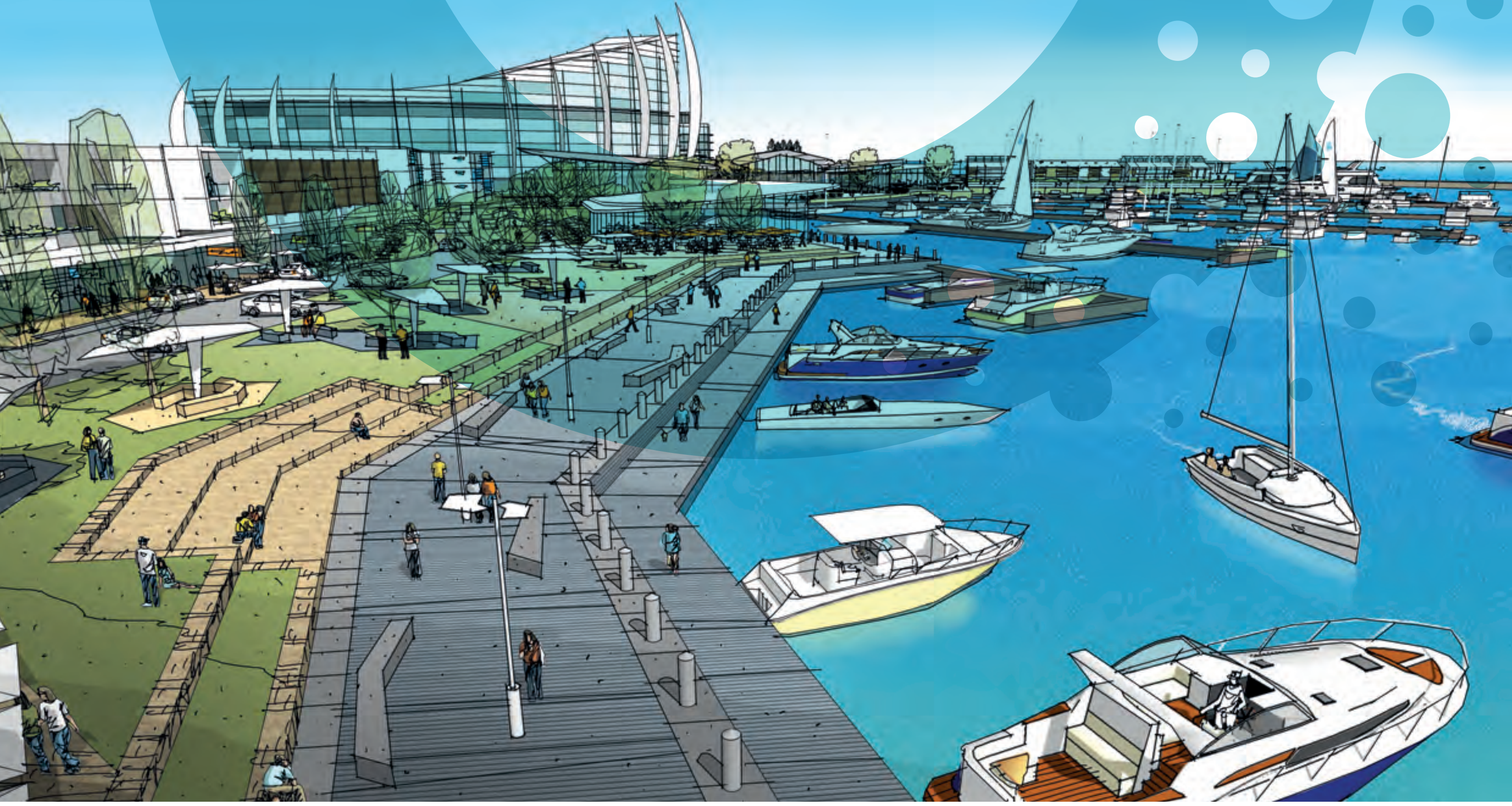
City of Joondalup

Ocean Reef MARINA

Public Environmental Review

November 2016



Prepared for City of Joondalup by

strategen ENVIRONMENTAL

Appendix 4: Supporting Investigations and Studies (No 2)

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Oceanica 2016b	BMT Oceanica: *Ocean Reef Marina Proposed Development – 2015 Sediment Survey*
Oceanica 2016c	BMT Oceanica: *Technical Note – Ocean Reef Marina Development PER: EQMF, EQC, EQP and Marine EIA advice*
Oceanica 2016d	BMT Oceanica: *Ocean Reef Benthic Habitat Map Report*
Oceanica 2016e	BMT Oceanica: *Ocean Reef Baseline Studies – Abalone Habitat and Abundance at Burns Beach Reef*
Oceanica 2016f	BMT Oceanica: *Roe's Abalone Environmental Sensitivity*
Rockwater 2015	Rockwater Properietary Limited: *Groundwater Modelling to Assess Nutrient Loads in Groundwater Discharging to the Ocean and Marina*
RPS APASA 2016	RPS APASA: *Phase 2: Water Quality Modelling*

Ocean Reef Marina Proposed Development - 2015 Sediment Survey

1058_01_008/2_Rev0

February 2016

Ocean Reef Marina Proposed Development - 2015 Sediment Survey

Prepared for

Strategen Pty Ltd

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Acronyms

Ag	Silver
Al	Aluminium
ANZECC & ARMCANZ	Australia and New Zealand Environment and Conservation Council/ Agriculture and Resource Management Council of Australia and New Zealand
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
EIL	Ecological Investigation levels
EPA	Environmental Protection Authority
Hg	Mercury
HIL	Health Investigation levels
LoR	Limit of Reporting
NAGD	National Assessment Guidelines for Dredging
Ni	Nickel
Pb	Lead
PSD	Particle size distribution
QA/QC	Quality assurance and quality control
RPD	Relative percentage difference
RSD	Relative standard deviation
Sb	Antimony
TBT	Tributyltin
TOC	Total organic carbon
Zn	Zinc

1. Introduction

1.1 Proposed development background

The City of Joondalup proposes to upgrade and expand the existing marine facilities at the Ocean Reef Boat Harbour, approximately 29 km north of the Perth central area, Western Australia (WA). The harbour lies adjacent to Marmion Marine Park (MMP) (Figure 1.1).

The Ocean Reef Marina Proposal includes (Strategen 2014):

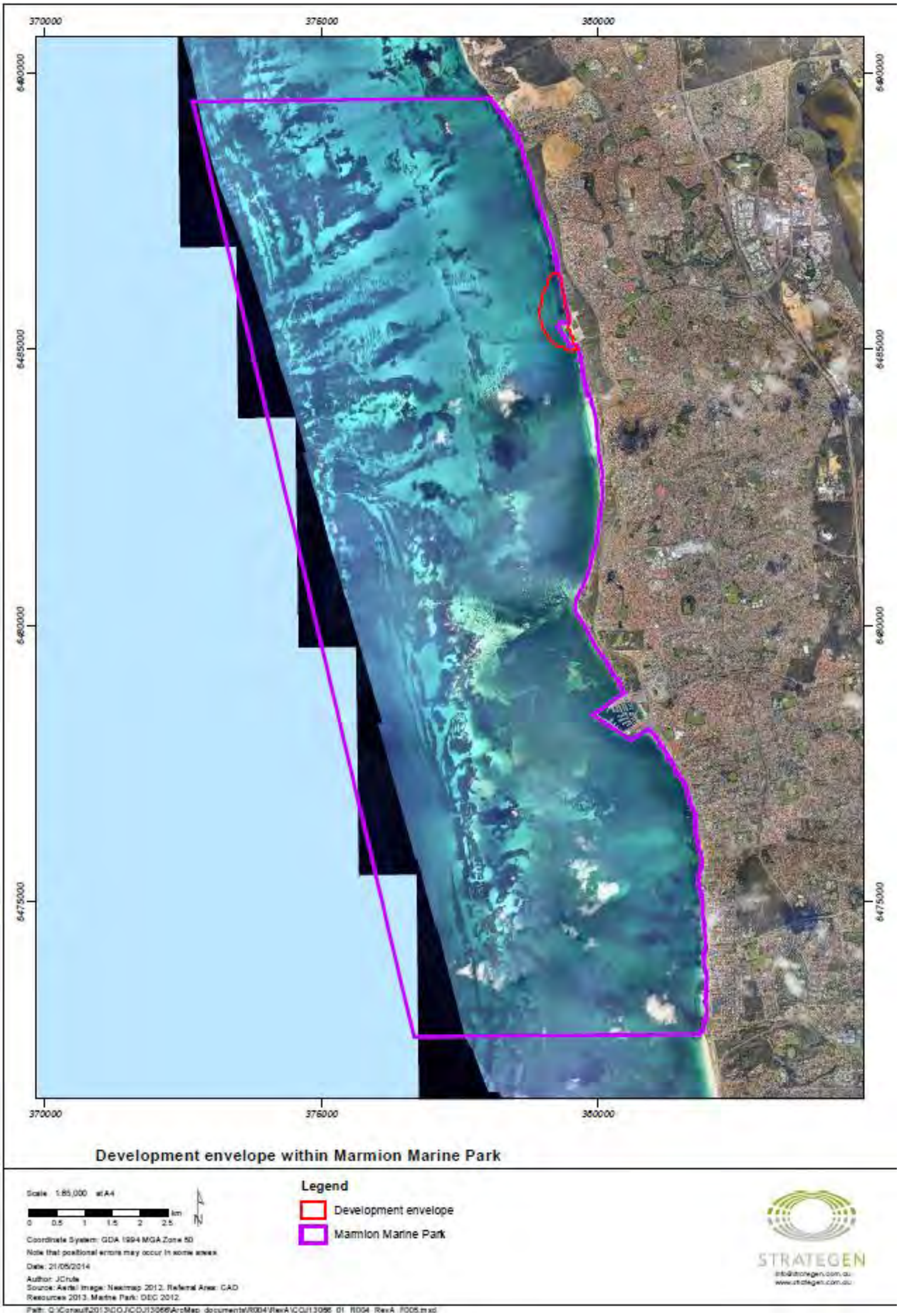
- construction of two new outer breakwaters
- removal of the existing breakwaters from the boat launching harbour
- dredging of sand and rock inside the harbour
- disposal of dredge spoil into land reclamations inside the breakwaters
- construction of jetties to support piled boat mooring pens
- operation and maintenance of the marina.

The existing Ocean Reef Boat Harbour is located outside the boundaries of the MMP (Figure 1.1). The proposed marina is estimated to encapsulate ~42 ha.

1.2 Sediment assessment requirements

The Ocean Reef Marina Proposal is being assessed by the Environmental Protection Authority (EPA) under Part IV of the *Environmental Protection Act (1986)* (EP Act) at the level of Public Environmental Review (PER). An Environmental Scoping Document (ESD) (EPA 2014), approved in consultation with the proponent by the EPA, requires the following:

"*Conduct monitoring as necessary to characterise the existing marine environmental quality (baseline water and sediment quality) in the area potentially affected by the proposal, with particular consideration to the environment of Marmion Marine Park. The characterisation needs to capture spatial variability in sediment quality and spatial and seasonal variation in relevant water quality parameters as informed by an assessment of threats and pressures to marine environmental values, both ecological and social. The characterisation is to inform dredge spoil management and the environmental quality monitoring and management plans required in 7a and 7b*."



Source: Strategen (2014)

Figure 1.1 Ocean Reef Marina Development Envelope and Marmion Marine Park footprint

1.3 Dredging and dredge material onshore disposal

The proposed marina development requires dredging with disposal directly into land reclamation. The approximate volume of sand and rock to be removed from outside the existing harbour and inside the existing harbour was derived from jet probing during the preliminary geotechnical investigation (Golder Associates 2015) (Table 1.1). All dredged material will be disposed of onshore.

Table 1.1 Volumes of sand and rock in the Ocean Reef Marina Development to be dredged during construction

Substrate	Outside the existing harbour	Inside the existing harbour	Total
Rock (m^3)	75,300	4,000	79,300
Sand (m^3)	10,500	10,000	20,500
Total	85,800	14,000	99,800

1.4 Purpose of this report

This document outlines the results of a sediment survey completed with three objectives:

- assess the material to determine whether sediments are of acceptable quality for dredging
- characterise the material to determine whether it is appropriate for onshore disposal
- characterise the baseline sediment quality within the marina development footprint.

Note that because onshore disposal is being pursued, a sea dumping permit is not required. Nevertheless, sampling was completed in general accordance with the National Assessment Guidelines for Dredging (NAGD) (CA 2009), but the Determining Authority was not required to be consulted.

2. Sediment Sampling Design and Rationale

2.1 Review of existing information on sediment contamination and baseline information

2.1.1 Inside the existing boat harbour

The existing Ocean Reef Boat Harbour is regularly dredged to maintain navigable depths. Recent sediment sampling was completed in 2013 (BMT Oceanica 2013) and showed total arsenic, chromium, lead, nickel and zinc were below NAGD screening levels (CA 2009), however some sites had elevated levels of tributyltin (TBT). Petroleum hydrocarbons were all below the laboratory limit of reporting (LoR). The BMT Oceanica (2013) sediment sampling within the existing harbour mainly focussed on the sand trap (north) and the harbour entrance, where sediments build up and require annual excavation for bypassing. As sufficient sediment characterisation data for this northern area exists from within the previous five years, it was not sampled as part of the current study. Sediment sampling within the existing harbour for this study therefore focussed on the southern section where there is a build up of finer sediments and at the boat ramp areas where there is a greater potential for contamination.

2.1.2 Outside the existing harbour

Areas outside of the existing harbour were not expected to contain any contaminants of concern since they are not exposed to significant sources of contamination. These sediments exist in shallow depths overlying limestone reef and are in high energy areas which result in thin lenses of sand overlying rock. Four sites located immediately north of the existing boat harbour were sampled in 2013, providing limited baseline data. These sites had low concentrations of nutrients and metals and no detectable concentrations of other contaminants.

2.2 Sediment contamination potential

Existing sediment data from inside the existing Ocean Reef Boat Harbour (BMT Oceanica 2013) showed total arsenic, chromium, lead, nickel and zinc were below the screening levels defined in the NAGD (CA 2009). As such, the current study analysed the total concentration of metals in sediments. Elevated concentrations of total TBT were recorded in sediments at two sites in the southern section of the harbour in 2013, but subsequent analysis showed elutriate concentrations of TBT were below the laboratory LoR. Due to the potential exceedance of TBT guidelines and associated risk to the environment, both total sediment TBT concentration and elutriate TBT concentration were analysed in the current study. Concentrations of hydrocarbons (TPHs, PAHs and BTEX) were all below laboratory LoRs in 2013, and thus were not measured in the current study. Nutrient concentrations are known to be low in these sediments and the likelihood for sulphur concentrations to be acid sulphate sediments is also low.

2.2.1 Potential contaminants of concern

Based on historical data and an assessment of potential contamination sources, the potential contaminants of concern were identified as:

- Metals (aluminium, antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc). Elutriate and bioavailable analysis would have been determined for samples that exceeded the NAGD (CA 2009) screening levels on a first-pass total metals assessment as needed.
- Organotins – TBT. Results were normalised by using the total organic carbon (TOC) concentrations as per the NAGD (CA 2009). As TBT had previously exceeded screening guidelines inside the existing harbour area, elutriate TBT was also sampled and analysed.

TBT was not analysed in sediment outside the existing harbour as there is no risk of contamination in this area.

Particle size distributions were assessed for (i) particle settling rates and (ii) contextual information of silt and clay (fines) contents in relation to metal and organics retention. Total organic carbon was also determined for the normalisation of TBT as required by the NAGD (CA 2009).

2.3 Sediment sampling areas

Sediment sampling sites (Figure 2.1) were categorised into two groups based on disturbance histories and potentially different levels of contaminations:

- Outside the existing harbour (DF and BS)
- Inside the existing harbour (EH).

Baseline has been determined from samples collected in the area outside the existing harbour but within the proposed development footprint (sites BS1-3 and DF1-3). Areas inside and outside the existing harbour will be dredged and data from both areas were combined for assessment against environmental and health guidelines.

A total of 11 sediment sites were sampled to meet requirements of the NAGD for a dredge volume of 20,500 m^3 of sand. When inspected in the field, site BS1 was located on reef and had to be moved to the nearest area of appropriate substrate (26 m outside the proposed dredge footprint). It is assumed that the sediments sampled at site BS1 are representative of the area to be dredged.

Outside the existing harbour the sediment tends to overlay limestone reefs so only the surface 0.5 m of sediment could be sampled. Inside the existing harbour, where sediment tends to accumulate, deeper sediment layers could be sampled. In all, 18 samples were collected for analysis to characterise a depth profile, where relevant, and to meet QA/QC requirements (Table 2.1). For field QA/QC purposes, triplicate sediment cores were collected at one site inside the existing harbour (EH2) and a 'field split' sample was taken at another site inside the existing harbour site (EH1).

