BAROSSA GAS EXPORT PIPELINE INSTALLATION EP REVISION

Treated Seawater and MEG Dispersion Modelling

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EXECUTIVE SUMMARY

Background

Barossa is an approved offshore natural gas development located approximately 300 kilometres north-west of Darwin. The extracted lean dry gas from the field will be exported through a new gas export pipeline (GEP) that will tie into the existing Bayu-Undan to Darwin gas export pipeline, which will then be liquefied for export at the existing Darwin Liquefied Natural Gas (LNG) facility at Wickham Point, Northern Territory.

As part of the Barossa development GEP installation environmental plan (EP) approvals process, a treated water discharge dispersion modelling study was commissioned at the most southern end of the pipeline for the following scenario:

- A 12,000 m^3 discharge over a period of 21.5 hours (558 m^3/hr), 3.5 m above the seafloor containing a 550 ppm initial concentration of the chemical treatment.

The purpose of the modelling was to determine the potential area of exposure from the chemical treatment within the treated seawater discharge.

The Barossa GEP installation EP was accepted by NOPSEMA in 2020 and continues to be the 'base case' for delivery of Barossa gas to Darwin. Hence, Santos continues to progress all regulatory approvals for this case.

Santos is currently investigating a 'new stage' of the approved development which represents a potential extension of the Barossa GEP. As such, the Barossa GEP could potentially be extended 23.1 km into Commonwealth waters, laid in parallel to the Bayu-Undan to Darwin pipeline and be connect to the DLNG facility. The extension supports a potential future opportunity to deliver gas via the pipeline to the DLNG facility while preserving the Bayu-Undan to Darwin pipeline for life extension and/or re-purposing opportunities.

Accordingly, to support the EP revision, Santos had commissioned a treated seawater dispersion modelling study for the following cases:

- Case 1 26" line – A 26" diameter length of pipeline between Darwin LNG and KP380 (~122.745 km) will be dewatered and the volume of treated seawater to be released (~41,359 m^3) containing Monoethylene Glycol ((MEG) ~1,000 m^3). The pig velocity of 1 m/s will result in an exit velocity for the treated seawater and MEG of 12.4 m/s (flow rate 1,086 m^3/hr) via the three port 4" diffuser pointed vertically upwards at +45 degrees positioned 3.5 m above the seabed. It is estimated that the treated seawater and MEG will be released over 35 hours.

- Case 2 26/34" hybrid line – A 34" diameter pipeline from Darwin LNG will be initially dewatered for a distance of ~59.745 km, followed by a 26" diameter pipeline which covers a length of 63.000 km to the offshore waters. The volume of treated seawater to be released is 55,614 m^3 containing 1,000 m^3 of MEG. The pig velocity of 1 m/s will result in an exit velocity for the treated seawater and MEG of 21.3 m/s (flow rate for the 34" is 1,867 m^3/hr and 26" is 1,086 m^3/hr) also via the three port 4" diffuser pointed vertically upwards at +45 degrees positioned 3.5 m above the seabed. It is estimated that the treated seawater and MEG will be released over 35 hours.

The treated seawater will have the same water temperature and salinity as the surrounding seawater (28.2^{o}C and 34.6 psu, respectively). The release location is 150 m north of the base case site.

As the MEG, which is a thermodynamic hydrate inhibitor is considered to pose little or no risk to the environment, the dispersion modelling study focused on the corrosion inhibitor/oxygen scavenger in the treated seawater as it has the greater toxicity. An initial dosage rate of 550 ppm (or mg/L) was examined for the two options.

Methodology

The physical mixing of the treated seawater can be separated into 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, as 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 is complete, the far-field phase examined the transported and mixing of the corrosion inhibitor by the ambient currents.

The extent and area of predicted exposure of the discharge were reported according to established species protection levels (PC) and corresponding No Observable Effect Concentration (NOEC) thresholds. As a conservative approach, the PC99% NOEC of 0.06 mg/L (1:9,167 dilution based on initial concentration of 550 ppm) was used as the minimum reporting threshold. Additional, reporting thresholds based on the 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. The NOEC values are typically derived from long term tests where organisms are exposed between 48 and 96 hrs. So, due to the short release duration (35 hours) and in turn short exposure times compared to the ecotoxicological testing, as an additional level of conservatism the values in each model 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.

Key Findings

The key findings are:

- For both cases the results showed that treated seawater (and MEG) would initially project upward at a 45-degree angle due to the diffuser orientation and the high exit velocities. Once the plume has lost its momentum, the neutrally buoyant plume mixed laterally due to the currents.
- One run out of the 25 per case, all with different metocean conditions had resulted in exposure to the shoulder of Shepparton Shoal south of the release location. Hence, a 4% probability of exposure at the PC95% of 0.1 ppm (or mg/L) for Case 1 and PC90% of 0.15 ppm (or mg/L) for Case 2, over a 12 hour continuous exposure period.
- The maximum distance from the release location to the PC99% was 5.54 km and 7.23 km for the Case 1 (26" line) and Case 2 (26/34" hybrid line), respectively. While the area of exposure was 2.98 km^2 and 4.68 km^2 for Cases 1 and 2, respectively, based on the PC99%.

1 INTRODUCTION

1.1 Background

Barossa is an approved offshore natural gas development located approximately 300 kilometres north-west of Darwin. The extracted lean dry gas from the field will be exported through a new gas export pipeline (GEP) that will tie into the existing Bayu-Undan to Darwin gas export pipeline, which will then be liquefied for export at the existing Darwin Liquefied Natural Gas (LNG) facility at Wickham Point, Northern Territory (NT).

The development area is located in Commonwealth waters with initial development occurring within petroleum production licence NT/L1, known as the Barossa Field. The initial development involves producing the Barossa Field through subsea wells and a network of subsea flowlines and marine risers to a Floating, Production, Storage and Offtake (FPSO) vessel. Processing will then occur on the FPSO to separate the natural gas and condensate. The extracted lean dry gas will be exported through a new gas export pipeline (GEP) that will tie into the existing Bayu-Undan to Darwin gas export pipeline. The lean dry gas will then be liquefied for export at the Darwin Liquefied Natural Gas (LNG) facility at Wickham Point, NT.

As part of the Barossa development GEP installation environmental plan (EP) approvals process, a treated water discharge dispersion modelling study was commissioned at the most southern end of the pipeline for the following scenario:

- A 12,000 m^3 discharge over a period of 21.5 hours (558 m^3/hr), 3.5 m above the seafloor containing a 550 ppm initial concentration of the chemical treatment.

The purpose of the modelling was to determine the potential area of exposure from the chemical treatment within the treated seawater discharge.

The Barossa GEP installation EP was accepted by NOPSEMA in 2020 and continues to be the 'base case' for delivery of Barossa gas to Darwin. Hence, Santos continues to progress all regulatory approvals for this case.

Santos is currently investigating a 'new stage' of the approved development which represents a potential extension of the Barossa GEP. As such, the Barossa GEP could potentially be extended 23.1 km into Commonwealth waters, laid in parallel to the Bayu-Undan to Darwin pipeline and be connect to the DLNG facility. The extension supports a potential future opportunity to deliver gas via the pipeline to the DLNG facility while preserving the Bayu-Undan to Darwin pipeline for life extension and/or re-purposing opportunities.

Accordingly, to support the EP revision, Santos had commissioned a treated seawater dispersion modelling study for the following cases:

- Case 1 26" line – A 26" diameter length of pipeline between Darwin LNG and KP380 (~122.745 km) will be dewatered and the volume of treated seawater to be released (~41,359 m^3) containing Monoethylene Glycol ((MEG) ~1,000 m^3). The pig velocity of 1 m/s will result in an exit velocity for the treated seawater and MEG of 12.4 m/s (flow rate 1,086 m^3/hr) via the three port 4" diffuser pointed vertically upwards at +45 degrees positioned 3.5 m above the seabed. It is estimated that the treated seawater and MEG will be released over 35 hours.

- Case 2 26/34" hybrid line – A 34" diameter pipeline from Darwin LNG will be initially dewatered for a distance of ~59.745 km, followed by a 26" diameter pipeline which covers a length of 63.000 km to the offshore waters. The volume of treated seawater to be released is 55,614 m^3 containing 1,000 m^3 of MEG. The pig velocity of 1 m/s will result in an exit velocity for the treated seawater and MEG of 21.3 m/s (flow rate for the 34" is 1,867 m^3/hr and 26" is 1,086 m^3/hr) also via the three port 4" diffuser pointed vertically upwards at +45 degrees positioned 3.5 m above the seabed. It is estimated that the treated seawater and MEG will be released over 35 hours.

The treated seawater will have the same water temperature and salinity as the surrounding seawater (28.2°C and 34.6 psu, respectively). The release location (see Table 1.1 and Figure 1.1), hereafter referred to as PTS (Pipeline To Shore) is 150 m north of the base case site.

As the MEG, which is a thermodynamic hydrate inhibitor is considered to pose little or no risk to the environment, the dispersion modelling study focused on the corrosion inhibitor/oxygen scavenger in the treated seawater as it has the greater toxicity. An initial dosage rate of 550 pm (or mg/L) was examined for the two options.

Table 1.1 Coordinates of the PTS treated seawater release location.

