SANTOS DARWIN PIPELINE DUPLICATION (DPD) PROJECT

Treated Seawater Modelling

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EXECUTIVE SUMMARY

Background

Santos is assessing environmental impacts and risks associated with the Darwin Pipeline Duplication (DPD) Project. The DPD Project involves the installation of a gas export pipeline (GEP) from a point (kilometre point (KP) 0) in Commonwealth waters (25 km from the Commonwealth/ NT waters boundary) to the Darwin LNG (DLNG) Facility on Wickham Point in Darwin Harbour (KP122.2). The pipeline will transfer dry gas from the offshore Barossa field to the DLNG facility. The new pipeline (nearshore Barossa GEP) would run alongside the existing Bayu-Undan (BU) to Darwin GEP, typically within 50 – 100 m thereby effectively duplicating that pipeline.

While highly unlikely, an unplanned ‘wet buckle’ event may occur during installation of the nearshore Barossa GEP, thereby causing flooding of the pipeline with seawater. In the event of a ‘wet buckle’ the raw seawater will need to be displaced from the pipeline with seawater treated with a preservation chemical consisting of a biocide, corrosion inhibitor and oxygen scavenger. The treated seawater would then be dewatered to facilitate continued installation of the pipeline. To support the impact assessment for contingency pipeline filling and dewatering of treated seawater, Santos has commissioned a dispersion modelling study. Given the 'wet buckle' may occur anywhere along the proposed pipeline between KP0 and KP122.2, the study examined discharges at three locations (KP84, KP102 and KP114), specifically selected due the proximity of pipeline to areas of importance (i.e. reefs, coral, etc).

Both pipeline over filling (overflow) and dewatering scenarios were considered. The volume of treated seawater released as overflow (600 m^3) with a corresponding release duration (38 minutes) has been estimated to be the same at all three locations. However, during dewatering the volume and release duration was varied due to the length of the pipe at the given location (KP84 – 19,958 m^3 over 21.4 hours; KP102 – 10,623 m^3 over 11.4 hours; and KP114 – 4,400 m^3 over 4.7 hours). The concentration of the preservation chemical was assumed to be 550 mg/L with the discharge of treated water during overflow and dewatering via a single 4” diameter outlet 0.5 m above the seafloor.

The main objective of the study was to determine the area of exposure of the preservation chemical at different concentrations and compare this to different No Observable Effect Concentration (NOEC) thresholds.

Methodology

The physical mixing of the treated seawater was assessed for two distinct zones: near-field and far-field. The near-field zone is defined by the region where the levels of mixing and dilution are purely controlled by the plume’s initial jet momentum and the static current. The buoyancy in this instance is negligible given that the treated seawater has the same density as the surrounding seawater. Once the near-field assessment was complete, the far-field phase examined the transported and mixing of the preservation chemical by the ambient currents.

The extent and area of predicted exposure of the discharge were reported against established No Observable Effect Concentrations (NOECs) and calculated species protection levels for Hydrosure, the preferred preservation chemical to be used to treat the seawater. As a conservative approach, the 99% of species protection level (PC99%) NOEC of 0.06 mg/L; (which is a dilution of 1:9,167 based on initial concentration of 550 mg/L) was used as the minimum reporting threshold. Additional reporting thresholds based on the species protection limits of PC95% (NOEC of 0.10 mg/L), PC90% (NOEC of 0.15 mg/L) and PC80% (NOEC of 0.23 mg/L), were also used to assess plume extents and areas of coverage.

While the NOEC values are typically derived from long term tests whereby organisms are exposed to the preservation chemical between 48 and 96 hrs, due to the short-term release duration (<22 hours) and in turn, short exposure times, as an additional level of conservatism, the values of each modelled cell were examined over a 12-hour duration. Consequently, the extent of the mixing zone was based on a NOEC threshold of 0.06 mg/L (PC99%) over a 12-hour continuous duration.

For completeness, the areas of exposure from the preservation chemical during the overflow and dewatering releases were also assessed over 24 and 48-hour exposure period.

Key Findings

The key findings are:

- The near-field results showed that treated seawater would initially project horizontally approximately 1 – 2 m due to the orientation of the outlet and the fast exit velocities. Once the plume had lost its momentum, it mixed laterally due to the currents as it is neutrally buoyant. The near identical current speeds at the three locations and water depths meant the dilutions achieved were similar in each scenario. The lowest dilutions predicted at the three locations at 10 m and 30 m were 1:13.6–1:13.8 and 1:39.9, equating to concentrations of 39.8–40.6 mg/L (or ppm) and 13.8 mg/L (or ppm).

- There was no predicted exposure above the lowest NOEC threshold (PC99%) of 0.06 mg/L (or 0.06 ppm) over a 12-hour period from the preservation chemical during overflow at all three locations.

- For treated seawater dewatering there was no exceedance of the PC99% threshold over a 24-hour period at KP84 and KP114. Whereas the area of exposure from the dewatering at KP102 had significantly reduced to 0.16 km^2 and limited to the PC99% threshold.

- There was no exceedance of the PC99% threshold over a 48-hour period at all three locations for treated seawater dewatering.

- For a conservative 12-hour exposure time the dewatering discharge at KP84 resulted in a preservation chemical plume (PC99%; NOEC of 0.06 mg/L) that was generally continuous up to ~1.4 km from the release location, with small isolated patches predicted up to 9.61 km. Isolated patches beyond 2 km were predicted to occur during 2 of the 25 simulations and the plume was predicted to travel a maximum distance of 9.61 km in only 1 simulation. The isolated patches were due to an accumulation of the treated seawater, which had occurred during a current reversal, causing it to concentrate. The predicted maximum distances from the release location to the PC95% and PC90% were significantly smaller: 1.02 km and 0.75 km, respectively. The potential areas of exposure based on the PC99%, PC95% and PC90% thresholds 0.40 km^2, 0.17 km^2 and 0.08 km^2, respectively.

- Similarly, for a dewatering discharge KP102 over a conservative 12-hour exposure period, there were isolated patches of the preservation chemical above PC99% (NOEC of 0.06 mg/L) up to 6.78 km from the dewatering release location due to the plume drifting into the shallow intertidal areas, reducing the potential for mixing and dilution. The modelling also predicted a continuous area of exposure up to ~4 km west offset from the release location due to the plume migrating into the shallower waters, mixing less, resulting in the concentration accumulating. The area of exposure for the PC99% threshold was 4.14 km^2. The maximum distances from the release location based on the PC95% and PC90% thresholds were 2.18 km and 1.59 km, respectively.

- For the dewatering discharge at KP114, the maximum distance from the release location and area of exposure based on the PC99% threshold was 2.40 km and 1.45 km^2, respectively. The preservation chemical concentrations did not trigger any other threshold over a conservative 12-hour continuous duration.

1 INTRODUCTION

1.1 Background

Santos is assessing environmental impacts and risks associated with the Darwin Pipeline Duplication (DPD) Project. The DPD Project involves the installation of a gas export pipeline (GEP) from a point (kilometre point (KP) 0) in Commonwealth waters (25 km from the Commonwealth/ NT waters boundary) to the Darwin LNG (DLNG) Facility on Wickham Point in Darwin Harbour (KP122.2). The pipeline will transfer dry gas from the offshore Barossa field to the DLNG facility. The new pipeline (nearshore Barossa GEP) would run alongside the existing Bayu-Undan (BU) to Darwin GEP, typically within 50 – 100 m thereby effectively duplicating that pipeline.

While highly unlikely, an unplanned ‘wet buckle’ event may occur during installation of the nearshore Barossa GEP, thereby causing flooding of the pipeline with seawater. In the event of a ‘wet buckle’ the raw seawater will need to be displaced from the pipeline with seawater treated with a preservation chemical consisting of a biocide, corrosion inhibitor and oxygen scavenger. The treated seawater would then be dewatered to facilitate continued installation of the pipeline. To support the impact assessment of pipeline filling and dewatering of treated seawater, Santos has commissioned a dispersion modelling study. Given the 'wet buckle' may occur anywhere along the proposed pipeline between KP0 and KP122.2, the study examined discharges at three locations (KP84, KP102 and KP114), specifically selected due the proximity of pipeline to areas of importance (i.e. reefs, coral, etc). Table 1.1 presents the coordinates of each location and Figure 1.1 is the location map.

Both pipeline over filling (overflow) and dewatering scenarios were considered. The volume of treated seawater released as overflow (600 m^3) with a corresponding release duration (38 minutes) has been estimated to be the same at all three locations. However, during dewatering the volume and release durations varied due to the length of the pipe at the given location (see Table 1.2) and modelled as a separate discharge. The assumed concentration of the preservation chemical was 550 mg/L during overflow and dewatering, and the discharge via a single 4” diameter outlet 0.5 m above the seafloor.

The main objective of the study was to determine the area of exposure of the preservation chemical over a 12-hour continuous duration and compare this to different No Observable Effect Concentration (NOEC) thresholds.

