalloids (Cu, Pb, Zn) and NH_X to define marine toxicant effect trigger values (for a 95% species level protection) are prescribed ANZECC & ARMCANZ (2000) values as per Table 2-1 of Section 2.1.1.

Table 3-3 Ambient seawater quality descriptive statistics

Statistic	S (psu)	NH_x (mg/L)	NO_x (mg/L)	TN (mg/L)	TP (mg/L)	E (MPN/ 100 mL)	Total Cu (mg/L)	Total Pb (mg/L)	Total Zn (mg/L)	Turbidity (NTU)
20th Percentile	32.65	<0.005	<0.001	0.079	<0.005	<1	<0.001	<0.0002	<0.005	0.2
Median	35.63	<0.005	0.005	0.121	0.005	<1	<0.001	<0.0002	<0.005	0.5
80th Percentile	36.36	0.009	0.049	0.334	0.012	3	<0.001	0.0006	0.010	2.7
Average	34.94	0.008	0.055	0.215	0.007	7.8	-	-		7.8
Std Dev	1.72	0.020	0.149	0.297	0.006	22.9	-	-		22.9
n	56	95	95	95	95	100	40	40	40	100

3.2.5 Seawater temperatures and water levels

Six hourly sub-sampled water levels and temperatures (2, 10 and 17 m above the seabed) from 30 minute measurements at locations in proximity to Burwood Beach (~23 m water depth) and the Belmont diffuser (~25-26 m water depth) are shown in Figure 3-7. The key characteristics of these measurements include:

- Water levels range over ~1.5 m with typical spring and neap variations of ~1 m and ~0.2 m, respectively.
- Water temperatures range from a minimum of 15-16 °C to a maximum of 22-23 °C. Weakly thermally stratified to well-mixed conditions through the water column typically occur from late autumn to start of winter (May-June) and spring (October). During late spring (November) to early autumn (April) the temperature difference between 2 m and 17 m above the seabed at both locations can exceeds 3 °C for brief periods, but typically are <3 °C interspersed with periods of relatively uniform temperature through the water column.
- There are several cooling events in February 2018 where the temperatures rapidly decrease from 21-22 °C to 15-16 °C. These cooling events likely are due to persistent north-easterly winds that when combined with the Coriolis force causes water to be deflected to the left, which results in offshore transport of surface waters that are replenished by cooler deeper waters. Further, a topographic driven back-eddy to the south of Port Stephens in the lee of the East Australian Current cause upwelling events of cooled water (Lee et al 2007). These interactions between the EAC, shoreline topography and wind forcing are not modelled in this study as a much larger model domain (Section 3.1) would be required to resolve the inter-related complexity of these processes. More importantly, these cooling events are short-lived and do not have a material impact on the predicted dilution factor over the time scales of this study's analysis (i.e. months).

In short, the thermal stratification dynamics of the nearshore waters in proximity to the outlet (diffuser) undergo relatively brief periods of temperature stratification from mid-spring to mid-autumn interspersed with mixing events that yield relatively isothermal conditions. During mid-autumn to mid-spring, isothermal to weakly stratified conditions are the norm. Selection of the representative dry and wet weather periods in Section 3.2.1 considered these measurements to characterise periods of stronger and weaker temperature stratification.

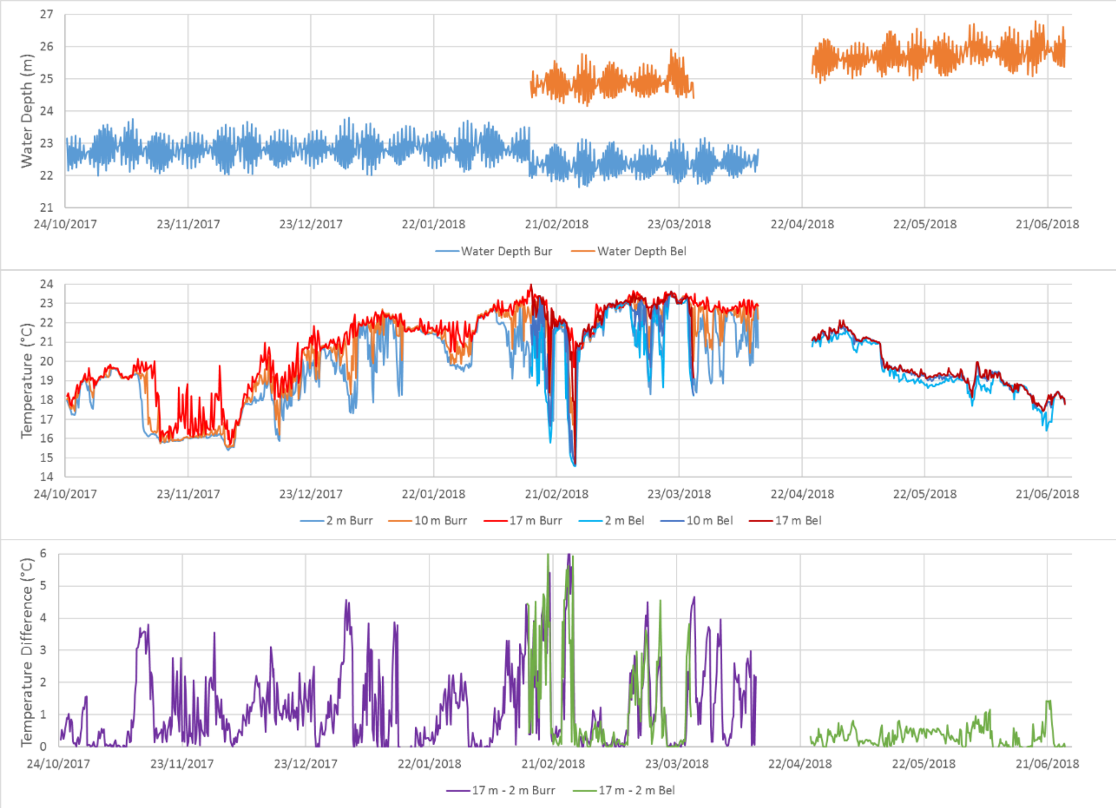


Figure 3-7 Sub-sampled 6 hourly (0000, 0600, 1200, 1800) water levels (top), temperatures (middle) and temperature differences between 2 m and 17 m above the seabed of 5 minute measurements at Belmont and Burwood thermistor chain deployments. All depths relative to the seabed

3.2.6 Current speeds and directions

Acoustic doppler current profiler (ADCP) measurements were collected at the same two locations as the water temperature and water level data described in Section 3.2.5, which are illustrated for the entire deployment periods in Figure 3-8 and from 14 February-24 March 2018 over the period with measurements at both locations in Figure 3-9. Observations of these current measurements include:

- Generally velocity components are greater along the north-south axis than the east-west axis.
- Generally the north-south velocity components at 10 m and 17 m above the seabed are greater than at 2 m above the seabed, whereas the east-west velocity components are similar amongst all three depths.

The Belmont site measurements were used to calibrate and validate the simulated water currents by the 3D hydrodynamic model in Section 4.2.3.

Figure 3-8 Sub-sampled 2 hourly (0000, 0200, etc.) northing and easting velocities of 5 minute measurements at Belmont and Burwood ADCP deployments. All depths relative to the seabed

Figure

Figure 3-9 As Figure 3-8 from 14 February-24 March 2018

3.2.7 BoM meteorology

Bureau of Meteorology (BoM) data is presented in Figure 3-10 for the following:

- 30 minute measurements of wind speed and direction, air temperature, relative humidity and air pressure at the Nobby Head BoM station 61055.
- Daily rainfall at the Lake Macquarie BoM station 61412.
- 30 minute measurements of cloud cover at the RAAF Williamtown BoM station 61078 where a ceilometer value of 1 (clear sky) is 0 cloud cover, and ceilometer values of 'SCT' (scattered cloud cover), 'BKN' (broken cloud cover) and 'OVC' (overcast) are estimated as 0.25, 0.5 and 1.0, respectively (not shown).

Table 3-4 provides descriptive statistics of these meteorological measurements, which are summarised as:

- Wind speeds typically range from 1.4 m/s (5th percentile) to 10.8 m/s (95th percentile) with an average of 5.2 m/s and median of 4.7 m/s.
- Wind directions from May-August (winter) had a greater proportion from the western to northern quadrant, whereas from November-March (summer) winds had a greater proportion from the eastern sector.
- Air temperatures ranged from 10.6 °C (5th percentile) to 25 °C (95th percentile) with an average of 18.3 °C and median of 18.5 °C.
- Relative humidity ranged from 39% (5th percentile) to 98% (95th percentile) with an average of 73% and median of 76%.
- Air pressure ranged from 1006 hPa (5th percentile) to 1028 hPa (95th percentile) with an average of 1017.2 hPa and median of 1017.4 hPa.
- Total rainfall was from 1 July 2017 to 30 June 2018 was 789 mm.

Selection of the representative dry and wet weather periods in Section 3.2.1 considered these measurements to characterise periods of surface heating and cooling, and variations in wind forcing and rainfall.

Table 3-4 Descriptive statistics of BoM meteorology

Statistic	WS (m/s)	WD (°)	Air T (°)	RH (%)	Press (hPa)	Rain (mm/day)
Average	5.2	200	18.3	73%	1017.2	1.7
Standard Deviation	2.8	103	4.6	18%	6.6	5.9
5th Percentile	1.4	30	10.6	39%	1006.0	0.0
10th Percentile	2.2	50	12.2	48%	1008.5	0.0
20th Percentile	2.5	80	14.2	59%	1011.6	0.0
50th Percentile	4.7	200	18.5	76%	1017.4	0.0
80th Percentile	7.2	310	22.3	90%	1022.9	0.6
90th Percentile	9.2	320	23.7	95%	1025.8	3.6
95th Percentile	10.8	340	25.0	98%	1028.0	10.8

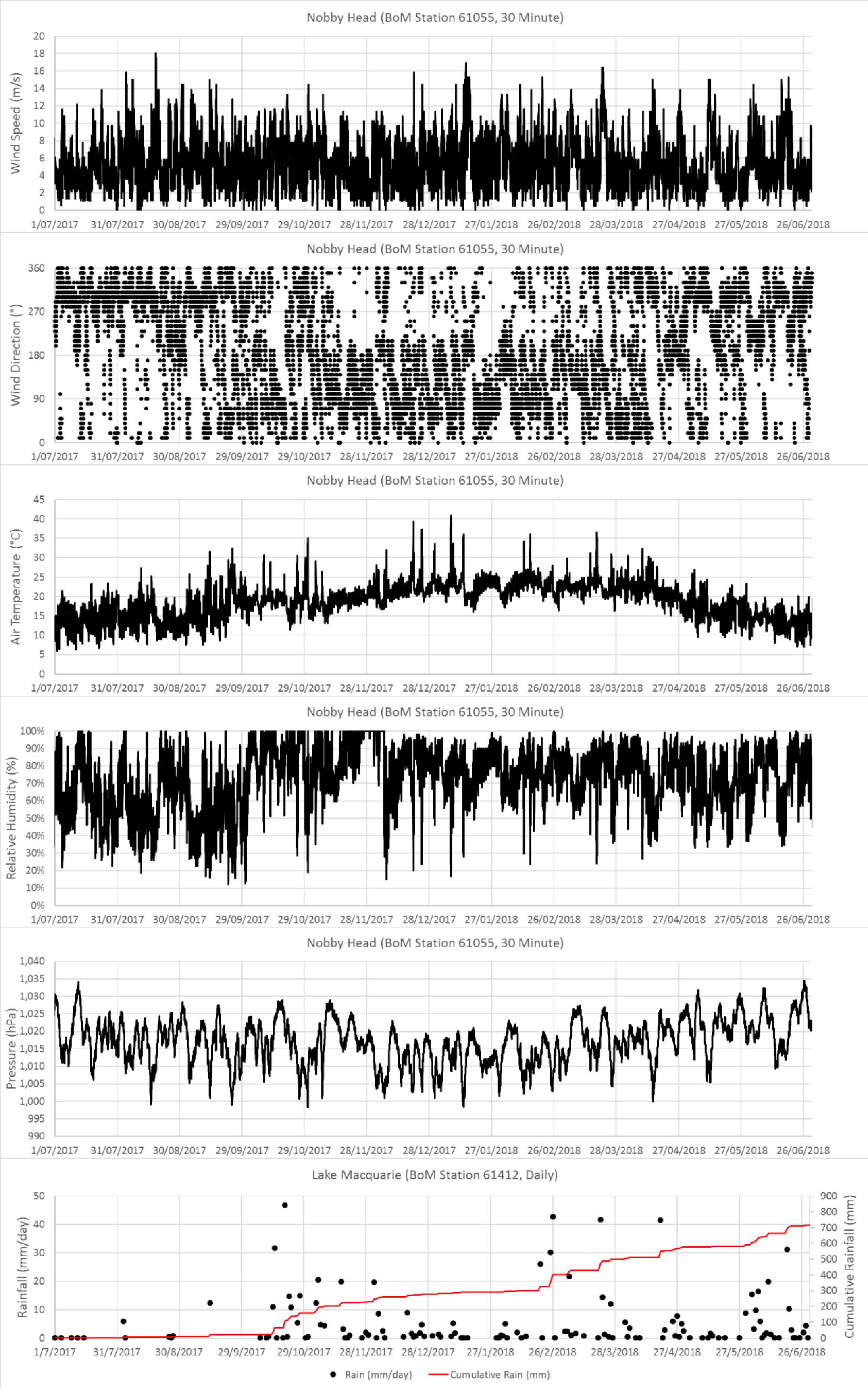


Figure 3-10 BoM measurements from Nobby Head (wind, temperature, relative humidity, air pressure) and Lake Macquarie (rainfall)