Identifier	Latitude (S)	Longitude (E)	Water Depth (m)
PTS	12° 1' 22.650"	129° 54' 25.620"	~54

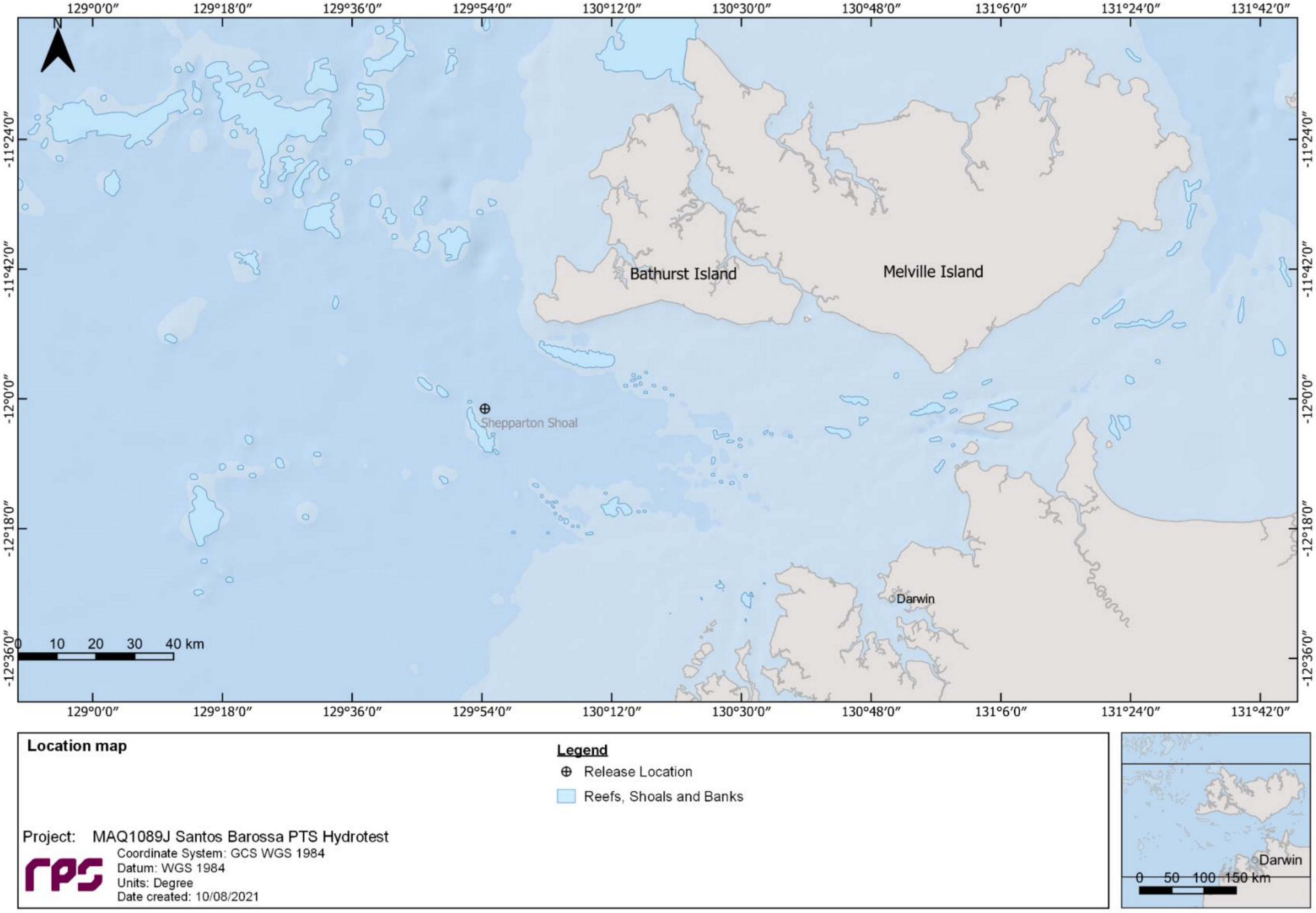


Figure 1.1 Map shows the 'new stage' PTS treated seawater release location.

2 SCOPE OF WORK

The physical mixing of the 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 and MEG; while the mixing of the corrosion inhibitor chemical is assessed in the far-field. 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 in this instance given that the treated seawater has the same density as the surrounding seawater. Once the near-field assessment is complete, the far-field phase examined the transport and mixing of the corrosion inhibitor by the ambient currents.

The scope of work included the following components:

1. Retrieve yearlong (2016) three-dimensional current data that included the combined influence of ocean drift and tidal currents, ensuring the timeframe is suitably long to be indicative of the variable current conditions;
2. Calculate the near-field plume dynamics (or initial dilution) based on the diffuser configuration and treated seawater characteristics for both cases under weak, moderate and strong static current speeds;
3. Establish the far-field model and simulate the mixing and dispersion of the corrosion inhibitor for the two proposed cases (i.e. Case 1 (26" line) and Case 2 (26/34" hybrid line)). Twenty-five simulations were run for each case with varying start times to ensure a range of current conditions were assessed. The models for both cases were run for an additional 38 hours after the cessation of the pipeline discharge; and
4. Overlay the results of all simulations to determine the potential area of exposure from the corrosion inhibitor for each case and report the potential area of exposure and the potential exposure to Shepparton Shoal, which is located 3 km west of the release location.

3 REGIONAL CURRENTS

The release location is southwest of Bathurst Island on the boundaries of the Joseph Bonaparte Gulf and the Beagle Gulf, a shallow (generally <100 m) waterbody bordered by the Timor Sea. The area is characterised by complex geomorphology (i.e. shoals, valleys and terraces) and is dominated by tidal (ranges > 4 m) and wind driven currents which are dependent on season (DEWHA, 2008). The strength of the tidal currents generally follows similar patterns to tidal sea-level, with localised enhancement around headlands and bathymetric constrictions (CSIRO, 2005).

To accurately account for the local current speeds and directions, a dataset was created that included the combined influence of tidal and ocean currents.

3.1 Development of Regional Current Data

3.1.1 Ocean currents

Data describing the three-dimensional flow of ocean currents for 2016 was obtained from HYCOM (Hybrid Coordinate Ocean Model; Chassignet et al., 2007), which is operated by the HYCOM Consortium, sponsored by the Global Ocean Data Assimilation Experiment (GODAE). HYCOM is a data-assimilative, three-dimensional ocean model that is run as a hindcast (for a past period), assimilating time-varying observations of sea surface height, sea surface temperature and in-situ temperature and salinity measurements (Chassignet et al., 2009). The HYCOM predictions for drift currents are produced at a horizontal spatial resolution of approximately 8.25 km (1/12th of a degree) over the region, at a frequency of once per day. HYCOM uses isopycnal layers in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain following coordinate in shallow coastal regions, and to z-level coordinates in the mixed layer and/or unstratified seas.

3.1.2 Tidal currents

Tidal current data was generated using RPS's advanced ocean/coastal model, HYDROMAP. The HYDROMAP model has been thoroughly tested and verified through field measurements throughout the world for over 30 years (Isaji and Spaulding, 1984; Isaji et al., 2001; Zigic et al., 2003). In fact, HYDROMAP tidal current data has been used as input to forecast (in the future) and hindcast (in the past) oil spills in Australian waters and forms part of the Australian National Oil Spill Emergency Response System operated by AMSA (Australian Maritime Safety Authority).

HYDROMAP employs a sophisticated sub-gridding strategy, which supports up to six levels of spatial resolution, halving the grid cell size as each level of resolution is employed. The sub-gridding allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, and/or of particular interest to a study.

The numerical solution methodology follows that of Davies (1977a, 1977b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji and Spaulding (1984) and Isaji et al. (2001).

3.2 Near-Seabed Current Validation

To confirm the suitability of the generated current data, the data was compared against month-long near-seabed current measurements at ITFFTB and DARBGF, which was sourced from the IMOS National Reference Station (NRS) Network[1] (IMOS; Figure 3.1). The water depths at the ITFFTB and DARBGF mooring locations were 108 m and 30 m respectively, which are not too dissimilar to the water depth at the release location (54 m).

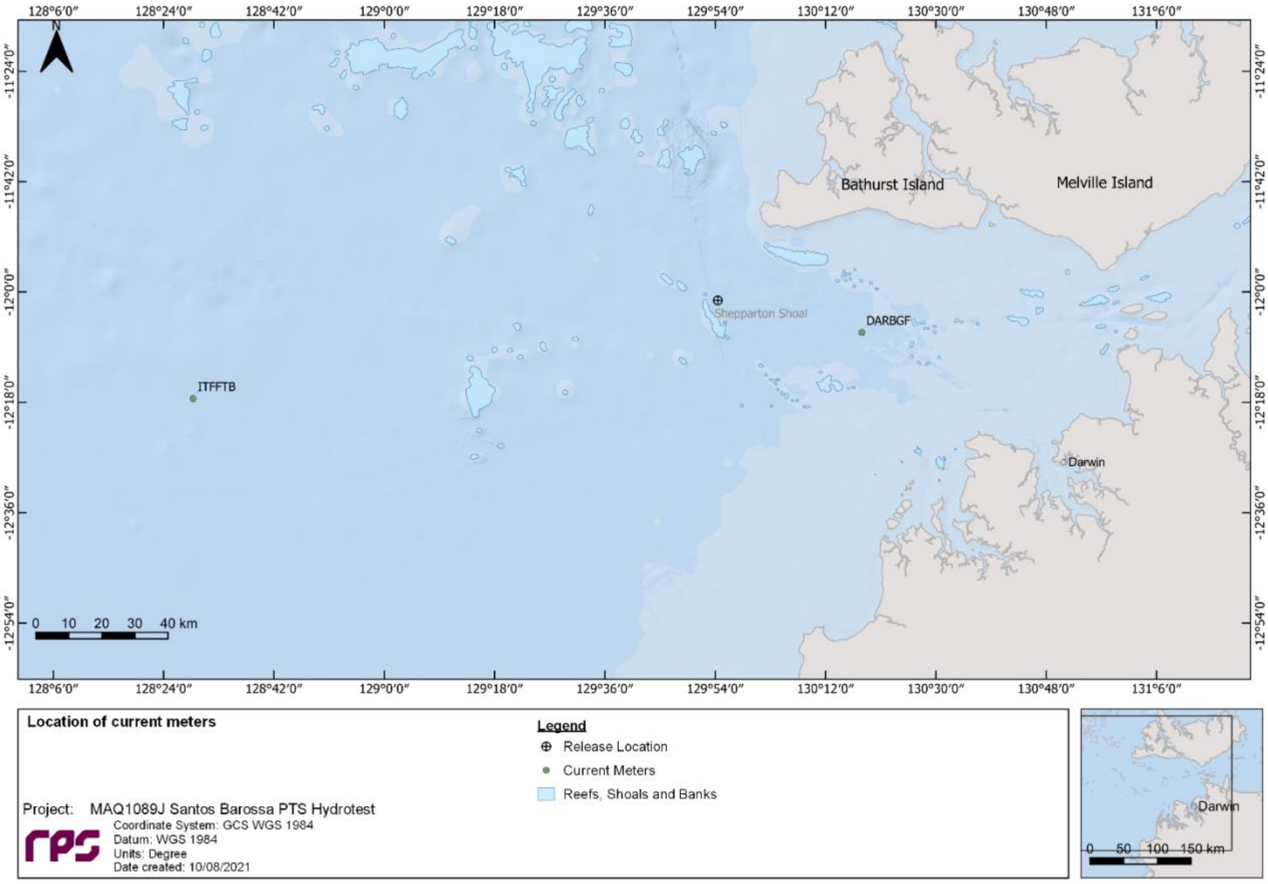


Figure 3.1 Locations of the IMOS current meter moorings.