Table 1.1 Coordinates of the Barossa DPD treated seawater release locations.

Identifier	Latitude	Longitude	Water Depth (m)
KP84	8,639,681.22	675,450.46	23.65
KP102	8,629,189.96	689,902.26	23.30
KP114	8,619,537.48	696,972.89	19.44

Table 1.2 Volumes of treated seawater and corresponding release durations during overflow and dewatering.

Scenario	Identifier	KP84	KP102	KP114
Scenario 1 – overflow	Volume of treated seawater released as overflow (m^3)		600	
	Release duration during overflow (hours)		0.63	

Scenario 2 – dewatering	Volume of treated seawater released during dewatering (m^3)	19,958	10,623	4,400
	Release duration during dewatering (hours)	21.37	11.37	4.7

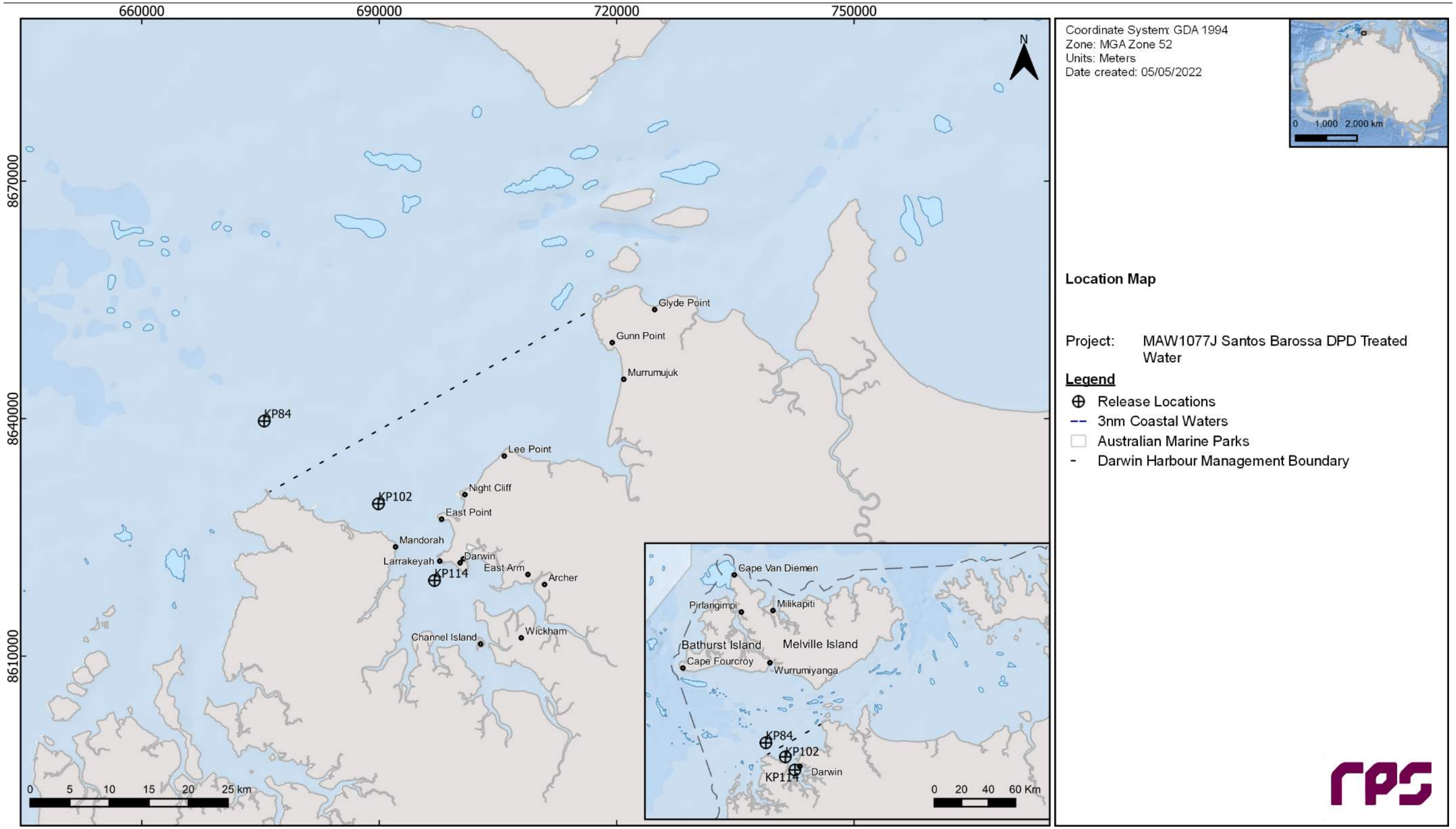

Figure 1.1 Barossa DPD treated seawater release locations.

2 SCOPE OF WORK

The physical mixing of the treated seawater discharge can be separated into two distinct zones: near-field and far-field. The near-field zone focusses on the mixing of the treated seawater. The near-field zone is defined by the region that is controlled by the plume’s initial jet momentum and the static current. Normally, the buoyancy difference is considered in the near-field, however, it is negligible because the treated seawater has the same density as the surrounding seawater. Once the near-field assessment was complete, the far-field phase examined the transport and mixing of the preservation chemical by the ambient currents.

The scope of work included the following components:

1. Model the near-field plume dynamics (or initial dilution) based on the release rate, outfall configuration and treated water characteristics under weak, moderate and strong current speeds;

2. Simulate the far-field mixing and dispersion of the release of the preservation chemical at the three locations for the overflow and dewatering as separate discharges. Due to the short release duration, 25 simulations were run at each location per discharge, each having randomly selected start times to ensure that a range of current conditions are examined;

3. Examine the concentrations of the preservation chemical during overflow and dewatering over a continuous 12-hour exposure period in each grid cell for each simulation separately; and

4. Combine the results for all 25 simulations representing the overflow and dewatering discharges and determine the potential area of exposure at all three locations.

For completeness, the areas of exposure from the preservation chemical during the overflow and dewatering releases were also assessed over 24 and 48-hour exposure period.

3 CURRENTS

3.1 Development of Regional Current Data

To simulate the hydrodynamics within Darwin Harbour and Beagle Gulf, a three-dimensional model was setup which accounted for tidal and oceanic currents, bathymetry, bottom roughness and wind stress. The model framework was developed through the combination of a large-scale regional model with smaller refined regions, or sub-domains. The D-FLOW model is ideally suited to represent the hydrodynamics of complex coastal waters, including regions where the tidal range creates large intertidal zones.

The three-dimensional simulations were generated using a rectangular grid in the horizontal with a series of interconnected (two-way, dynamically-nested) grids of varying resolution; a technique referred to as “domain decomposition”. This allows for the generation of a series of grids with progressively increasing spatial resolution, down to an appropriate scale for accurate resolution of the hydrodynamics to resolve flows more accurately along the coastline, around islands and over regions with more complex bathymetry. The main advantage of domain decomposition over traditional one-way, or static, nesting systems is that the model domains interact seamlessly, allowing transport and feedback between the regions of different scales. The ability to dynamically couple multiple model domains offer a flexible framework for hydrodynamic model development. In the vertical, a sigma-coordinate approach was employed to divide the water column into a series of layers.

D-FLOW allows for the establishment of a:

- Detailed bathymetry of the study area with wetting and drying of the intertidal zones simulated in applicable areas;

- Boundary elevation forcing data in the form of water levels representing the tides was sourced from the TPXO8.0 database, which is derived from sea-surface topography measurement by the TOPEX/Poseidon satellite-borne radar altimeters; TOPEX). While elevation data representing the ocean currents sourced from Hybrid Coordinate Ocean Model (HYCOM); and

- Spatially-varying surface wind data.

To optimise the computational effort required for a large, multi-layered model domain, and to achieve adequate horizontal and temporal resolution, a multiple-grid (domain-decomposition) strategy was applied using five sub-domains of varying horizontal grid cell size (Figure 3.1). The horizontal resolution within Darwin Harbour was 80 m (sub-grid 4), 240 m for the intermediate region (sub-grid 3), 720 m, 2.2 km and 6.5 km for the outer domains (sub-grids 2, 1 and 0, respectively).

A combination of datasets was used and merged to describe the shape of the seabed within Darwin Harbour and the intermediate area, including spot depths and contours which were digitised from nautical charts released by the hydrographic offices. For the outer domains, depths extracted from the General Bathymetric Chart of the Oceans (GEBCO) dataset on a 15 arc-second interval grid was used.