3.2.8 Hunter River discharge, temperature and salinity

Hourly Hunter River discharge was estimated as the combined discharge from the following stations:

- Hunter River at Greta (station number 210064). This station was also used to represent the water temperature and salinity of the Hunter River. Conductivity (µS/cm) was measured at this station (corrected to 25 °C), which was converted to TDS (mg/L) via the multiplicative constant of 0.5992 used for the effluent salinity estimation (Section 3.2.1).
- Williams River at Glen Martin (Mill Dam Falls, station number 210010).
- Paterson River at Gostwyck (station number 210079).

Daily averages of Hunter River discharge (Q), river water temperature (°C) and salinity (g/kg) are shown in Figure 3-11.

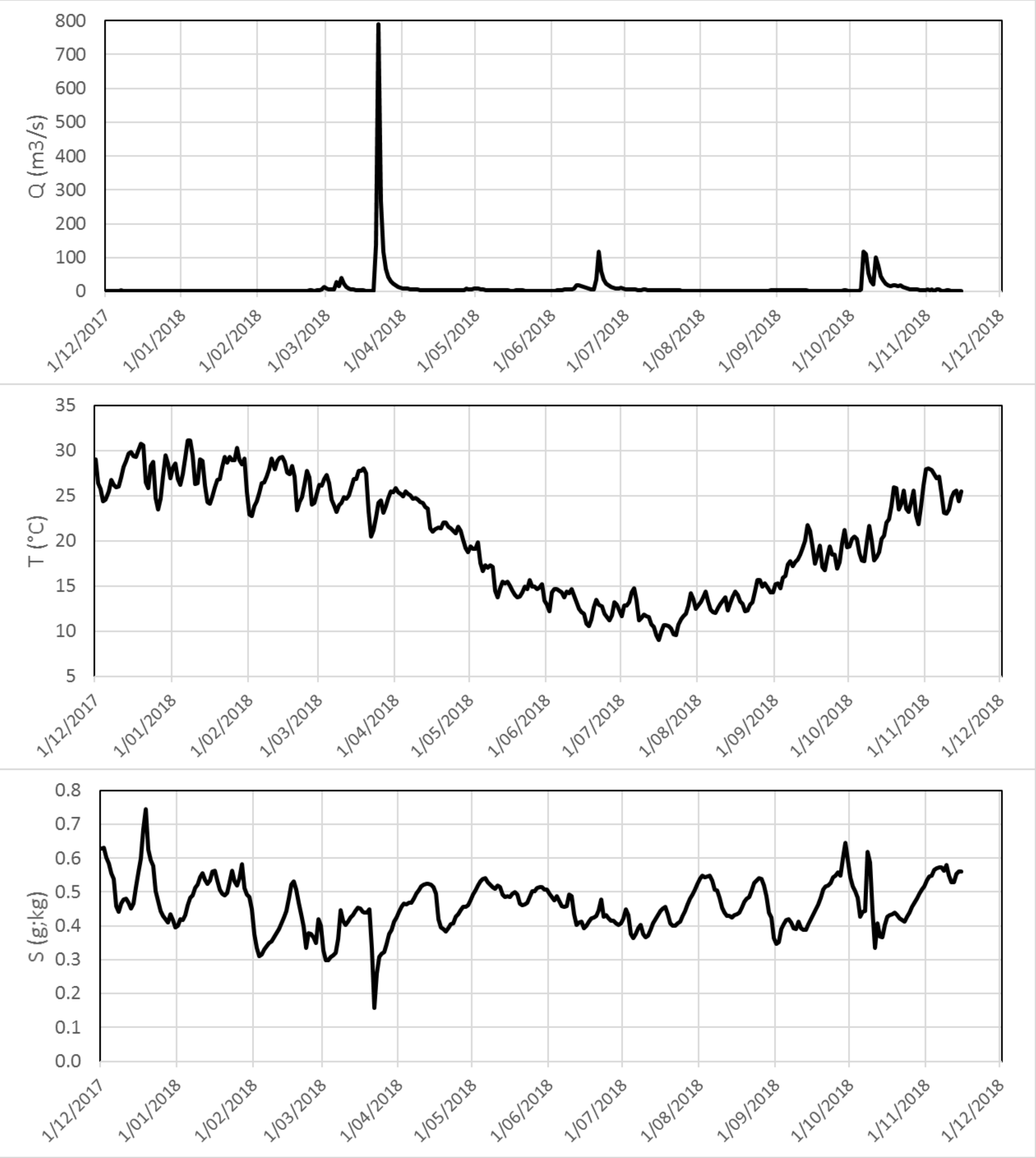


Figure 3-11 Daily averages of Hunter River discharge, temperature and salinity

3.3 3D hydrodynamic model input data

3.3.1 Meteorology

Spatially and temporally varying wind speed (WS) and wind direction (WD)inputs over the sea surface of the model domain were obtained from the second version of the NCEP (National Centers for Climate Predictions) Climate Forecast System (CFSv2, Suranjana *et al.* 2014). The time series of these parameters from the grid cell that contains data from the BoM weather station at Nobby Head (Station No: 61055 for WS, WD) are shown in Figure 3-12 with comparison to CFSv2 data, which correspond very well for wind direction, whereas wind speeds are somewhat underestimated by CFSv2 relative to the BoM measurements.

Air temperature, relative humidity and cloud cover inputs are required for the model's heat exchange module. Air temperature and relative humidity inputs were from the BoM weather station at Nobby Head (Station No: 61055) (Section 3.2.7). Cloud cover from RAAF Williamtown (BoM Station No: 61078) was utilised (Section 3.2.7). Rainfall from Nobby Head was applied (Section 3.2.7).

Hence, a combination of spatially variable CFSv2 data (winds) and uniform BoM measurements (rainfall, cloud cover, air temperature, relative humidity, air pressure) were used as meteorological inputs for the 3D model.

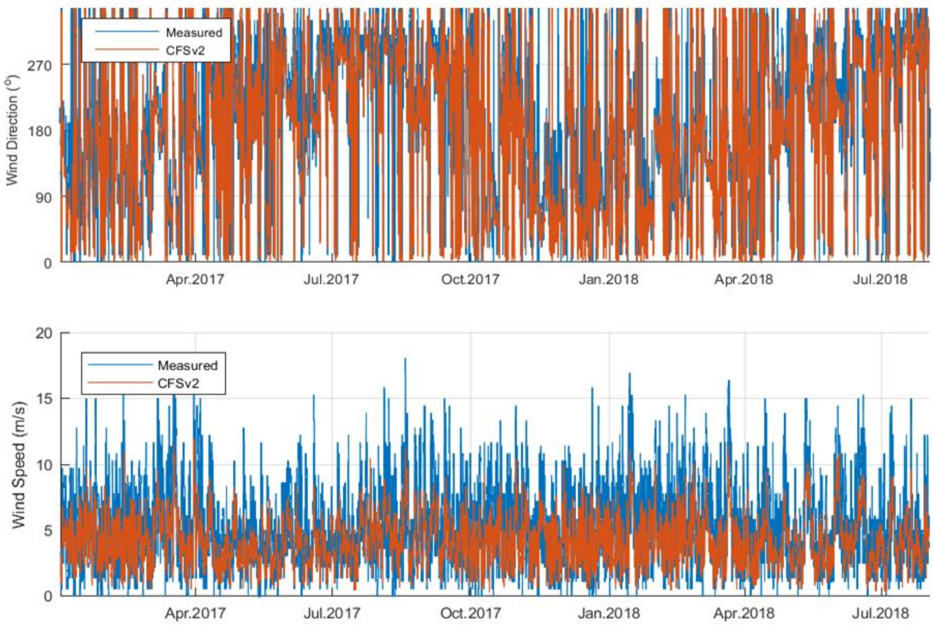


Figure 3-12 Comparison of BoM and CFSv2 wind speed and direction measurements in proximity to the BoM Nobby Head station

3.3.2 Other boundary conditions

Offshore

Hydrodynamic data was sourced from the global ocean circulation model HYCOM (Chassignet et al. 2007). A flatter open boundary condition was used to directly drive the model with HYCOM currents along the open boundaries.

The model domain was initialised with HYCOM temperature and salinity. Horizontally, vertically and temporally varying temperature and salinity data from HYCOM was applied at the open boundaries to maintain realistic temperature and salinity stratification within the model domain.

Tidal water level variations and depth-averaged current velocities from the Technical University of Denmark's DTU10 tidal model (Cheng and Andersen, 2010) were superimposed on the HYCOM water levels to include the effect of tides at the open boundaries.

Figure 3-13 illustrates a time series of vertical profiles of currents, temperatures and salinities from a representative location along the northern open boundary. Surface elevations are illustrated in Figure 3-14.

Hunter River

The Hunter River discharge, salinity and temperature model inputs are shown in Section 3.2.8.