Figure 3.2 and Figure 3.3 show a comparison between the measured and predicted currents at ITFFTB and DARBGF, respectively during January 2016. The comparisons reveal that the predicted currents offer a very good agreement with the measured current speed and directions at both locations, with the magnitudes and timings of the peaks and troughs matching well.

With the modelled data being able to correctly resolve the currents at both locations, it was considered that the local circulation patterns at the release location would also be adequately resolved and that the model is considered suitable for the dispersion modelling study herein.

[1] Australia's Integrated Marine Observing System (IMOS) is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

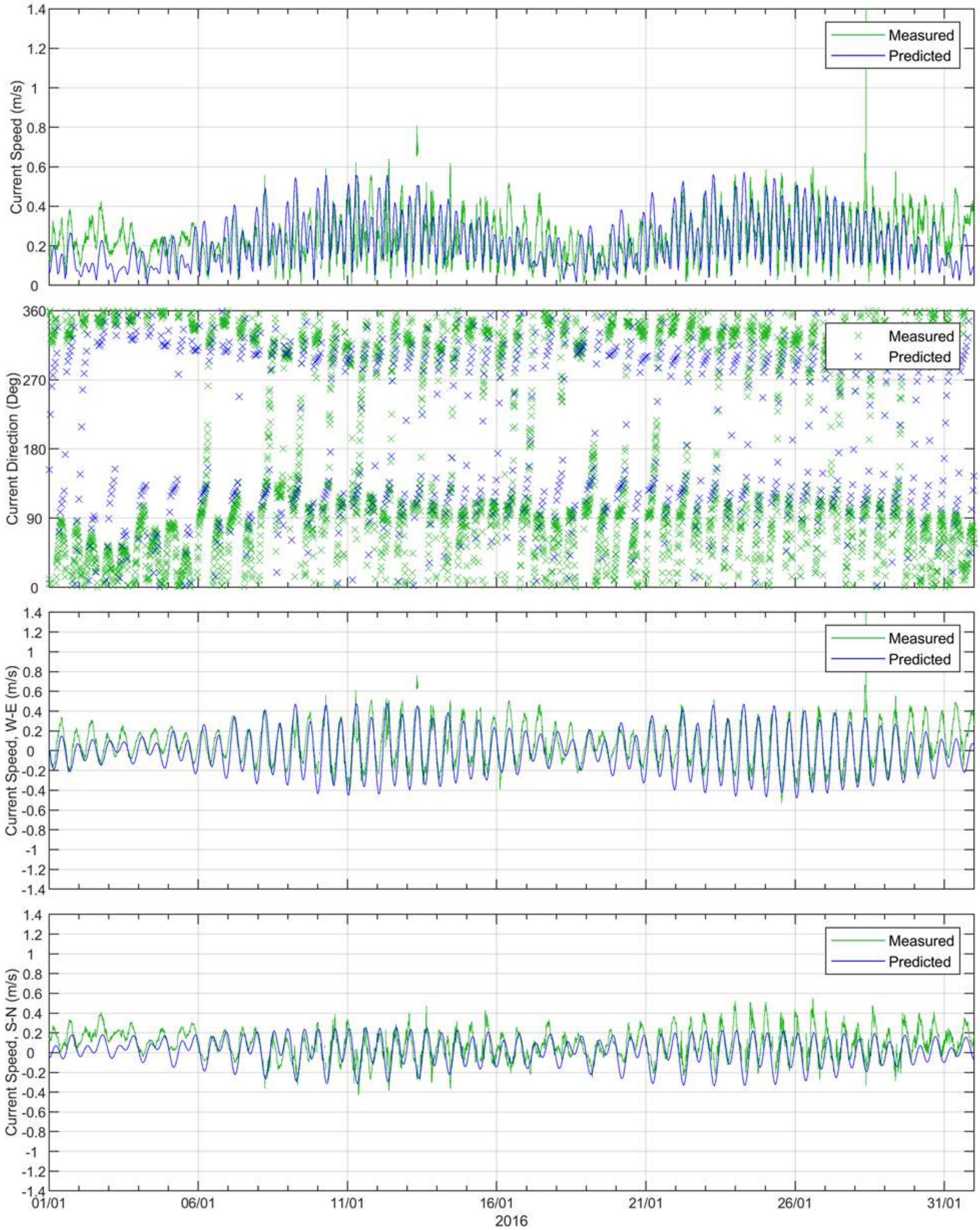


Figure 3.2 Comparison of measured (green timeseries) and predicted (blue timeseries) current speeds, directions, and East-West and North-South components, 10 m above the seabed at mooring ITFFTB.

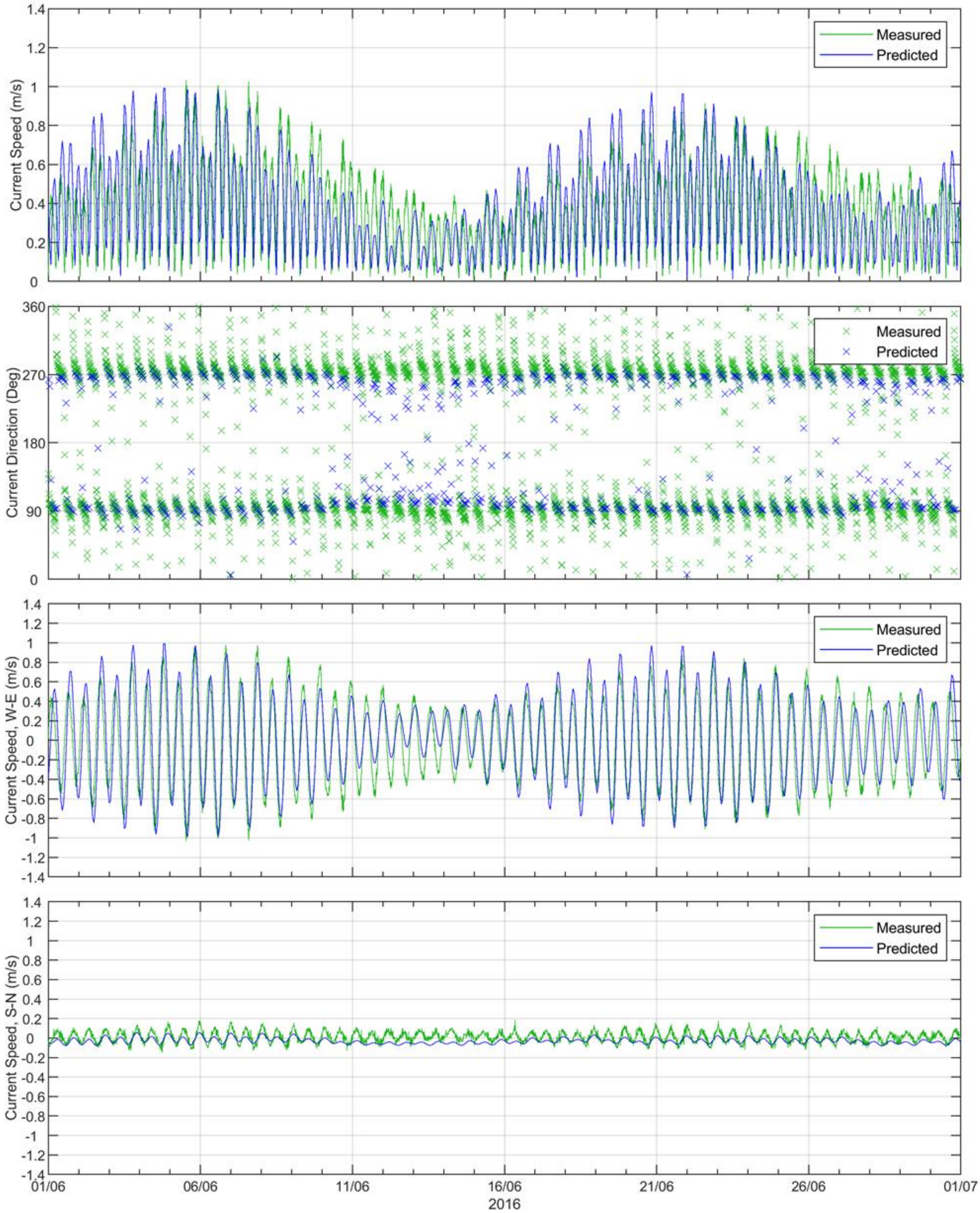


Figure 3.3 Comparison of measured (green timeseries) and predicted (blue timeseries) current speeds, directions, and East-West and North-South components, 10 m above the seabed at mooring DARBGF.

3.3 Near-Seabed Currents

Table 3.1 displays the predicted average and maximum near-seabed bottom currents at the release location, derived by combining the 2016 ocean and tidal datasets described above.

Figure 3.4 and Figure 3.5 show the monthly and annual near-seabed current rose distributions, respectively. 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 data showed that the currents predominantly flowed along the southeast–northwest axis. Average monthly current speeds ranged between 0.36 and 0.43 m/s. Additionally, the maximum current speeds ranged between 1.01 and 1.13 m/s (Table 3.1).

Table 3.1 Predicted average and maximum near-seabed currents adjacent to KP380. Data was based on 2016 conditions.