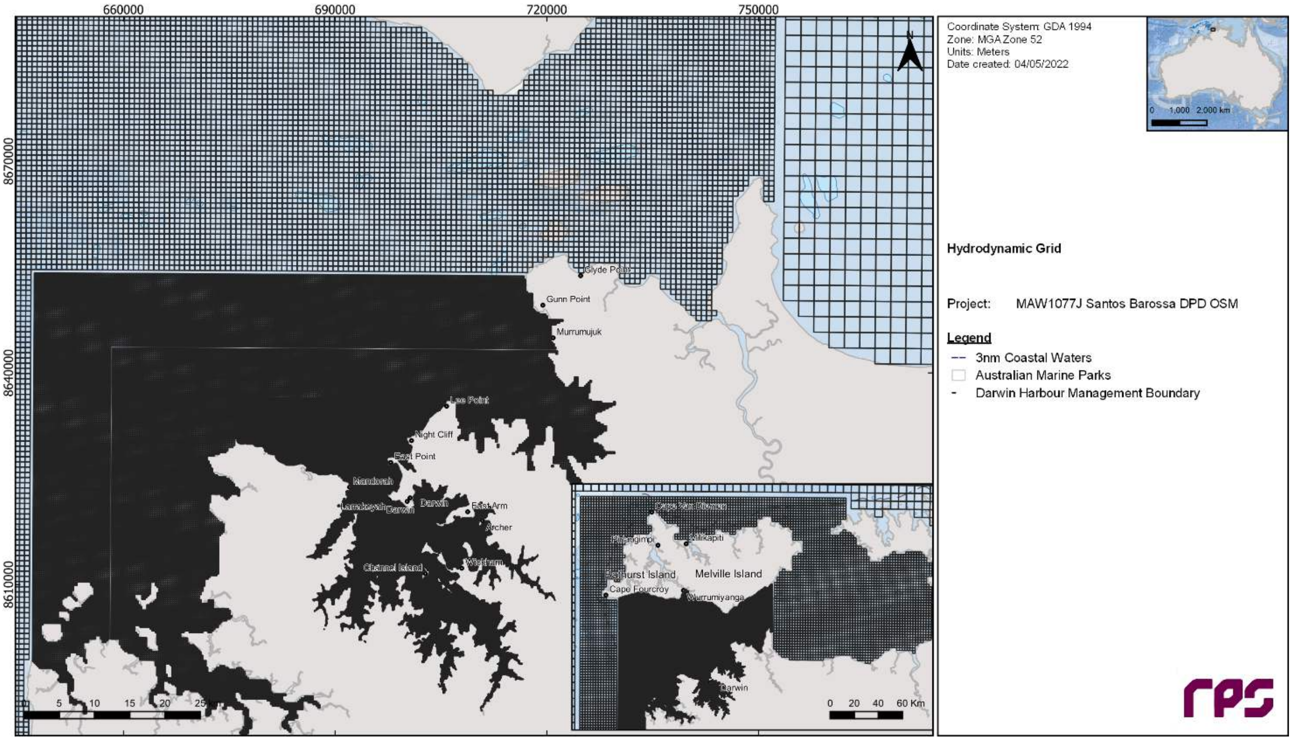

Figure 3.1 Detail of the hydrodynamic model grid.

3.2 Boundary Conditions

3.2.1 Overview

While the hydrodynamics in Darwin Harbour are controlled primarily by tidal flows, oceanic and wind forcing were explicitly included to account for the conditions beyond the port limits.

The model was forced on the open boundaries of the outer sub-domain with time series of water elevation obtained for the chosen simulation period. Spatial and temporal variation in wind forcing across the entire domain was accounted for by applying spatially-varying wind speed and wind direction data that varied over time.

3.2.1.1 Water Elevation

Water elevations at hourly intervals were obtained from the TPXO8.0 database, which is derived from measurements of sea-surface topography by the TOPEX/Poseidon satellite-borne radar altimeters. Tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary (M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1), two long-period (M_f, M_m) and three non-linear (M_4, MS_4, MN_4) harmonic constituents at a spatial resolution of 0.25°.

The tidal sea level data was augmented with non-tidal (or oceanic) sea level elevation data from the global Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2007, 2009; Halliwell, 2004), created by the USA’s National Ocean Partnership Program (NOPP) as part of the Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite instrumentation, along with atmospheric forcing conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density, sea height variations and the rotation of the Earth. The model has a global coverage with a horizontal resolution of 1/12th of a degree (~7 km at mid-latitudes) and a temporal resolution of 24 hours.

3.2.1.2 Wind Forcing

Wind forcing was included in the hydrodynamic model as a boundary condition to capture its effect on water currents. For this model, wind data was sourced from the National Center for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR; see Saha *et al.*, 2010). The CFSR wind model includes observations from many data sources: surface observations, upper-atmosphere air balloon observations, aircraft observations and satellite observations. The model is capable of accurately representing the interaction between the earth's oceans, land and atmosphere. The gridded wind data output is available at a horizontal resolution of 0.25° (~33 km) and a temporal resolution of 1 hour.

3.3 Near-Seabed Currents

Figure 3.2 shows the predicted annual near-seabed current rose distributions at treated seawater release Locations 1, 2 and 3. Note the convention for defining current direction is the direction the current flows towards, which is used to reference current direction throughout this report. Each branch of the rose represents the currents flowing to that direction, with north to the top of the diagram. Sixteen directions are used. The branches are divided into segments of different colour, which represent the current speed ranges for each direction. Speed intervals of 0.1 m/s are predominantly used in these current roses. The length of each coloured segment is relative to the proportion of currents flowing within the corresponding speed and direction.

The predicted near-seabed currents predominantly flowed along the east-west axis at KP84 and southeast-northwest axis at KP102 and KP114. Average monthly speeds ranged from 0.38 to 0.43 m/s, 0.52 to 0.60 m/s and 0.43 to 0.50 m/s at KP84, KP102 and KP114, respectively. Additionally, the maximum current speeds ranged between 1.04 and 1.22 m/s, 1.37 and 1.62 m/s and 1.16 and 1.31 m/s at the respective sites.

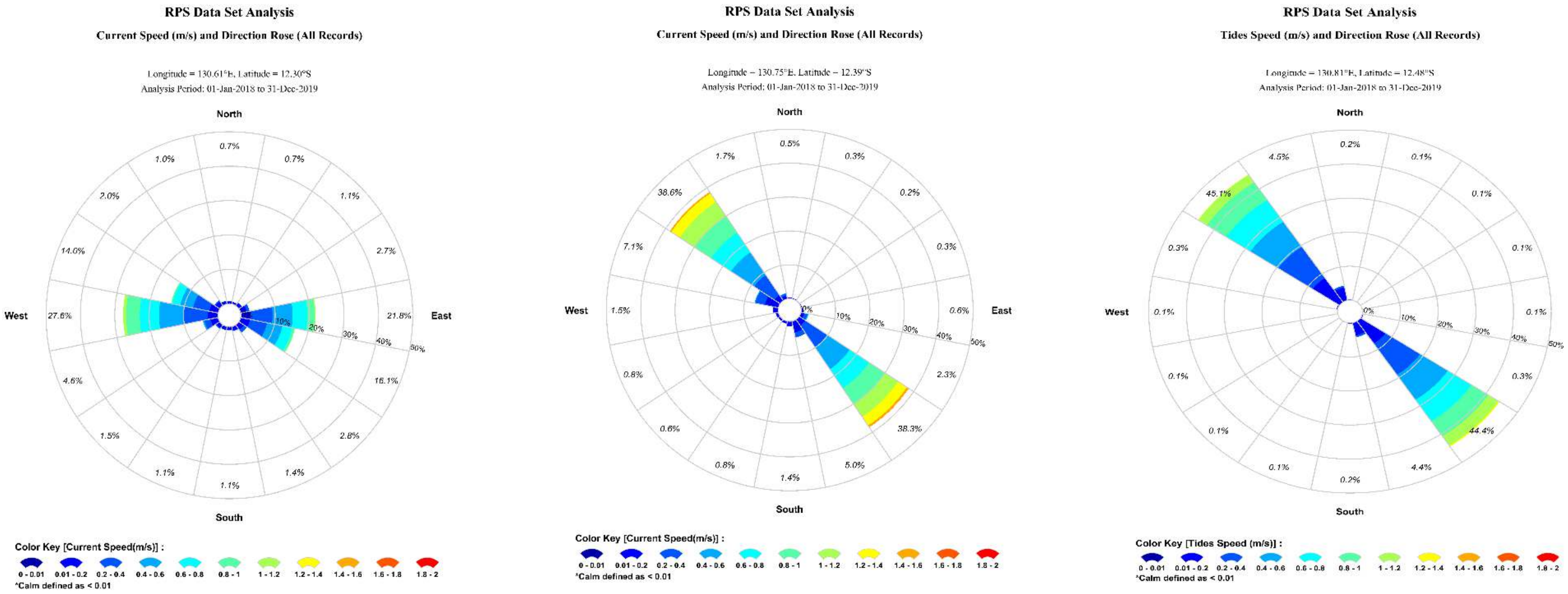

Figure 3.2 Annual near-seabed current rose plots near KP84 (Left), KP102 (Middle) and KP114 (Right). derived from the 2019 – 2020 water level dataset.