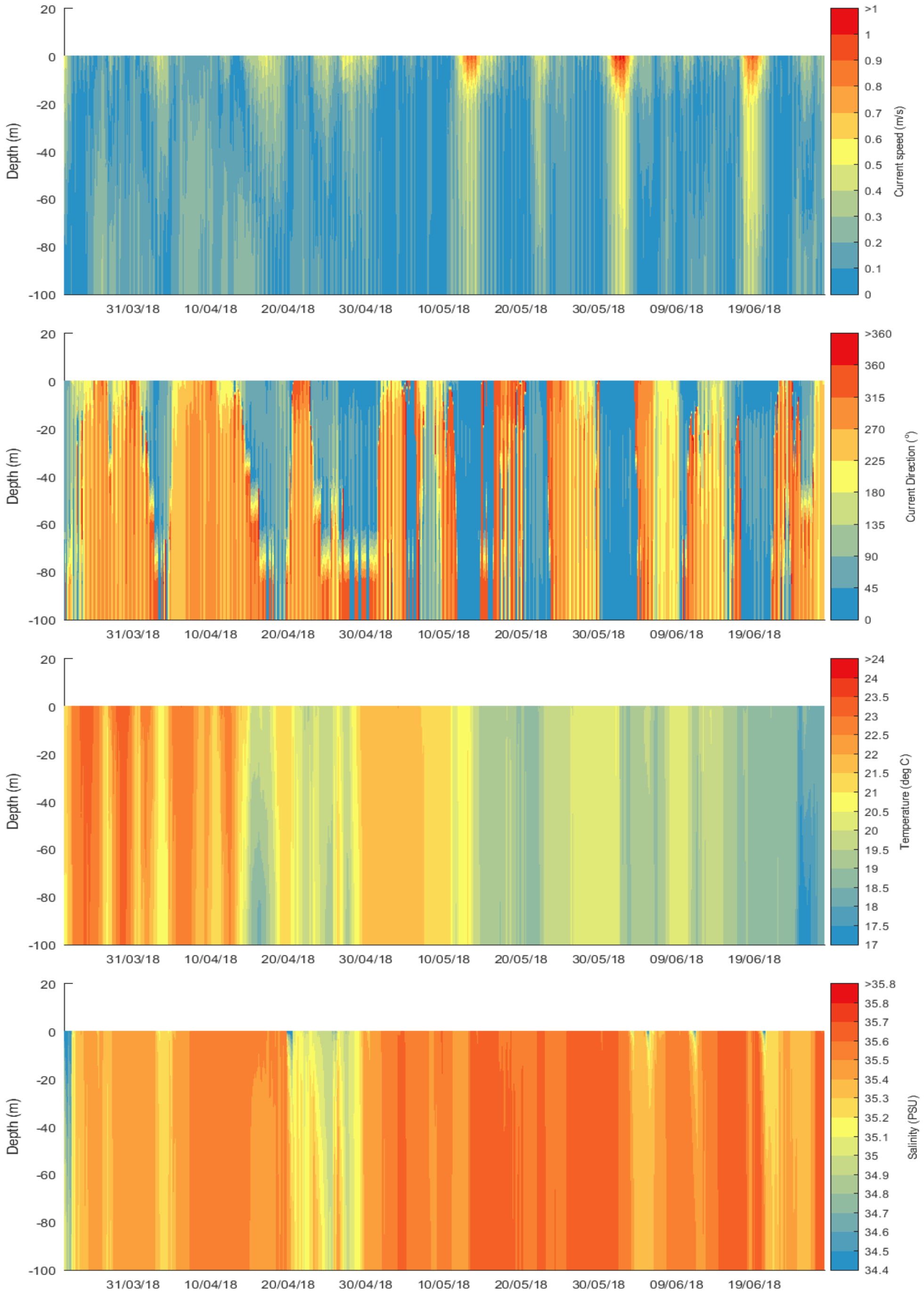


Figure 3-13 Representative vertical profiles at the northern offshore boundary of current speeds (top) and directions (upper middle), temperatures (lower middle) and salinities (bottom) with time

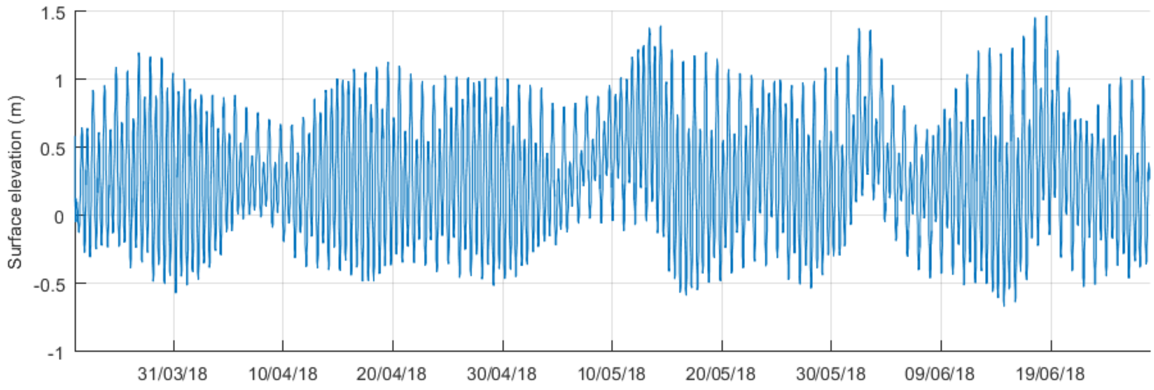


Figure 3-14 Surface elevations at a representative point on the northern offshore boundary with time

3.3.3 Diffuser configuration

The diffuser configuration is comprised of the original 1992 diffuser (Australian Water and Coastal Studies 1991) and a 2004 augmentation (Lawson and Treloar 2002) as summarised in Table 3-5. The original diffuser and the augmentation operate concurrently.

Table 3-5 Diffuser configuration

Specification	Original Diffuser (1992)	Diffuser Augmentation (2004)
Number of Ports	55	110
Diffuser Length (m)	121	61
Diameter (mm)	110	
Depth (m)	22	
Spacing (m)	2.2	0.55
Above Seabed (m)	2	1.8
Discharge Angle	Horizontal to Seabed	
Configuration	Adjacent nozzles discharge in opposing directions	

The diffuser was configured into the MIKE 3 FM hydrodynamic simulations with the Jirka (2004) plume integral model option, whereby the vertical position above the diffuser port grid location in which the plume is inserted is on the basis of one of the following criteria:

- If the plume is positively buoyant (e.g. lower salinity than ambient seawater) then inserted at level above the diffuser nozzle once the plume density is the same as ambient.
- If the plume is negatively buoyant (e.g. higher salinity than ambient seawater) then inserted at level below the diffuser nozzle once the plume density is the same as ambient.
- If the local jet axial velocity falls below 1% of the initial exit velocity then the plume is inserted at that level.
- If the plume reaches the water surface then the plume is inserted into the surface layer.
- If the plume reaches the bottom then the plume is inserted into the bottom layer.

The model grid cells at the diffuser have a length scale of ~30 m. Hence, the original and augmented portions of the diffuser have ~14 (55 nozzles over 121 m) and ~55 (110 nozzles over 61 m) diffuser nozzles per grid cell.

In order to reduce the modelling run times, the number of ports was reduced by a factor of ~7 yielding 2 ports per grid cell for the original diffuser in alternating directions, and 8 ports per grid cell for the augmented diffuser in alternating directions. The diameter of the nozzle increases from 0.11 m for the actual ports to 0.28 m for the simulated ports to maintain the same exit velocity of ~0.64 m/s for total characteristic outflow discharge of 1 m^3/s. Hence, the plume diameters are initially ~3 fold greater in the simulations than the actual configuration.

3.3.4 Conservative tracer

Discharges from the diffuser into the marine environment were tracked with an initial conservative tracer concentration of 1.0. A value of 0.0 was given to the Hunter River inputs and seawater inputs via the open boundaries. Further the model domain was initialised with a value of 0.0. The dilution of the outlet (diffuser) outflows with the ambient seawater was readily tracked on the basis of the simulated conservative tracer values of the diffuser discharge throughout the model domain. The simulated area of impact (or effect) was defined on a probabilistic basis in Section 4.4 where the required dilution factor satisfies the quantitative WQOs as defined in Section 4.1.

3.3.5 Scenario inputs of diffuser discharge, salinity and temperature for baseline treated effluent and comingled brine-treated effluent

Estimates of the discharge, salinity and temperature for the WWTW treated wastewater discharge and the Normal Full Operation (16.4 ML/day potable water supply) capacity of the TDP are provided in Table 3-6. Figure 3-15, Figure 3-16 and Figure 3-17 show the diffuser discharge, salinity and temperature, respectively, for the WWTW baseline and Normal Full Operation of the TDP, which serve as model inputs. For the Normal Full Operation scenarios, the treated effluent-brine mixture discharge, salinity and temperature was estimated on the basis of volume, mass and heat balances of the time varying (discharge, temperature) and constant (salinity) WWTW effluent values, and the average estimates of the TDP brine properties (discharge, temperature and salinity). The following observations are noted:

- The outlet (diffuser) discharge for the Normal Full Operation scenario is not substantially greater than the baseline WWTW effluent scenario with a relative increase of ~50%.
- However, the salinity does markedly increase whereby for the Normal Full Operation scenario, the treated wastewater-brine mixture salinity primarily ranges from 20 psu to 35-40 psu. Hence for this scenario both positively (outlet salinity <35 psu) and negatively (outlet salinity >35 psu) buoyant plumes are expected to occur when discharged into seawater (~35 psu).
- Estimated variations in the outlet (diffuser) water temperatures between the two scenarios are predicted to be minimal.

Table 3-6 Model inputs for diffuser discharge, salinity and temperature for baseline WWTW effluent and comingled effluent-brine scenarios

Parameter	Baseline WWTW Discharge	Comingled WWTW-Brine Discharge	Justification
Operating Hours (hrs/day)	24		Plant to operate continuously (GHD 2019).
Discharge (ML/day)	Figure 3-15 (black)	Figure 3-15 (red)	Brine discharge of 28.2 ML/day (Section 2.3.2) comingled with WWTW treated effluent (Section 3.2.1).
Discharge (m^3/s)			
Salinity (psu)	Figure 3-16 (black)	Figure 3-16 (red)	Brine salinity of 65 psu (Section 2.3.2) comingled with WWTW treated effluent median of 4.1 psu (Section 3.2.1).
Temperature (°C)	Figure 3-17 (black)	Figure 3-17 (red)	Characteristic GW source temperature is ~19°C (Section 3.2) comingled with WWTW treated effluent (Section 3.2.1).

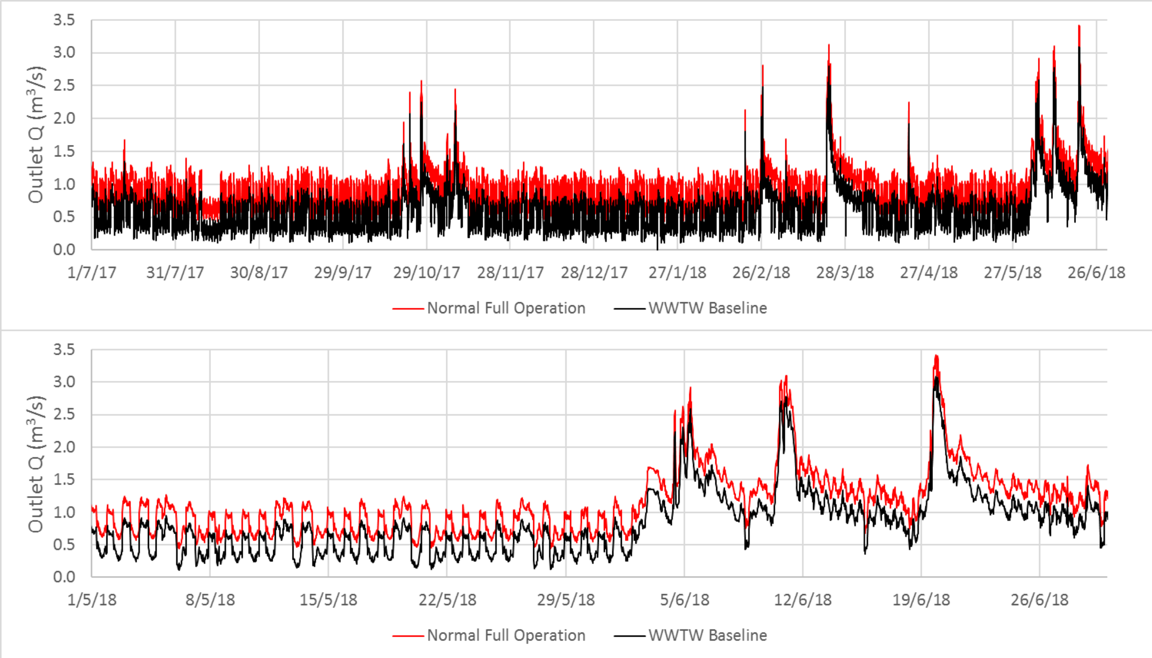


Figure 3-15 Baseline SCADA WWTW and estimated Normal Full Operation discharges (top), and zoom of both scenarios over the last 2 months (bottom)