Month	Average current speed (m/s)	Maximum current speed (m/s)	General Direction
January	0.37	1.02	Northwest–Southeast
February	0.39	1.06	Northwest–Southeast
March	0.39	1.01	Northwest–Southeast
April	0.37	1.10	Northwest–Southeast
May	0.38	1.13	Northwest–Southeast
June	0.37	1.04	Northwest–Southeast
July	0.38	1.07	Northwest–Southeast
August	0.42	1.07	Northwest–Southeast
September	0.43	1.06	Northwest–Southeast
October	0.39	1.09	Northwest–Southeast
November	0.39	1.07	Northwest–Southeast
December	0.36	1.04	Northwest–Southeast
Minimum	**0.36**	**1.01**	
Maximum	**0.43**	**1.13**	

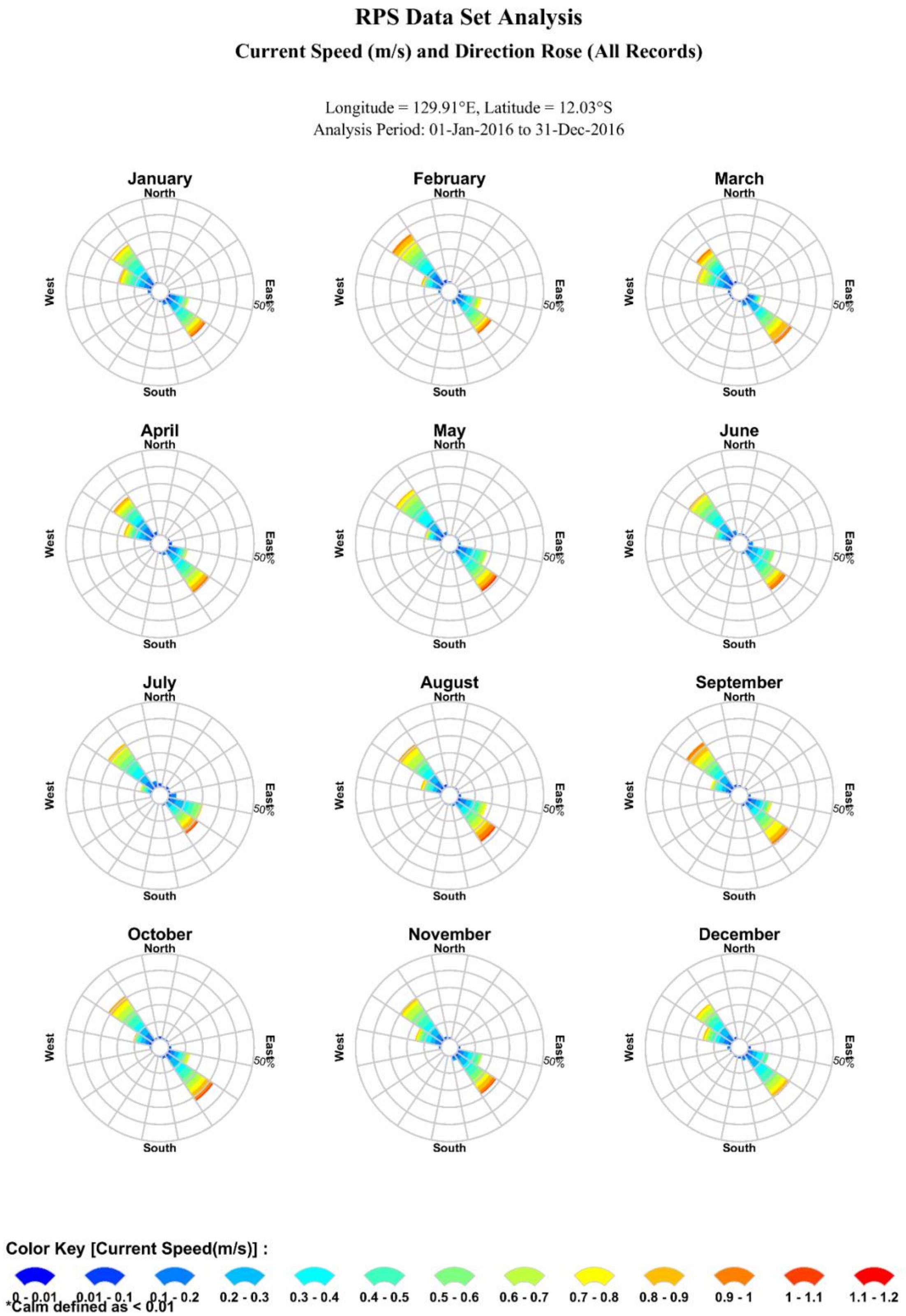


Figure 3.4 Monthly near-seabed current rose plots near the release location. Derived by combining the tidal currents and ocean currents for 2016. The colour key shows the current magnitude (m/s), the compass direction provides the current direction flowing TOWARDS and the length of the wedge gives the percentage of the record for a particular speed and direction combination.

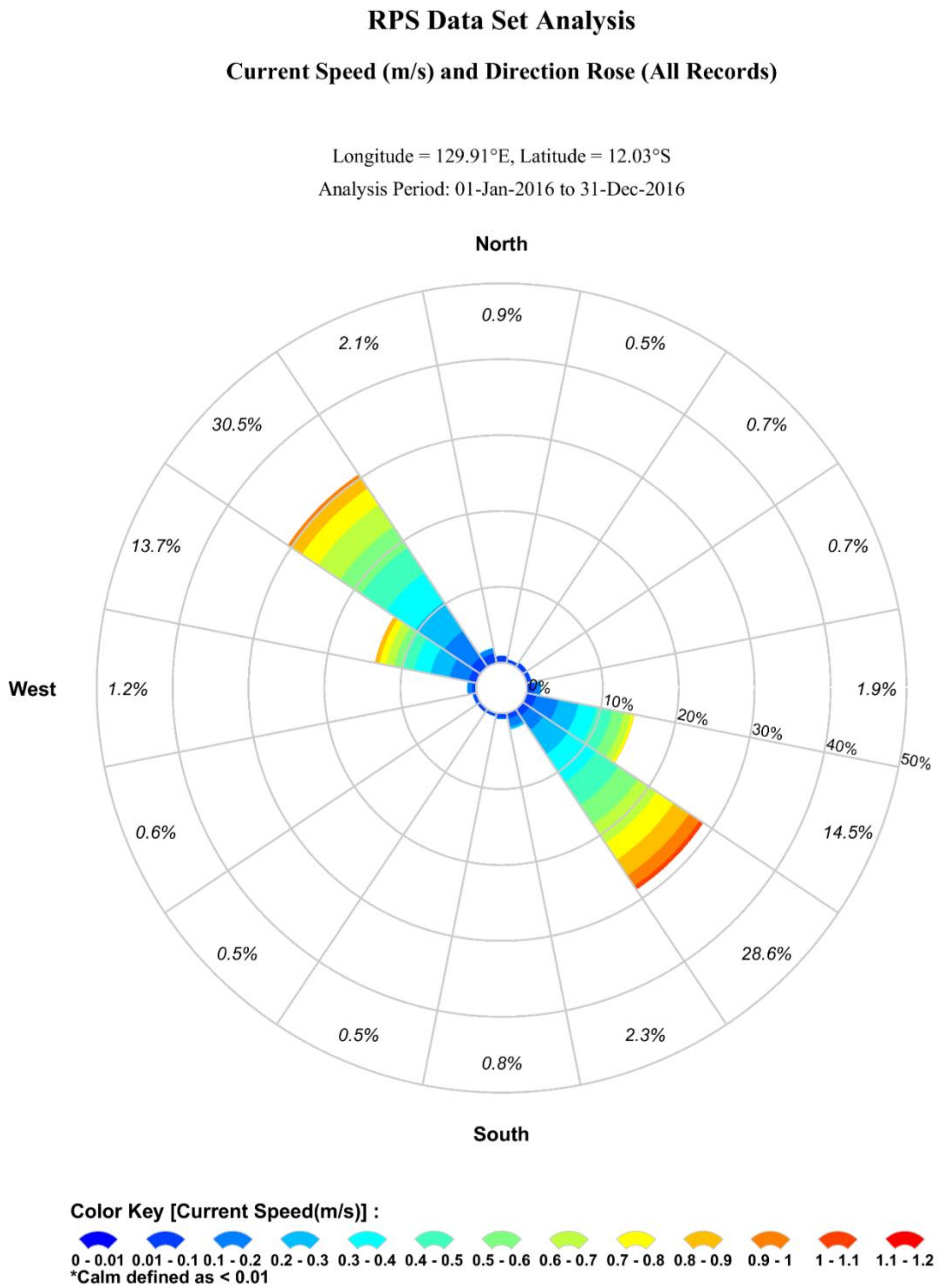


Figure 3.5 Annual near-seabed current rose plots near the release location. Derived by combining the tidal currents and ocean currents for 2016. The colour key shows the current magnitude (m/s), the compass direction provides the current direction flowing TOWARDS and the length of the wedge gives the percentage of the record for a particular speed and direction combination.

4 WATER TEMPERATURE AND SALINITY

The average annual water temperature and salinity throughout the water column adjacent to the release location (see Table 4.1) was obtained from the World Ocean Atlas 2013 database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration) and its co-located World Data Centre for Oceanography (see Levitus et al., 2013; NODC, 2013).

Table 4.1 Average annual water temperature and salinity through the water column adjacent to the release location.

Water depth (m)	Temperature (°C)	Salinity (psu)
0	28.7	34.4
10	28.7	34.5
20	28.6	34.5
30	28.4	34.5
40	28.3	34.6
50	28.2	34.6

5 ENVIRONMENTAL REPORTING CRITERIA

Monoethylene Glycol (MEG) is used to prevent hydrate formation in pipelines (i.e., thermodynamic hydrate inhibitor (Teixeira et al., 2017)). It is readily biodegraded under both aerobic and anaerobic environments and does not bioaccumulate in aquatic organisms (Staples et al. 2001). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000) specify a marine low reliability trigger value of 50,000 µg/L (50 ppm) for MEG in sea water. The World Health Organization (WHO) has reported a no observed effect concentration (NOEC) of 24,000 ppm for MEG (WHO, 2000). Furthermore, MEG is considered a PLONOR (Pose Little or No Risk to the Environment) chemical by the OSPAR commission (OSPAR, 2019). As such the study focused on the concentrations from the corrosion inhibitor.

Santos plan to use a combined biocide/oxygen scavenger such as Hydrosure 0-3670R to treat the seawater and flowline preservation. Whole of Effluent Toxicity (WET) testing was conducted to assess the toxicity of the effluent on a suite of relevant local species under a range of exposure concentrations using the recommended protocols from ANZECC and ARMCANZ (2000). The No Observable Effects Concentration (NOEC) for a 99% species protection level (PC) was 0.06 mg/L and 0.1 mg/L for the PC95% (Chevron 2015). The NOEC values for varying species protection levels and the dilutions to achieve the concentration based on a dosage of 550 ppm are presented in Table 5.1.