4 WATER TEMPERATURE AND SALINITY

Table 4.1. provides a summary of the annual average water temperature and salinity values near the seabed at the release locations. The temperature and salinity data throughout the water column was obtained from the World Ocean Atlas 2018 database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration, NOAA) and its co-located World Data Centre for Oceanography (Levitus *et al.*, 2013).

The water temperature and salinity values are relatively similar between the three locations (28.4 to 28.8 C and 34.0 to 34.4 psu). The data aligns with the Darwin Harbour water quality monitoring program (https://depws.nt.gov.au/water/water-management/darwin-harbour/darwin-harbour-region-report-cards/2018-report-cards).

Table 4.1 Average water temperature and salinity near the seabed at the treated seater release locations.

	KP84	KP102	KP114
Temperature (°C)	28.4	28.4	28.8
Salinity (psu)	34.4	34.4	34.0

5 ENVIRONMENTAL REPORTING CRITERIA

Santos plan to use a preservation chemical such as Hydrosure 0-3670R to treat the seawater to be pumped into the pipeline. Table 5.1 presents a summary of the No Observable Effects Concentrations (NOEC) that were derived from the whole of effluent toxicity (WET) testing results for Hydrosure (Chevron 2015). During WET testing, a suite of relevant local species were exposed under a range of concentrations using the recommended protocols from ANZECC and ARMCANZ (2000). The NOEC values for varying species protection levels and the dilutions to achieve the concentration based on a dosage of 550 mg/L are presented in Table 5.1.

While the NOEC values are derived from long term ecological tests typically between 48 and 96 hrs, due to the short-term release periods (< 22.0 hrs) and with the tides altering direction, the dose that environmental receptors shall receive will be less than those exposed in the toxicological tests. Hence, as an additional level of conservatism, the concentrations in each model cell was examined over a 12-hour continuous duration. Consequently, the extent of the mixing zone was based on a NOEC threshold of 0.06 mg/L (PC99%) over a 12-hour continuous duration.

Table 5.1 NOEC values for varying species protection levels for Hydrosure 0-3670R based on WET testing (from Chevron, 2015).

Species protection level	NOEC threshold (mg/L)	Dilution to achieve the NOEC threshold based on an inhibitor dosing concentration of 550 mg/L (or ppm)
NOEC PC99%	0.06	1:9,167
NOEC PC95%	0.10	1:5,500
NOEC PC90%	0.15	1:3,667
NOEC PC80%	0.23	1:2,391

6 NEAR-FIELD MODEL

6.1 Description of the Near-Field Model: CORMIX

The near-field mixing and dispersion was simulated using the three-dimensional flow model, CORMIX. CORMIX is a mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones. CORMIX contains a series of elements for the analysis and design of single or multi-port discharges. Discharges may be submerged or above surface, buoyant or denser than receiving water and the receiving water may be stratified or unstratified. The emphasis of the model is the influence of the geometry and dilution characteristics on the initial mixing zone (Doneker & Jirka, 1990; Jirka *et al.*, 1991). CORMIX is widely applied worldwide and has been validated in many independent studies (http://www.cormix.info/validations.php).

CORMIX specifies the average dilution or bulk dilution (flux averaged) as 1.7 times the centreline dilution. The centreline is defined by the points of maximum concentration (maximum temperature, minimum dilution etc.) at each vertical section along the longitudinal axis. Accordingly, centreline depth is defined as the depth of the maximum concentration point (maximum temperature, minimum dilution) along the longitudinal axis.

6.2 Near-Field Model Setup

Table 6.1 is a summary of the treated seawater discharge characteristic for the near-field model setup with the flow rate and outlet configuration at all three treated seawater release locations.

Table 6.1 Summary of the near-field modelling inputs.

Parameter	KP84	KP102	KP114
Flow rate (m^3/s)	0.26		
Outlet configuration	Single 4” outlet orientated horizontally with pipeline		
Discharge height (m) above the seabed	0.5		
Discharge temperature (same as ambient seawater)	28.4 °C		28.8 °C
Discharge salinity (same as ambient seawater)	34.4 psu		34.0 psu

Along with the ambient water temperature and salinity (see Section 4), a range of current speeds were included in the near-field model. The yearlong seabed current data was analysed and the 5th, 50th and 95th percentile current speeds were chosen to reflect the potentially contrasting dilution and advection cases:

- 5th percentile (or 5 percent of the time the currents will be below the identified speed): weak currents, low dilution and slow advection;
- 50th percentile (or 50 percent of the time the currents will be below the identified speed): moderate currents, average dilution and advection; and
- 95th percentile current speed (or 95 percent of the time the currents will be below the identified speed): strong currents, high dilution and rapid advection to nearby areas.

The 5th, 50th and 95th percentile values are referenced as weak, moderate and strong current speeds, respectively.

Table 6.2 Static current speeds for each location.

Identifier	5th Percentile (Weak) Current Speed (m/s)	50th Percentile (Moderate) Current Speed (m/s)	95th Percentile (Strong) Current Speed (m/s)
KP84	0.08	0.35	0.79
KP102	0.05	0.34	0.83
KP114	0.04	0.30	0.82

7 NEAR-FIELD RESULTS

Due to the fast exit velocities, the treated seawater would initially project horizontally at a rapid speed approximately 1–2 m from the outlet. Once the plume had lost its momentum, it mixed laterally due to the currents as it is neutrally buoyant.

Table 7.1 presents the predicted dilutions and preservation chemical concentrations at 10 m and 30 m (horizontally) from each location with varying static current speeds. Due to the near identical current speeds at the three locations, the predicted dilutions achieved and in turn the preservation chemical concentrations at the designated distances are very similar.

For KP84, within 30 m of discharge the predicted concentration reduced from 550 mg/L to 9.4 and 13.8 mg/L (or ppm) under strong and weak current conditions, respectively. Meaning that within 30 m the minimum dilution was 1:58.4 and 1:39.9 for the strong and weak currents, respectively.

For KP102 within 30 m the predicted concentration was 10.2 and 13.8 mg/L (or ppm) under strong and weak currents, respectively. The corresponding minimum dilutions were 1:54.1 and 1:39.9, respectively.

For KP114 within 30 m, the predicted concentration had reduced from 550 mg/L to 9.2 and 13.5 mg/L (or ppm) under strong and weak current conditions, respectively. Meaning that within 30 m the minimum dilution was 1:60.0 and 1:40.7 for the strong and weak currents, respectively.

Note that these predictions rely on the persistence of current speed and direction over time and does not account for the build-up of the plume.

Table 7.1 Predicted near-field plume characteristics at 10 m and 30 m from the release location for each case.

Location	Current speed (m/s)	Distance from the release location (m)	Plume centre (minimum) dilution (1:x)	Plume centre concentration (mg/L or ppm) based on an initial concentration of 550 mg/L	Plume diameter (m)
KP84	Weak (0.08)	10.0	13.8	39.8	1.2
		30.0	39.9	13.8	3.2
	Moderate (0.35)	10.0	14.3	38.4	1.2
		30.0	40.4	13.6	3.1
	Strong (0.79)	10.0	14.1	39.0	1.0
		30.0	58.4	9.4	4.7
KP102	Weak (0.05)	10.0	13.8	39.8	1.1
		30.0	39.9	13.8	3.8
	Moderate (0.34)	10.0	14.2	38.6	0.9
		30.0	57.2	9.6	2.1
	Strong (0.83)	10.0	14.2	38.6	0.9
		30.0	54.1	10.2	2.1
KP114	Weak (0.04)	10.0	13.8	39.8	1.2
		30.0	40.7	13.5	3.3
	Moderate (0.30)	10.0	13.6	40.6	1.1
		30.0	39.9	13.8	3.3
	Strong (0.82)	10.0	14.0	39.4	1.0
		30.0	60.0	9.2	4.8

8 FAR-FIELD MODELLING

As previously mentioned, the far-field modelling expands on the near-field work by allowing the time-varying nature of currents to be included, and the potential for recirculation of the plume back to the discharge location to be assessed. In this case, preservation chemical concentrations near the release location can be increased due to the discharge plume mixing with the remnant plume from an earlier time. This may be a potential source of episodic increases in pollutant concentrations in the receiving waters.

8.1 Description of the Near-Field Model: MUDMAP

The mixing and dispersion of the treated water discharge was predicted using the three-dimensional discharge and plume behaviour model, MUDMAP. The far-field calculation (passive dispersion stage) employs a particle-based, random walk procedure. Any chemicals (constituents) within the discharge stream are represented by a sample of Lagrangian particles. These particles are moved in three dimensions over each subsequent time step according to the prevailing local current data as well as horizontal and vertical mixing coefficients.