Table 2.1 Number of sites, sample numbers per depth, and QA/QC samples within the area outside the existing harbour and the area inside the existing harbour

Sample depths	Outside the existing harbour (DF and BS)	Inside the existing harbour (EH)	Triplicates (x1)	Field splits (x1)
0-0.5 m	6	5	2 extra (EH 2)	2 extra (EH 1)
0.5–1.0 m	0	3	-	-
Subtotal	**6**	**8**	**2**	**2**
Total samples	**18**			

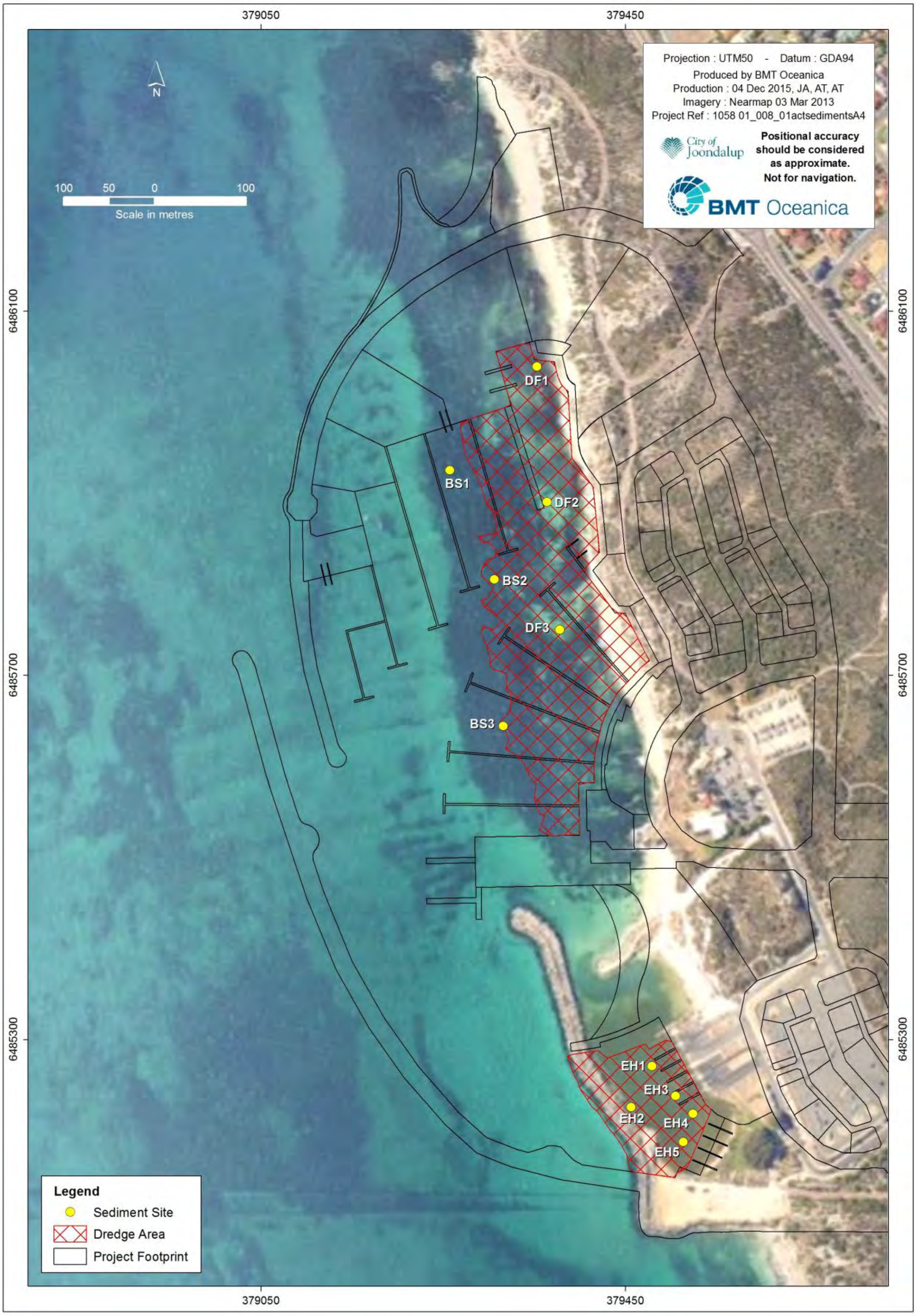


Figure 2.1 Sediment sampling sites for the Ocean Reef Marina Proposed Development 2015 survey

2.4 Data analysis

Normalisation of TBT

Sediment TBT concentrations were normalised to 1% TOC prior to reporting. For samples with a TOC range of 0.2–10%, a multiplier was determined using the formula (1/x, where x is the TOC concentration). The TBT concentration was multiplied by the determined multiplier and this concentration represents the normalised to 1% TOC TBT concentration. If a TBT concentration was below the LoR (limit of reporting), half the LoR value was used for normalisation purposes.

Analyte concentrations below the limit of reporting

Analyte concentrations that were too low to be accurately quantified were recorded as below the LoR. Generally, half the laboratory LoR value will be used as a substitute for data below the LoR, in accordance with the NAGD (CA 2009).

Quality assurance and quality control assessment

There were two types of field QA/QC samples:

- Field splits, where one sample was collected, homogenised, split into three in the field and analysed individually. Two samples were analysed at the primary laboratory and one sample was analysed at the secondary laboratory for comparison.
- Triplicates, where three cores were obtained at the same location and analysed individually at the primary laboratory.

The results of the field QA/QC sampling were analysed as described in the NAGD (CA 2009) by calculating the Relative Percent Difference (RPD) between two samples, and Relative Standard Deviation (RSD) between three samples. The results should agree within an RPD or RSD of ±50%, although the NAGD (CA 2009) notes that this may not always be the case where the sediments are heterogeneous.

2.4.2 Field split samples

Field splits were samples at a minimum of 5% of sampling locations. The RPD was calculated for field replicates as follows:

$$RPD\ (\%) = \frac{(difference\ beteween\ field\ splits)\ \times 100}{(average\ of\ field\ splits)}$$

The acceptable RPD for field splits is ±50% (CA 2009).

2.4.3 Triplicate samples

Sediments were samples in triplicates at a minimum of 10% of the sampling locations. The RSD was calculated for field triplicates as follows:

$$RSD\ (\%) = \frac{(standard\ deviation\ of\ triplicate)\ \times 100}{(average\ of\ triplicate)}$$

The acceptable RSD for triplicates is ±50% (CA 2009).

2.5 Assessment frameworks

2.5.1 Dredging and onshore disposal

Sediment characterisation to inform dredged material management and to develop dredge monitoring and management plans was completed as a requirement of the ESD. Results were assessed via the framework outline in the NAGD (CA 2009). Although the guidelines provide a framework for environmental impact assessment and permitting for ocean disposal (which will not be pursued here) they also provide a useful reference for the assessment of potential impacts on the marine environment associated with other disposal regimes.

Onshore disposal of the dredged material from harbour expansion works or development in a marine environment requires assessment under the *Contaminated Sites Act 2003.* Ecological Investigation Levels (EILs) are intended to be used as an initial screening assessment to determine whether there is a potential risk to the environment. If the EILs are exceeded further site-specific risk-based investigations will be required to determine whether contaminants levels are likely to pose an actual risk.

Health Investigation Levels (HILs) determine whether contaminated sediments disposed to land can pose a risk to human health through direct exposure (such as ingestion and inhalation) or indirect exposure (such as through groundwater contamination). The appropriate HIL will be dependent on the future usage of the onshore disposal site and is defined as one of four exposure areas:

- residential with garden/accessible soil (exposure level A)
- residential with minimal opportunities for soil access (exposure level B)
- public open space such as parks, playgrounds and playing fields (exposure level C)
- commercial/industrial (exposure level D).

2.5.2 Baseline

The ESD was developed for the Proposal under the *Environmental Protection Act 1986* to provide the EPA with information necessary to support a decision on the development and any environmental conditions that may be required to mitigate the environmental impacts. Characterisation of the baseline sediment quality was completed to fulfil the requirement of the ESD.

3. Sediment Sampling Implementation Results

The sediment survey was completed on 28 October 2015 using commercially qualified SCUBA divers (ADAS 2815.1). Cores were retrieved by driving in 50 mm diameter PVC pipe (1.5 m long) with a star picket hammer and sealing the ends with rubber bungs to extract the cores. Cores were retrieved to the vessel in the upright position. Once on the vessel, cores were extracted from the PVC pipe, measured and visually assessed for sediment profile characteristics (Appendix A). Sediments were homogenised, placed into the required laboratory sample containers, kept on ice in an esky and then transferred to the laboratories on the same day.

3.1 Penetration depth

Samples were collected from all of the sites and penetration depth varied from 0.2 to 1.0 m (Figure 3.1).

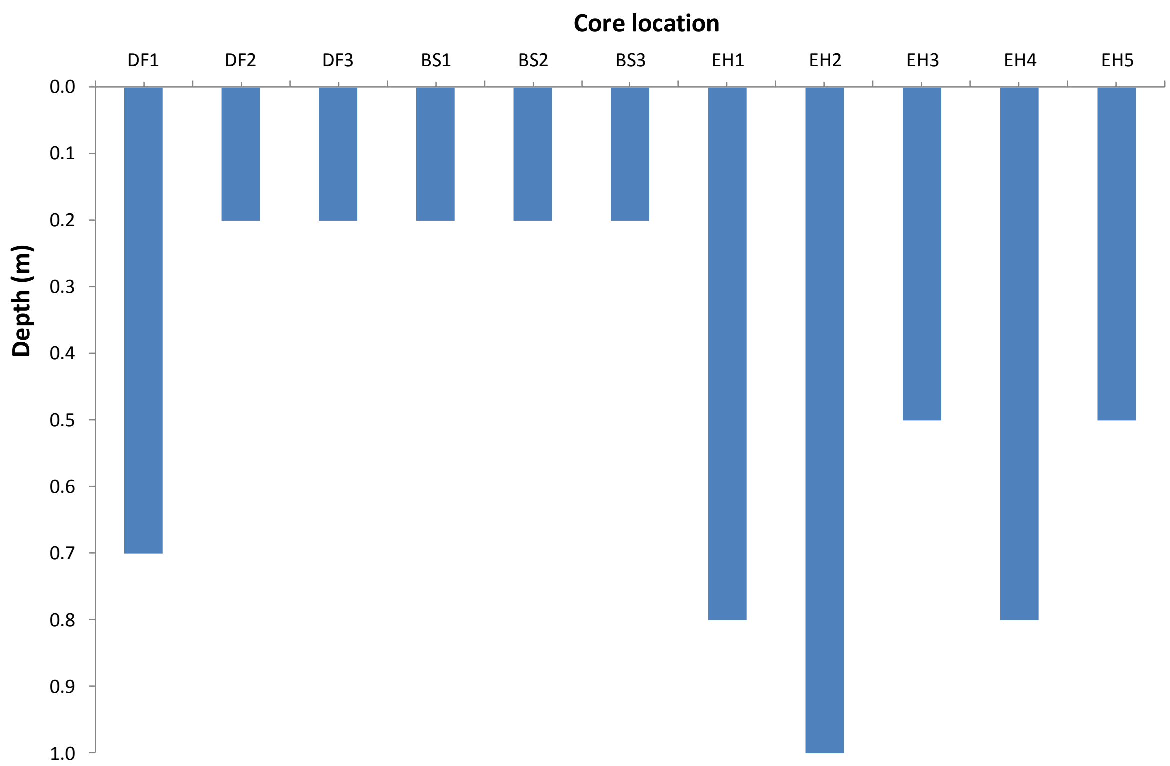


Figure 3.1 Penetration depth of cores at all sites

3.2 Particle size distribution

Sediments outside the existing harbour (DF and BS sites) were generally dominated by medium to coarse grained sands with very small amounts of silts, while sites inside the existing harbour (EH sites) were generally dominated by very fine to medium grained sands and had a higher proportion of silts (Table 3.1, Figure 3.2, Appendix B).

Table 3.1 Particle size distribution of sediments samples from Ocean Reef

Sediment composition	Wentworth size category (µm)	Outside the existing harbour						Inside the existing harbour										
		BS1-S	BS2-S	BS3-S	DF1-S	DF2-S	DF3-S	EH1 0.5-1m	EH1-Sa	EH1-Sb	EH2 -0.5-1m	EH2-S1	EH2-S2	EH2-S3	EH3-S	EH4 0.5-1m	EH4-S	EH5-S
Total gravel	**>2000**	15.7	1.3	2.5	0.5	0.0	0.0	1.1	0.2	1.7	2.1	1.1	9.2	1.7	3.4	1.2	1.1	3.6
Very coarse sand	1000-2000	15.2	0.7	5.1	1.2	0.1	0.1	0.7	0.5	0.7	1.3	0.3	2.0	1.0	5.4	2.7	0.9	0.7
Coarse sand	500-1000	38.7	9.6	54.3	28.3	39.7	3.4	2.0	2.8	2.2	5.6	2.7	5.9	4.0	5.4	16.4	8.9	4.4
Medium sand	250-500	28.2	74.1	12.9	64.7	60.0	72.4	13.2	12.2	12.3	18.3	31.8	18.7	22.3	16.4	20.2	15.8	14.1
Fine sand	125-250	1.2	12.1	9.4	5.3	0.3	21.0	17.2	17.8	17.4	19.6	28.5	19.8	23.6	21.6	23.9	20.0	18.4
Very fine sand	63-125	0.1	0.4	6.0	0.0	0.0	0.5	20.1	21.5	20.8	18.2	13.8	16.1	17.6	15.7	14.7	17.7	18.9
Total sand	**63-2000**	83.3	96.8	87.7	99.5	100.0	97.4	53.2	54.8	53.5	63.0	77.1	62.5	68.5	64.5	77.9	63.3	56.6
Coarse silt	31-63	0.4	1.1	4.1	0.0	0.0	1.4	19.8	20.2	19.8	15.9	10.1	13.3	13.9	13.1	9.3	15.5	17.6
Medium silt	16-31	0.3	0.3	2.6	0.0	0.0	0.4	13.7	13.3	13.2	10.5	6.5	8.4	8.8	9.7	6.2	10.8	12.0
Fine silt	8-16	0.3	0.3	1.7	0.0	0.0	0.5	7.4	7.1	7.1	5.4	3.4	4.2	4.5	5.5	3.4	5.8	6.3
Very fine silt	4-8	0.0	0.2	0.9	0.0	0.0	0.2	3.0	2.8	2.9	2.1	1.4	1.6	1.8	2.3	1.4	2.3	2.5
Total silt	**4-63**	1.0	1.9	9.4	0.0	0.0	2.6	43.9	43.4	43.0	33.8	21.4	27.6	29.0	30.7	20.4	34.4	38.5
Total clay	**0-4**	0.0	0.0	0.5	0.0	0.0	0.0	1.8	1.6	1.7	1.1	0.4	0.8	0.8	1.5	0.6	1.2	1.3

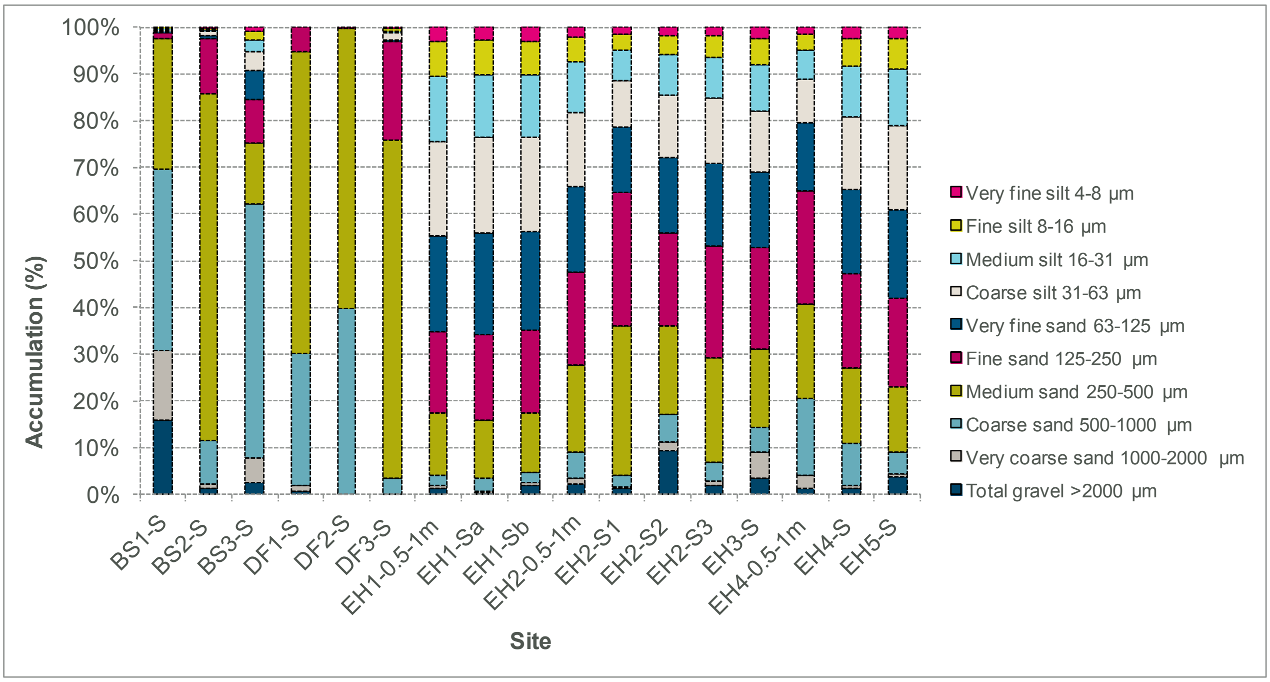


Figure 3.2 Particle size distribution of Ocean Reef sediment samples

3.2.1 Settling velocity

The 50% and 90% of particle settling velocities and times are shown in Table 3.2. For all sediments, 50% of the material would settle through 1 m of water column in less than 6 minutes (0.1 hours).

For all sediments, 90% of the material would settle through 1 m of water column in less than 108 minutes (1.8 hours). For sediments outside the existing harbour, 90% of material would settle in through 1 m of water column in less than 6 minutes, while sediments from inside the existing harbour had much higher settling times with over half of the samples taking longer than one hour.