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

While the NOEC values are derived from long term ecological tests whereby organisms are exposed for periods typically between 48 and 96 hrs, in this instance the release duration short (35 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.

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 and 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 5.2 is a summary of the treated seawater discharge configuration and properties used as input into CORMIX. For both options, the treated seawater and MEG is to be discharged via a three port 4” diffuser pointed vertically upwards at +45 degrees positioned 3.5 m above the seabed. The treated seawater will have the same water temperature and salinity as the surrounding seawater (28.2°C and 34.6 psu, respectively) and will therefore be neutrally buoyant.

Table 5.2 Summary of the treated seawater and MEG discharge characteristics.

Parameter	Case 1 26” Line	Case 2 26/34” Hybrid Line
Total volume of treated seawater released (m^3)	41,359	55,614
Total volume of MEG released (m^3)	1,000	1,000
Exit diffuser velocity (m/s)	12.4	21.3
Diffuser configuration	Three 4” ports spaced 4” apart and oriented vertically upwards at +45 degrees	
Discharge height (m) above the seabed	3.5	
Discharge salinity (psu)	34.6 - same as ambient	
Discharge temperature (°C)	28.2 - Same as ambient	

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 (Table 5.3) 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 5.3 Adopted annual seabed static current adjacent to the release site.

Depth	5th Percentile (Weak) Current Speed (m/s)	50th Percentile (Moderate) Current Speed (m/s)	95th Percentile (Strong) Current Speed (m/s)
50	0.05	0.35	0.85

7 NEAR-FIELD RESULTS

The near-field results showed that for both cases the treated seawater (and MEG) would initially shoot upward at a 45-degree angle due to the diffuser orientation and the high exit velocities. The initial mixing that takes place will largely be due to the high exit velocities. Once the plume has lost its momentum, the neutrally buoyant plumes were predicted to travel laterally and mix/disperse with the currents.

Table 7.1 presents the predicted near-field plume characteristics and corrosion inhibitor concentrations at 10 m and 30 m (horizontally) from the release location for each case and varying static current speeds, based on an initial concentration of 550 ppm (or mg/L).

For Case 1 (26” line), within 30 m of discharge the initial corrosion inhibitor concentration reduced from 550 ppm to 5.1 and 6.1 mg/L (or ppm) under weak and strong current conditions, respectively. Meaning that within 30 m the minimum dilution was 1:107.5 and 1:90.1 for the weak and strong currents, respectively.

Alternatively, for Case 2 the inhibitor concentrations within 30 m of discharge reduced to 21.3 and 7.3 mg/L (or ppm) under weak and moderate currents, respectively. The concentration at 30 m from the release location under the strong current conditions was 7.7 mg/L (or ppm). Hence, the minimum dilution was 1:25.8 and 1:75.1 for the weak and moderate currents, respectively, and 1:71 under strong current conditions.

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.

Case	Current speed (m/s)	Distance from the release location (m)	Plume centre dilution (1:x)	Plume centre concentration (mg/L or ppm) based on an initial concentration of 550 ppm	Plume diameter (m)
Case 1 26” Line	Weak (0.05)	10.0	30.1	18.3	1.7
		30.0	107.5	5.1	4.8
	Moderate (0.35)	10.0	39.8	13.8	1.4
		30.0	111.9	4.9	2.5
	Strong (0.85)	10.0	38.7	14.2	0.9
		30.0	90.1	6.1	1.5
Case 2 26/34” Hybrid Line	Weak (0.05)	10.0	9.5	57.8	1.3
		30.0	25.8	21.3	3.4
	Moderate (0.35)	10.0	23.6	23.3	1.8
		30.0	75.1	7.3	4.0
	Strong (0.85)	10.0	24.8	22.1	1.4
		30.0	71.0	7.7	2.7

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, 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 discharges 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 and McAllister, 1997, 1998).

8.2 Far-Field Model Setup

Table 8.1 presents a summary of the far-field model parameters used to simulate the corrosion inhibitor chemical dilutions within the treated seawater.

As previously mentioned, 25 simulations were run and each simulation had a different start time, which ensured a range of current conditions were sampled. Once the simulations were complete, the results were overlayed to determine the potential area of exposure based on 12 hour continuous exposure periods.

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 1 m grid in the vertical was used to track the movement and fate of the treated seawater plume and 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 corrosion inhibitor dispersion modelling assumptions.

Parameter	Case 1 26" Line		Case 2 26/34" Hybrid Line	
Total volume of treated seawater released (m^3)	41,359		55,614	
Release duration (hours)	35			
Model simulation length (days)	3			
Treated seawater temperature (°C)	28.2 - Same as ambient			
Treated seawater salinity (psu)	34.6 - Same as ambient			
Initial corrosion inhibitor dosing concentration (ppm or mg/L)	550			
Corrosion inhibitor threshold concentration (ppm or mg/L)/trigger values based on a continuous exposure over 12 hours	PC99%	PC95%	PC90%	PC80%
	0.06	0.10	0.15	0.23

9 FAR-FIELD RESULTS

9.1 General Observations

Figure 9.1 and Figure 9.2 illustrate the corrosion inhibitor concentrations between 11 am to 6 pm 2nd April 2016 for Case 1 (26" line) for the simulation commencing at 2am 2nd April 2016 which had experienced weak current conditions. Additionally, Figure 9.3 and Figure 9.4 illustrate the predicted concentrations based on Case 2 inputs for the same period. The figures illustrate the maximum predicted concentrations for the particular time as an aerial plan view and the nearby Shepparton Shoal.

The images have been included to illustrate the movement and concentrations of the corrosion inhibitor 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 concentrations during this period demonstrate decreasing concentrations with increasing distance from the release location.

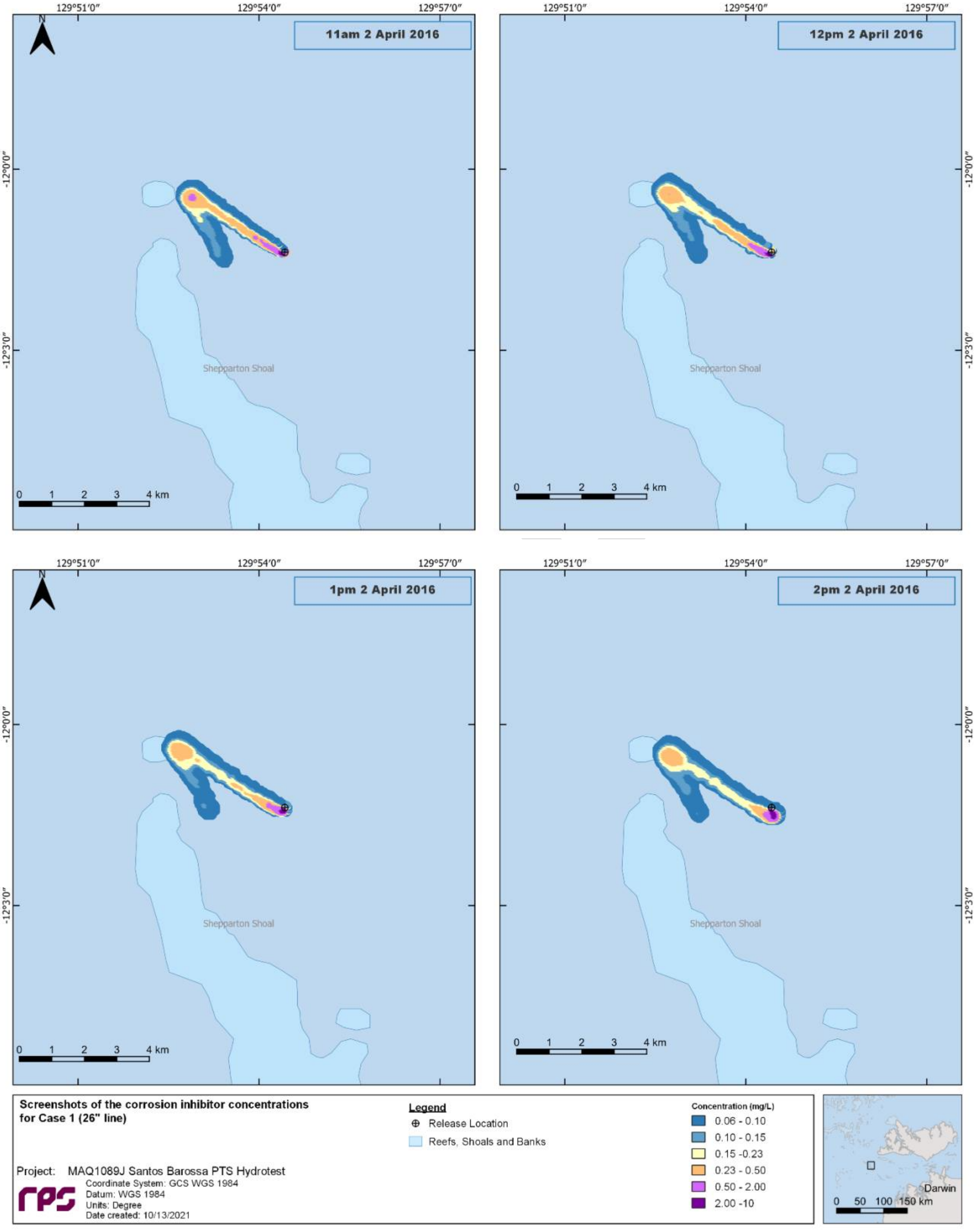


Figure 9.1 Predicted corrosion inhibitor concentrations between 11 am to 2 pm 2nd April 2016 for Case 1 (26" line).