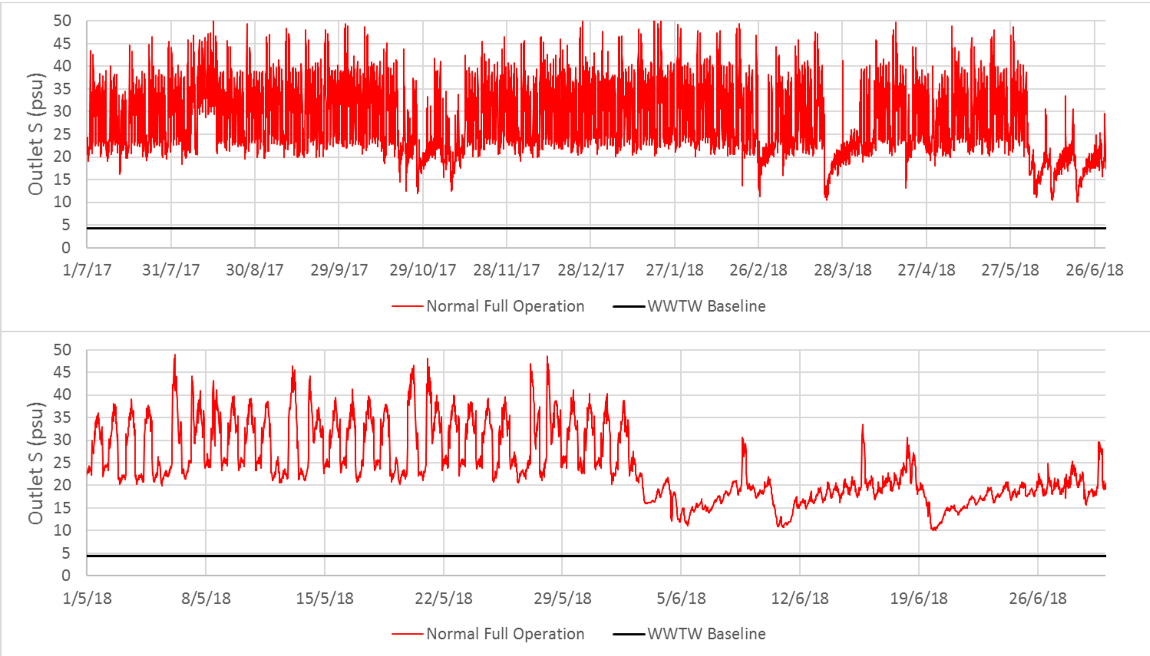


Figure 3-16 As Figure 3-15 for salinity

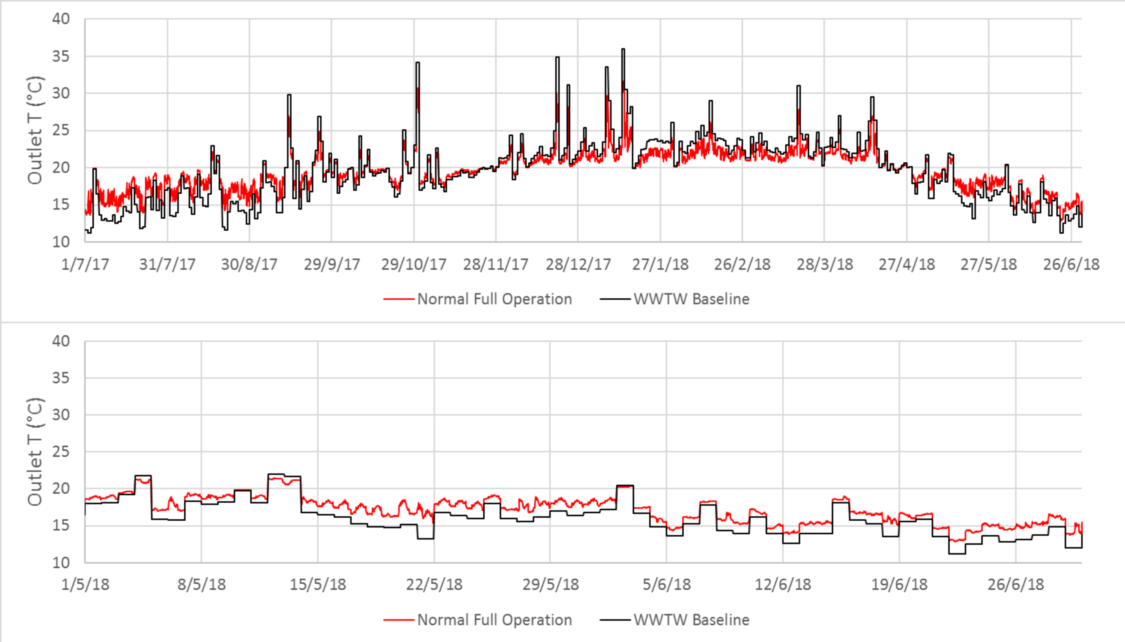


Figure 3-17 As Figure 3-16 for temperature

3.4 Model outputs

The model outputs are presented as temporal probability spatial contours of the dilution factors of the outlet (diffuser) discharges by the ambient seawater over the assessment periods (dry and wet weather effluent flows) for each of the two scenarios (existing effluent and proposed brine-effluent discharges) (Section 2.3.2). These simulated dilution factor contours are presented as the spatial extent in which the WQOs for human health, marine ecosystem and ambient salinity (see Section 4.1) are exceeded for 1%, 5%, 10%, 20% and 50% of the time. These are referred to as probability exceedance contours.

Marine toxicity impacts are negligible and require small dilution factors (~1) to meet the WQOs (see Section 4.1) that are readily met via near-field mixing in the immediate vicinity of the diffuser (see Section 4.2). Therefore no 3D modelling outputs are provided for the marine toxicity WQO as it is satisfied within metres of the diffuser.

4. Results

4.1 Estimation of WQO dilution factors

Dilution factors to meet the WQOs were estimated as per the methodology in Section 2.1 with a summary in Table 4-2 for the baseline effluent and proposed effluent-brine scenarios for the dry and wet weather periods. The dilution factors for each of the WQOs were estimated from:

- C_A (median ambient seawater concentrations), marine ecosystem SSTVs, marine toxicity MTTVs and the human health RPCGV were the same for both scenarios.
- The 20th and 90th percentile WWTW effluent concentrations were utilised for C_O (outlet concentrations) for the wet and dry weather periods, respectively, for the baseline scenario (refer to Sections 1.4 and 2.1.1).
- A mass balance was used to estimate C_O for the proposed effluent-brine scenario as the 20th and 90th percentile WWTW effluent concentrations for the wet and dry weather periods, respectively (Section 3.2.2), design brine quality concentrations (Section 3.2.3) and average brine discharge (Section 2.3.2). Additionally, the average WWTW effluent discharge (Section 3.2.1) over the wet and dry weather periods was used.
- Salinity estimates of the proposed effluent-brine outlet discharge (C_O) were 27.2 psu and 16.9 psu for the dry and wet weather periods, respectively. These salinities are lower than ambient seawater (35 psu), and thereby result in positively buoyant plumes. In order to evaluate the area of impact (or effect) near the seabed for negatively buoyant (sinking) plumes of the proposed effluent-brine discharge when C_O greater than ambient seawater (35 psu), a representative dilution factor of 14 was estimated for the maximum salinity of 48.7 psu (Section 3.3.5).

The dilution factors from Table 4-2 to meet the marine ecosystem, marine toxicity, ambient salinity (for C_O<35 psu and C_O>35 psu) and human health WQOs for both the baseline and proposal scenarios during wet and dry weather periods are summarised in Table 4-1. The dilution factors for each WQO use the same analyte across the baseline and proposal scenarios[9]. Generally, the addition of brine to the WWTW effluent reduces the WQO dilution factors due to lower brine concentrations (pre-dilution) and increased salinity (outflow salinities thereby closer to ambient marine waters) relative to the baseline case. These dilution factors are presented as probability exceedance percentiles in Section 4.4 as described in Section 3.4.

Table 4-1 Dilution factors to define area of impact (or effect) for human health, marine toxicity, marine ecosystem and ambient salinity WQOs. WQ analyte used to define dilution factor also noted

WQO	Analyte	Dry Weather Baseline Dilution Factor	Dry Weather Proposal Dilution Factor	Wet Weather Baseline Dilution Factor	Wet Weather Proposal Dilution Factor
Human Health	Enterococci	47	29	22	18
Marine Toxicity	NH_X	0.8	0.7	0.0	0.1
Marine Ecosystem	NO_X	234	203	142	144
Ambient Salinity (Above Seabed $S_{Diffuser}$<35 psu)	ΔS	31	8	31	18
Ambient Salinity (On Seabed $S_{Diffuser}$>35 psu)	ΔS	NA	14	NA	NA

[9] Dilution factors for metals and metalloids (Cu, Pb, Zn) and some nutrient analytes (TN, TP) can only be estimated for the baseline scenario, but not the proposal scenario due to a lack of brine WQ estimates. In order to standardise the comparative analysis of the spatial area of impact (or effect) for both scenarios, the same analyte was used to estimate the dilution factor for each WQO.

Table 4-2 Dilution factors for baseline and TDP Normal Full Operation scenarios to meet marine ecosystem, marine toxicity, marine salinity and human health WQOs

Parameter	NH_X	NO_X	TN	TP	E	Cu	Pb	Zn	ΔS	TSS	References and Comments
C_A: Ambient (mg/L, cfu/100 ml, psu)	0.0025	0.005	0.121	0.005	0.5	0.0005	0.0001	0.0025	35	0.5	Section 3.2.4, median of reference sites
Q_B: Brine Discharge (m^3/s)					0.326						Section 2.3.2, average discharge
C_B: Brine (mg/L, cfu/100 ml, psu)	0.44	6.7	ND[10]	ND	0[11]	ND	ND	ND	65	0[12]	Sections 3.2.3 and 3.3.1, estimates
C_V: Marine Ecosystem SSTV (mg/L)	0.009	0.049	0.334	0.012						2.7	
C_V: Marine Toxicity MMTV (mg/L)	0.91					0.0013	0.0044	0.015			
C_V: Human Health RPCGV (cfu/100 ml)					35						Section 2.1.1
C_V: Ambient Salinity (psu)									1		
Dry Weather Baseline Scenario (WWTW Effluent) – Low Effluent Discharge											
C_O: Effluent (mg/L, cfu/100 ml, psu)	0.76	10.4	13.3	3.5	1,622	0.0040	0.0006	0.0572	4.3	21	Section 3.2.2, 90th percentile except for median salinity
Marine Ecosystem Dilution Factor	116	234	62	485						9.3	
Marine Toxicity Dilution Factor	0.8					4.3	0.1	4.4			Calculated as per equation in Section 2.1
Human Health Dilution Factor					47.0						
Ambient Salinity Dilution Factor									30.7		
Dry Weather Normal Full Operation Scenario (Comingled WWTW Effluent and TDP Brine) – Low WWTW Effluent Discharge											
Q_W: WWTW Discharge (m^3/s)					0.54						Section 3.2.1, average discharge over dry weather period
C_O: Effluent-Brine (mg/L, cfu/100 ml, psu)	0.64	9.0	NE[13]	NE	1,011	NE	NE	NE	27.2	13.1	$C_O=(Q_B x C_B+Q_W x C_W)/(Q_B+Q_W)$
Marine Ecosystem Dilution Factor	98	203	NE	NE						5.7	
Marine Toxicity Dilution Factor	0.7					NA	NA	NA			Calculated as per Section 2.1
Human Health Dilution Factor					29.3						
Ambient Salinity Dilution Factor									7.8		
Wet Weather Baseline Scenario (WWTW Effluent) – High WWTW Effluent Discharge											
C_O: Effluent (mg/L, cfu/100 ml, psu)	0.02	6.3	7.8	1.9	761	0.0012	0.0001	0.0276	4.3	5	Section 3.2.2, 20th percentile except for median salinity
Marine Ecosystem Dilution Factor	3	142	36	263						2	
Marine Toxicity Dilution Factor	0.0					0.9	0.0	2.0			Calculated as per equation in Section 2.1
Human Health Dilution Factor					22.0						
Ambient Salinity Dilution Factor									30.7		
Wet Weather Normal Full Operation Scenario (Comingled WWTW Effluent-Brine and TDP Brine) – High WWTW Effluent Discharge											
Q_W: WWTW Discharge (m^3/s)					1.25						Section 3.2.1, average discharge over wet weather period
C_O: Effluent-Brine (mg/L, cfu/100 ml, psu)	0.11	6.4	NE	NE	604	NE	NE	NE	16.9	4.0	$C_O=(Q_B x C_B+Q_W x C_W)/(Q_B+Q_W)$
Marine Ecosystem Dilution Factor	16	144	NE	NE						1.6	
Marine Toxicity Dilution Factor	0.1					NA	NA	NA			Calculated as per Section 2.1
Human Health Dilution Factor					17.5						
Ambient Salinity Dilution Factor									18.1		

Light orange shading identifies maximum dilution factors that are reported in Table 4-1.

Light yellow shading is the highest dilution factor, but not used as only estimate for the existing WWTW effluent case and not for the proposed WWTW-TDP comingled cases.

[10] No data.

[11] Assume desalination process removes all pathogens.

[12] Assume desalination process removes all TSS.

[13] No estimate.