MUDMAP treats the Lagrangian particles as conservative tracers (i.e. they are not removed over time to account for chemical interactions, decay or precipitation). Predicted concentrations will therefore be conservative overestimates where these processes actually do occur. Each particle represents a proportion of the discharge, by mass, and particles are released at a given rate to represent the rate of the discharge (mass per unit time). Concentrations of constituents are predicted over time by counting the number of particles that occur within a given depth level and grid square and converting this value to mass per unit volume.

The system has been extensively validated and applied for discharge operations in Australian waters (e.g. Burns *et al.*, 1999; King & McAllister, 1997, 1998).

8.2 Far-Field Model Setup

Table 8.1 presents a summary of the far-field model inputs used to calculate the transport and mixing of the preservation chemical by the ambient currents for the overflow and dewatering. As previously mentioned, 25 simulations were run (for each location and discharge type) and each simulation had randomly chosen start times from the historical dataset to ensure a range of current conditions were sampled.

MUDMAP uses a three-dimensional grid to represent the water depth and bathymetric profiles of the study area. For this modelling assessment, a 30 m grid in the horizontal and 2 m grid in the vertical was used to track the movement and fate of the treated seawater plume to adequately replicate the mixing and near-field dilutions achieved under similar current conditions in the immediate vicinity of the release location. Similarly, horizontal and vertical dispersion coefficients (used to control the exchange of the plume in the horizontal and vertical directions respectively) of 0.5 m^2/s and 0.001 m^2/s were carefully selected through sensitivity testing to recreate the concentrations as predicted during the near-field modelling.

Table 8.1 Summary of far-field modelling inputs.

<table>
<tr><th>Parameter</th><th colspan="12">KP84</th><th colspan="12">KP102</th><th colspan="12">KP114</th></tr>
<tr><td>Volume of treated seawater released as overflow (m^3)</td><td colspan="36">600</td></tr>
<tr><td>Release duration during overflow (hours)</td><td colspan="36">0.63</td></tr>
<tr><td>Model simulation length (days) for the overflow</td><td colspan="36">1</td></tr>
<tr><td>Volume of treated seawater released during dewatering (m^3)</td><td colspan="12">19,958</td><td colspan="12">10,623</td><td colspan="12">4,400</td></tr>
<tr><td>Release duration during dewatering (hours)</td><td colspan="12">21.37</td><td colspan="12">11.37</td><td colspan="12">4.7</td></tr>
<tr><td>Model simulation length (days)</td><td colspan="12">2.2</td><td colspan="12">2.00</td><td colspan="12">1.6</td></tr>
<tr><td>Initial preservation chemical concentration (ppm or mg/L)</td><td colspan="36">550</td></tr>
<tr><td rowspan="2">Preservation chemical threshold concentrations (ppm or mg/L) based on a continuous exposure over 12 hours</td><td colspan="9">NOEC PC99%</td><td colspan="9">NOEC PC95%</td><td colspan="9">NOEC PC90%</td><td colspan="9">NOEC PC80%</td></tr>
<tr><td colspan="9">0.06</td><td colspan="9">0.10</td><td colspan="9">0.15</td><td colspan="9">0.23</td></tr>
</table>

9 FAR-FIELD RESULTS

9.1 General Observations

Figure 9.1 to Figure 9.3 show the maximum predicted preservation chemical concentrations during dewatering over a 12-hour period (2-hour intervals) as an aerial plan view for the first simulation at each location. The images have been included to illustrate the predicted movement and concentrations of the preservation chemical as a result of the time-varying current directions and speeds. It can be seen how the tides dominate the local currents and cause the plume to bend and change direction from the northwest to the southeast under the influence of the flood tide currents. The predicted preservation chemical concentrations during this period demonstrate decreasing concentrations with increasing distance from the release location.

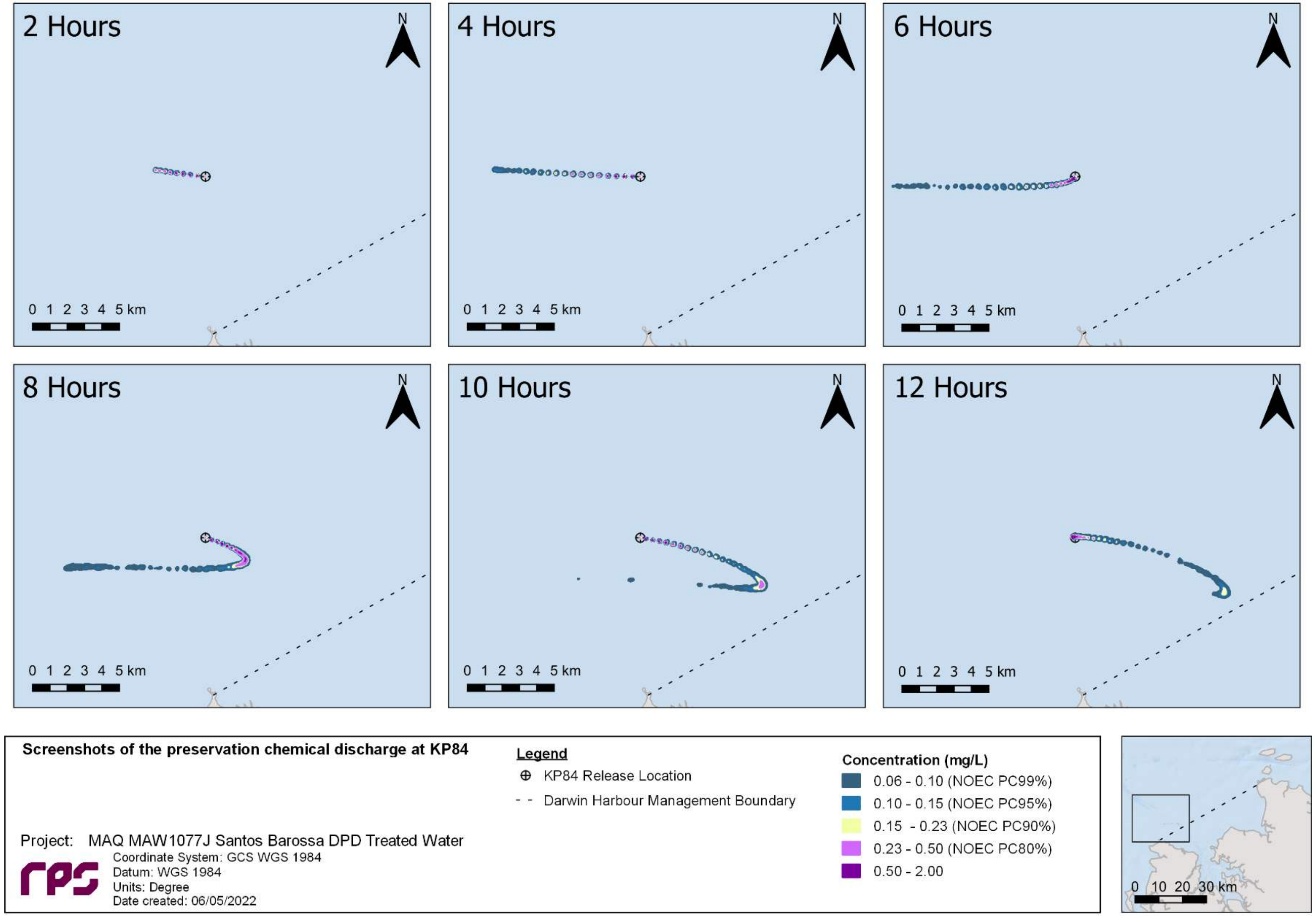

Figure 9.1 Predicted preservation chemical concentrations during dewatering for simulation 1 at KP84 between 11 am to 11 pm 15th October 2019 for KP84.