Table 3.2 Particle settling velocities and time for sediment samples

Category	50% of particles		90% of particles	
Sample	Minimum settling velocity of 50% of particles (mm s^{-1})	Time for 50% of particles to settle over 1 m (hours)	Minimum settling velocity of 90% of particles (mm s^{-1})	Time for 90% of particles to settle over 1 m (hours)
Outside the existing harbour				
BS1-S	466.2	0.0	97.3	0.0
BS2-2	109.5	0.0	43.3	0.0
BS3-S	306.1	0.0	3.5	0.1
DF1-S	148.5	0.0	62.8	0.0
DF2-S	183.3	0.0	97.5	0.0
DF3-S	87.6	0.0	31.6	0.0
Inside the existing harbour				
EH1-0.5-1m	4.4	0.1	0.2	**1.8**
EH1-Sa	4.5	0.1	0.2	**1.6**
EH1-Sb	4.6	0.1	0.2	**1.7**
EH2-0.5-1m	10.3	0.0	0.3	1.0
EH2-S1	29.0	0.0	0.6	0.5
EH2-S2	19.4	0.0	0.4	0.7
EH2-S3	15.4	0.0	0.4	0.8
EH3-S	15.1	0.0	0.2	**1.2**
EH4-0.5-1m	30.8	0.0	0.6	0.5
EH4-S	10.1	0.0	0.2	**1.2**
EH5-S	6.9	0.0	0.2	**1.3**

Note:

1. **Bold text** indicates a settling time >1 hour

3.3 Total organic carbon content

The TOC content of all sediment samples was low, ranging from below the LoR (<0.2 %) to 4.9% (Table 3.3). In samples outside the existing harbour, TOC was less than or equal to the LoR. In sediments inside the existing harbour TOC ranged from 0.7–4.9%.

Table 3.3 Total organic carbon content of the sediment samples

Sediment sample	Total organic carbon (%)
Limit of Reporting	**<0.2**
Outside the existing harbour	
DF1 -S	<0.2
DF2-S	<0.2
DF3-S	0.2
BS1-S	<0.2
BS2-S	<0.2
BS3-S	0.2
Inside the existing harbour	
EH1-Sa	4.6
EH1-Sb	4.9
EH1-0.5-1.0	4.6
EH2-S1	1.1
EH2-S2	2.8
EH2-S3	1.8
EH2-0.5-1.0	2.9
EH3-S	1.5
EH4-S	1.7
EH4-0.5-1.0	0.7
EH5-S	3.6

3.4 Metals

Total metal concentrations in the proposed dredge sediments (both inside and outside the existing harbour) were below the NAGD screening levels, EILs[1] and the HILs (Table 3.4). Sediments outside of the existing harbour had very low levels of metals with concentrations of Ag, Sb, As, Cd, Cu Hg, Ni and Pb all near or below the limits of reporting. Sediments inside the existing harbour were below the NAGD screening levels, but did have slightly elevated concentrations of Al, As, Cd, Cr, Cu, Hg, Ni, Pb and Zn. The current study results confirmed previous campaigns (Oceanica 2010; BMT Oceanica 2013) results which found concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn elevated in harbour sediments, but well below the NAGD screening levels (CA 2009). These sediments inside the existing harbour did have a greater proportion of fines and greater TOC contents which would increase the potential for the sediments to retain metals. Full laboratory reports for metals are in Appendix C.

[1] *Where EILs are a range; corrections for cation exchange capacity and pH are normally required. Data for corrections were not available for this study and exceedances of the lower value in the range do not necessarily reflect an environmental risk.*

Table 3.4 Total metal concentrations (mg kg^{-1}) in sediment samples from Ocean Reef

Metal	Ag	Al	Sb	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
LoR[1]	**<1**	**<20**	**<2**	**<2**	**<0.1**	**<0.2**	**<0.2**	**<0.01**	**<0.7**	**<1**	**<0.5**
NAGD[2] Screening Levels	**1**	**n/a**	**2**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**200**
NAGD SQ[3] High Values	**3.7**	**n/a**	**25**	**70**	**10**	**370**	**270**	**1**	**52**	**220**	**410**
EIL[4]	**n/a**	**n/a**	**n/a**	**50**	**n/a**	**75-160**	**30-120**	**n/a**	**10-270**	**270**	**25-500**
EIL[5]	**n/a**	**n/a**	**n/a**	**80**	**n/a**	**120-270**	**45-200**	**n/a**	**20-350**	**440**	**45-800**
HIL A	**n/a**	**n/a**	**n/a**	**100**	**20**	**100**	**6000**	**40**	**400**	**300**	**n/a**
HIL B	**n/a**	**n/a**	**n/a**	**500**	**150**	**500**	**30000**	**120**	**1200**	**1200**	**n/a**
HIL'C	**n/a**	**n/a**	**n/a**	**300**	**90**	**300**	**17000**	**80**	**1200**	**600**	**n/a**
HIL D	**n/a**	**n/a**	**n/a**	**3000**	**900**	**3600**	**240000**	**730**	**6000**	**1500**	**n/a**
Outside the existing harbour											
DF1 -S	<1	240	<2	<2	0.1	9	0.2	<0.01	<0.7	<1	1
DF2-S	<1	230	<2	<2	0.1	8.5	0.3	<0.01	<0.7	<1	1
DF3-S	<1	310	<2	<2	0.2	12	0.3	<0.01	<0.7	<1	1.1
BS1-S	<1	250	<2	2	0.1	8.1	0.3	<0.01	<0.7	<1	1.1
BS2-S	<1	280	<2	<2	0.1	11	0.3	<0.01	<0.7	<1	1.2
BS3-S	<1	260	<2	2	<0.1	8.2	0.4	<0.01	<0.7	<1	1.4
Inside the existing harbour											
EH1-Sa	<1	2900	<2	7	0.8	25	14	0.03	5.7	21	110
EH1-Sb	<1	2300	<2	7	0.7	24	13	0.03	5.4	20	98
EH1-0.5-1.0	<1	2200	<2	7	0.7	23	13	0.03	5.6	24	100
EH2-S1	<1	530	<2	3	0.2	13	2.6	<0.01	1	2	15
EH2-S2	<1	950	<2	5	0.4	16	6.5	0.01	2.5	5	45
EH2-S3	<1	740	<2	4	0.3	14	4.7	<0.01	2	4	32
EH2-0.5-1.0	<1	1100	<2	6	0.5	17	7	0.01	3.1	5	51
EH3-S	<1	1600	<2	6	0.3	15	9.6	0.01	4.4	42	140
EH4-S	<1	1200	<2	3	0.3	15	5.5	0.01	1.9	32	39
EH4-0.5-1.0	<1	610	<2	3	0.2	12	2.3	<0.01	0.9	5	15
EH5-S	<1	1900	<2	5	0.6	21	9.7	0.02	3.2	14	65

Notes:

1. LoR = limit of reporting
2. NAGD = National Assessment Guidelines for Dredging
3. NAGD SQ = National Assessment Guidelines for Dredging Sediment Quality
4. EIL = Environmental Investigation Level for public open spaces in National Environment Protection (Assessment of Site Contamination) Measure (NEPC 2013)
5. EIL = Environmental Investigation Level for Commercial/Industrial space in National Environment Protection (Assessment of Site Contamination) Measure (NEPC 2013)
6. HIL = Health Investigation Levels in the National Environment Protection (Assessment of Site Contamination) Measure (NEPC 2013)
   i. HIL A - residential with garden/accessible soil
   ii. HIL B - residential with minimal opportunities for soil access
   iii. HIL C - public open space such as parks, playgrounds and playing fields
   i. HIL D - commercial/industrial

3.5 TBT

Normalised TBT concentrations in sediments from inside the existing harbour were below the NAGD screening level, with the exception of site EH3–S which was slightly above the screening level (Table 3.5; Appendix D). Elutriate TBT exceeded the ANZECC & ARMCANZ (2000) 95% Species Protection Trigger Value (applicable to harbours) at site EH3–S (Table 3.5). Previously, all normalised concentrations of total TBT were below the NAGD screening level of 9 µg kg^{-1} and all elutriate TBT concentrations were below the LoR (Oceanica 2010; BMT Oceanica 2013).

Table 3.5 Total, normalised (1% TOC) and elutriate tributyltin concentrations from inside the existing Ocean Reef harbour

Sample	Total TBT (µg Sn kg^{-1})	Normalised TBT (µg Sn kg^{-1})	Elutriate TBT (µg Sn L^{-1})
NAGD Screening Level	9	9	NA
NAGD Sediment Quality High Value	70	70	NA
99% Species Protection Trigger Value[1]	n/a	n/a	0.0004
95% Species Protection Trigger Value[1]	n/a	n/a	0.006
90% Species Protection Trigger Value[1]	n/a	n/a	0.02
Limit of Reporting (LoR)	<0.5	n/a	<0.002
EH1-Sa	2.7	0.59	n/a
EH1-Sb	2.4	0.49	n/a
EH1-0.5-1.0	**13**	2.83	0.0021
EH2-S1	<0.5	0.23*	0.0027
EH2-S2	2.5	0.89	0.0020
EH2-S3	1.9	1.06	0.0029
EH2-0.5-1.0	**11**	3.79	0.0029
EH3-S	**14**	**9.33**	**0.0200**
EH4-S	12	7.06	0.0048
EH4-0.5-1.0	3.5	5.00	0.0031
EH5-S	**20**	5.56	0.0036

Note:
1. ANZECC/ARMCANZ (2000) Trigger Values for marine water
2. NAGD = National Assessment Guidelines for Dredging
3. **Bold text** = exceeded NAGD Screening Level or exceeded 95% Species Protection Trigger Value
4. Asterisk (*) indicates that half the limit of reporting value was used in the normalisation formula

4. Quality Assurance/Quality Control (QA/QC)

The results of QA/QC analyses are summarised in Table 4.1 and the full laboratory report in Appendix E. Mercury is not included in Table 4.1 as mercury concentrations were below LoR in triplicate samples and were 0.03 mg kg^{-1} in all split samples showing no intra or inter-laboratory variation.

Intra-laboratory variability was below the acceptable threshold of ±50% (CA 2009) for all analytes, as indicated by the RPD of intra-laboratory splits (Table 4.1). Therefore, all analyte concentrations were measured with an acceptable level of precision within the primary laboratory.

Inter-laboratory variability was within the relevant limits for all analytes, except for lead, which exceeded the ±50% threshold (Table 4.1). Therefore, lead was measured with an unacceptable level of precision between the primary and secondary laboratories. The high level of inter-laboratory variability may be attributed to different laboratory equipment and capabilities to detect ultra trace elements and concentrations. The concentration of lead with a RPD outside the recommended limits is flagged as an estimate rather than precise value, in accordance with the NAGD (CA 2009).

The variability of metal concentrations on a scale of centimetres, as indicated by the RSD of field triplicates, was within the ±50% limit recommended by the NAGD (CA 2009) for all analytes except for normalised TBT (Table 4.1). This suggests that the small-scale spatial variability of total metals and TOC within the sediment was sufficiently low for the sampling to adequately characterise the material to be dredged.

Table 4.1 Quality assurance / quality control analyses for Ocean Reef sediment samples

Analyte	QA/QC sample type	Sample splits			Field triplicates
	Test statistics & limit (CA 2009)	Intra-laboratory splits RPD (%)	Inter-laboratory splits RPD (%)		RSD (%)
	QA/QC sample	EH1_Sa, EH1_Sb	EH1_Sa, EH1_Sc	EH1_Sb, EH1_Sc	EH2 S1, S2, S3
Total metals	Arsenic	0	4.2	4.2	25.0
	Cadmium	13.3	3.7	17.0	33.3
	Total chromium	4.1	12.8	8.7	10.7
	Copper	7.4	6.9	14.3	42.4
	Lead	4.9	**62.5**	**58.1**	41.7
	Nickel	5.4	21.4	16.0	41.7
	Zinc	11.5	20.0	8.5	49.1
Organics	TOC	6.3	2.2	4.2	45.0
	TBT Normalised	18.5	14.5	4.0	**60.3**

Notes:
1. Values in **bold blue** exceed RPD/RSD acceptable threshold of 50% specified by the NAGD (CA 2009)
2. QA/QC = quality assurance/quality control, RPD = relative percent difference, RSD = relative standard deviation

The analysis laboratories also undertook the required testing of blanks, spikes and standards and complete laboratory duplicates. The full QA/QC reports are provided in Appendix C–Appendix E.

5. Assessment of Sediments

Quality control and assurance during sampling and from laboratory analysis was very good and confidence in the quality of results is high.

5.1 Dredging and onshore disposal sediment characteristics

The proposed sediments to be dredged were located both inside the existing harbour and outside the existing harbour (Figure 2.1). Sediments inside the harbour had particle size distributions dominated by very fine to medium grained sands with significant proportions of silts (20–44%) and moderate TOC concentrations. Dredge sediments outside of the existing harbour were shallow sandy sediments with low silt/clay proportions (0–10%) and low TOC concentrations. Suspension of sediments during dredging will be very short lived for sediments dredged outside of the existing harbour, while sediments from inside the existing harbour have the potential to remain suspended in the water column longer; but it should be noted that clay content is the most important factor in relation to long term suspension and all sediments had very low proportions of clay (<2%).

All sediments to be dredged had total metal concentrations that were below the NAGD screening levels, the NAGD Sediment Quality High Values, EILs[2] and the HILs. Concentrations of metals in proposed dredge sediments outside the existing harbour were very low, while concentrations in sediments inside the existing harbour were slightly elevated, but still well below the NAGD screening levels. Metal concentrations in the proposed sediment to be dredged pose very little risk to the environment during dredging or onshore disposal.

Elevated concentrations of TBT were found in sediments located inside the existing harbour, but most were below the NAGD screening levels and all were below the NAGD Sediment Quality High Value. Although measurable concentrations of TBT were detected, the elutriate concentrations were below the 95% Species Protection Trigger Value in all but one sample. It is unlikely that harmful concentrations of TBT would be released from sediments during dredging and the onshore disposal of this material is considered an effective management action and an overall benefit to the marine environment.

5.2 Baseline sediment characteristics

Sediments located outside the existing harbour have not been exposed to potential contamination and are considered to have natural background concentrations of metals. These data may be used as the baseline concentrations to measure against for future monitoring. These sediments were shallow sandy sediments, typically overlying flat limestone pavement, with low silt/clay proportions (0–10%) and low TOC concentrations. Measured metal concentration (in mg kg^{-1}) ranges for:

- silver were all below the LoR (<1)
- aluminium ranged from 230–310
- antimony were all below LoR (<2)
- arsenic were all less than or equal to the LoR
- cadmium ranged from below LoR to 0.2
- total chromium ranged from 8.1–12
- copper ranged from 0.2–0.4
- mercury were all below LoR (<0.01)

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[2] *Where EILs are a range; corrections for cation exchange capacity and pH are normally required. Data for corrections were not available for this study and exceedances of the lower value in the range do not necessarily reflect an environmental risk.*

- nickel were all below LoR (<0.7)
- lead were all below LoR (<1)
- zinc ranged from 1–1.4.