4.2 Near-field modelling

Near-field modelling as described in Section 2.2 was carried out to confirm that the existing diffuser arrangement can accommodate the additional brine discharge from operation of the TDP for the Normal Full Operation brine discharge of 28.2 ML/day. To compare the near-field mixing performance of the baseline effluent and proposed comingled effluent-brine discharges, UM3 simulations were configured with the following inputs:

- The original and augmented diffuser segments were modelled with specifications in Table 4-3.
- The 90th (high discharge) and 10th percentile (low discharge) effluent discharges served as inputs as summarised in Table 4-3.[14]
- Characteristic temperatures, salinities and currents of the receiving marine waters were based on measurements as summarised in Table 4-4.

Table 4-3 Diffuser and outlet discharge inputs for near-field modelling

Parameter	Original Diffuser (1992)	Diffuser Augmentation (2004)	Justification
Number of Ports	55	110	Table 3-5
Port Diameter (m)	0.11		Table 3-5
Port Depth (m)	22		Table 3-5
Port Spacing (m)	2.2	0.55	Table 3-5
Port Opening Vertical Angle relative to Horizontal	0°		Table 3-5
Port Opening Horizontal Angle	0°		Currents dominated by north-south component (Section 3.2.6). Assume all ports oriented to north. UM3 cannot simulate alternating port opening directions of existing diffuser. All port openings in same direction as currents to predict worst case.
% of Total Outlet Discharge	33.3%	66.7%	Total outlet diffuser flow for the two diffuser segments proportional to the number of ports
High WWTW Baseline Flow (m^3/s)	0.321	0.643	90th (high) and 10th (low) percentiles of WWTW outlet (diffuser) discharge measurements (Section 3.2.1)
Low WWTW Baseline Flow (m^3/s)	0.087	0.175	
TDP Brine with HIGH WWTW Baseline Flow (m^3/s)	0.430	0.860	90th (high) and 10th (low) percentiles of estimated WWTW-brine mixture discharge for TDP brine discharge of 28.2 ML/day (potable water supply of 16.4 ML/day) (Section 3.3.5)
TDP Brine with LOW WWTW Baseline Flow (m^3/s)	0.196	0.392	
All Outflow Temperatures (°C)	20		Representative 19 °C with 1°C heating through TDP. Salinity has much greater effect on plume density.
WWTW Baseline S (psu)	4.3		Median salinity of WWTW (Section 3.2.1)

[14] Note that the 3D hydrodynamic simulations use temporally varying temperatures, salinities and discharge of outlet waters.

Parameter	Original Diffuser (1992)	Diffuser Augmentation (2004)	Justification
High Salinity at TDP Brine with LOW WWTW Baseline Flow (psu)	38.0		90th (high) and 10th (low) percentiles of estimated WWTW effluent-TDP brine mixture salinity for TDP brine discharge of 28.2 ML/day (potable water supply of 16.4 ML/day) (Section 3.3.5)
Low Salinity at TDP Brine with HIGH WWTW Baseline Flow (psu)	19.7		

Table 4-4 Marine environment inputs for near-field modelling

Parameter	High Currents	Low Currents	Justification
Near-Surface Current Speed (m/s)	0.304	0.050	90th (high) and 10th (low) percentiles of ADCP current speeds (Section 3.2.6).
Mid-Depth Current Speed (m/s)	0.155	0.029	
Near-Seabed Current Speed (m/s)	0.099	0.016	
Current Direction	0°		Alignment with port openings simulated. Worst case in terms of mixing.
Seawater Temperature (°C)	20		Representative value and same as outlet (diffuser) to focus on effect of salinity (Section 3.2.5).
Seawater Salinity (psu)	35		Representative value (Section 3.2.5).

The exit velocities from the port nozzles are very low for the 90th (0.61 m/s and 0.78 m/s for the baseline and proposed scenarios, respectively) and 10th (0.17 m/s and 0.35 m/s for the baseline and proposed scenarios, respectively) percentile outlet discharges. Hence, the diffusers have been designed primarily to rely on positive buoyancy plume mixing (i.e. rising plumes), and not jet-induced mixing (i.e. typically exit velocities of ~5 m/s yield effective jet-induced mixing). Given the median effluent salinity of 4.3 psu relative to the seawater salinity of ~35 psu, this is an effective mechanism for the baseline case. Next, UM3 near-field modelling of the baseline effluent and proposed effluent-brine outflows from the original and augmented diffuser sections are described in Figure 4-1 and Figure 4-2 for low and high current speeds, respectively.

4.2.1 Baseline effluent simulations

UM3 simulations of the original diffuser segment have substantially greater near-field dilution than the augmented section. This is illustrated by the existing baseline WWTW case where:

- For low ambient current speeds the average plume dilution of the:
  - Low effluent discharge (10th percentile, Figure 4-1 upper left) decreases from 970 to 325-fold for the original and augmented diffuser sections, respectively.
  - High effluent discharge (90th percentile, Figure 4-1 upper right) decreases from 340 to 120-fold for the original and augmented diffuser sections, respectively.
- For high ambient currents the average plume dilution of the:
  - Low effluent discharge (10th percentile, Figure 4-2 upper left) decreases from 3,900 to 1,000-fold for the original and augmented diffuser sections, respectively.
  - High effluent discharge (90th percentile, Figure 4-2 upper right) decreases from 1,075 to 300-fold for the original and augmented diffuser sections, respectively.

The primary mechanism for the decreased dilution of the augmented diffuser section (0.55 m spacing between ports) relative to the original diffuser (2.2 m spacing between ports) is due to the spacing between adjacent ports. The shorter spacing between adjacent ports along the augmented diffuser section results in merging of adjacent plumes more rapidly than the original diffuser, thereby decreasing dilution efficiency. One measure to improve the near-field dilution of the augmented diffuser section is to cap ports. For example, if four adjacent ports were capped with every fifth port remaining uncapped, then an equivalent port spacing of 2.2 m as the original diffuser would result with improved near-field dilution.

These baseline near-field modelling cases also demonstrate that dilution increases with higher ambient current speeds. This is caused by the interaction between shear mixing (mixing caused by the currents of the ambient marine waters) and buoyancy driven mixing (mixing induced as the plume of lower density rises through the ambient waters).

These baseline near-field modelling cases also demonstrate that lower outlet discharges (e.g. 10^{th} percentile) yield greater dilution than higher effluent flow rates (e.g. 90^{th} percentile). Smaller plume diameters from lower discharge rates have greater entrainment efficiency of ambient waters into the plume than larger plume diameters of higher flow rates.

4.2.2 Proposed effluent-brine simulations

High WWTW discharge

The comingled effluent-brine during high WWTW effluent discharge (90^{th} percentile) yields a characteristic salinity of 19.7 psu. This salinity is lower than ambient marine waters (35 psu) so the same mechanism of buoyancy driven mixing (i.e. plume rising through the ambient waters) occurs as the baseline effluent case (i.e. characteristic salinity of 4.8 psu) (Section 4.2.1). However, the proposed brine-effluent discharge will have lower near-field dilution than the baseline effluent case due to less vigorous buoyancy driven mixing due to its higher salinity. This is illustrated in the UM3 near-field modelling results whereby for:

- Low ambient currents (Figure 4-1 lower right) the average plume dilution of 245 and 85-fold of the proposed comingled discharge for the original and augmented diffuser sections, respectively, are lower than the baseline effluent case of 340 and 120-fold for the original and augmented diffuser sections (Figure 4-1 upper right), respectively.
- High ambient currents (Figure 4-2 lower right) the average plume dilution of 810 and 220-fold of the proposed comingled discharge for the original and augmented diffuser sections, respectively, are lower than the baseline effluent case of 1,075 and 300-fold for the original and augmented diffuser sections (Figure 4-1 upper right), respectively.

Though dilution is lower for the proposed effluent-brine case than the baseline effluent case due to the combination of less buoyancy-driven mixing (due to higher salinity), a high degree of near-field dilution is predicted nonetheless.

Low WWTW discharge

In contrast, the proposed effluent-brine during low WWTW effluent discharge (10^{th} percentile) yields a characteristic salinity of 38.0 psu, which is greater than the ambient marine waters (35 psu). Under these conditions, a negatively buoyant plume occurs that falls to the seabed with low near-field dilution. This is illustrated by the UM3 near-field modelling during:

- Low ambient currents (Figure 4-1 lower left panel) where the falling plume intersects the seabed within several meters of the diffuser the average plume dilution is only 14 and 21-fold for the proposed comingled discharge for the original and augmented diffuser sections, respectively.

- High ambient currents (Figure 4-2 lower left panel) where the falling plume intersects the seabed within ~5 m of the diffuser the average plume dilution is only 31 and 45-fold for the proposed comingled discharge for the original and augmented diffuser sections, respectively.

Clearly, near-field dilution of this negatively buoyant plume case is markedly lower than any of the rising buoyant plumes previously evaluated. This is due to the short vertical distance (~1-2 m) over which buoyancy driven mixing of the falling plume occurs prior to intersecting the seabed.

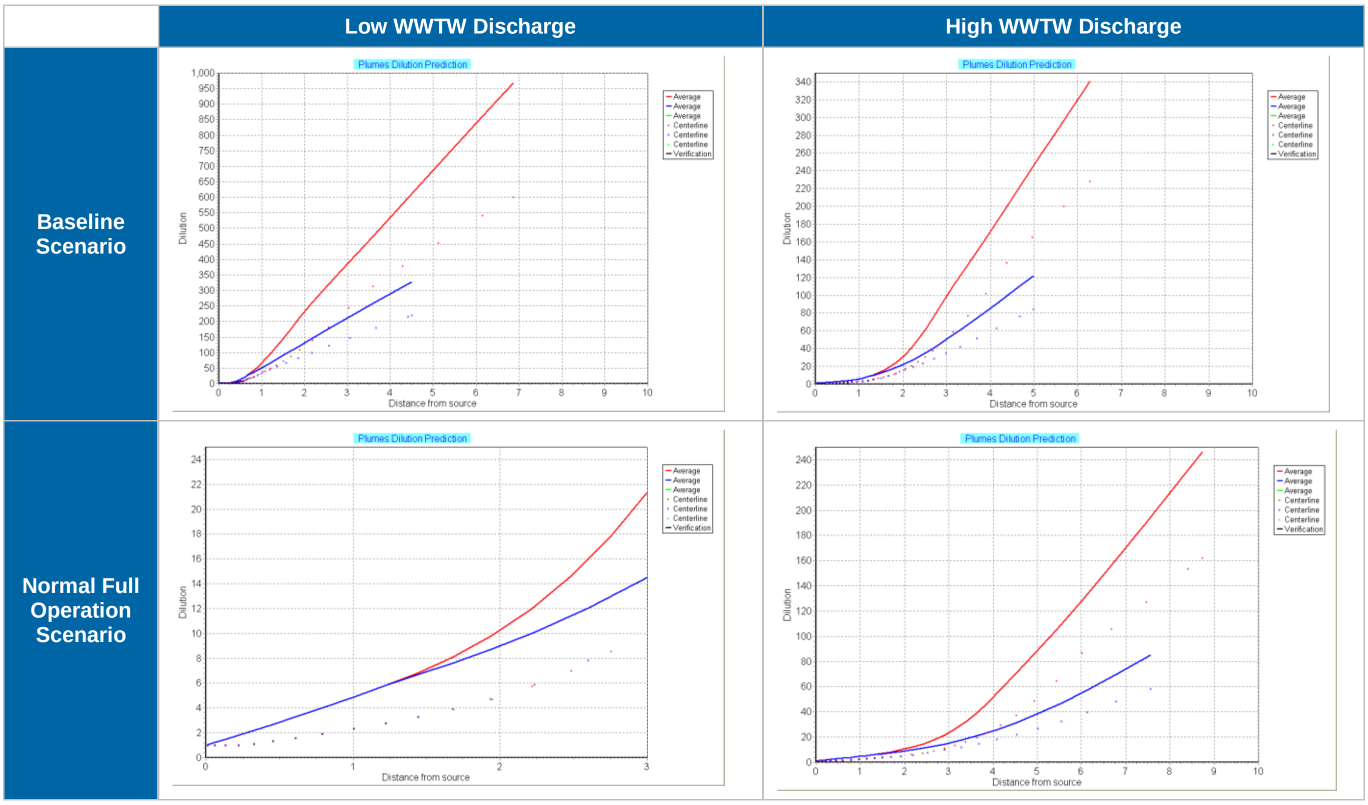


Figure 4-1 UM3 near-field dilutions for low ambient marine current speeds for the 1992 original (red) and 2004 augmented diffuser (blue) ports