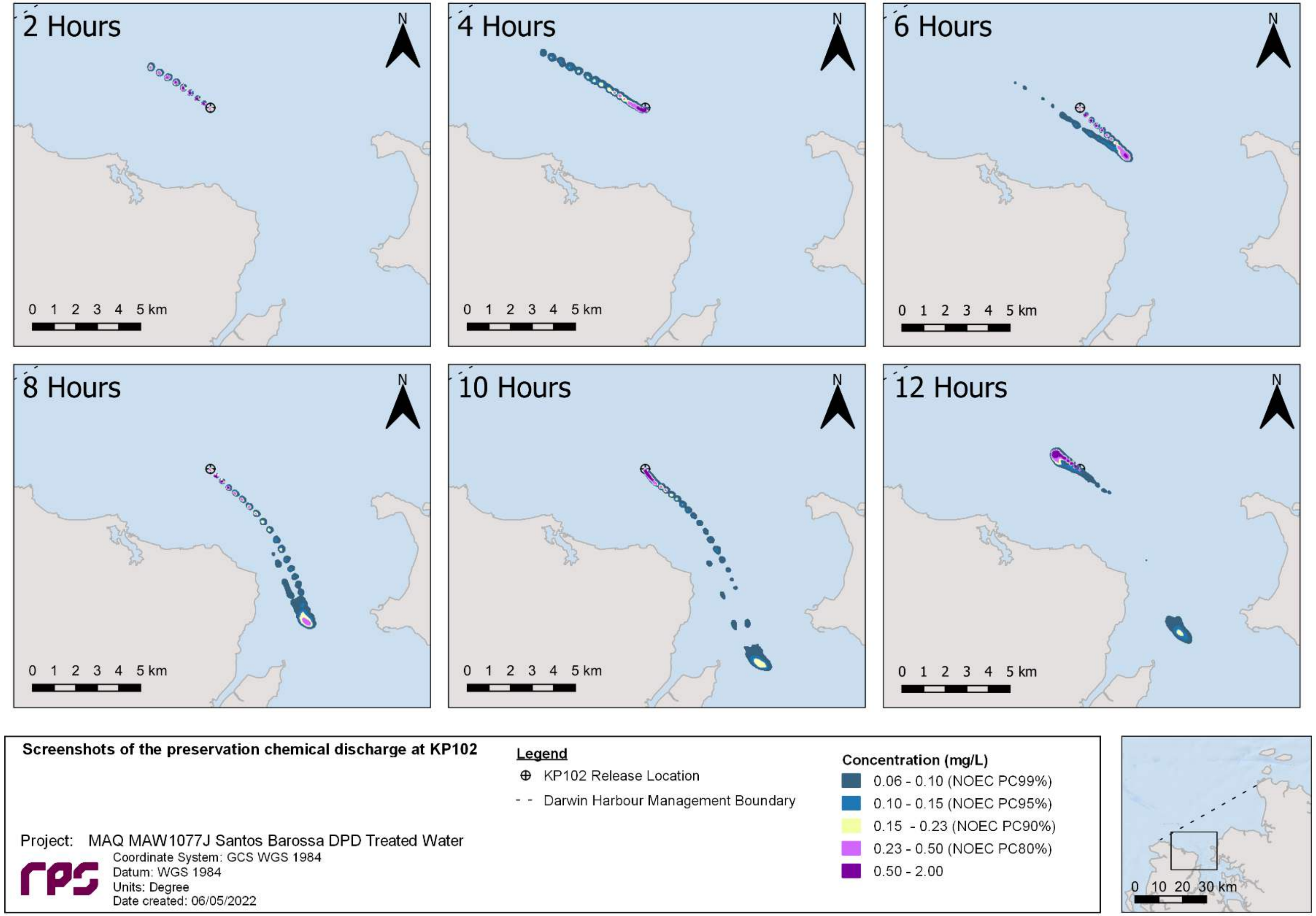

Figure 9.2 Predicted preservation chemical concentrations during dewatering for simulation 1 at KP102 between 3 pm 21st April to 3 am 22nd April 2020.

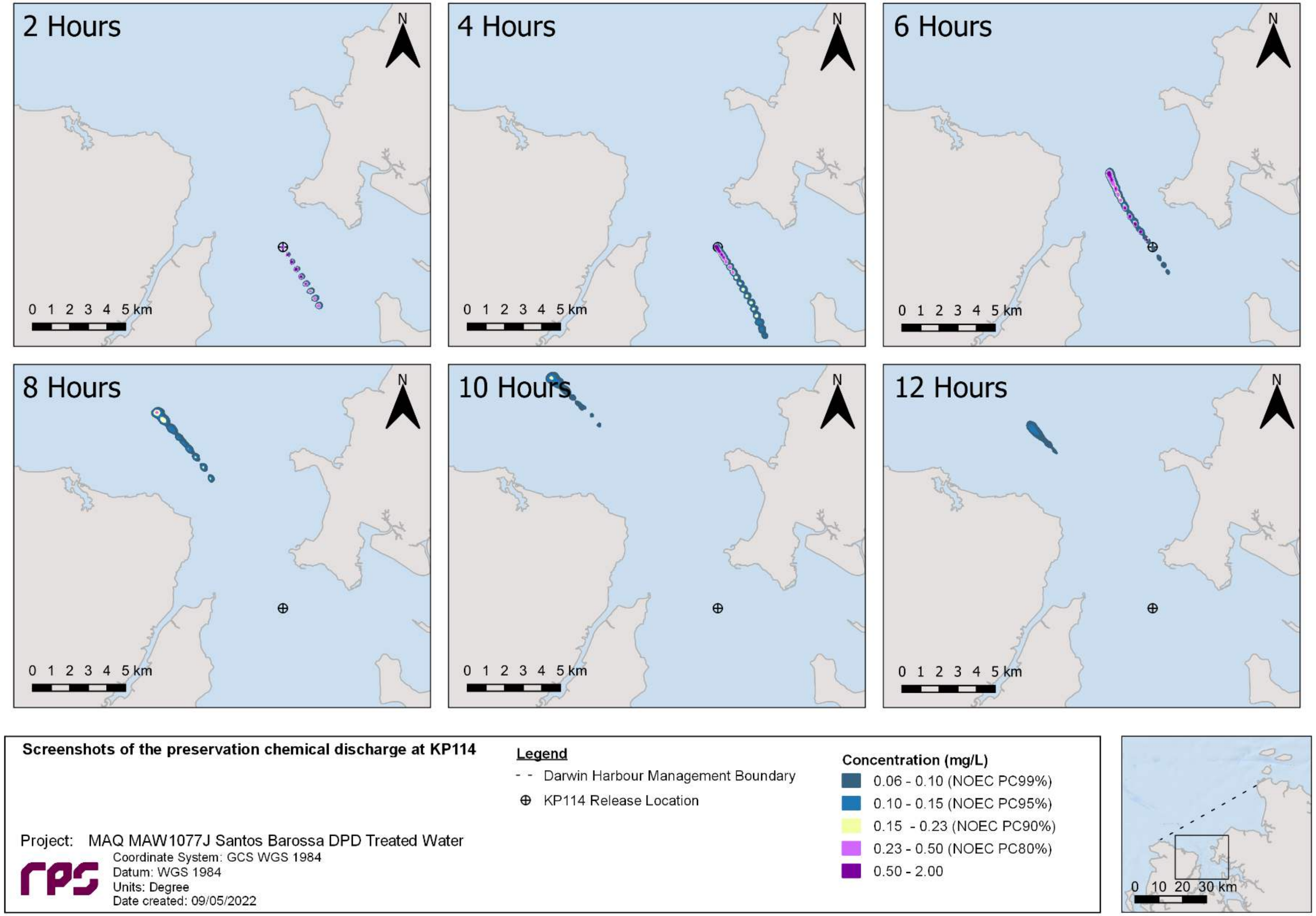

Figure 9.3 Predicted preservation chemical concentrations during dewatering for simulation 1 at KP114 between 7 am to 7 pm 16th October 2020.

9.2 Combined Analysis Over 12- Hour Period

There was no predicted exposure above 0.06 mg/L (or 0.06 ppm) over a 12-hour period from the preservation chemical during overflow at all three locations.

Figure 9.4 to Figure 9.6 illustrate the predicted maximum distances and area of exposure by the preservation chemical at the three locations during dewatering. It should be noted that area presented is created by overlaying the results of the 25 individual simulations and therefore does not represent the area of effect from a discharge, rather represents the area within which the effects of a discharge could potentially occur dependant on environmental conditions Table 9.1 summarises the maximum distances from the release locations and area of exposure for each NOEC value.

At KP84, the preservation chemical plume was generally continuous up to ~1.4 km from the release location based on the PC99% threshold (NOEC of 0.06 mg/L), with small isolated patches predicted up to 9.61 km. The isolated patches more than ~2 km away were predicted to occur during 2 of the 25 simulations and the plume was predicted to travel a maximum distance of 9.61 km for only 1 simulation. The isolated patches were due to an accumulation, which had occurred further away during a current reversal, causing it to concentrate. The predicted maximum distances from the release location to the PC95% (NOEC of 0.10 mg/L) and PC90% (NOEC of 0.15 mg/L) were significantly smaller: 1.02 km and 0.75 km, respectively. The potential areas of exposure based on the PC99%, PC95% and PC90% thresholds were 0.40 km^2, 0.17 km^2 and 0.08 km^2, respectively.

Likewise for KP102, there were isolated patches of the preservation chemical above PC99% (NOEC of 0.06 mg/L) up to 6.78 km from the release location due to the plume drifting into the shallow intertidal areas and reducing the potential for mixing and dilution. The modelling also predicted a continuous area of exposure up to ~4 km west offset from the release location due to the plume migrating into the shallower waters, mixing less and the concentration accumulating. The area of exposure for the PC99% threshold was 4.14 km^2. The maximum distances from the release location based on the PC95% and PC90% thresholds were 2.18 km and 1.59 km, respectively.

For the discharge at KP114, the maximum distance from the release location and the area of exposure of the preservation chemical based on the PC99% threshold was 2.40 km and 1.45 km^2, respectively. The preservation chemical concentrations did not trigger any other threshold over a 12-hour continuous duration.