6. References

ANZECC, ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1: The Guidelines. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT, October 2000

BMT Oceanica (2013) Ocean Reef Boat Harbour – Dredging Environmental Impact Assessment. Prepared for Department of Transport by BMT Oceanica Pty Ltd and BMT JFA Consultants Pty Ltd, Report No. 235_05_001/2_Rev0, Perth, Western Australia, November 2013

CA (2009) National Assessment Guidelines for Dredging. Commonwealth of Australia, Canberra, ACT

EPA (2014) Ocean Reef Marina Environmental Scoping Document. Assessment Number 2012 Environmental Protection Authority, Western Australia, approved 26 September 2014

Golder Associates (2015 DRAFT) Preliminary Geotechnical Investigation Ocean Reef Marina. Prepared by Golder Associates for the City of Joondalup April 2015

NEPC (2013) National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1) National Environment Protection Council, 2013

Oceanica (2010) Maintenance Dredging Ocean Reef Boating Facility Sediment Bypassing Environmental Impact Assessment. Prepared by Oceanica Consulting Pty Ltd in association with JFA Consultants Pty Ltd for the Department of Transport, Report No. 235_002/1, Rev2, Perth, Western Australia

Strategen (2014) Ocean Reef Marina – EP Act Referral Supporting Document. Prepared for City of Joondalup by Strategen Environmental Consultants Pty Ltd, Perth, Western Australia, May 2014

Appendix A

Sediment field log

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15 8:45	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	APW/BO/SC/JR	**Wave heights (direction/height):**	W .5
Project number & name:	1058-01-008	**Winds (direction/speed):**	W 1-3Kn
Project location:	Ocean Reef	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
DF1	002	Surface	~0.7	Surface	Y 4 - lost camera	Yes 4 No

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
top bottom	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	Gravel, sand, silt, clay, MBG, sandy clay, etc.	VWS WS MS PS VPS	Yes No	Fibrous wood Decomposed plant materials	Rock fragments Shell content rubble	Presence of anthropogenic items Sampling issues
top 0-0.7 bottom	18	sand	MS	NO	NO	Minimal (<5%) shell fragment	none
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	ApW/BD/SC/JR	**Wave heights (direction/height):**	W .5
Project number & name:	1058-01-008	**Winds (direction/speed):**	W 1-3Kn
Project location:	Ocean Reef Boat Harbour	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
DF2	004	*Surface	surface scrape	Surface Scrape	Yes No N	Yes Y No

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
top bottom							
all	18	sand	MS	N	N	0	none
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	APW/BD/SC/JR	**Wave heights (direction/height):**	.7
Project number & name:	1058_01_088	**Winds (direction/speed):**	W - 4-5 Kn
Project location:	Ocean Reef Boat Harbour	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
DF3	005	~~Surface 5 0.5~~ surface	surface scrap	surface Scrap	✓	✓

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
all	IS	sand	WS	N	N	N	none

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	APW/BD/SC/JR	**Wave heights (direction/height):**	.75
Project number & name:	10584_07_008	**Winds (direction/speed):**	W 4-5kn
Project location:	Ocean Reef BH	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
BS1	006	Surface	surface scrape	surface scrape	✓	✓

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
All	15/18	sand/gravel	VPS	NO	none	large shells, ~30% shell	none
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	ADW/BD/SC/JR	**Wave heights (direction/height):**	.5
Project number & name:	1058-07-008	**Winds (direction/speed):**	W 4-5 kn
Project location:	Ocean Reef BH	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
BS5	007	Surface	surface scrape	surface scrape	N	Yes

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
top bottom							
all	1S	sand	WS	Yes - small part of black sand	none	none	algae present small portion of black sand
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	Tidal state:	high/low, ebb/flood, spring/neap
Field personnel:	ApW, BD, SC, JR	Wave heights (direction/height):	.5
Project number & name:	1038-01-008	Winds (direction/speed):	W 4-5 kn
Project location:	Ocean Reef BH	Underwater visibility (m):	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
BS3	008	surface	surface scrape	surface scrape	Yes No n	Yes No Y

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
top bottom	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20			Yes No	Flora or wood Decomposed plant materials	Rock fragments Shell content rubble	Presence of anthropogenic items Sampling issues
all	14/15	Sand	MS	Y - some	No	<2% shell fragments	some seds darker85.colour
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	APW, BD, JR, SC	**Wave heights (direction/height):**	none - in BH
Project number & name:	1058_07_008	**Winds (direction/speed):**	W 15Kn
Project location:	Ocean Reef BH	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
EH1	009	1.0	0.8-9	~0.4		yes

DESCRIPTION

sediment ~~overlap~~ overlying rock ~ 0.9 m

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
top bottom	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20			Yes No	Flora or wrack Detritus plant material	Rock fragments Shell content rubble	Presence of anthropogenic items Sampling issue
0-0.8	15	silt/clay	WS	Yes-faint	wrack fragments detritus	none	none
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	APW, BD, SC, JR	**Wave heights (direction/height):**	none - in Boat Harbour
Project number & name:	1058_07_008	**Winds (direction/speed):**	W 4-5 Kn
Project location:	Ocean Reef BH	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
EH2	012	1.0	~1.0	1.0	y	y

DESCRIPTION

no horizons

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
0-50cm	1S	silty sand	MS	Yes - strong	lots of wrack	0%	None
0.5-1m	1S	silty sand	MS	Yes - strong	wrack fragments	0%	none
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	APW, BD, SC, JR	**Wave heights (direction/height):**	none - in Boat Harbour
Project number & name:	1058 - OF - 008	**Winds (direction/speed):**	W 4-5 kn
Project location:	Ocean Reef BH	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
EH3	013	1	0.5	0.5	~~Yes~~ No	Yes

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
0-0.4	15	silt/sand	WS	Y	Y - wrack fragments	rock fragments	Black anoxic layer at surface
0.4-0.5	18	silt/sand	VWS	Y	N	N	None
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15 2:25	Tidal state:	high/low, ebb/flood, spring/neap
Field personnel:	Adr, BD, SC, JR	Wave heights (direction/height):	none - in boat harbour
Project number & name:	1038-01-088	Winds (direction/speed):	W 4-5 kn
Project location:	Ocean Reef BH	Underwater visibility (m):	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
EH4	014	2	0.8	0.8	no	y

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
0.7 0.8	18	coarse sand	PS	N	N	<5% shells	none
0.3 0.7	18	sand	VWS	N	N	no	none
0. 0.3	18	silt/mud f. sand	WS	Y	N/wrack fragments	no	none

SEDIMENT LOG

CONDITIONS

Date & time:	28/10/15	**Tidal state:**	high/low, ebb/flood, spring/neap
Field personnel:	ApW, BD, SC, JR	**Wave heights (direction/height):**	None - in Boat Harbour
Project number & name:	#1058-01_008	**Winds (direction/speed):**	W 4-5Kn
Project location:	Ocean Reef BH	**Underwater visibility (m):**	

SITE

Site name	GPS waypoint (#)	Target Penetration (m)	Actual Penetration (m)	Recovered length (m)	Benthic photos taken?	Core photos taken?
EHS	0015	2	~0.5	~0.5	Yes	Yes

DESCRIPTION

Horizon (cm)	Colour	Texture	Sorting	Sulfidic Odour	Organic Matter	Debris (%)	Other Comments
top bottom							
0.25 0.5	18	silt/sand	VWS	N	Y weed fragments	N	— NA
0 0.25	15	silt/sludge	WS	Y	N	N	— NA
top bottom							
top bottom							
top bottom							
top bottom							
top bottom							

Appendix B

Particle size distribution laboratory reports

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	BS1-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	4-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.00**
Very Fine Silt % (4-8µm)	0.04
Fine Silt % (8-16µm)	0.26
Medium Silt % (16-31µm)	0.27
Course Silt % (31-63µm)	0.43
Total Silt (4-63µm)	**1.00**
Very Fine sand % (63-125µm)	0.12
Fine sand % (125-250µm)	1.17
Medium sand % (250-500µm)	28.24
Coarse sand % (500-1000µm)	38.66
Very Coarse sand % (1000-2000µm)	15.15
Total Sand (63-2000µm)	**83.34**
Total Gravels (>2000µm)	**15.66**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	751.92
Minimum settling velocity of 50% of particles (mm s^1)	466.22
Time for 50% of particles to settle over 1 m (hours)	0.001
D10 (µm)	343.50
Minimum settling velocity of 90% of particles (mm s^1)	97.30
Time for 90% of particles to settle over 1 m (hours)	0.003
SOP Name	SOP-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	38.66
1000	15.15
2000	12.16
4000	0.00
8000	3.50
16000	0.00

Sample visual assessment
Sand with some rock and shell present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	BS2-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	4-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.00**
Very Fine Silt % (4-8µm)	0.20
Fine Silt % (8-16µm)	0.27
Medium Silt % (16-31µm)	0.30
Course Silt % (31-63µm)	1.10
Total Silt (4-63µm)	**1.87**
Very Fine sand % (63-125µm)	0.44
Fine sand % (125-250µm)	12.07
Medium sand % (250-500µm)	74.07
Coarse sand % (500-1000µm)	9.57
Very Coarse sand % (1000-2000µm)	0.69
Total Sand (63-2000µm)	**96.83**
Total Gravels (>2000µm)	**1.30**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	364.46
Minimum settling velocity of 50% of particles (mm s^1)	109.53
Time for 50% of particles to settle over 1 m (hours)	0.003
D10 (µm)	229.05
Minimum settling velocity of 90% of particles (mm s^1)	43.26
Time for 90% of particles to settle over 1 m (hours)	0.006
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	9.57
1000	0.69
2000	0.57
4000	0.72
8000	0.00
16000	0.00

Sample visual assessment
Sand with some shell present.

PARTICLE SIZE ANALYSIS REPORT
Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	BS3-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	4-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.45**
Very Fine Silt % (4-8µm)	0.89
Fine Silt % (8-16µm)	1.74
Medium Silt % (16-31µm)	2.63
Course Silt % (31-63µm)	4.10
Total Silt (4-63µm)	**9.36**
Very Fine sand % (63-125µm)	6.03
Fine sand % (125-250µm)	9.42
Medium sand % (250-500µm)	12.87
Coarse sand % (500-1000µm)	54.32
Very Coarse sand % (1000-2000µm)	5.09
Total Sand (63-2000µm)	**87.73**
Total Gravels (>2000µm)	**2.46**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	609.23
Minimum settling velocity of 50% of particles (mm s^1)	306.06
Time for 50% of particles to settle over 1 m (hours)	0.001
D10 (µm)	64.69
Minimum settling velocity of 90% of particles (mm s^1)	3.45
Time for 90% of particles to settle over 1 m (hours)	0.080
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	54.32
1000	5.09
2000	2.46
4000	0.00
8000	0.00
16000	0.00

Sample visual assessment
Sand with some shell present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	DF1-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	4-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.00**
Very Fine Silt % (4-8µm)	0.00
Fine Silt % (8-16µm)	0.00
Medium Silt % (16-31µm)	0.00
Course Silt % (31-63µm)	0.00
Total Silt (4-63µm)	**0.00**
Very Fine sand % (63-125µm)	0.00
Fine sand % (125-250µm)	5.31
Medium sand % (250-500µm)	64.70
Coarse sand % (500-1000µm)	28.27
Very Coarse sand % (1000-2000µm)	1.18
Total Sand (63-2000µm)	**99.47**
Total Gravels (>2000µm)	**0.53**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	424.38
Minimum settling velocity of 50% of particles (mm s^1)	148.51
Time for 50% of particles to settle over 1 m (hours)	0.002
D10 (µm)	276.03
Minimum settling velocity of 90% of particles (mm s^1)	62.83
Time for 90% of particles to settle over 1 m (hours)	0.004
SOP Name	SOP-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	28.27
1000	1.18
2000	0.53
4000	0.00
8000	0.00
16000	0.00

Sample visual assessment
Sand with some shell present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	DF2-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	4-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.00**
Very Fine Silt % (4-8µm)	0.00
Fine Silt % (8-16µm)	0.00
Medium Silt % (16-31µm)	0.00
Course Silt % (31-63µm)	0.00
Total Silt (4-63µm)	**0.00**
Very Fine sand % (63-125µm)	0.00
Fine sand % (125-250µm)	0.28
Medium sand % (250-500µm)	59.95
Coarse sand % (500-1000µm)	39.70
Very Coarse sand % (1000-2000µm)	0.06
Total Sand (63-2000µm)	**100.00**
Total Gravels (>2000µm)	**0.00**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	471.50
Minimum settling velocity of 50% of particles (mm s^1)	183.32
Time for 50% of particles to settle over 1 m (hours)	0.002
D10 (µm)	343.83
Minimum settling velocity of 90% of particles (mm s^1)	97.48
Time for 90% of particles to settle over 1 m (hours)	0.003
SOP Name	SOP-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	39.70
1000	0.06
2000	0.00
4000	0.00
8000	0.00
16000	0.00

Sample visual assessment
Sand with some shell present.

PARTICLE SIZE ANALYSIS REPORT
Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	DF3-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	4-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.00**
Very Fine Silt % (4-8µm)	0.22
Fine Silt % (8-16µm)	0.51
Medium Silt % (16-31µm)	0.44
Course Silt % (31-63µm)	1.44
Total Silt (4-63µm)	**2.60**
Very Fine sand % (63-125µm)	0.53
Fine sand % (125-250µm)	21.02
Medium sand % (250-500µm)	72.38
Coarse sand % (500-1000µm)	3.38
Very Coarse sand % (1000-2000µm)	0.06
Total Sand (63-2000µm)	**97.37**
Total Gravels (>2000µm)	**0.03**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	325.98
Minimum settling velocity of 50% of particles (mm s^1)	87.63
Time for 50% of particles to settle over 1 m (hours)	0.003
D10 (µm)	195.64
Minimum settling velocity of 90% of particles (mm s^1)	31.56
Time for 90% of particles to settle over 1 m (hours)	0.009
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	3.38
1000	0.06
2000	0.03
4000	0.00
8000	0.00
16000	0.00

Sample visual assessment
Sand with some shell present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH1-Sa
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	2-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.62**
Very Fine Silt % (4-8µm)	2.82
Fine Silt % (8-16µm)	7.07
Medium Silt % (16-31µm)	13.31
Course Silt % (31-63µm)	20.18
Total Silt (4-63µm)	**43.38**
Very Fine sand % (63-125µm)	21.52
Fine sand % (125-250µm)	17.81
Medium sand % (250-500µm)	12.20
Coarse sand % (500-1000µm)	2.78
Very Coarse sand % (1000-2000µm)	0.46
Total Sand (63-2000µm)	**54.78**
Total Gravels (>2000µm)	**0.22**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	73.94
Minimum settling velocity of 50% of particles (mm s^1)	4.51
Time for 50% of particles to settle over 1 m (hours)	0.062
D10 (µm)	14.38
Minimum settling velocity of 90% of particles (mm s^1)	0.17
Time for 90% of particles to settle over 1 m (hours)	1.629
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	2.78
1000	0.46
2000	0.11
4000	0.10
8000	0.00
16000	0.00

Sample visual assessment
Sandy mud with shell and some plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH1-Sb
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	2-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.74**
Very Fine Silt % (4-8µm)	2.92
Fine Silt % (8-16µm)	7.14
Medium Silt % (16-31µm)	13.19
Course Silt % (31-63µm)	19.75
Total Silt (4-63µm)	**43.01**
Very Fine sand % (63-125µm)	20.78
Fine sand % (125-250µm)	17.45
Medium sand % (250-500µm)	12.35
Coarse sand % (500-1000µm)	2.24
Very Coarse sand % (1000-2000µm)	0.73
Total Sand (63-2000µm)	**53.54**
Total Gravels (>2000µm)	**1.70**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	74.94
Minimum settling velocity of 50% of particles (mm s^1)	4.63
Time for 50% of particles to settle over 1 m (hours)	0.060
D10 (µm)	14.07
Minimum settling velocity of 90% of particles (mm s^1)	0.16
Time for 90% of particles to settle over 1 m (hours)	1.701
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	2.24
1000	0.73
2000	0.73
4000	0.09
8000	0.89
16000	0.00

Sample visual assessment
Sandy mud with shell and some plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH1-0.5-1m
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	2-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.82**
Very Fine Silt % (4-8µm)	3.01
Fine Silt % (8-16µm)	7.40
Medium Silt % (16-31µm)	13.69
Course Silt % (31-63µm)	19.82
Total Silt (4-63µm)	**43.93**
Very Fine sand % (63-125µm)	20.11
Fine sand % (125-250µm)	17.15
Medium sand % (250-500µm)	13.19
Coarse sand % (500-1000µm)	2.01
Very Coarse sand % (1000-2000µm)	0.70
Total Sand (63-2000µm)	**53.16**
Total Gravels (>2000µm)	**1.09**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	72.76
Minimum settling velocity of 50% of particles (mm s^1)	4.37
Time for 50% of particles to settle over 1 m (hours)	0.064
D10 (µm)	13.70
Minimum settling velocity of 90% of particles (mm s^1)	0.15
Time for 90% of particles to settle over 1 m (hours)	1.794
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	2.01
1000	0.70
2000	0.44
4000	0.66
8000	0.00
16000	0.00

Sample visual assessment
Sandy mud with shell and some plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH2-S1
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	2-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.40**
Very Fine Silt % (4-8µm)	1.37
Fine Silt % (8-16µm)	3.40
Medium Silt % (16-31µm)	6.47
Course Silt % (31-63µm)	10.14
Total Silt (4-63µm)	**21.38**
Very Fine sand % (63-125µm)	13.81
Fine sand % (125-250µm)	28.46
Medium sand % (250-500µm)	31.84
Coarse sand % (500-1000µm)	2.69
Very Coarse sand % (1000-2000µm)	0.28
Total Sand (63-2000µm)	**77.08**
Total Gravels (>2000µm)	**1.14**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	187.43
Minimum settling velocity of 50% of particles (mm s^1)	28.97
Time for 50% of particles to settle over 1 m (hours)	0.010
D10 (µm)	26.98
Minimum settling velocity of 90% of particles (mm s^1)	0.60
Time for 90% of particles to settle over 1 m (hours)	0.463
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume
Extended range by sieving	

Extended size, µm	Extended percent retained at size
500	2.69
1000	0.28
2000	0.56
4000	0.52
8000	0.06
16000	0.00

Sample visual assessment
Sandy mud with shell and some rocks and plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH2-S2
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	2-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.76**
Very Fine Silt % (4-8µm)	1.65
Fine Silt % (8-16µm)	4.23
Medium Silt % (16-31µm)	8.43
Course Silt % (31-63µm)	13.28
Total Silt (4-63µm)	**27.59**
Very Fine sand % (63-125µm)	16.15
Fine sand % (125-250µm)	19.75
Medium sand % (250-500µm)	18.71
Coarse sand % (500-1000µm)	5.87
Very Coarse sand % (1000-2000µm)	1.99
Total Sand (63-2000µm)	**62.47**
Total Gravels (>2000µm)	**9.19**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	153.34
Minimum settling velocity of 50% of particles (mm s^1)	19.39
Time for 50% of particles to settle over 1 m (hours)	0.014
D10 (µm)	21.78
Minimum settling velocity of 90% of particles (mm s^1)	0.39
Time for 90% of particles to settle over 1 m (hours)	0.710
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	5.87
1000	1.99
2000	1.81
4000	1.30
8000	6.07
16000	0.00

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH2-S3
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	2-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.79**
Very Fine Silt % (4-8µm)	1.76
Fine Silt % (8-16µm)	4.49
Medium Silt % (16-31µm)	8.80
Course Silt % (31-63µm)	13.93
Total Silt (4-63µm)	**28.98**
Very Fine sand % (63-125µm)	17.59
Fine sand % (125-250µm)	23.64
Medium sand % (250-500µm)	22.33
Coarse sand % (500-1000µm)	3.99
Very Coarse sand % (1000-2000µm)	0.97
Total Sand (63-2000µm)	**68.53**
Total Gravels (>2000µm)	**1.70**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	136.44
Minimum settling velocity of 50% of particles (mm s^1)	15.35
Time for 50% of particles to settle over 1 m (hours)	0.018
D10 (µm)	20.86
Minimum settling velocity of 90% of particles (mm s^1)	0.36
Time for 90% of particles to settle over 1 m (hours)	0.774
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	3.99
1000	0.97
2000	1.02
4000	0.58
8000	0.11
16000	0.00