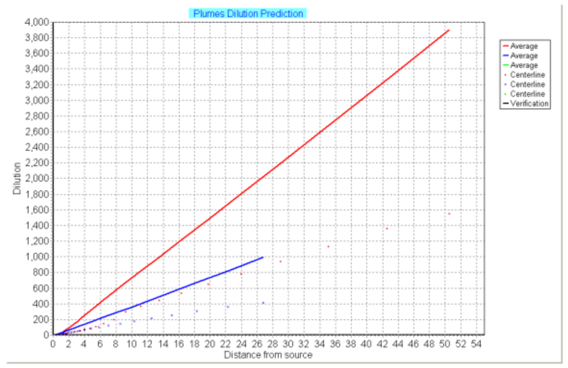
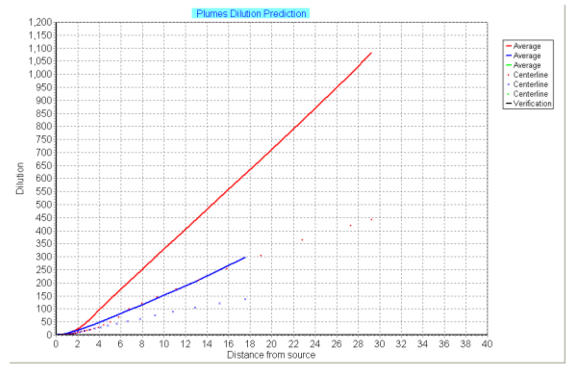
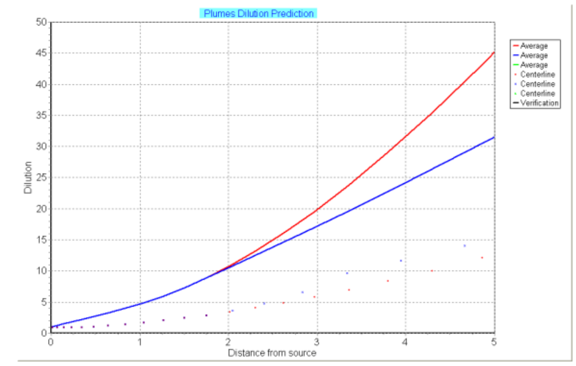
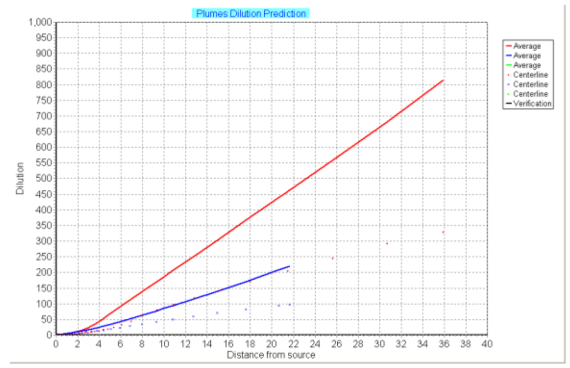
	Low WWTW Discharge	High WWTW Discharge
Baseline Scenario		
Normal Full Operation Scenario		

Figure 4-2 As Figure 4-1 for high ambient current marine speeds

4.2.3 Near-field dilution capacity analysis

The near-field dilution capacity of the existing baseline effluent and proposed effluent-brine scenarios with the 90th percentile WWTW discharges for low (10th percentile) and high (90th percentile) current speeds are shown in Table 4-5. A lower limit of the dilution capacity during low current speeds (10th percentile) and upper diffuser discharge (90th percentile) for the baseline effluent and proposed effluent-brine scenarios yields estimates of 145 and 108-fold, respectively. The dilution capacity of the ambient waters increase to 847 and 633-fold for the existing baseline effluent and proposed effluent-brine scenarios, respectively, for high (90th percentile) current speeds.

In short, the lower range of dilution capacity of the ambient marine waters during low currents (10th percentile) of ~100 fold is similar to the predicted dilution from buoyancy driven mixing by the near-field model (Section 4.2) for the augmented portion of the diffuser during high WWTW discharge (90th percentile), whereby:

- The baseline effluent case is simulated to have 340 and 120-fold dilution for the original and augmented diffuser segments, respectively.
- The proposed effluent-brine case is simulated to have 245 and 85-fold for the original and augmented diffuser cases, respectively.

In short, this dilution capacity assessment indicates that the upper physical limit of near-field dilution is ~100-150 and ~600-850 during low (10th percentile) and high (90th percentile) current speeds at the diffuser site as bounded by the depth, length of the diffuser and the current speeds.

Table 4-5 Dilution capacity assessment

Parameter	High Currents 90th Percentile	Low Currents 10th Percentile	Justification
Average Current Speed (m/s)	0.186	0.032	
Plume Width (m)	200		Table 3-5
Water Depth (m)	22		Table 3-5
90th Percentile Baseline Scenario Flow (m/s)	0.964		Table 4-3
Baseline Scenario Dilution Factor	847	145	
90th Percentile Normal Full Operation Scenario Flow (m/s)	1.291		Table 4-3
Normal Full Operation Scenario Dilution Factor	633	108	

4.3 Calibration and validation of 3D model

4.3.1 Model calibration

Calibration of the simulated currents from 21 February-24 March 2018 with the ADCP measurements at the Belmont monitoring site are illustrated for the north-south currents (v velocity) and east-west components (u-velocity) in Figure 4-3. Generally, the simulated currents compare well with measurements whereby:

- The simulated and measured u-velocities (~-0.1 m/s (west) to ~0.1 m/s (east)) are generally lower than the v-velocities (~-0.2 m/s (south) to ~0.2 m/s (north)).
- The simulated velocities matched reasonably well with the measurements throughout the water column and generally captured the multi-day periodicities of the dataset.

The MAE and IOA quantitative indices of model performance for the u- and v- velocities are shown in Table 4-6, which indicate good model performance for near surface and mid-depth v-velocities, and mid-depth and near seabed u-velocities (IOA>0.6) and satisfactory performance for near surface u-velocities and near seabed v-velocities (IOA>0.5).

Table 4-6 Model performance indices of the calibration period

Model Performance Statistic	Near Surface u	Near Surface v	Mid-Depth u	Mid-Depth v	Near Seabed u	Near Seabed v
MAE	0.05	0.08	0.05	0.07	0.06	0.05
IOA	0.55	0.73	0.68	0.72	0.60	0.54

4.3.2 Model validation

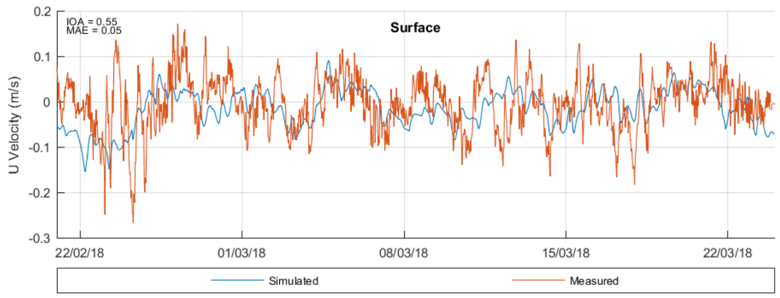
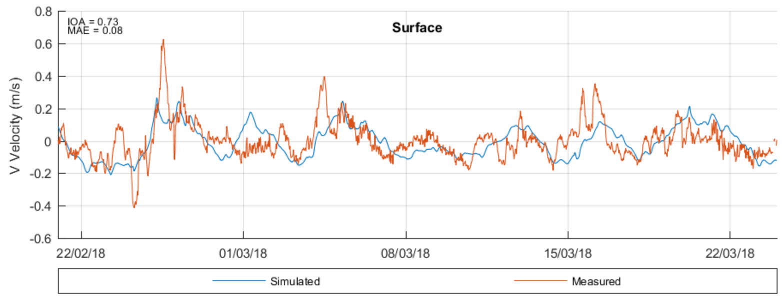
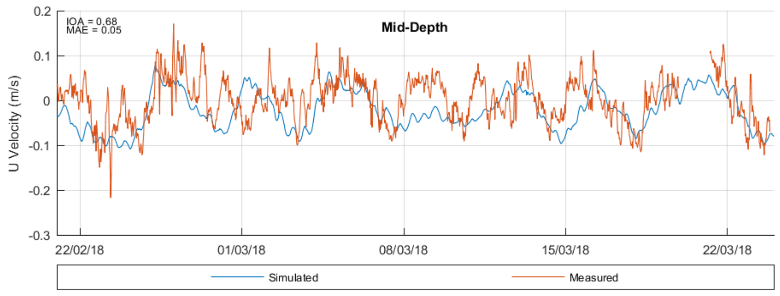
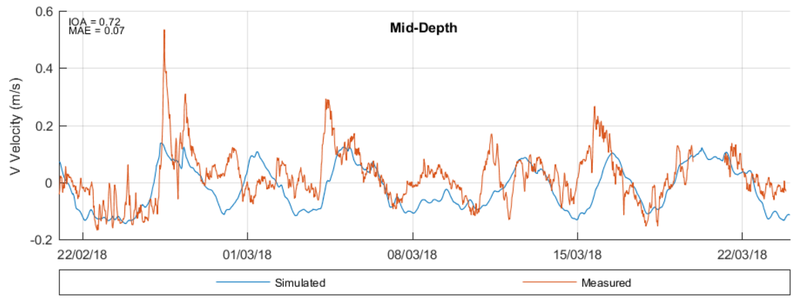
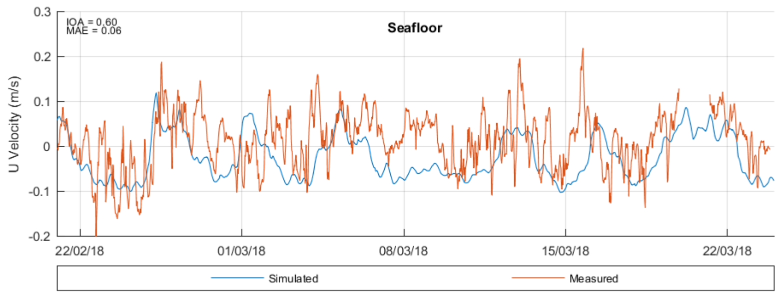
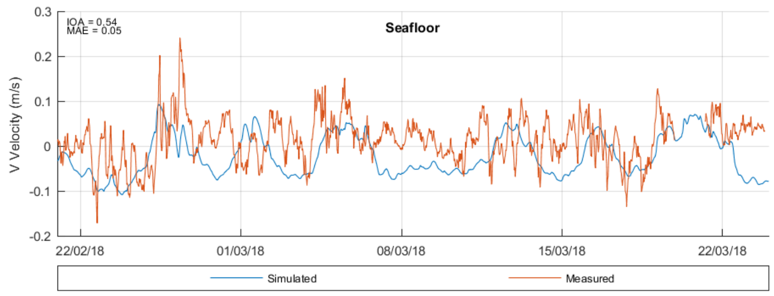
Validation of the simulated currents from 24 April-27 June 2018 with the ADCP measurements at the Belmont monitoring site are illustrated for the north-south currents (v velocity) and east-west components (u-velocity) in Figure 4-4. Similar to the model calibration period, generally the simulated currents compared well with measurements whereby:

- The simulated and measured u-velocities (~-0.1 m/s (west) to ~0.1 m/s (east)) are generally lower than the v-velocities (~-0.2 m/s (south) to ~0.2 m/s (north)).
- The simulated velocities matched reasonably well with the measurements throughout the water column and generally captured the multi-day periodicities of the dataset.

The MAE and IOA quantitative indices of model performance for the u- and v- velocities are shown in Figure 4-2, which indicate good model performance for near surface, mid-depth and near seabed v-velocities, and near surface and mid-depth u-velocities (IOA>0.6), and satisfactory performance for near seabed u-velocities (IOA>0.5).