Table 9.1 Summary of the maximum distances and areas of exposure by the preservation chemical during dewatering for each NOEC value at the three locations. Results are derived from 25 simulations, each simulation was individually assessed based over a 12-hour continuous exposure period for the NOEC values.

Location	Initial chemical dosing (ppm or mg/L)	Species protection level	NOEC value (mg/L)	Area of exposure (km^2)	Maximum horizontal distance from the release location (km)
1 – KP84	550	NOEC PC99%	0.06	0.40	9.61
		NOEC PC95%	0.10	0.17	1.02
		NOEC PC90%	0.15	0.08	0.75
		NOEC PC80%	0.23	0.04	0.36
2 – KP102	550	NOEC PC99%	0.06	4.14	6.78
		NOEC PC95%	0.10	2.18	4.33
		NOEC PC90%	0.15	1.59	4.13
		NOEC PC80%	0.23	0.96	3.84
3 – KP114	550	NOEC PC99%	0.06	1.45	2.40
		NOEC PC95%	0.10	-	-
		NOEC PC90%	0.15	-	-
		NOEC PC80%	0.23	-	-

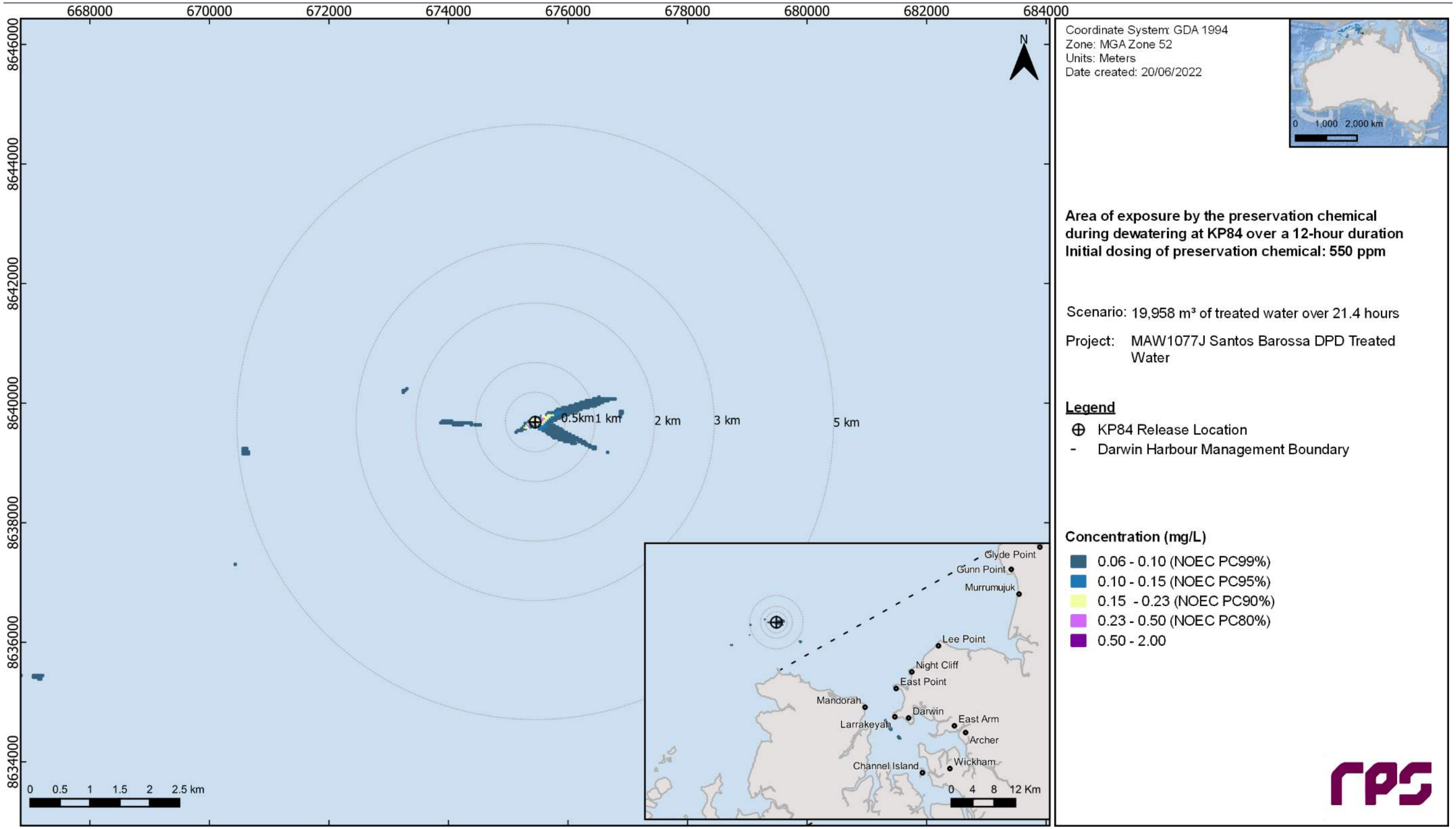

Figure 9.4 Predicted concentrations of the preservation chemical over a 12-hour exposure period during dewatering from KP84. The results were calculated from 25 simulations with different metocean conditions.

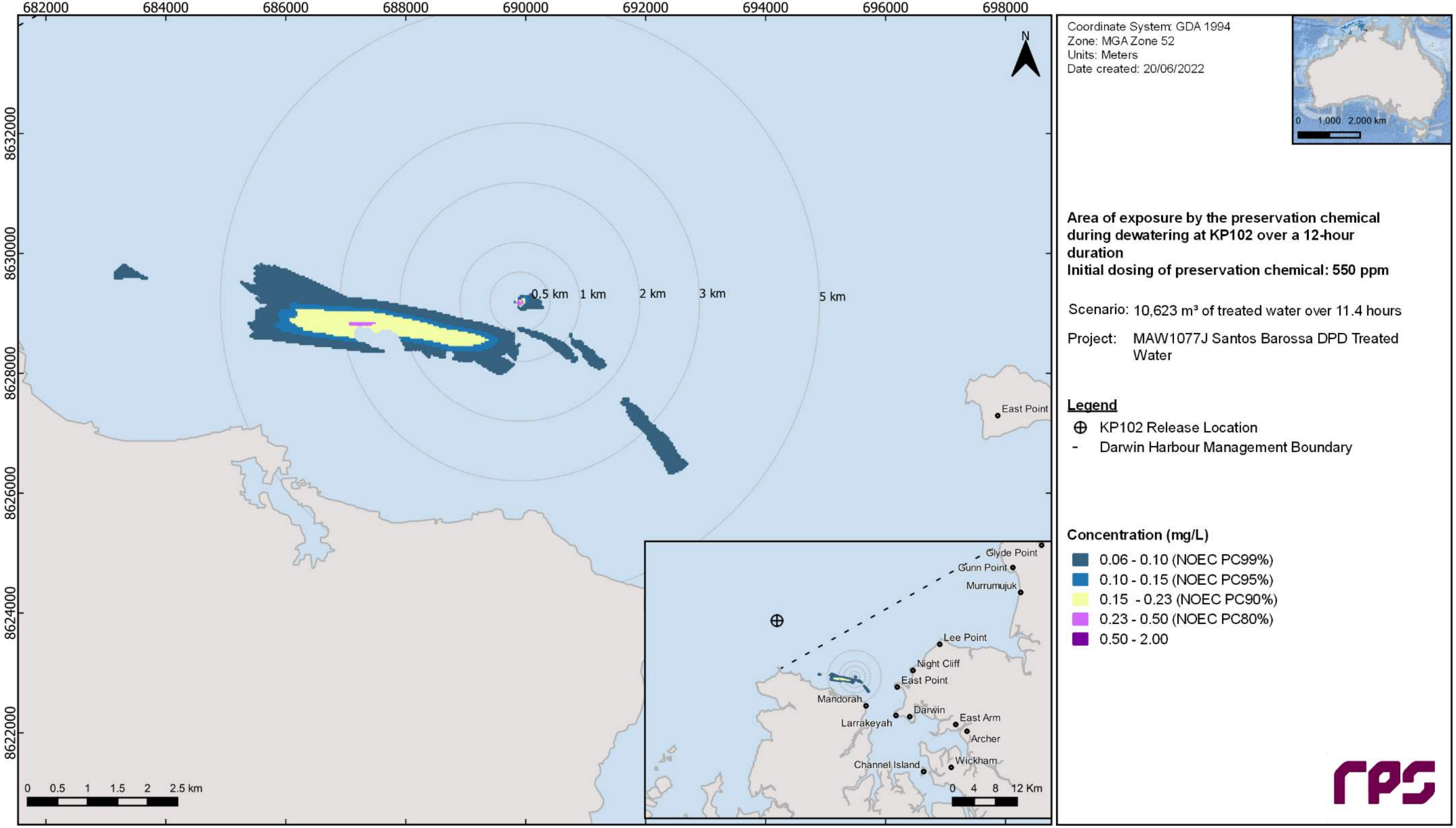

Figure 9.5 **Predicted concentrations of the preservation chemical over a 12-hour exposure period during dewatering from KP102. The results were calculated from 25 simulations with different metocean conditions.**