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH2-0.5-1m
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	3-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.10**
Very Fine Silt % (4-8µm)	2.07
Fine Silt % (8-16µm)	5.37
Medium Silt % (16-31µm)	10.47
Course Silt % (31-63µm)	15.89
Total Silt (4-63µm)	**33.81**
Very Fine sand % (63-125µm)	18.19
Fine sand % (125-250µm)	19.64
Medium sand % (250-500µm)	18.29
Coarse sand % (500-1000µm)	5.60
Very Coarse sand % (1000-2000µm)	1.30
Total Sand (63-2000µm)	**63.02**
Total Gravels (>2000µm)	**2.08**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	111.91
Minimum settling velocity of 50% of particles (mm s^1)	10.33
Time for 50% of particles to settle over 1 m (hours)	0.027
D10 (µm)	17.98
Minimum settling velocity of 90% of particles (mm s^1)	0.27
Time for 90% of particles to settle over 1 m (hours)	1.042
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	5.60
1000	1.30
2000	1.70
4000	0.37
8000	0.00
16000	0.00

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH3-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	3-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.46**
Very Fine Silt % (4-8µm)	2.33
Fine Silt % (8-16µm)	5.52
Medium Silt % (16-31µm)	9.70
Course Silt % (31-63µm)	13.15
Total Silt (4-63µm)	**30.69**
Very Fine sand % (63-125µm)	15.66
Fine sand % (125-250µm)	21.60
Medium sand % (250-500µm)	16.41
Coarse sand % (500-1000µm)	5.41
Very Coarse sand % (1000-2000µm)	5.37
Total Sand (63-2000µm)	**64.45**
Total Gravels (>2000µm)	**3.40**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	135.19
Minimum settling velocity of 50% of particles (mm s^1)	15.07
Time for 50% of particles to settle over 1 m (hours)	0.018
D10 (µm)	16.98
Minimum settling velocity of 90% of particles (mm s^1)	0.24
Time for 90% of particles to settle over 1 m (hours)	1.168
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	5.41
1000	5.37
2000	0.31
4000	3.03
8000	0.00
16000	0.07

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

PARTICLE SIZE ANALYSIS REPORT
Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH4-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	3-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.21**
Very Fine Silt % (4-8µm)	2.29
Fine Silt % (8-16µm)	5.83
Medium Silt % (16-31µm)	10.79
Course Silt % (31-63µm)	15.52
Total Silt (4-63µm)	**34.43**
Very Fine sand % (63-125µm)	17.70
Fine sand % (125-250µm)	20.00
Medium sand % (250-500µm)	15.83
Coarse sand % (500-1000µm)	8.90
Very Coarse sand % (1000-2000µm)	0.86
Total Sand (63-2000µm)	**63.29**
Total Gravels (>2000µm)	**1.06**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	110.89
Minimum settling velocity of 50% of particles (mm s^1)	10.14
Time for 50% of particles to settle over 1 m (hours)	0.027
D10 (µm)	16.86
Minimum settling velocity of 90% of particles (mm s^1)	0.23
Time for 90% of particles to settle over 1 m (hours)	1.185
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	8.90
1000	0.86
2000	0.44
4000	0.28
8000	0.20
16000	0.15

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

PARTICLE SIZE ANALYSIS REPORT

Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH4-0.5-1m
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	3-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**0.57**
Very Fine Silt % (4-8µm)	1.41
Fine Silt % (8-16µm)	3.44
Medium Silt % (16-31µm)	6.23
Course Silt % (31-63µm)	9.28
Total Silt (4-63µm)	**20.36**
Very Fine sand % (63-125µm)	14.65
Fine sand % (125-250µm)	23.92
Medium sand % (250-500µm)	20.23
Coarse sand % (500-1000µm)	16.35
Very Coarse sand % (1000-2000µm)	2.70
Total Sand (63-2000µm)	**77.85**
Total Gravels (>2000µm)	**1.22**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	193.41
Minimum settling velocity of 50% of particles (mm s^1)	30.85
Time for 50% of particles to settle over 1 m (hours)	0.009
D10 (µm)	26.66
Minimum settling velocity of 90% of particles (mm s^1)	0.59
Time for 90% of particles to settle over 1 m (hours)	0.474
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	16.35
1000	2.70
2000	0.73
4000	0.42
8000	0.00
16000	0.07

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

PARTICLE SIZE ANALYSIS REPORT
Size distribution analysis by laser diffraction and wet sieving

Customer: BMT Oceanica
Contact: Jonathon Anderson
Address: PO Box 462, Wembley, WA 6913
Date Received: 28/10/2015
Date of Issue: 6/11/2015

Summary Report

Sample Name:	EH5-S
Sampling Date:	28/10/2015
Sample Type:	Sediment
MAFRL Job Code:	BMTO15-38
Client Reference:	1058-01-008
Analysis Date	3-Nov-15
Instrument	Mastersizer3000
RI/ABS:	2.74 / 1
Dispersant	Water
Additives	10mL Sodium Hexametaphosphate
Sonication (s)	300
Size Classifications	
Total Clay % (0-4µm)	**1.33**
Very Fine Silt % (4-8µm)	2.50
Fine Silt % (8-16µm)	6.34
Medium Silt % (16-31µm)	12.04
Course Silt % (31-63µm)	17.65
Total Silt (4-63µm)	**38.53**
Very Fine sand % (63-125µm)	18.90
Fine sand % (125-250µm)	18.43
Medium sand % (250-500µm)	14.07
Coarse sand % (500-1000µm)	4.42
Very Coarse sand % (1000-2000µm)	0.75
Total Sand (63-2000µm)	**56.57**
Total Gravels (>2000µm)	**3.57**
Settling Velocity calculations using Stokes Law	
Parameters	
Particle density (ρp)(g/cm^3)	2.65
Liquid density (ρf) (g/cm^3)	1.025
Acceleration due to Gravity (g) (ms^{-2})	9.81
Liquid viscosity (η) (cp)	1.074
*Liquid parameters based on seawater of 35ppt @ 20°C	
Calculations	
D50 (µm)	91.59
Minimum settling velocity of 50% of particles (mm s^1)	6.92
Time for 50% of particles to settle over 1 m (hours)	0.040
D10 (µm)	15.80
Minimum settling velocity of 90% of particles (mm s^1)	0.21
Time for 90% of particles to settle over 1 m (hours)	1.350
SOP Name	SOP-LV-3REPS-default.msop
Analysis Model	General Purpose
Result Units	Volume

Extended range by sieving

Extended size, µm	Extended percent retained at size
500	4.42
1000	0.75
2000	0.33
4000	2.25
8000	0.60
16000	0.38

Sample visual assessment
Sandy mud with shell and some rock and plant material present.

Appendix C

Metals laboratory reports

Marine and Freshwater Research Laboratory Environmental Science
Telephone: +61 8 93602907 Facsimile: +61 8 93606613

Accreditation Number: 10603
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Murdoch UNIVERSITY

SEDIMENT DATA

Contact: Jonathan Anderson
Customer: BMT Oceanica
Address: PO Box 462, Wembley WA 6913

Date of Issue: 16/11/2015
Date Received: 28/10/2015
Our Reference: BMTO15-38
Your Reference: 15-51
Your Job No: 1058_01_008

METHOD SAMPLE CODE	Sampling Date	ICP002 Total Ext Ag mg/kg	ICP002 Total Ext Al mg/kg	ICP002 Total Ext As mg/kg	ICP002 Total Ext Cd mg/kg	ICP002 Total Ext Cr mg/kg	ICP002 Total Ext Cu mg/kg	ICP002 Total Ext Ni mg/kg	ICP002 Total Ext Pb mg/kg	ICP002 Total Ext Zn mg/kg
Reporting Limit		**<1**	**<20**	**<2**	**<0.1**	**<0.2**	**<0.2**	**<0.7**	**<1**	**<0.5**
File		**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**
DF1 -S	28/10/2015	<1	240	<2	0.1	9.0	0.2	<0.7	<1	1.0
DF2-S	28/10/2015	<1	230	<2	0.1	8.5	0.3	<0.7	<1	1.0
DF3-S	28/10/2015	<1	310	<2	0.2	12	0.3	<0.7	<1	1.1
BS1-S	28/10/2015	<1	250	2	0.1	8.1	0.3	<0.7	<1	1.1
BS2-S	28/10/2015	<1	280	<2	0.1	11	0.3	<0.7	<1	1.2
BS3-S	28/10/2015	<1	260	2	<0.1	8.2	0.4	<0.7	<1	1.4
EH1-Sa	28/10/2015	<1	2900	7	0.8	25	14	5.7	21	110
EH1-Sb	28/10/2015	<1	2300	7	0.7	24	13	5.4	20	98
EH1-0.5-1.0	28/10/2015	<1	2200	7	0.7	23	13	5.6	24	100
EH2-S1	28/10/2015	<1	530	3	0.2	13	2.6	1.0	2	15
EH2-S2	28/10/2015	<1	950	5	0.4	16	6.5	2.5	5	45
EH2-S3	28/10/2015	<1	740	4	0.3	14	4.7	2.0	4	32
EH2-0.5-1.0	28/10/2015	<1	1100	6	0.5	17	7.0	3.1	5	51
EH3-S	28/10/2015	<1	1600	6	0.3	15	9.6	4.4	42	140
EH4-S	28/10/2015	<1	1200	3	0.3	15	5.5	1.9	32	39
EH4-0.5-1.0	28/10/2015	<1	610	3	0.2	12	2.3	0.9	5	15
EH5-S	28/10/2015	<1	1900	5	0.6	21	9.7	3.2	14	65

Note: Results expressed as dry weight basis.

Signatory: Lirong Han
Date: 16/11/2015

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

Marine and Freshwater Research Laboratory
Environmental Science
Telephone: +61 8 93602907 Facsimile: +61 8 93606613

WORLD RECOGNISED ACCREDITATION
Accreditation Number: 10603
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SEDIMENT DATA

Contact: Jonathan Anderson
Customer: BMT Oceanica
Address: PO Box 462, Wembley WA 6913

Date of Issue: 16/11/2015
Date Received: 28/10/2015
Our Reference: BMTO15-38
Your Reference: 15-51
Your Job No: 1058_01_008

METHOD SAMPLE CODE	Sampling Date	ICP002 Total Ext Ag mg/kg	ICP002 Total Ext Al mg/kg	ICP002 Total Ext As mg/kg	ICP002 Total Ext Cd mg/kg	ICP002 Total Ext Cr mg/kg	ICP002 Total Ext Cu mg/kg	ICP002 Total Ext Ni mg/kg	ICP002 Total Ext Pb mg/kg	ICP002 Total Ext Zn mg/kg	
Reporting Limit		**<1**	**<20**	**<2**	**<0.1**	**<0.2**	**<0.2**	**<0.7**	**<1**	**<0.5**	
File		**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	**15111201**	
QA/QC Data						**QA value**					**Acceptance Criteria**
BS2-S Duplicate % Difference		6.7%	3.4%	6.0%	15.2%	2.2%	1.9%	9.3%	<RL	18.8%	<20%
EH2-S1 Duplicate % Difference		17.7%	3.0%	3.5%	4.1%	2.0%	3.8%	2.6%	6.6%	0.1%	<20%
EH4-S Duplicate % Difference		5.9%	2.8%	8.9%	5.7%	2.0%	4.6%	3.2%	3.7%	2.0%	<20%
EH1-0.5-1 Spike Recovery		114.5%	94.9%	105.1%	92.5%	98.5%	107.7%	92.2%	92.8%	97.9%	80%-120%
Blank		<1	<20	<2	<0.1	<0.2	<0.2	<0.7	<1	<0.5	< Report Limit
Inhouse Standard 3		94.8%	108.6%	94.6%	98.5%	100.3%	98.1%	98.8%	98.8%	102.1%	80%-120%
Inhouse Standard 3		98.3%	110.7%	100.9%	96.8%	100.4%	96.6%	97.4%	98.5%	100.7%	80%-120%
Certified Standard		94.9%	106.2%	83.7%	93.2%	98.6%	90.5%	99.4%	95.7%	88.5%	80%-120%

Signatory: Lirong Han
Date: 16/11/2015

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

Marine and Freshwater
Research Laboratory
Environmental Science
Telephone: +61 8 93602907 Facsimile: +61 8 93606613

Accreditation Number: 10603
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NATA's accreditation requirements.
Accredited for compliance with ISO/IEC 17025.

Murdoch UNIVERSITY

SEDIMENT DATA

Contact: Jonathan Anderson
Customer: BMT Oceanica
Address: PO Box 462, Wembley WA 6913

Date of Issue: 16/11/2015
Date Received: 28/10/2015
Our Reference: BMTO15-38
Your Reference: 15-51
Your Job No: 1058_01_008

METHOD SAMPLE CODE	Sampling Date	ICP002 Total Ext Ag mg/kg	ICP002 Total Ext Al mg/kg	ICP002 Total Ext As mg/kg	ICP002 Total Ext Cd mg/kg	ICP002 Total Ext Cr mg/kg	ICP002 Total Ext Cu mg/kg	ICP002 Total Ext Ni mg/kg	ICP002 Total Ext Pb mg/kg	ICP002 Total Ext Zn mg/kg
Reporting Limit		<1	<20	<2	<0.1	<0.2	<0.2	<0.7	<1	<0.5
File		15111201	15111201	15111201	15111201	15111201	15111201	15111201	15111201	15111201

Signatory: Lirong Han
Date: 16/11/2015

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Marine and Freshwater Research Laboratory
Environmental Science
Telephone: +61 8 93602907 Facsimile: +61 8 93606613

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Murdoch UNIVERSITY

SEDIMENT DATA

Contact: Jonathan Anderson
Customer: BMT Oceanica
Address: PO Box 462, Wembley WA 6913

Date of Issue: 16/11/2015
Date Received: 28/10/2015
Our Reference: BMTO15-38
Your Reference: 15-51
Your Job No: 1058_01_008

METHOD SAMPLE CODE	Sampling Date	6200 TOC % C	ICP007 Total Ext Hg mg/kg	ICP002 Total Ext Sb mg/kg
Reporting Limit		**<0.2**	**<0.01**	**<2**
File		**15111101**	**15111102**	**15111201**
DF1 -S	28/10/2015	<0.2	<0.01	<2
DF2-S	28/10/2015	<0.2	<0.01	<2
DF3-S	28/10/2015	0.2	<0.01	<2
BS1-S	28/10/2015	<0.2	<0.01	<2
BS2-S	28/10/2015	<0.2	<0.01	<2
BS3-S	28/10/2015	0.2	<0.01	<2
EH1-Sa	28/10/2015	4.6	0.03	<2
EH1-Sb	28/10/2015	4.9	0.03	<2
EH1-0.5-1.0	28/10/2015	4.6	0.03	<2
EH2-S1	28/10/2015	1.1	<0.01	<2
EH2-S2	28/10/2015	2.8	0.01	<2
EH2-S3	28/10/2015	1.8	<0.01	<2
EH2-0.5-1.0	28/10/2015	2.9	0.01	<2
EH3-S	28/10/2015	1.5	0.01	<2
EH4-S	28/10/2015	1.7	0.01	<2
EH4-0.5-1.0	28/10/2015	0.7	<0.01	<2
EH5-S	28/10/2015	3.6	0.02	<2

Note: Results expressed as dry weight basis.