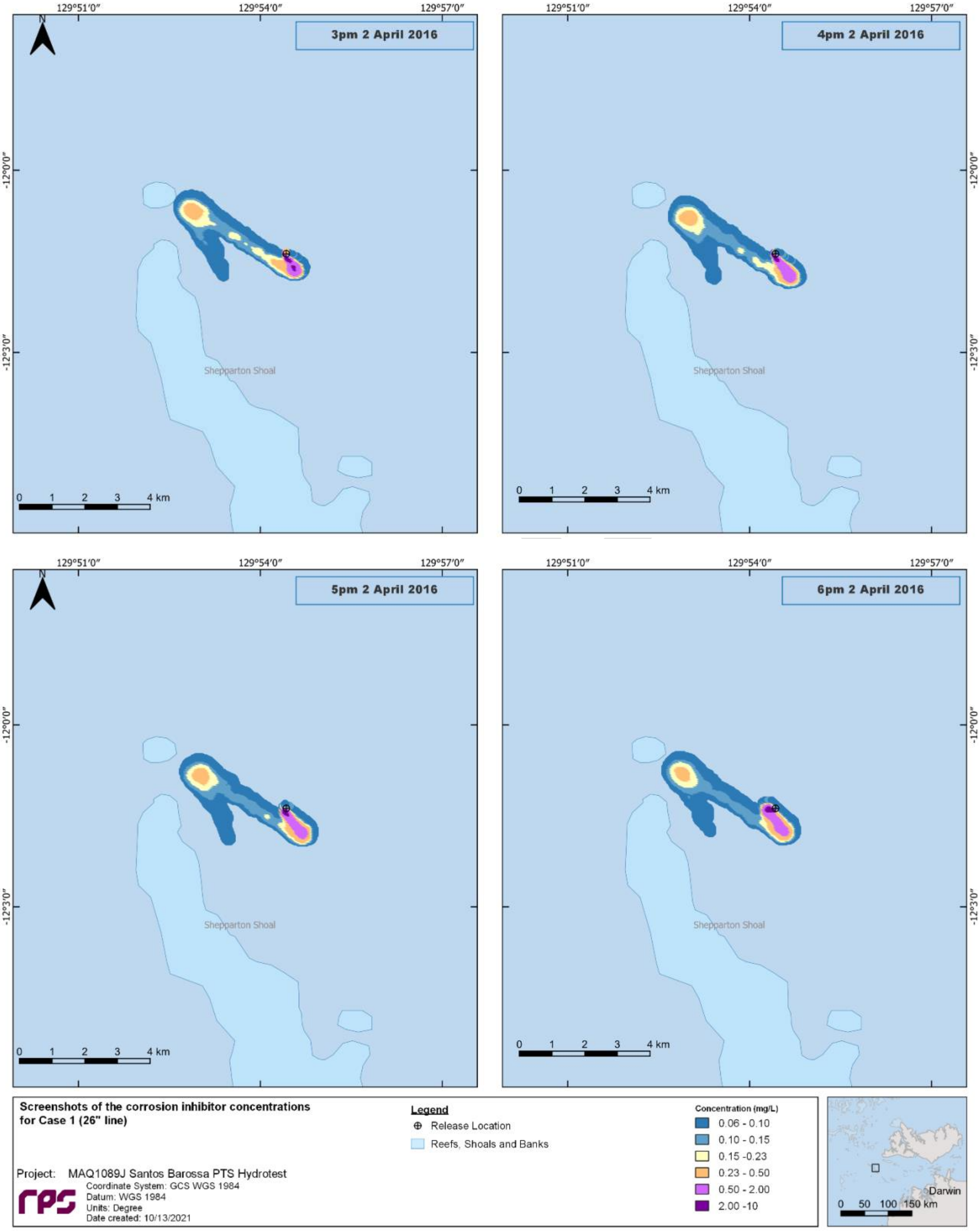


Figure 9.2 Predicted corrosion inhibitor concentrations between 3 pm to 6 pm 2nd April 2016 for Case 1 (26" line).

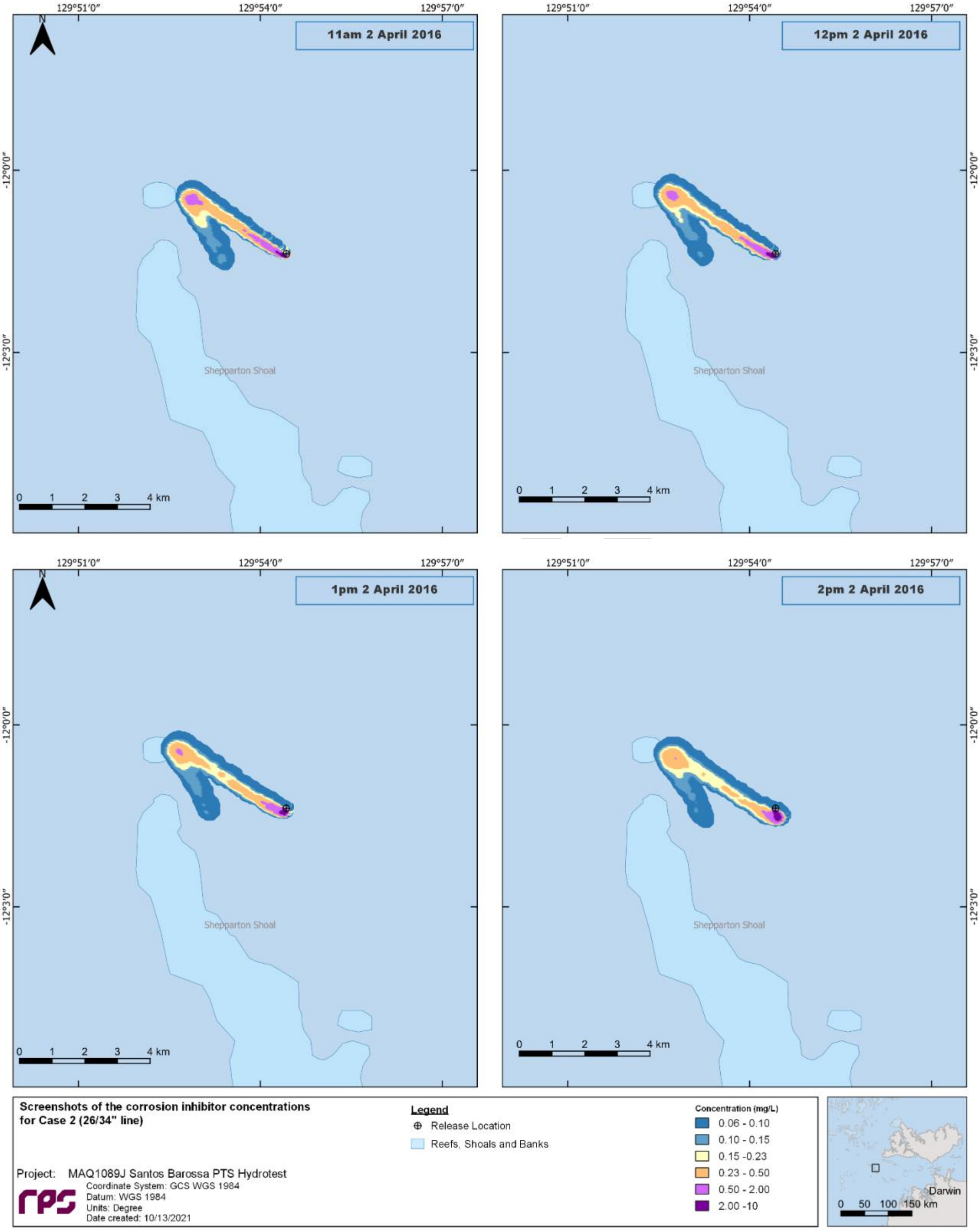


Figure 9.3 Predicted corrosion inhibitor concentrations between 11 am to 2 pm 2nd April 2016 for Case 2 (26/34" line).

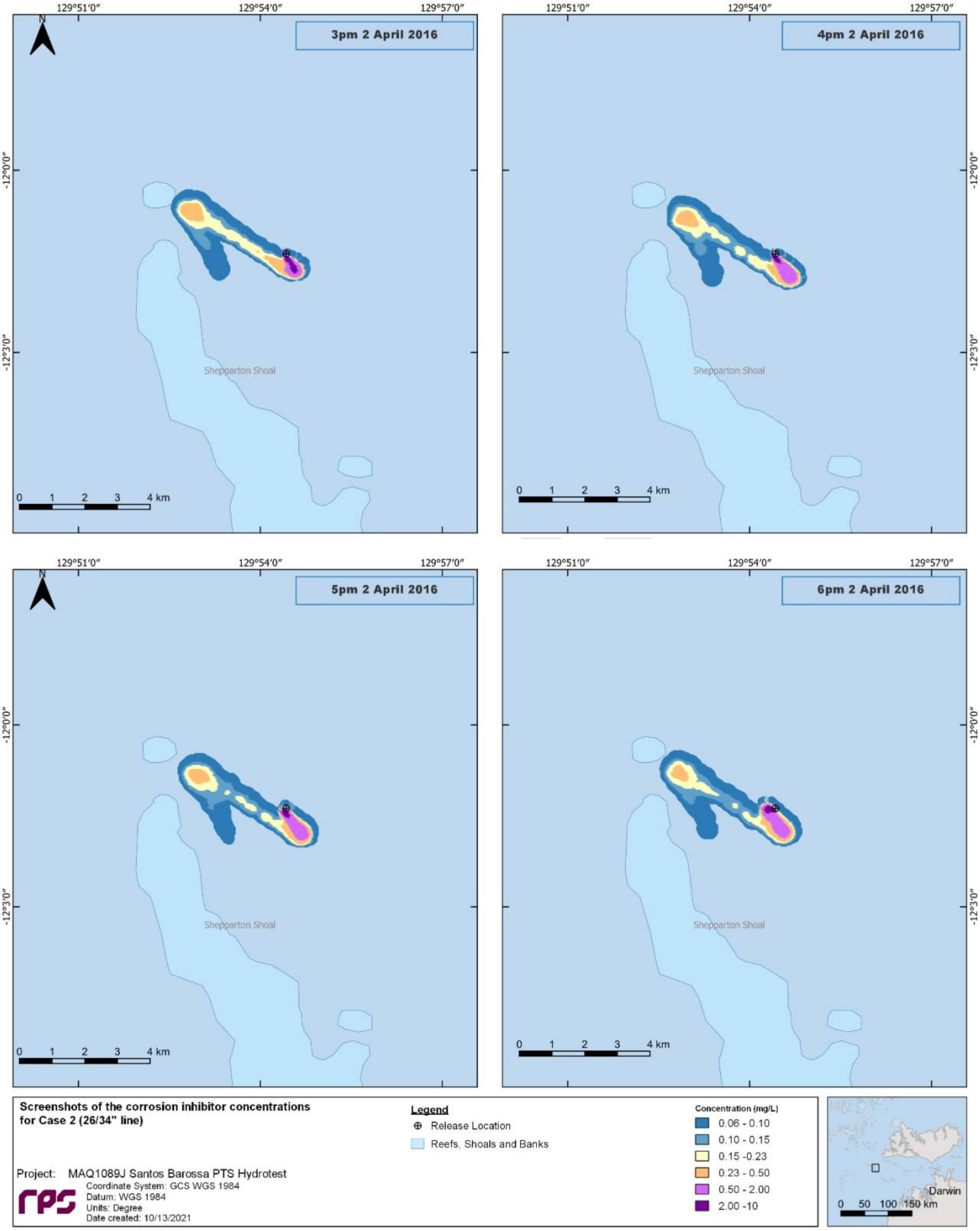


Figure 9.4 Predicted corrosion inhibitor concentrations between 3 pm to 6 pm 2nd April 2016 for Case 2 (26/34" line).