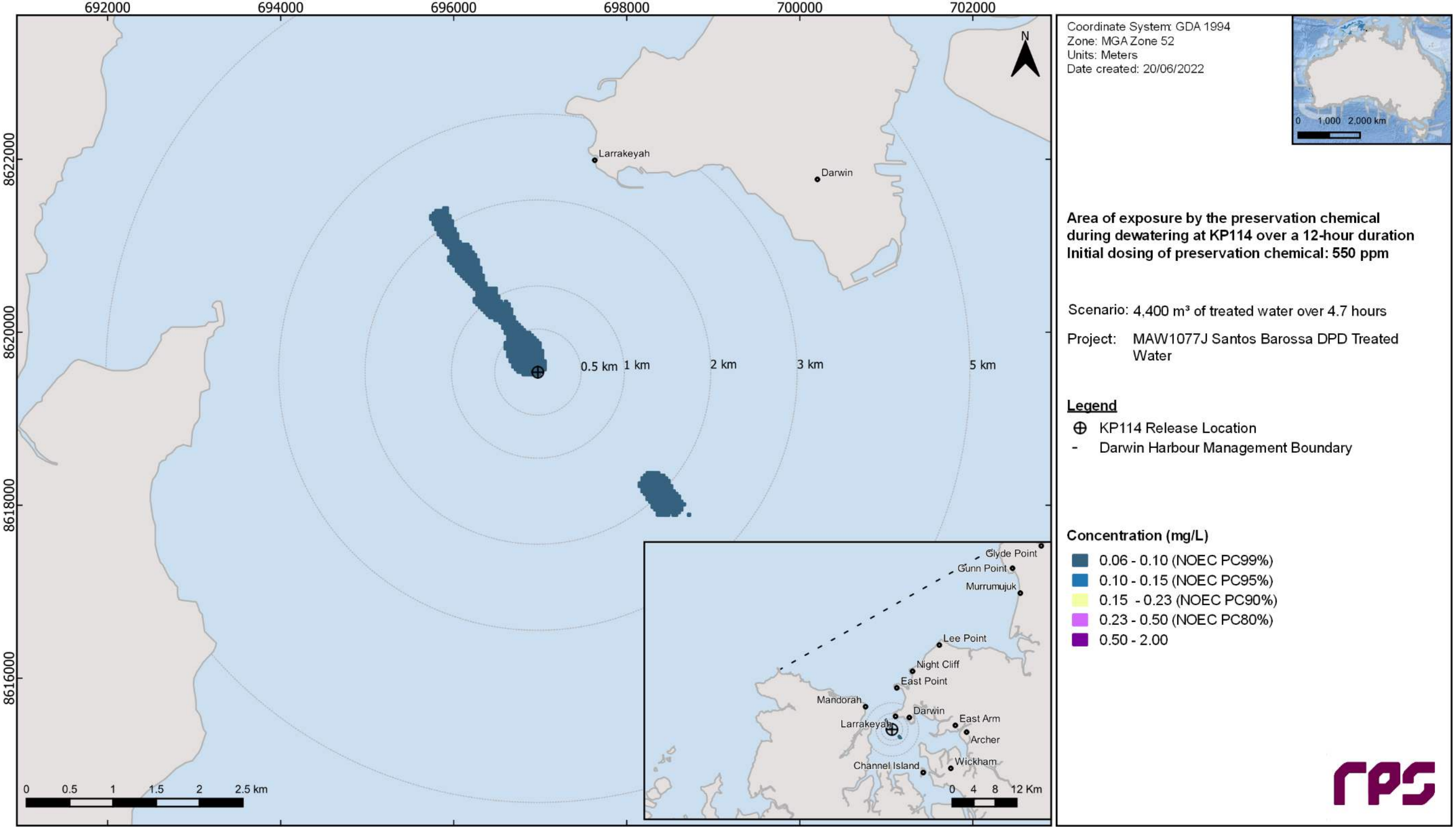

Figure 9.6 Predicted concentrations of the preservation chemical over a 12-hour exposure period during dewatering from KP114. The results were calculated from 25 simulations with different metocean conditions.

9.3 Combined analysis over 24 and 48-hour period

There was no exceedance of the PC99% threshold predicted over a 24-hour period at KP84 and KP114. The area of exposure from the dewatering at KP102 had significantly reduced to 0.16 km^2 and limited to the PC99% threshold (see Figure 9.7).

There was no exceedance of the PC99% threshold over a 48-hour period at all three locations.

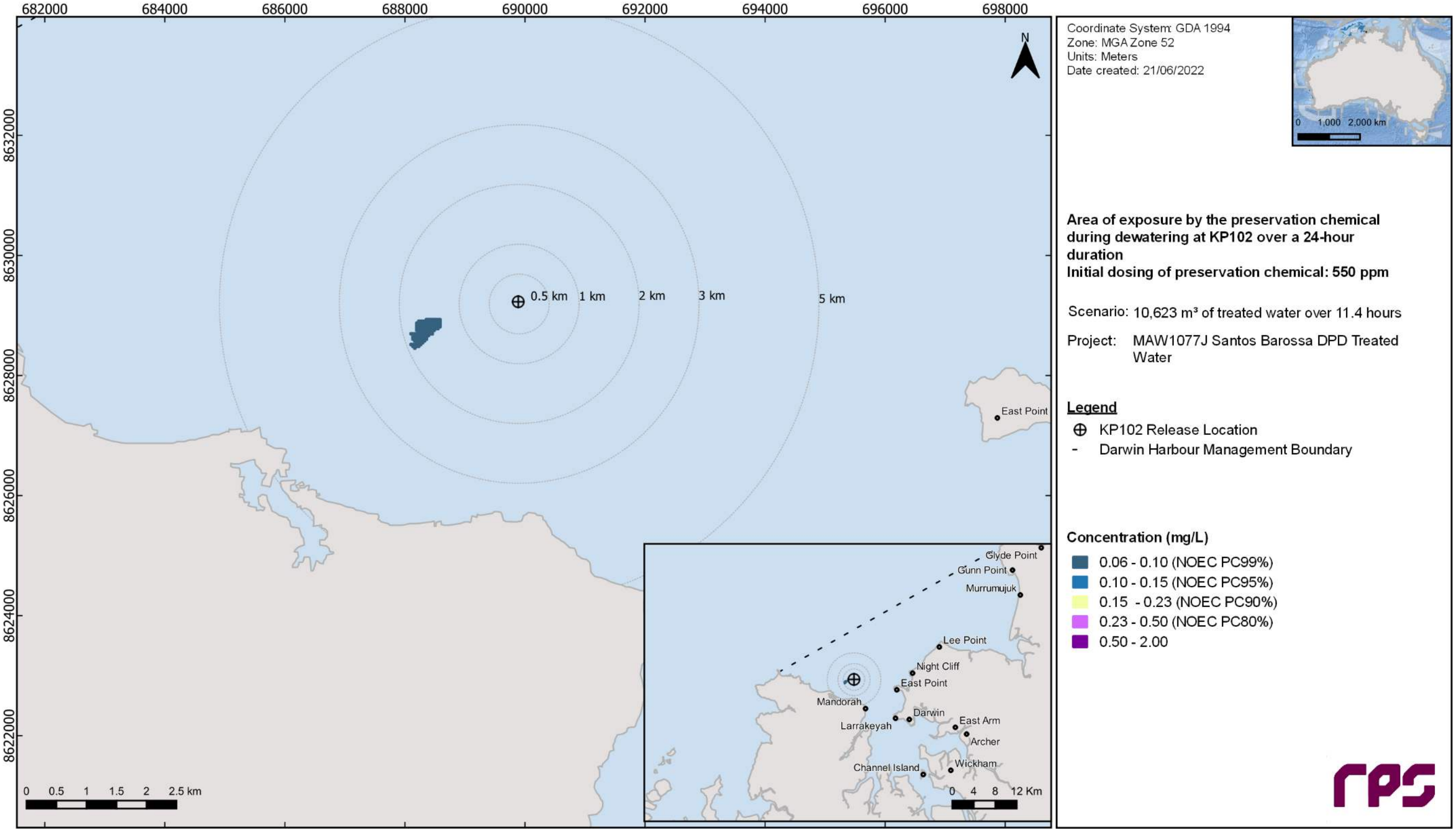

Figure 9.7 Predicted concentrations of the preservation chemical over a 24-hour exposure period during dewatering from KP102. The results were calculated from 25 simulations with different metocean conditions.

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