Signatory: Lirong Han
Date: 16/11/2015

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

Marine and Freshwater Research Laboratory
Environmental Science
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SEDIMENT DATA

Contact: Jonathan Anderson
Customer: BMT Oceanica
Address: PO Box 462, Wembley WA 6913

Date of Issue: 16/11/2015
Date Received: 28/10/2015
Our Reference: BMTO15-38
Your Reference: 15-51
Your Job No: 1058_01_008

METHOD	Sampling	6200	ICP007	ICP002
SAMPLE CODE	Date	TOC	Total Ext Hg	Total Ext Sb
		% C	mg/kg	mg/kg
Reporting Limit		<0.2	<0.01	<2
File		15111101	15111102	15111201

QA/QC Data	QA value			Acceptance Criteria
BS2-S Duplicate % Difference	7%			<20%
EH2-S1 Duplicate % Difference	7%			<20%
EH4-S Duplicate % Difference	2%			<20%
EH4-0.5-1.0 Duplicate % Difference	7%			<20%
EH5-S Duplicate % Difference	2%			<20%
Blank	<0.2			< Report Limit
Inhouse Standard 9911	96%			80%-120%
Inhouse Standard 9911	103%			80%-120%
Inhouse Standard 9911+	101%			80%-120%
		QA value		
EH1-0.5-1.0 Duplicate % Difference		1.3%		<20%
EH2-2 Spike Recovery		97.7%		80%-120%
Blank		<0.01		< Report Limit
Inhouse Standard 3		102.5%		80%-120%
Inhouse Standard 3		101.9%		80%-120%
Certified Standard		100.6%		80%-120%
			QA value	
BS2-S Duplicate % Difference			11.7%	<20%

Signatory: Lirong Han
Date: 16/11/2015

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

Marine and Freshwater Research Laboratory
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Accreditation Number: 10603
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Murdoch University

SEDIMENT DATA

Contact: Jonathan Anderson
Customer: BMT Oceanica
Address: PO Box 462, Wembley WA 6913

Date of Issue: 16/11/2015
Date Received: 28/10/2015
Our Reference: BMTO15-38
Your Reference: 15-51
Your Job No: 1058_01_008

METHOD SAMPLE CODE	Sampling Date	6200 TOC % C	ICP007 Total Ext Hg mg/kg	ICP002 Total Ext Sb mg/kg	
Reporting Limit		**<0.2**	**<0.01**	**<2**	
File		**15111101**	**15111102**	**15111201**	
EH2-S1					
EH2-S1 Duplicate % Difference				4.4%	<20%
EH4-S					
EH4-S Duplicate % Difference				6.6%	<20%
EH1-0.5-1 Spike Recovery				107.7%	80%-120%
Blank				<2	< Report Limit
Inhouse Standard 3				99.9%	80%-120%
Inhouse Standard 3				102.4%	80%-120%
Certified Standard				107.0%	80%-120%

Signatory: Lirong Han
Date: 16/11/2015

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

Appendix D

TBT laboratory report

Australian Government
Department of Industry, Innovation and Science

National Measurement Institute

NATA

REPORT OF ANALYSIS

Report No. RN1093160

Client	: MURDOCH UNIVERSITY MARINE & FRESHWATER RESEARCH LAB SOUTH STREET MURDOCH WA 6150	**Job No.** **Quote No.** **Order No.** **Date Sampled** **Date Received**	: MURD03/151103 : QT-02002 : BMT15-38 : : 3-NOV-2015
Attention	: KRZYSZTOF WIENCZUGOW	**Sampled By**	: CLIENT
Project Name	:		
Your Client Services Manager	: RICHARD COGHLAN	**Phone**	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
W15/019939	.	WATER EH1_0.5-1.0
W15/019940	.	WATER EH2_S-1
W15/019941	.	WATER EH2_S-2
W15/019942	.	WATER EH2_S-3

Lab Reg No.		**W15/019939**	**W15/019940**	**W15/019941**	**W15/019942**	
Sample Reference	**Units**	.	.	.	.	**Method**
Organotins						
Monobutyltin as Sn	ng/L	15	8.8	11	11	NR_35
Dibutyltin as Sn	ng/L	2.2	<2	<2	4.4	NR_35
Tributyltin as Sn	ng/L	2.1	2.7	2.0	2.9	NR_35
Surrogate: Tripropyltin	%REC	107	97	105	103	NR_35
Dates						
Date extracted		11-NOV-2015	11-NOV-2015	11-NOV-2015	11-NOV-2015	
Date analysed		12-NOV-2015	12-NOV-2015	12-NOV-2015	12-NOV-2015	

Luke Baker, Analyst
Organics - NSW
Accreditation No. 198

Danny Slee, Section Manager
Organic - NSW
Accreditation No. 198

30-NOV-2015

REPORT OF ANALYSIS

Report No. RN1093160

Client : MURDOCH UNIVERSITY MARINE & FRESHWATER RESEARCH LAB SOUTH STREET MURDOCH WA 6150		**Job No.**	: MURD03/151103
		Quote No.	: QT-02002
		Order No.	: BMT15-38
		Date Sampled	:
		Date Received	: 3-NOV-2015
Attention : KRZYSZTOF WIENCZUGOW		**Sampled By**	: CLIENT
Project Name :			
Your Client Services Manager : RICHARD COGHLAN		**Phone**	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
W15/019943	.	WATER EH2_0.5-1.0
W15/019944	.	WATER EH3_S
W15/019945	.	WATER EH4_S
W15/019946	.	WATER EH4_0.5-1.0

Lab Reg No.		W15/019943	W15/019944	W15/019945	W15/019946	
Sample Reference	**Units**	.	.	.	.	**Method**
Organotins						
Monobutyltin as Sn	ng/L	21	25	8.1	4.8	NR_35
Dibutyltin as Sn	ng/L	<2	53	<2	<2	NR_35
Tributyltin as Sn	ng/L	2.9	20	4.8	3.1	NR_35
Surrogate: Tripropyltin	%REC	96	102	104	99	NR_35
Dates						
Date extracted		11-NOV-2015	11-NOV-2015	11-NOV-2015	11-NOV-2015	
Date analysed		12-NOV-2015	12-NOV-2015	12-NOV-2015	12-NOV-2015	

Luke Baker, Analyst
Organics - NSW
Accreditation No. 198

Danny Slee, Section Manager
Organic - NSW
Accreditation No. 198

30-NOV-2015

REPORT OF ANALYSIS

Report No. RN1093160

Client	: MURDOCH UNIVERSITY MARINE & FRESHWATER RESEARCH LAB SOUTH STREET MURDOCH WA 6150	**Job No.**	: MURD03/151103
		Quote No.	: QT-02002
		Order No.	: BMT15-38
		Date Sampled	:
		Date Received	: 3-NOV-2015
Attention	: KRZYSZTOF WIENCZUGOW	**Sampled By**	: CLIENT
Project Name	:		
Your Client Services Manager	: RICHARD COGHLAN	**Phone**	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
W15/019947	.	WATER EH5_S
W15/019948	.	ELUTRIATE WATER

Lab Reg No.		W15/019947	W15/019948			
Sample Reference	**Units**	.	.			**Method**
Organotins						
Monobutyltin as Sn	ng/L	14	5.5			NR_35
Dibutyltin as Sn	ng/L	<2	<2			NR_35
Tributyltin as Sn	ng/L	3.6	<2			NR_35
Surrogate: Tripropyltin	%REC	95	104			NR_35
Dates						
Date extracted		11-NOV-2015	11-NOV-2015			
Date analysed		12-NOV-2015	12-NOV-2015			

Luke Baker, Analyst
Organics - NSW
Accreditation No. 198

Danny Slee, Section Manager
Organic - NSW
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Results relate only to the sample(s) tested.

REPORT OF ANALYSIS

Report No. RN1093160

This Report supersedes reports: *RN1092954*
RN1091167 *RN1091171*

Australian Government

National Measurement Institute

QUALITY ASSURANCE REPORT

Client: MURDOCH UNIVERSITY

NMI QA Report No: MURD03/151103 **Sample Matrix:** Liquid

Analyte	Method	LOR	Blank	Sample Duplicates			Recoveries	
				Sample	Duplicate	RPD	LCS	Matrix Spike
		ng/L	ng/L	ng/L	ng/L	%	%	%
Organics Section								
Organotin								
Monobutyltin	NR_35	2	<2	NA	NA	NA	76	NA
Dibutyltin	NR_35	2	<2	NA	NA	NA	97	NA
Tributyltin	NR_35	2	<2	NA	NA	NA	113	NA
Organotin Surrogate								
Tripropyltin (%Rec)	NR_35	-	-	NA	NA	NA	119	NA

Results expressed in percentage (%) or ng/L wherever appropriate.
Acceptable Spike recovery is 30-150% (monobutyltin and Tripropyltin); 40-160% (dibutyltin and tributyltin).
Maximum acceptable RPDs on spikes and duplicates is 60%.
'NA ' = Not Applicable.
RPD= Relative Percentage Difference, LCS = Laboratory Control Spike, LOR = Limit of Reporting.
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Signed:

Danny Slee
Organics Manager, NMI-North Ryde

Date: **13/11/2015**

Australian Government

National Measurement Institute

QUALITY ASSURANCE REPORT

Client: MURDOCH UNIVERSITY

NMI QA Report No: MURD03/151103/1 **Sample Matrix:** Solid

Analyte	Method	LOR	Blank	Sample Duplicates			Recoveries	
				Sample	Duplicate	RPD	LCS	Matrix Spike
		ng/g	ng/g	ng/g	ng/g	%	%	%
Organics Section								
Organotin								
Monobutyltin	NR_35	0.5	<0.5	NA	NA	NA	60	NA
Dibutyltin	NR_35	0.5	<0.5	NA	NA	NA	109	NA
Tributyltin	NR_35	0.5	<0.5	NA	NA	NA	146	NA
Organotin Surrogate								
Tripropyltin (%Rec)	NR_35	-	-	NA	NA	NA	94	NA

Results expressed in percentage (%) or ng/g wherever appropriate.
Acceptable Spike recovery is 30-150% (monobutyltin and Tripropyltin); 40-160% (dibutyltin and tributyltin)
Maximum acceptable RPDs on spikes and duplicates is 60%.
'NA ' = Not Applicable.
RPD= Relative Percentage Difference, LCS = Laboratory Control Spike, LOR = Limit of Reporting.
This report shall not be reproduced except in full.

Signed:

Danny Slee
Organics Manager, NMI-North Ryde

Date: **17/11/2015**

Australian Government
Department of Industry, Innovation and Science
National Measurement Institute
NATA

REPORT OF ANALYSIS

Report No. RN1091172

Client	: MURDOCH UNIVERSITY MARINE & FRESHWATER RESEARCH LAB SOUTH STREET MURDOCH WA 6150	**Job No.** **Quote No.** **Order No.** **Date Sampled** **Date Received**	: MURD03/151103/1 : QT-02002 : BMTO15-38 : : 3-NOV-2015
Attention	: KRZYSZTOF WIENCZUGOW	**Sampled By**	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	**Phone**	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
W15/019949	.	SOIL EH1_0.5-1.0
W15/019950	.	SOIL EH2_S-1
W15/019951	.	SOIL EH_S-2
W15/019952	.	SOIL EH2_S-3

Lab Reg No.		W15/019949	W15/019950	W15/019951	W15/019952	
Sample Reference	**Units**	.	.	.	.	**Method**
Organotins						
Monobutyltin as Sn	ng/g	<0.5	<0.5	<0.5	<0.5	NR_35
Dibutyltin as Sn	ng/g	3.0	<0.5	<0.5	<0.5	NR_35
Tributyltin as Sn	ng/g	13	<0.5	2.5	1.9	NR_35
Surrogate: Tripropyltin	%REC	88	83	84	91	NR_35
Dates						
Date extracted		10-NOV-2015	10-NOV-2015	10-NOV-2015	10-NOV-2015	
Date analysed		11-NOV-2015	11-NOV-2015	11-NOV-2015	11-NOV-2015	

Danny Slee, Section Manager
Organic - NSW
Accreditation No. 198

17-NOV-2015

Lab Reg No.		W15/019949	W15/019950	W15/019951	W15/019952	
Sample Reference	**Units**	.	.	.	.	**Method**
Trace Elements						
Total Solids	%	34.5	54.8	41.2	51.2	NT2_49

REPORT OF ANALYSIS

Report No. RN1091172

Lab Reg No.		W15/019949	W15/019950	W15/019951	W15/019952	
Sample Reference	Units	.	.	.	.	Method

Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

17-NOV-2015

REPORT OF ANALYSIS

Report No. RN1091172

Client	: MURDOCH UNIVERSITY MARINE & FRESHWATER RESEARCH LAB SOUTH STREET MURDOCH WA 6150	**Job No.** **Quote No.** **Order No.** **Date Sampled** **Date Received**	: MURD03/151103/1 : QT-02002 : BMTO15-38 : : 3-NOV-2015
Attention	: KRZYSZTOF WIENCZUGOW	**Sampled By**	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	**Phone**	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
W15/019953	.	SOIL EH2_0.5-1.0
W15/019954	.	SOIL EH3_S
W15/019955	.	SOIL EH4_S
W15/019956	.	SOIL EH4_0.5-1.0

Lab Reg No.		**W15/019953**	**W15/019954**	**W15/019955**	**W15/019956**	
Sample Reference	**Units**	.	.	.	.	**Method**
Organotins						
Monobutyltin as Sn	ng/g	<0.5	<0.5	<0.5	<0.5	NR_35
Dibutyltin as Sn	ng/g	1.2	2.8	1.5	<0.5	NR_35
Tributyltin as Sn	ng/g	11	14	12	3.5	NR_35
Surrogate: Tripropyltin	%REC	95	98	95	105	NR_35
Dates						
Date extracted		10-NOV-2015	10-NOV-2015	10-NOV-2015	10-NOV-2015	
Date analysed		11-NOV-2015	11-NOV-2015	11-NOV-2015	11-NOV-2015	

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17-NOV-2015

Lab Reg No.		**W15/019953**	**W15/019954**	**W15/019955**	**W15/019956**	
Sample Reference	**Units**	.	.	.	.	**Method**
Trace Elements						
Total Solids	%	41.0	60.8	53.1	67.5	NT2_49

REPORT OF ANALYSIS

Report No. RN1091172

Lab Reg No.		W15/019953	W15/019954	W15/019955	W15/019956	
Sample Reference	Units	.	.	.	.	Method

Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

17-NOV-2015

REPORT OF ANALYSIS

Report No. RN1091172

Client	: MURDOCH UNIVERSITY MARINE & FRESHWATER RESEARCH LAB SOUTH STREET MURDOCH WA 6150	**Job No.**	: MURD03/151103/1
		Quote No.	: QT-02002
		Order No.	: BMTO15-38
		Date Sampled	:
		Date Received	: 3-NOV-2015
Attention	: KRZYSZTOF WIENCZUGOW	**Sampled By**	: CLIENT
Project Name	:		
Your Client Services Manager	: RICHARD COGHLAN	**Phone**	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
W15/019957	.	SOIL EH5_S

Lab Reg No.		**W15/019957**				
Sample Reference	**Units**	.				**Method**
Organotins						
Monobutyltin as Sn	ng/g	<0.5				NR_35
Dibutyltin as Sn	ng/g	3.7				NR_35
Tributyltin as Sn	ng/g	20				NR_35
Surrogate: Tripropyltin	%REC	99				NR_35
Dates						
Date extracted		10-NOV-2015				
Date analysed		11-NOV-2015				

Danny Slee, Section Manager
Organic - NSW
Accreditation No. 198

17-NOV-2015

Lab Reg No.		**W15/019957**				
Sample Reference	**Units**	.				**Method**
Trace Elements						
Total Solids	%	33.4				NT2_49

Andrew Evans, Analyst
Inorganics - NSW
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17-NOV-2015

REPORT OF ANALYSIS

Report No. RN1091172

All results are expressed on a dry weight basis.

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Results relate only to the sample(s) tested.

This Report supersedes reports: *RN1089896* *RN1091165*

Appendix E

AAA laboratory reports

REPORT OF ANALYSIS

Laboratory Reference: A15/5576 [R00]

Client:	BMT Oceanica Pty Ltd Lev 1, 353 Cambridge Street Wembley WA 6913	**Order No:**	1058_01_008
		Project:	Sediment - Ocean Reef Baseline
		Sample Type:	sediment
		No. of Samples:	1
Contact:	Jonathan Anderson	**Date Received:**	29/10/2015
		Date Completed:	12/11/2015

Laboratory Contact Details:

Client Services Manager: Jane Struthers
Technical Enquiries: Andrew Bradbury
Telephone: +61 8 9325 9799
Fax: +61 8 9325 4299
Email: perth@advancedanalytical.com.au
andrew.bradbury@advancedanalytical.com.au

Attached Results Approved By:

Rama Nimmagadda
Technical Manager

Comments:
All samples tested as submitted by client. All attached results have been checked and approved for release.
This is the Final Report and supersedes any reports previously issued with this reference number.
Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

Accreditation No. 15109

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North Ryde NSW 2113 Australia
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contact@advancedanalytical.com.au
www.advancedanalytical.com.au

Batch Number: A15/5576 [R00]
Project Reference: Sediment - Ocean Reef Baseline

Laboratory Reference: **Client Reference:** **Date Sampled:** **Analysis Description**	**-** **-** **-** **Method**	**-** **-** **-** **Units**	**1** **EH1_S_c** **28/10/2015**
Moisture Content			
Moisture Content	04-004	%	64.6
Trace Elements			
Antimony	04-001	mg/kg	<0.5
Arsenic	04-001	mg/kg	7.3
Cadmium	04-001	mg/kg	0.83
Chromium	04-001	mg/kg	22
Copper	04-001	mg/kg	15
Lead	04-001	mg/kg	11
Mercury	04-002	mg/kg	0.03
Nickel	04-001	mg/kg	4.6
Silver	04-001	mg/kg	0.46
Zinc	04-001	mg/kg	90
Organotins			
Monobutyl tin	04-026	µgSn/kg	1.7
Dibutyl tin	04-026	µgSn/kg	1.9
Tributyl tin	04-026	µgSn/kg	2.4
Surrogate 1 Recovery	04-026	%	85
Date Extracted	04-026	-	9/11/2015
Date Analysed	04-026	-	9/11/2015
Subcontract Analysis			
Total Organic Carbon	SUB	%	4.7

Method	Method Description
04-004	Moisture by gravimetric, %
04-001	Metals by ICP-OES, mg/kg
04-002	Mercury by CVAAS, mg/kg
04-026	Organotins by GCMS, µgSn/kg
SUB	Subcontracted Analysis

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www.advancedanalytical.com.au

Batch Number: A15/5576 [R00]
Project Reference: Sediment - Ocean Reef Baseline

Result Comments

[<] Less than
[INS] Insufficient sample for this test
[NA] Test not required

Solid sample and metals results are reported on a dry weight basis.
TBT results are reported on a wet weight basis.
TOC analysis was subcontracted to Sydney Analytical Laboratories (NATA Number 1884); reference SAL report number SAL25608C.