9.2 Combined Analysis

One run (Simulation 19) out of the 25, all with different metocean conditions, for each case resulted in exposure to the shoulder of Shepparton Shoal south of the release location. Hence, a 4% probability of exposure at the NOEC PC95% (0.1 ppm or mg/L) for Case 1 and NOEC PC90% (0.15 ppm or mg/L) for Case 2. Figure 9.5 and Figure 9.6 illustrate the extent of the predicted corrosion inhibitor concentrations over a continuous 12 hour exposure period based on a dosage of 550 ppm for a single run (simulation 19) for Cases 1 and 2, respectively.

Figure 9.7 and Figure 9.8 illustrate the extent of the predicted corrosion inhibitor concentrations based on all 25 simulations for Case 1 (26" line) and Case 2 (26/34" hybrid line), respectively.

Table 9.1 summarises the maximum distance from the release location and area of exposure for the NOEC values for each case modelled. The table also presents the distance of each concentration to Shepparton Shoal.

The maximum distance from the release location to the PC99% of 0.06 ppm (or mg/L) was 5.54 km and 7.23 km for the Case 1 (26" line) and Case 2 (26/34" hybrid line), respectively. Additionally, the maximum distance from the release location to the PC95% of 0.10 ppm (or mg/L) was 5.29 km and 5.33 km for Case 1 and Case 2, respectively. Furthermore, for both cases the maximum distance based on the PC80% (0.23 mg/L) did not exceed 0.2 km (Table 9.1).

The conservative 'outer envelope' area of exposure was 2.98 km^2 and 4.68 km^2 for Cases 1 and 2, respectively, based on the PC99% NOEC threshold of 0.06 ppm and a 12 hour continuous exposure period.

Table 9.1 Summary of the maximum distance from the release location and area of exposure for each NOEC value. Also presented is the minimum distance to Shepparton shoal for each NOEV value. The results are derived from 25 simulations and each simulation was individually assessed based on the 12 hour continuous exposure period for the NOEC values.

Case	Initial chemical dosing (ppm or mg/L)	Species protection level	NOEC value (mg/L)	Maximum horizontal distance from the release location (km)	Area of exposure (km^2)	Minimum distance from Shepparton Shoal (km)
Case 1 - 26" Line	550	PC99%	0.06	5.54	2.98	Exposure
		PC95%	0.10	5.29	0.39	Exposure
		PC90%	0.15	0.27	0.03	2.82
		PC80%	0.23	0.13	0.02	2.92
Case 2- 26/34" Hybrid Line	550	PC99%	0.06	7.23	4.68	Exposure
		PC95%	0.10	5.33	0.67	Exposure
		PC90%	0.15	5.19	0.08	Exposure
		PC80%	0.23	0.20	0.02	2.86

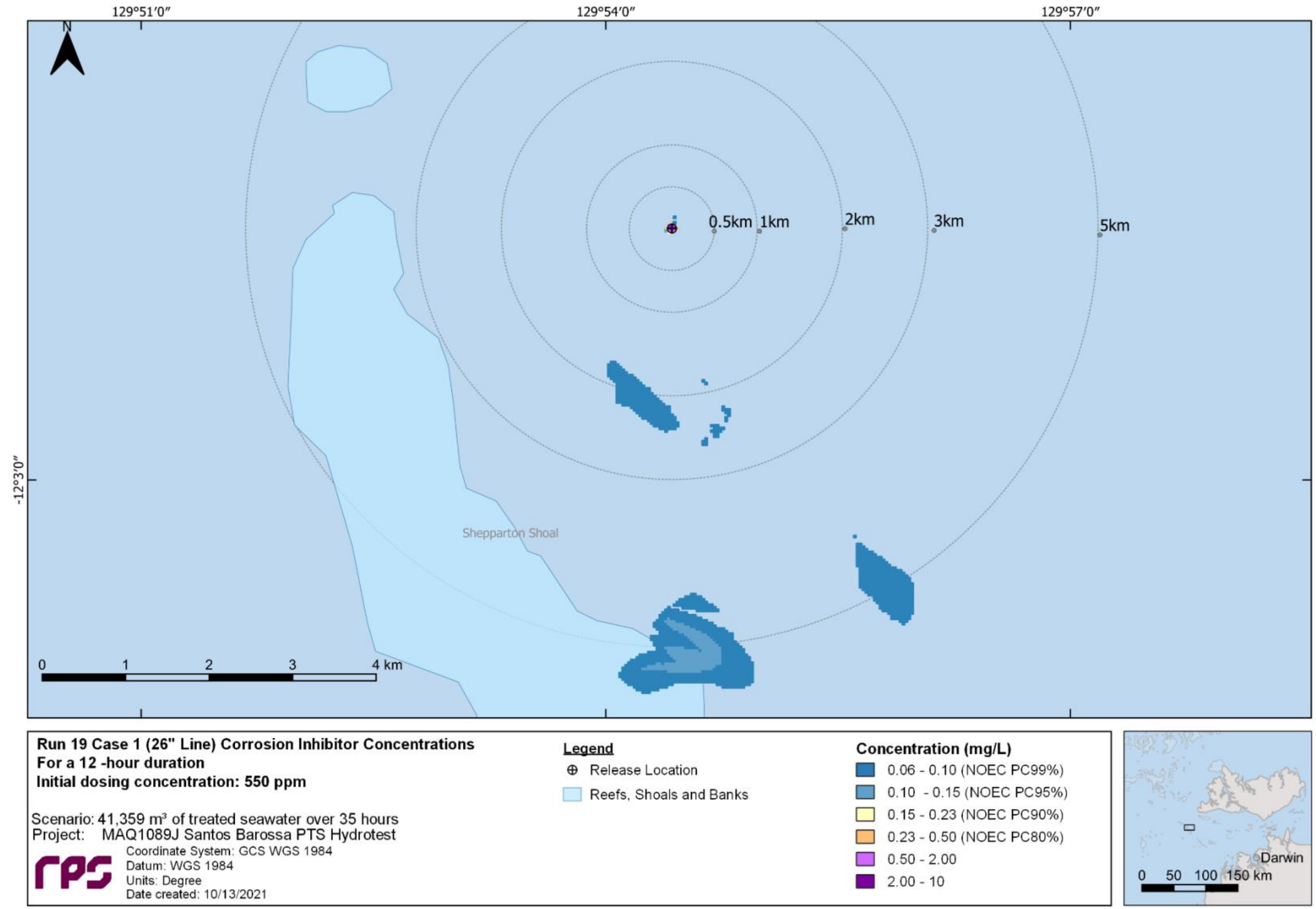


Figure 9.5 Predicted corrosion inhibitor concentrations assessed over a 12 hour continuous exposure period for Case 1 (26" line) simulation 19. The results were calculated from 25 simulations with different metocean conditions.