Table 4-7 Model performance indices of the validation period

Model Performance Statistic	Near Surface u	Near Surface v	Mid-Depth u	Mid-Depth v	Near Seabed u	Near Seabed v
MAE	0.05	0.07	0.04	0.06	0.05	0.04
IOA	0.63	0.71	0.66	0.68	0.59	0.6

<table>
<tr><th></th><th>u-Velocity</th><th>v-Velocity</th></tr>
<tr><td>Near-Surface (20 m above seabed)</td><td>
</td><td>
</td></tr>
<tr><td>Mid-Depth (12 m above seabed)</td><td>
</td><td>
</td></tr>
<tr><td>Seabed (2 m above seabed)</td><td>
</td><td>
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</table>

Figure 4-3 Comparison of simulated and measured u- and v- velocities at the near surface, mid-depth and near seabed over the model calibration period

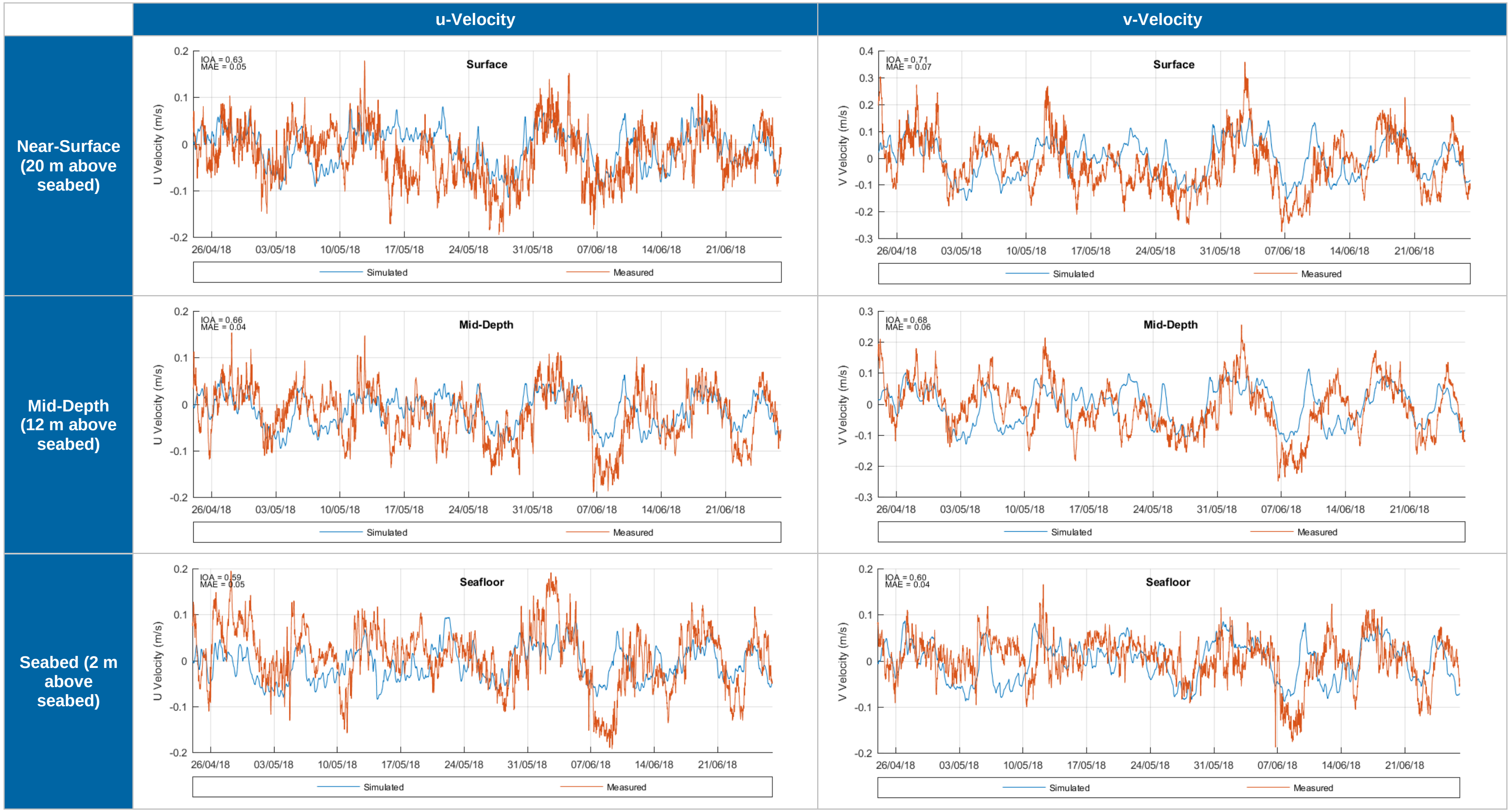

Figure 4-4 As Figure 4-3 over the model validation period

4.4 3D modelling scenarios

4.4.1 Dry weather case (21 April-18 May 2018)

The 4 week duration of the representative dry weather period from 21 April to 18 May 2018 spans two neap-spring tidal cycles. The spatial extent of impacts (or effects) on the basis of the assessment dilution factors for the ambient salinity, human health and ecosystem productivity WQOs in Table 4-1 (refer to Section 4.1) are presented as probability exceedance contours in Figure 4-5 (refer to Section 3.4).

Human Health WQO

The dilution factor of 47 for the human health WQO of the baseline scenario occurs within ~300 m of the augmented diffuser segment for 95% of the time (5^{th} percentile probability exceedance contour, upper left panel Figure 4-5). The area of impact (or effect) is approximately the same for the proposed effluent-brine discharge for the dilution factor of 29 (upper right panel Figure 4-5) as the existing baseline.

Generally, the human health WQO is predicted to be achieved closer in proximity to the longer (121 m) original diffuser segment (~2 m spacing between 55 ports), which has greater dilution efficiency than the shorter (61 m) augmented diffuser segment (~0.5 m spacing between 110 ports) in agreement with the near-field modelling in Section 4.2.

Ambient Salinity WQO

The dilution factor of 31 for the ambient salinity WQO for the baseline scenario is within ~100 m of the diffuser for 95% of the time (5^{th} percentile probability exceedance contour) (middle left panel Figure 4-5). A smaller area of impact (or effect) of the proposed effluent-brine scenarios is predicted due to the considerably lower dilution factor of 8 (middle right panel of Figure 4-5) than the baseline scenarios. Similar to the human health WQO, the ambient salinity WQO is achieved at least 95% of the time (5^{th} percentile probability exceedance contour) in the immediate vicinity of the diffuser.

Figure 4-6 illustrates the probability exceedance contours for a dilution factor of 45 in the three layers above the seabed. A dilution factor of 14 for the maximum salinity of the proposed effluent brine discharge scenario occurs in the immediate vicinity of the diffuser. For illustrative purpose, the dilution factor of 45 (nearly 3 fold greater than dilution factor of 14) occurs within ~50 m of the diffuser for 99.9% of the time (0.1% probability exceedance curve) over the representative dry weather period.

Marine Ecosystem WQO

The baseline and proposed scenarios are predicted to have similar sized areas of effect for the marine ecosystem WQO during the representative dry weather period. The dilution factor of 234 for the marine ecosystem WQO for the baseline effluent scenario predicts a spatial extent of the 5^{th} percentile probability exceedance contour from ~1.2 km (north) to ~500 m (south) (lower left panel Figure 4-5). The higher discharge of the proposed scenario relative to the baseline scenario is offset by its lower dilution factor (203) due to pre-dilution of the high WWTW effluent concentrations by the TDP brine.

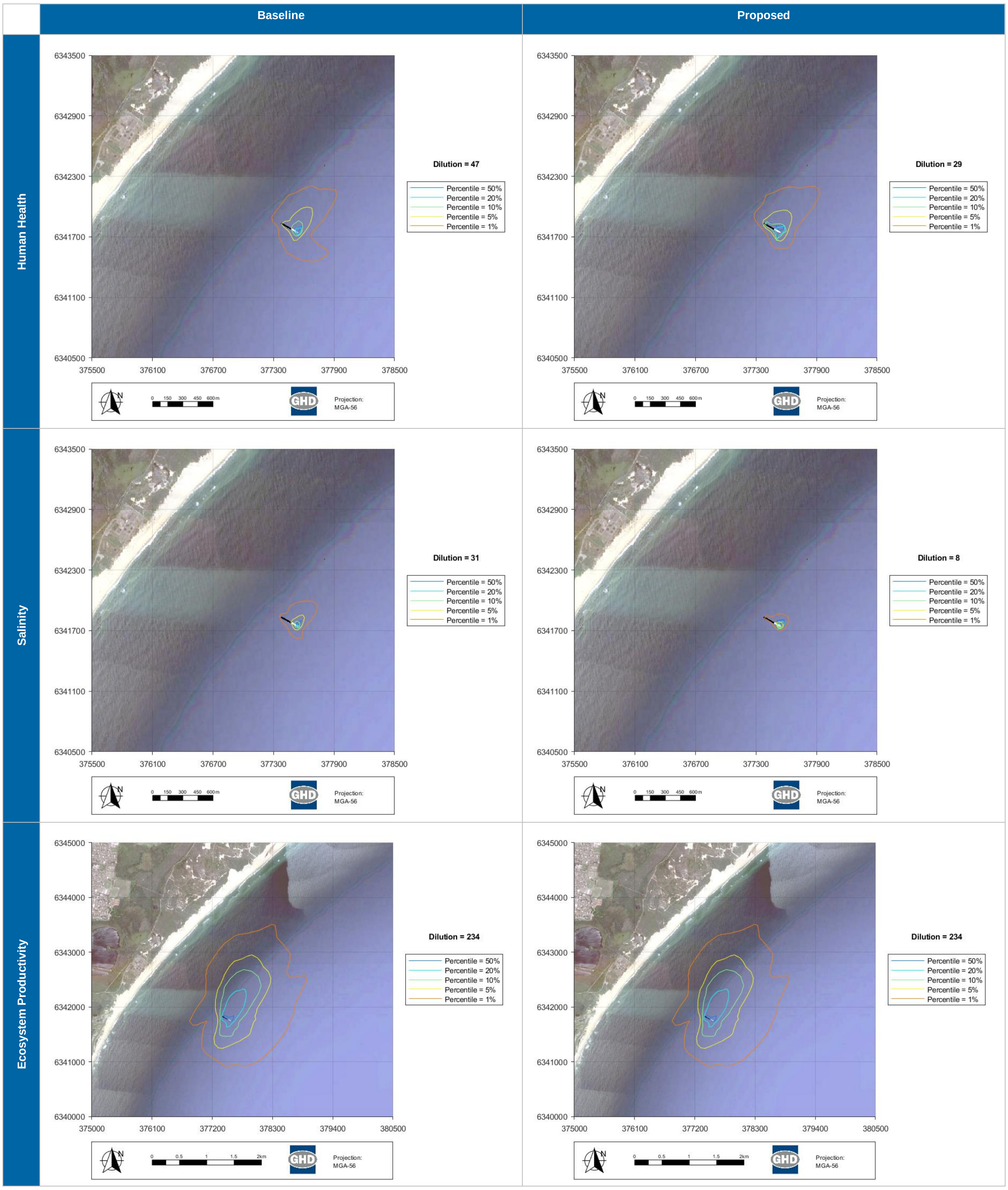

Figure 4-5 1%, 5%, 10%, 20% and 50% percentile probability exceedance contours of the WQO dilution factors during the dry weather period (21 April-18 May 2018) for the baseline (left) and proposed (right) cases for human health (top), ambient salinity (middle) and marine ecosystem (bottom)

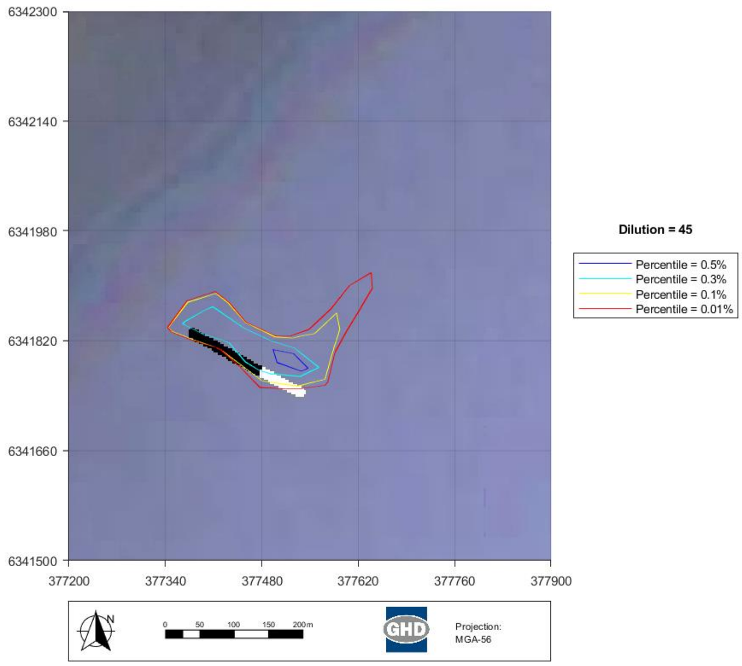

Figure 4-6 The 0.01%, 0.1%, 0.3% and 0.5% percentile probability exceedance curves for a dilution factor of 14 for the three model layers above the seabed

4.4.2 Wet weather case (2-29 June 2018)

The 4 week duration of the representative wet weather period from 2-29 June 2018 spanned two neap-spring tidal cycles. The spatial extent of impacts (or effects) on the basis of the assessment dilution factors for the ambient salinity, human health and marine ecosystem WQOs in Table 4-1 (refer to Section 4.1) are presented as percentile contours in Figure 4-7 (refer to Section 3.4).