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contact@advancedanalytical.com.au
www.advancedanalytical.com.au

Batch Number: A15/5576 [R00]
Project Reference: Sediment - Ocean Reef Baseline

QUALITY ASSURANCE REPORT

TEST	UNITS	Blank	Duplicate Sm#	Duplicate Results	Spike Sm#	Spike Results
Antimony	mg/kg	<0.5	[NT]	[NT]	A15/5514-A-1	96%
Arsenic	mg/kg	<0.4	[NT]	[NT]	A15/5514-A-1	100%
Cadmium	mg/kg	<0.1	[NT]	[NT]	A15/5514-A-1	103%
Chromium	mg/kg	<0.1	[NT]	[NT]	A15/5514-A-1	100%
Copper	mg/kg	<0.1	[NT]	[NT]	A15/5514-A-1	102%
Lead	mg/kg	<0.5	[NT]	[NT]	A15/5514-A-1	95%
Mercury	mg/kg	<0.01	[NT]	[NT]	A15/5514-A-1	109%
Nickel	mg/kg	<0.1	[NT]	[NT]	A15/5514-A-1	95%
Silver	mg/kg	<0.1	[NT]	[NT]	A15/5514-A-1	107%
Zinc	mg/kg	<0.5	[NT]	[NT]	A15/5514-A-1	96%

TEST	UNITS	Blank	Duplicate Sm#	Duplicate Results	Spike Sm#	Spike Results
Monobutyl tin	µgSn/kg	<0.50	[NT]	[NT]	A15/5576-1	85%
Dibutyl tin	µgSn/kg	<0.50	[NT]	[NT]	A15/5576-1	82%
Tributyl tin	µgSn/kg	<0.50	[NT]	[NT]	A15/5576-1	88%
Surrogate 1 Recovery	%	88	[NT]	[NT]	A15/5576-1	167%

TEST	UNITS	Blank
Total Organic Carbon	%	[NA]

TEST	Units	Blank	Duplicate Sm#	Duplicate Results	Spike Sm#	Spike Results
Monobutyl tin	µgSn/kg	[NT]	[NT]	[NT]	External	85%
Dibutyl tin	µgSn/kg	[NT]	[NT]	[NT]	External	88%
Tributyl tin	µgSn/kg	[NT]	[NT]	[NT]	External	91%
Surrogate 1 Recovery	%	[NT]	[NT]	[NT]	External	92%

Comments:
RPD = Relative Percent Deviation
[NT] = Not Tested
[N/A] = Not Applicable
'#' = Spike recovery data could not be calculated due to high levels of contaminants
Acceptable replicate reproducibility limit or RPD: 30%
Acceptable matrix spike & LCS recovery limits: Trace elements 70-130%
Organic analyses 50-150%
SVOC & speciated phenols 10-140%
Surrogates 10-140%

When levels outside these limits are obtained, an investigation into the cause of the deviation is performed before the batch is accepted or rejected, and results are released.

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www.advancedanalytical.com.au

REPORT OF ANALYSIS

Laboratory Reference: A15/5576-B [R00]

Client:	BMT Oceanica Pty Ltd Lev 1, 353 Cambridge Street Wembley WA 6913	**Order No:**	1058_01_008
		Project:	Sediment - Ocean Reef Baseline - Elutriate
		Sample Type:	sediment - Elutriate TBT
		No. of Samples:	2
Contact:	Jonathan Anderson	**Date Received:**	29/10/2015
		Date Completed:	11/11/2015

Laboratory Contact Details:

Client Services Manager: Jane Struthers
Technical Enquiries: Andrew Bradbury
Telephone: +61 8 9325 9799
Fax: +61 8 9325 4299
Email: perth@advancedanalytical.com.au
andrew.bradbury@advancedanalytical.com.au

Attached Results Approved By:

Rama Nimmagadda
Technical Manager

Comments:
All samples tested as submitted by client. All attached results have been checked and approved for release.
This is the Final Report and supersedes any reports previously issued with this reference number.
Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

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www.advancedanalytical.com.au

Batch Number: A15/5576-B [R00]
Project Reference: Sediment - Ocean Reef Baseline - Elutriate

Laboratory Reference: Client Reference: Date Sampled: Analysis Description	- - - Method	- - - Units	1 EH1_S_c 28/10/2015	2 Elutriate Blank NA
Elutriate - Organotins				
Tributyl tin	04-061	µgSn/L	<0.002	<0.002
Surrogate 1 Recovery	04-061	%	67	110
Date Extracted	04-061	-	9/11/2015	9/11/2015
Date Analysed	04-061	-	10/10/2015	10/10/2015

Method	Method Description
04-061	Tributyltin in saline waters by GCMS, µgSn/L

Result Comments
[<] Less than
[INS] Insufficient sample for this test
[NA] Test not required

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www.advancedanalytical.com.au

Batch Number: A15/5576-B [R00]
Project Reference: Sediment - Ocean Reef Baseline - Elutriate

QUALITY ASSURANCE REPORT

TEST	UNITS	Blank	Duplicate Sm#	Duplicate Results	Spike Sm#	Spike Results
Tributyl tin	µgSn/L	<0.001	[NT]	[NT]	External	95%
Surrogate 1 Recovery	%	128	[NT]	[NT]	External	110%

Comments:
RPD = Relative Percent Deviation
[NT] = Not Tested
[N/A] = Not Applicable
'#' = Spike recovery data could not be calculated due to high levels of contaminants
Acceptable replicate reproducibility limit or RPD: 30%
Acceptable matrix spike & LCS recovery limits: Trace elements 70-130%
Organic analyses 50-150%
SVOC & speciated phenols 10-140%
Surrogates 10-140%
When levels outside these limits are obtained, an investigation into the cause of the deviation is performed before the batch is accepted or rejected, and results are released.

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TECHNICAL NOTE

CLIENT:	**Strategen Environmental**		
PROJECT NO:	1058-02-001	**DATE:**	22 March 2016
SUBJECT:	Ocean Reef Marina Development PER: EQMF, EQC, EQP and Marine EIA advice		

Pertaining to compilation of the Ocean Reef Marina (ORM) Development (the 'Project') Public Environmental Review (PER), this Technical Note describes the Marine Environmental Quality Plan (EQP) and overarching marine Environmental Quality Management Framework (EQMF), as relevant to:

- defining terminology, issues and parameters for environmental impact assessment (EIA)
- a gap analysis of modelled/predicted environmental impacts, particularly of the parameters assessed in RPS APASA (2016)
- setting the framework for environmental monitoring and management plans (EMMPs) for construction and operational activities
- alignment with the ecological and social values specified by the Marmion Marine Park Management Plan (CALM 1992), with reference to recommendations of the MPRA's (2012) ten-year audit report.

1. Environmental Quality Management Framework

The Environmental Scoping Document (ESD; EPA 2014) requires the following component of work to contribute towards the protection of marine environmental quality:

> "*Provide an Environmental Quality Plan (EQP, i.e. a map) that spatially defines the Environmental Values (EVs, both ecological and social), Environmental Quality Objectives (EQOs) and Levels of Ecological Protection (LEPs) that currently apply to the area. The EQP should consider the Marine Parks and Reserves Authority's 10 year audit of the implementation Marmion Marine Park Management Plan 2002-2012.*"

Following release of the ESD, the EPA (2015a) published their Environmental Assessment Guideline for Protecting the Quality of Western Australia's Marine Environment (EAG 15), which is also directly relevant and applicable to the EIA and management of the Project.

A conceptual depiction of the EQMF, sourced directly from EAG15 is provided as Figure 1.1.

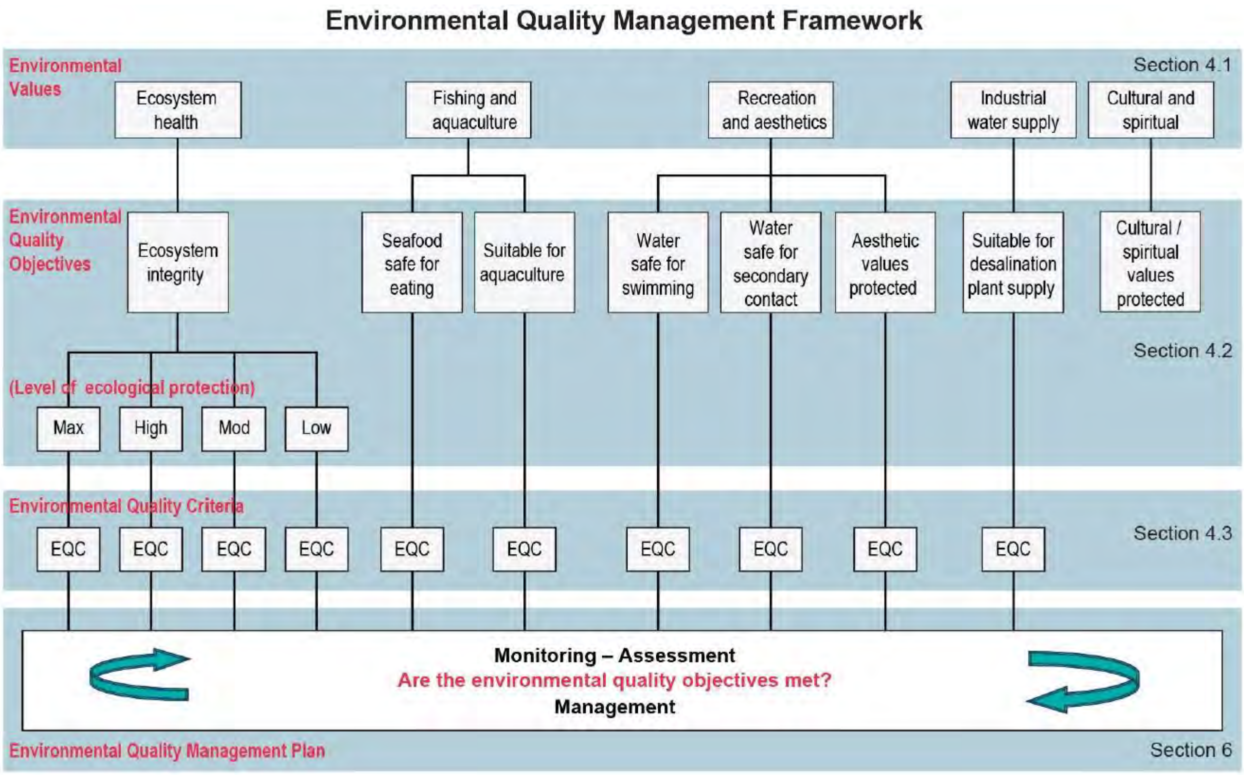

Figure 1.1 Environmental Management Quality Framework (EPA 2015)

In consideration of the EQMF (Figure 1.1), the Project PER must describe how each of the EVs will be protected by meeting EQOs, by assessment against relevant Environmental Quality Criteria (EQC), where:

> *"EQC represent scientifically based limits of acceptable change to a measureable environmental quality indicator that is important for the protection of the associated environmental value. A fundamental requirement of EQC is that they should be clear, readily measurable and auditable...*
>
> *In order to determine which are the relevant water quality indicators for monitoring, and hence for the development of EQC, a conceptual model of the system should be developed that represents how the system works. The model should also show the key threats to environmental quality and associated pressure/response relationships. The level of knowledge about the area will determine the level of detail and confidence in the model…*
>
> *The environmental quality criteria are divided into relatively simple and easy to measure environmental quality guidelines (EQG) and more robust environmental quality standards (EQS). Indicators for the development of EQG should be closer to the pressure end of the pressure/response relationship (e.g. chlorophyll a concentration…) and give early warning of a potential problem. The EQS are generally more difficult to measure and based on indicators located at the response end of the relationship"* [1] *(EPA 2015a)*

As such, EAG 15 (EPA 2015a) recommends that EQC (including EQG and EQS) be developed on a project-specific basis, and does not prescribe specific water quality indicators/EQC.

[1] *N.B. For the environmental value 'ecosystem health' different EQC will apply depending on the level of ecological protection to be met (see Figure 1).*

A marine environmental quality risk matrix has been developed for the Project (see Attachment A), which outlines:

- the potential threats to EVs arising from the construction and operation phases of the Project, including pressure-response relationships
- commentary on the residual risk to the EVs following environmental impact assessment
- EQC developed for monitoring to ensure risks to EVs are managed to within acceptable levels

The pressure-response relationships and EQC are conceptualised for the:

i. **construction phase** of the Project in Figure 1.2
ii. **operational phase** of the Project in Figure 1.3

While this document identifies the relevant EQC and framework for assessment, the details of monitoring and contingency management measures shall be described in the Marine Construction Monitoring and Management Plan (for construction of the marina) and the Marine Environmental Quality Management Plan (for operation of the marina).

EPA (2015a) also acknowledges that:

> "*Good examples of this approach are found in the Environmental Quality Criteria Reference Document for Cockburn Sound (EPA 2005a) which is a supporting document to the State Environmental (Cockburn Sound) Policy 2005 (EPA 2005b).*[2]
>
> *Once the relevant indicators, and associated EQC, have been identified an environmental quality monitoring program can be designed to measure the selected indicators and assess performance against the EQC*."

Section 2 below provides Project-specific consideration of applicable EQC before defining the EQP.

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[2] *Recently superseded by EPA (2015b) Environmental Quality Criteria Reference Document for Cockburn Sound (March 2015)*

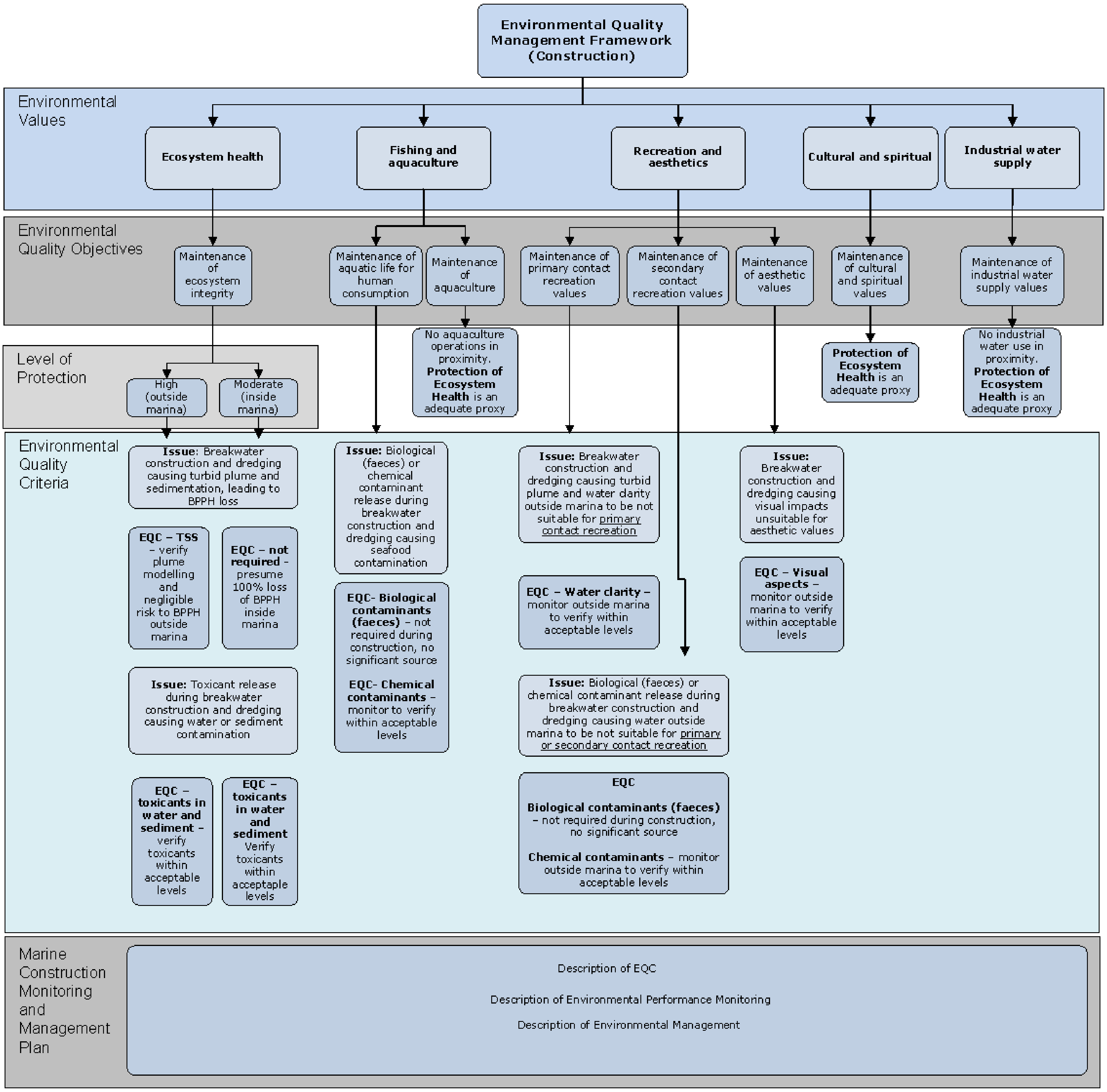


Figure 1.2 Conceptual Environmental Quality Management Framework for the construction phase of the Project