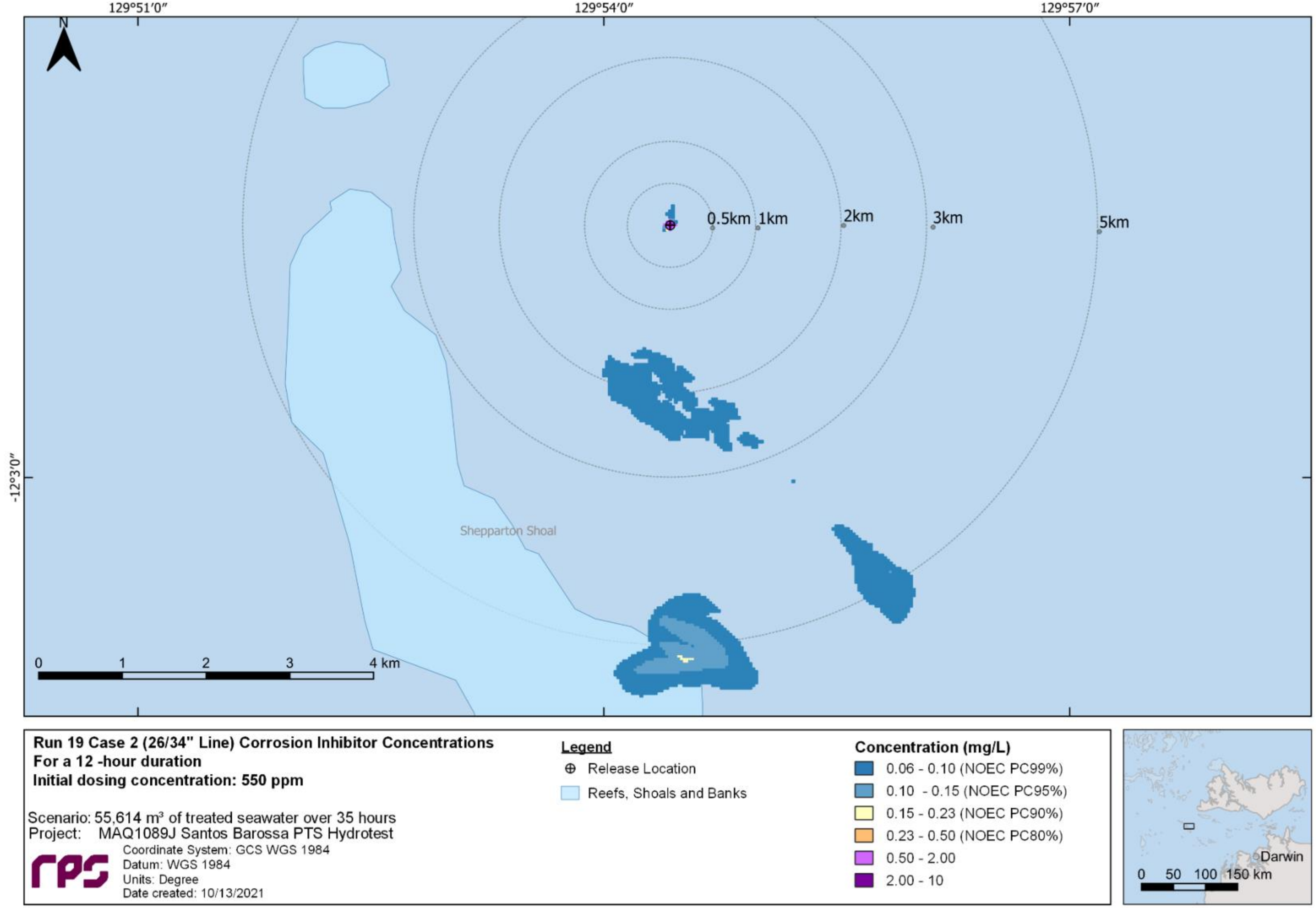
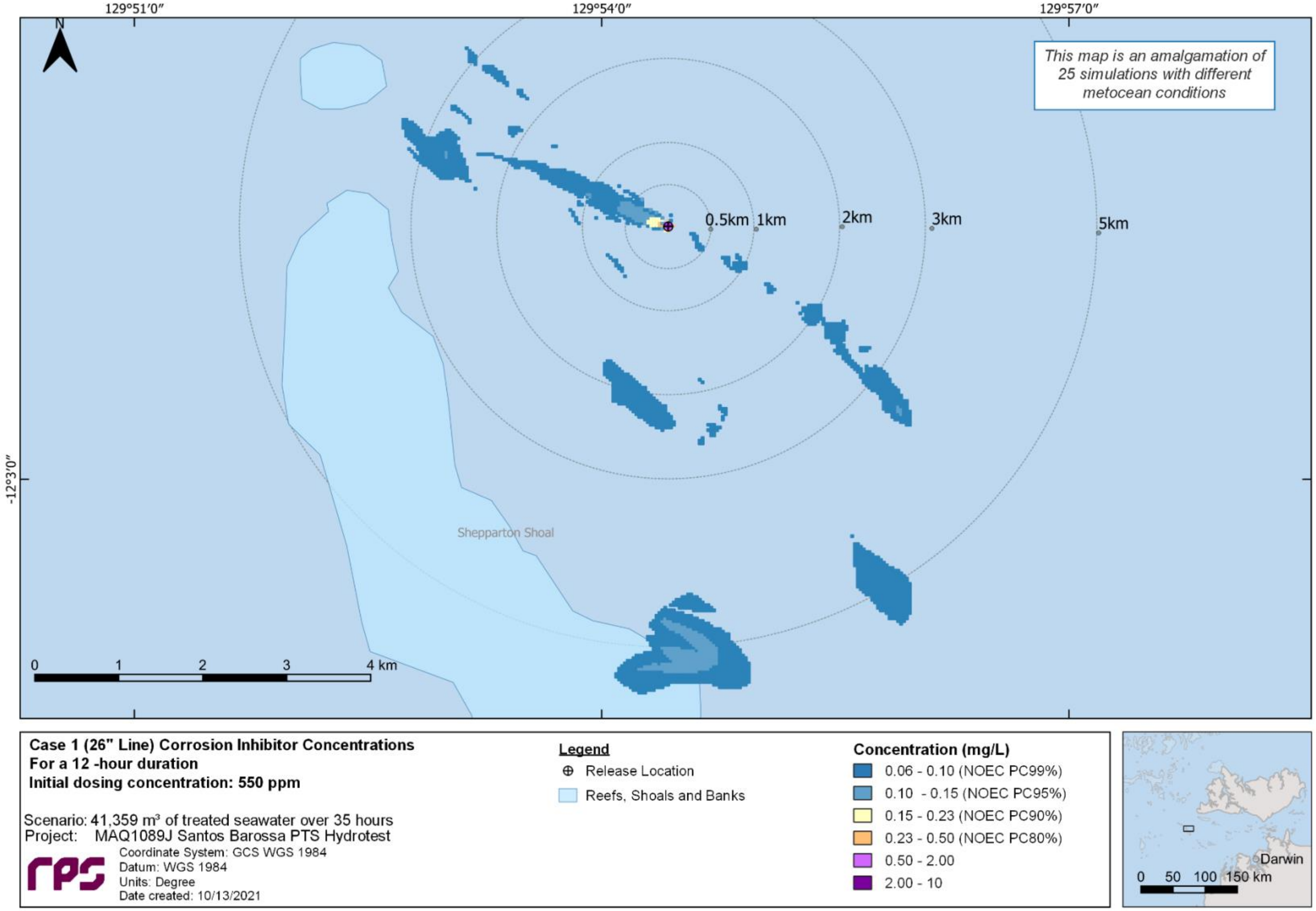


Figure 9.6 Predicted corrosion inhibitor concentrations assessed over a 12 hour continuous exposure period for the Case 2 (26/34" hybrid line) simulation 19.



Case 1 (26" Line) Corrosion Inhibitor Concentrations
For a 12 -hour duration
Initial dosing concentration: 550 ppm

Scenario: 41,359 m³ of treated seawater over 35 hours
Project: MAQ1089J Santos Barossa PTS Hydrotest
Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree
Date created: 10/13/2021

Legend
⊕ Release Location
Reefs, Shoals and Banks

Concentration (mg/L)
0.06 - 0.10 (NOEC PC99%)
0.10 - 0.15 (NOEC PC95%)
0.15 - 0.23 (NOEC PC90%)
0.23 - 0.50 (NOEC PC80%)
0.50 - 2.00
2.00 - 10

Figure 9.7 Predicted corrosion inhibitor concentrations assessed over a 12 hour continuous exposure period for Case 1 (26" line). The results were calculated from 25 simulations with different metocean conditions.

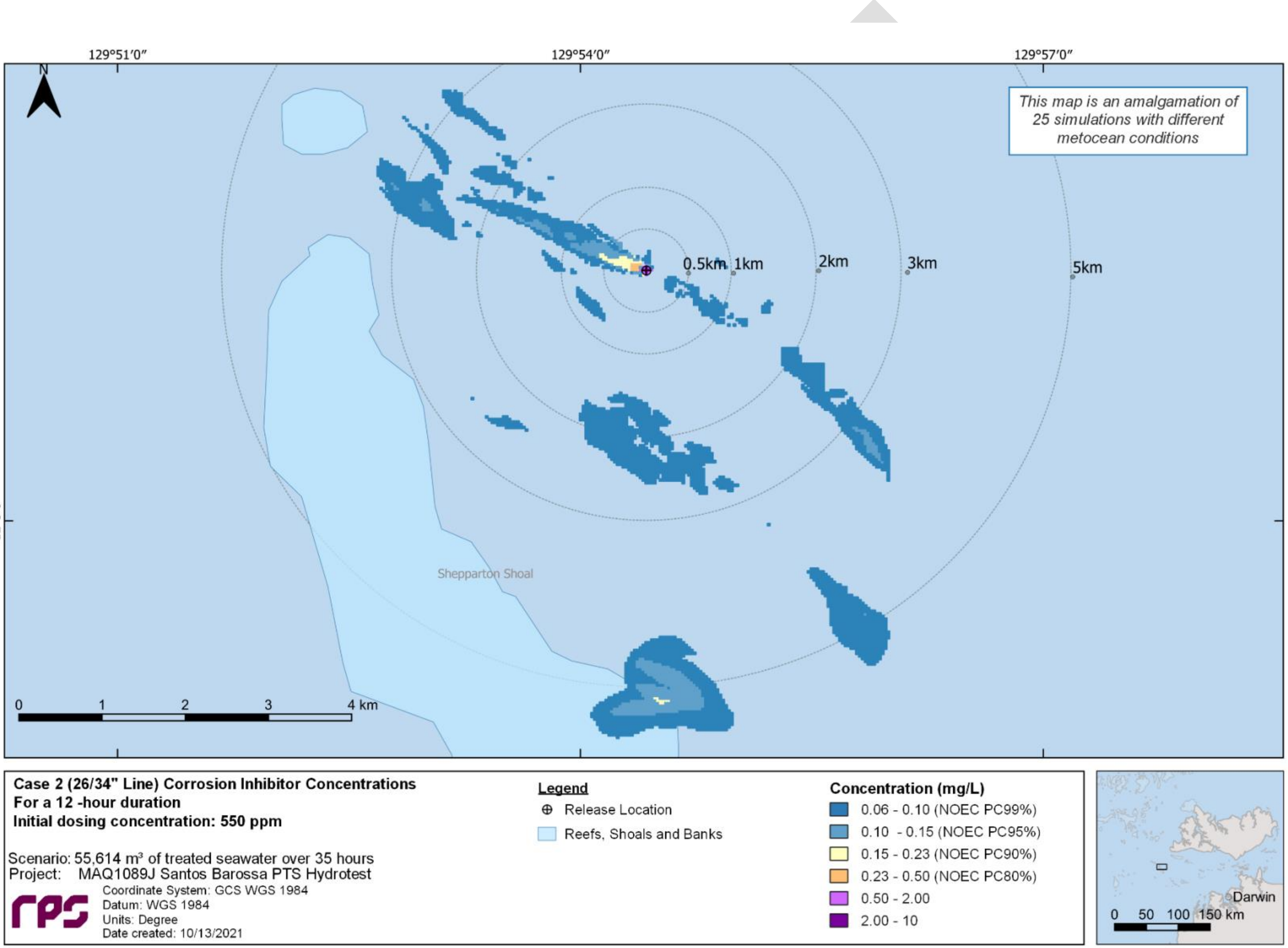


Figure 9.8 Predicted corrosion inhibitor concentrations assessed over a 12 hour continuous exposure period for the Case 2 (26/34" hybrid line). The results were calculated from 25 simulations with different metocean conditions.

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