Human Health WQO

As with the dry weather baseline case (Section 4.4.1), the dilution factor of 22 for the human health WQO of the baseline scenario is achieved within ~500 m of the diffuser segment for 95% of the time (5^{th} percentile probability exceedance contour, upper left panel Figure 4-7). The area of impact (or effect) increases marginally for the proposed effluent-brine scenario during the wet weather period for a dilution factor of 18 (upper right panel Figure 4-7) relative to the baseline.

The spatial extent of the predicted impact (or effect) areas for the human health WQO during wet weather WWTW discharge conditions are substantially greater than those for the respective dry weather cases. However, the predicted impact (or effect) areas are similar over the two seasons between the baseline and proposed future scenarios.

Ambient Salinity WQO

The ambient salinity WQO for the baseline scenario is predicted to be met within ~500 of the diffuser for 95% of the time (5^{th} percentile probability exceedance contour) (middle left panel Figure 4-7). The impact (or effect) area of the proposed scenario (middle right panel Figure 4-7) is marginally smaller to the existing case (5^{th} percentile contour within ~400 m of the diffuser), in part because of the lower dilution factor relative to the existing case. During both dry and wet seasons, the area of impact (or effect) is marginally smaller for the proposed comingled case relative to the existing effluent case.

Marine Ecosystem WQO

The proposed addition of the brine nutrient inputs to the WWTW effluent during the representative wet weather period predicts a similar area of effect for the marine ecosystem WQO relative to the baseline effluent scenario (lower panels Figure 4-7). The dilution factor of 142 for the marine ecosystem WQO of the baseline scenario predicts the 5th percentile probability exceedance contour up to ~1 km from the diffuser (lower left panel Figure 4-7).

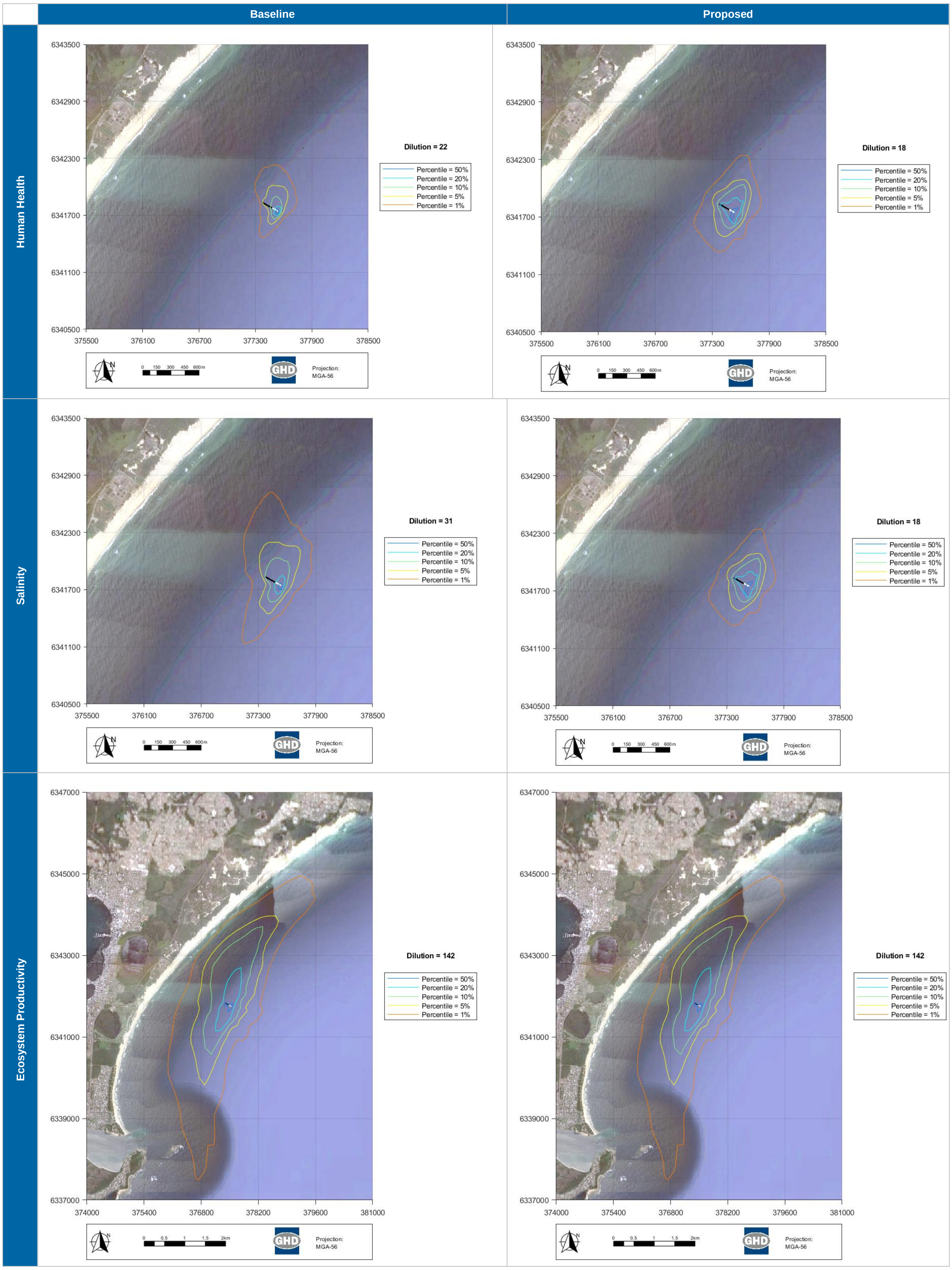

Figure 4-7 1%, 5%, 10%, 20% and 50% percentile probability exceedance contours of the WQO dilution factors of the wet weather period (2-29 June 2018) for the baseline (left) and proposed (right) scenarios for human health (top), salinity (middle) and marine ecosystem (bottom)

5. Conclusions and recommendations

The key conclusions in regards to the water quality impacts (effects) of the release of the proposed brine-effluent discharge into the marine environment via the existing diffuser include:

- The marine toxicity WQO is met within ~1 m of the diffuser because of the low dilution factor of <1 (Section 4.1). UM3 near-field modelling predicts this dilution factor is met immediately upon release into the marine environment (Section 4.2).
- The spatial area to meet the human health WQO dilution factor for human health is predicted to be similar between the existing and proposed scenarios during the representative dry (~300 m for 95% of the time) and wet (up to ~500 m of the diffuser for 95% of the time) periods. Exceedances of the human health WQO are greater than ~1 km from the nearest beach, and thereby do not pose a material risk to swimmers.
- The spatial area to meet the ambient marine salinity WQO (ΔS of 1 psu) is predicted to be substantially smaller during the dry weather (<100 m for 95% of the time) than the wet weather (<500 m from the diffuser for 95% of the time) periods. Generally, the largest spatial extent of the WQO is due to buoyant plumes reaching the near-surface and then undergoing dilution under natural mixing processes. Generally, the spatial area of impact of salinity was less (dry season) or similar (wet season) during the baseline relative to the proposed scenarios. For proposed effluent-brine outflows with high salinity during the dry season (maximum of ~48 psu), a dilution factor for the ambient salinity WQO of 14 is readily met in the immediate vicinity of the diffusers.
- The spatial area of effect of the marine ecosystem WQO is predicted to be similar across dry and wet season periods and baseline and proposed scenarios (~1 km of the diffuser for 95% of the time).

It is recommended that salinity (ambient salinity WQO), enterococci (human health WQO), ammonia and metals (marine toxicant WQO) are (or continue to be) measured along with nutrients and chlorophyll a (marine ecosystem WQO). It is recommended that spatial monitoring of the spatial areas of impact (or effect) be designed with consideration of the existing ecological monitoring programs for the Belmont and Burwood WWTW outfalls and other relevant studies.

The key finding from this assessment is that the proposed brine-effluent discharge through the existing diffuser is predicted to have the same or smaller areas of impact (or effect) in terms of human health, ambient salinity and marine ecosystem WQOs. Therefore significant impacts to WQOs are not likely from the proposed brine-effluent discharge.

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7. Acronyms and abbreviations

Acronym/Abbreviation	Meaning
°	Degree
°C	Degrees Celsius
∆S	Salinity Difference
2D	Two-Dimensional
3D	Three-Dimensional
ADCP	Acoustic Doppler Current Profiler
Air T	Air Temperature
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BKN	Broken Cloud Cover
BOD	Biochemical Oxygen Demand
BoM	Bureau of Meteorology
C_A	Ambient Concentration
C_{MZ}	Edge of Mixing Zone Concentration
C_O	Outlet (Diffuser) Concentration
CFSv2	Climate Forecast System version 2
Chl a	Chlorophyll a
C-Map	DHI Worldwide Bathymetry Database
D	Dilution Factor
DHI	Danish Hydraulic Institute
DPI	Department of Primary Industries
DTV	Default Trigger Values
E	Enterococci
EOMAP	Earth Observation and Environmental Services
EPL	Environment Protection Licence
FC	Faecal Coliforms
FM	Flexible Mesh
FRP	Filterable Reactive Phosphorus
g/kg	Grams per Kilogram
GHD	GHD Pty Ltd
hPa	Hectopascals
HYCOM	Hybrid Coordinate Ocean Model
IOA	Index of Agreement
km	Kilometre
LHWP	Lower Hunter Water Plan
m	Meter
M	Median
m/s	Meters per Second
m^3/s	Cubic Meters per Second
MAE	Mean Absolute Error
mg/L	Milligrams per Litre
MIKE 3 FM	DHI 3D Hydrodynamic Model with Flexible Mesh
ml	Millilitres
ML/day	Megalitres per Day

Acronym/Abbreviation	Meaning
mm	Millimetre
MPN	Most Probable Number
MTTV	Marine Toxicant Trigger Value
N	Number of Comparison Measurements
NCEP	National Centers for Climate Predictions
NH_3	Ammonia
NH_4	Ammonium
NH_X	Reduced Inorganic Nitrogen
NO_2	Nitrite
NO_3	Nitrate
NO_X	Oxidised Inorganic Nitrogen
NSW	New South Wales
OEH	Office of Environment and Heritage
$\bar{O}$	Mean of the Observations during the Comparison Period
O_i	Observed Value at Comparison Time i
P_{air}	Air Pressure
P_i	Predicted Value at Comparison Time i
Q	Discharge
OVC	Overcast
Press	Pressure
psu	Practical Salinity Unit
RH	Relative Humidity
RPCGV	Recreational Primary Contract Guideline Value
S	Salinity
S_O	Salinity of Outlet (Diffuser) Discharge
S_S	Salinity of Ambient Seawater
SCADA	Supervisory Control and Data Acquisition
SCT	Scattered Cloud Cover
SSTV	Site Specific Trigger Value
T	Temperature
TDP	Temporary Desalination Plant
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
u	Eastward Current Velocity Component
UM3	Updated Merge 3 (near-field mixing model)
µS/cm	Microsiemens per Centimetre
US EPA	United States Environmental Protection Agency
v	Northward Current Velocity Component
WD	Wind Direction
WS	Wind Speed
WQO	Water Quality Objective
WWTW	Wastewater Treatment Works

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