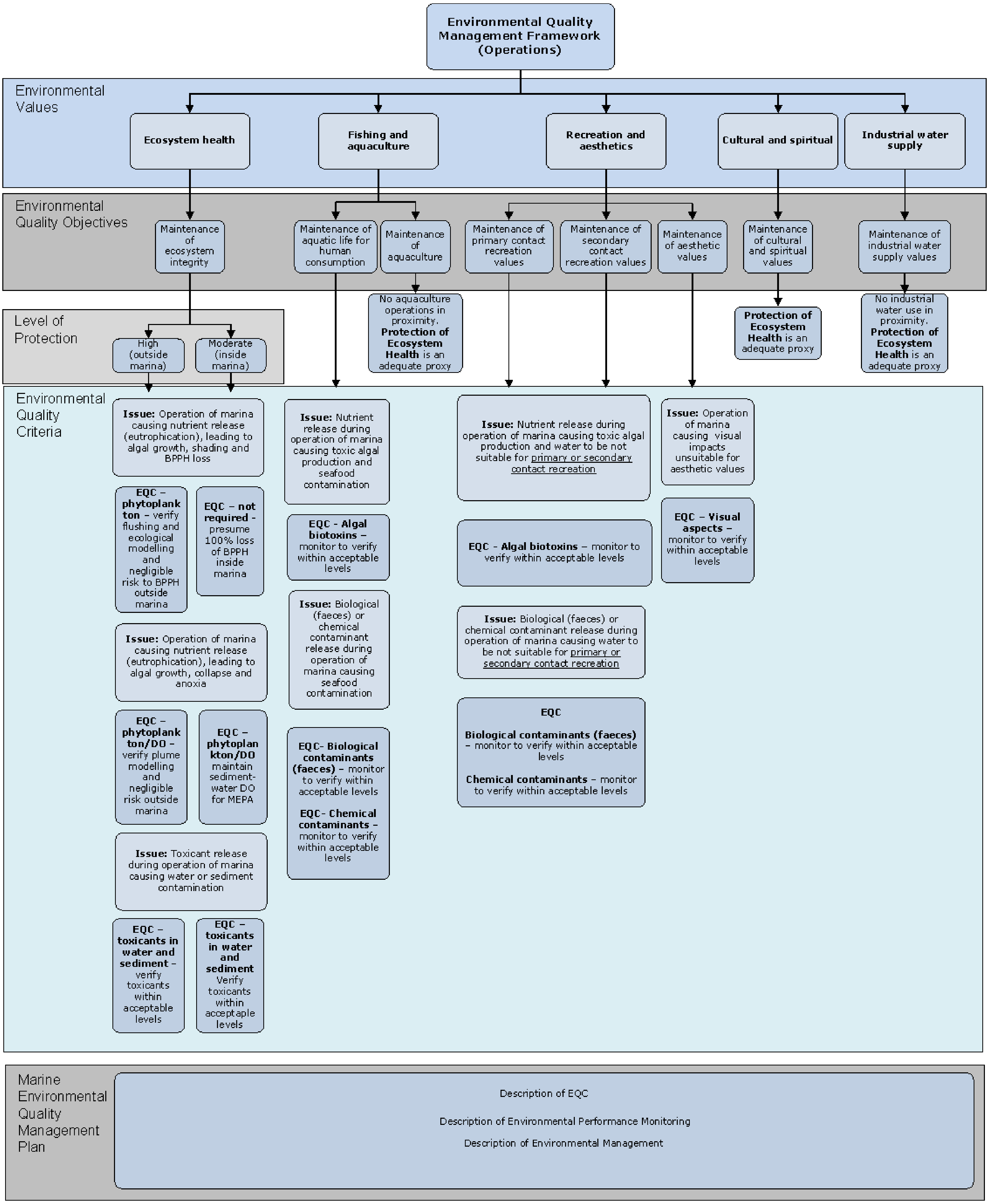


Figure 1.3 Conceptual Environmental Quality Management Framework for the operational phase of the Project

2. Environmental Quality Criteria

2.1 Ecosystem Health

To protect the EV of Ecosystem Health the EQO is to "*Maintain ecosystem integrity - this means maintaining the structure (e.g. the variety and quantity of life forms) and functions (e.g. the food chains and nutrient cycles) of marine ecosystems to an appropriate level*" (EPA 2015a).

The stressor-response relationships potentially impacting on Ecosystem Health were identified in the marine environmental quality risk matrix (Attachment A) and conceptual models for construction (Figure 1.2) and operation (Figure 1.3) as follows:

- Marina construction and operation causing nutrient release (eutrophication), leading to algal growth, shading and BPPH loss (see Section 2.1.1)
- Marina construction and operation causing nutrient release (eutrophication), leading to algal growth, collapse and anoxia (see Section 2.1.1)
- Toxicant release during construction and operation of marina causing water or sediment contamination (see Section 2.1.2)
- Marina construction and dredging causing turbid plume and sedimentation, leading to BPPH loss (see Section 5.1)

2.1.1 Potential impacts from changes in flushing

In the context of ecosystem health, the concern regarding changes in marina flushing regime is the consequent potential for eutrophication inside and/or outside of marina waters. Longer flushing times may lead to nutrient accumulation and algal/phytoplankton stimulation ('algal blooms'), possibly leading to reduced water clarity and potential shading impacts on BPPH. Further, collapse and biodegradation of algal blooms can lead to reduced dissolved oxygen availability in the water column and sediments; with knock-on effects such as sediment toxicant release from altered redox conditions, and mortality of (or avoidance by) benthic and pelagic fauna.

To assess the risk of eutrophication (and consequential effects) from an altered flushing regime of ORM, predictions of water quality were based on a hydrodynamic model that simulated water movement (current velocity and direction). This enabled the prediction of the flushing characteristics of the marina, and the degree to which nutrients (and other substances) diluted and dispersed within and outside of the marina. RPS APASA (2016) modelled the e-folding ('flushing') time during eight 15-day periods that were selected to be representative examples covering spring and neap tide conditions in each season. **The range of predicted maximum flushing time for each period was 2.3 to 7.3 days** (Table 7.1 of RPSA APASA 2016).

For comparison, the flushing times of similar marinas (BMT Oceanica 2012a) have been ascertained as:

- Hillary's Boat harbour: Flushing times ~4 days (average algal concentrations inside the marina ~3.3 times the value of 'outside' waters)
- Success Harbour: Flushing times ~1 day (average algal concentrations inside the marina ~2.0 times the value of 'outside' waters)
- Jervoise Bay Northern Harbour: Flushing times ~10–11 days (average algal concentrations inside the marina ~6.5 times the value of 'outside' waters)

Once flushing characteristics for ORM were ascertained, water quality investigations focussed on nutrient-related water quality, as the scoping phase of the project identified phytoplankton stimulation as a potential risk to water quality. Therefore the second component of the flushing study considered the potential for accumulation of nutrients within the marina, which are assumed to be sourced only from ongoing groundwater discharge into ORM (RPS APASA 2016). The analysis assumed that the nutrient inputs (dissolved inorganic nitrogen and phosphorous) behave as unreactive conservative tracers, and while this is unrealistic, it is a conservative approach that allows upper bound potential effects to be assessed (RPS APASA 2016). The results for this component of the flushing assessment, regarding the potential for nitrogen and phosphorus accumulation within ORM, are tabulated in Table 7.2 and Table 7.3 of RPS APSA (2016); summarised in Table 2.1 below.

Table 2.1 Predicted maximum and guideline nutrient concentrations in Ocean Reef Marina

Nutrient	Predicted maximum concentration in ORM at any location (80th percentile; RPS APASA 2016)	ANZECC & ARMCANZ (2000) guideline for south west Australia (80th percentile)
Total nitrogen ug/L	570	230
Total phosphorous ug/L	3.7	20 (summer) 40 (winter)

The worst case P80 results for phosphorus within ORM were significantly below the guideline value. However, the worst case nitrogen concentrations exceed the guideline value. This component of the assessment considers nitrogen only as passive tracer, which is a conservative assumption. This assumption was therefore relaxed in the ecological modelling component of the study where the impact of these nitrogen levels on algal growth was investigated.

To specifically assess the potential for algal growth within and outside the marina following development, RPS APASA (2016) also conducted ecological modelling to conservatively over-estimate algal concentrations within and outside the harbour during each season (Figure 2.1 to Figure 2.4). In almost all scenarios, elevations in algal concentrations were restricted to within the marina, with only minor elevations in algal concentration outside of the marina, near its mouth (Figure 2.1 to Figure 2.4).

RPS APASA (2016) concluded that, the results indicate that the potential for groundwater supported algal growth within ORM of around 0.01 to 0.03 gC/m3 is of a similar order, albeit slightly higher, to that of **typical background values for Perth coastal waters (0.01 gC/m3); i.e. algal concentrations within ORM ~ 3 times the value of 'outside waters'**.

For comparison, the increased algal concentrations of similar marinas (BMT Oceanica 2012a) have been ascertained as:

- Hillary's Boat harbour: average algal concentrations inside the marina ~3.3 times the value of 'outside' waters
- Success Harbour: average algal concentrations inside the marina ~2.0 times the value of 'outside' waters
- Jervoise Bay Northern Harbour: average algal concentrations inside the marina ~6.5 times the value of 'outside' waters

Inside the marina, sensitive BPPH will not be present such that potential consequences of shading from algal growth are irrelevant. However, a moderate ecological protection area (MEPA) will be likely emplaced (see Section 4 - EQP), and EQC will need to be developed and monitored during construction (subsequent to breakwater installation) and operation to demonstrate that algal elevations (and potential dissolved oxygen depression) are within acceptable bounds.

Outside of the marina, a high ecological protection area (HEPA) will be likely emplaced (see Section 4 - EQP). RPS APASA (2016) concludes that the algae attributable to the ORM source would be difficult to detect within a few hundred meters of the entrance. Further, of the 24 scenarios examined through summer, autumn, winter and spring (Figure 2.1 to Figure 2.4), algal concentration greater than 0.01 gC/m3 never occurred outside of the marina during summer (Figure 2.1) or autumn (Figure 2.2), and only occurred in close proximity to the entrance once during winter (on 17 July 2013; Figure Figure 2.3) and once during spring (9 October 2013; Figure 2.4). Outside of the marina, the risk of eutrophic effects (loss of BPPH and/or anoxia) are therefore considered negligible during summer and autumn. Similarly, algal concentrations greater than 0.01 gC/m3 near the ORM entrance during winter and spring are infrequent and transient (due to the high variability in weather during these seasons, with calm periods punctuated by increased flushing during storm events; RPS APASA 2016); such that the risk of eutrophic effects (loss of BPPH and/or anoxia) are also considered negligible during winter and spring. Monitoring outside of the marina during construction (subsequent to breakwater installation) and operation should focus on validating the predicted/modelled lack of algal elevations (and potential dissolved oxygen depression) are within acceptable bounds.

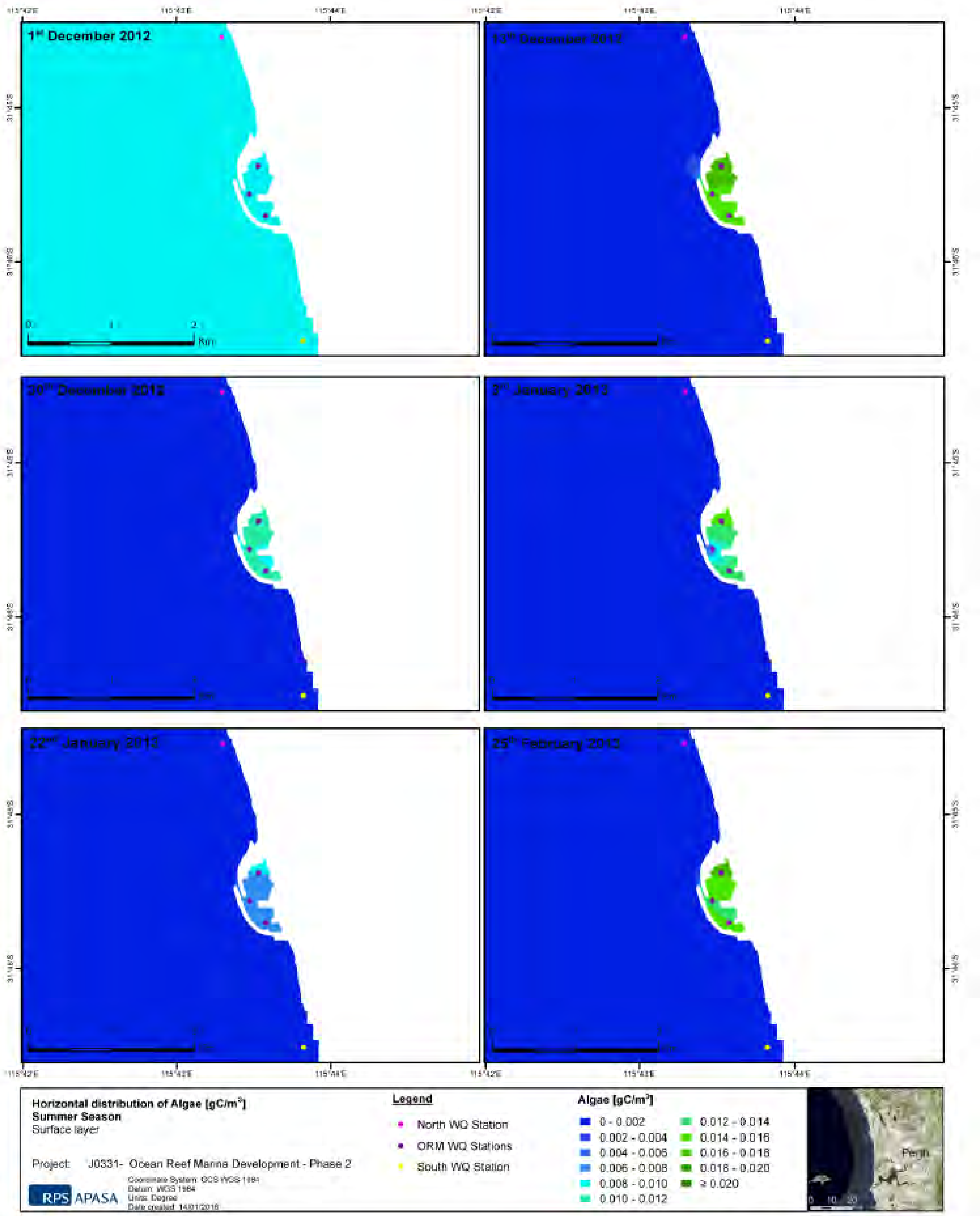


Figure 2.1 **Maps showing spatial variations in surface layer algal concentrations at selected time instances for the <u>summer</u> season scenario (RPS APASA 2016)**

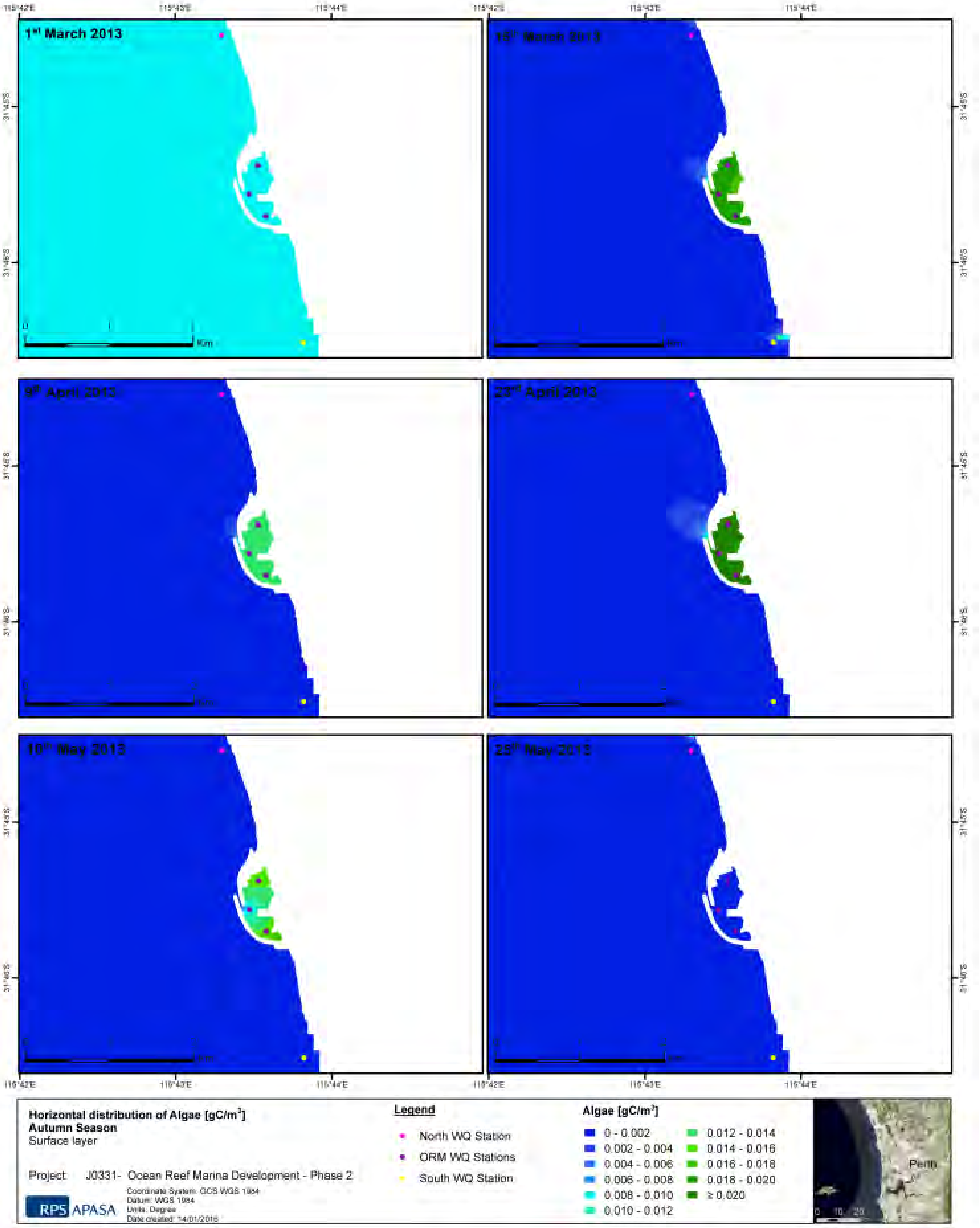


Figure 2.2 **Maps showing spatial variations in surface layer algal concentrations at selected time instances for the <u>autumn</u> season scenario (RPS APASA 2016)**

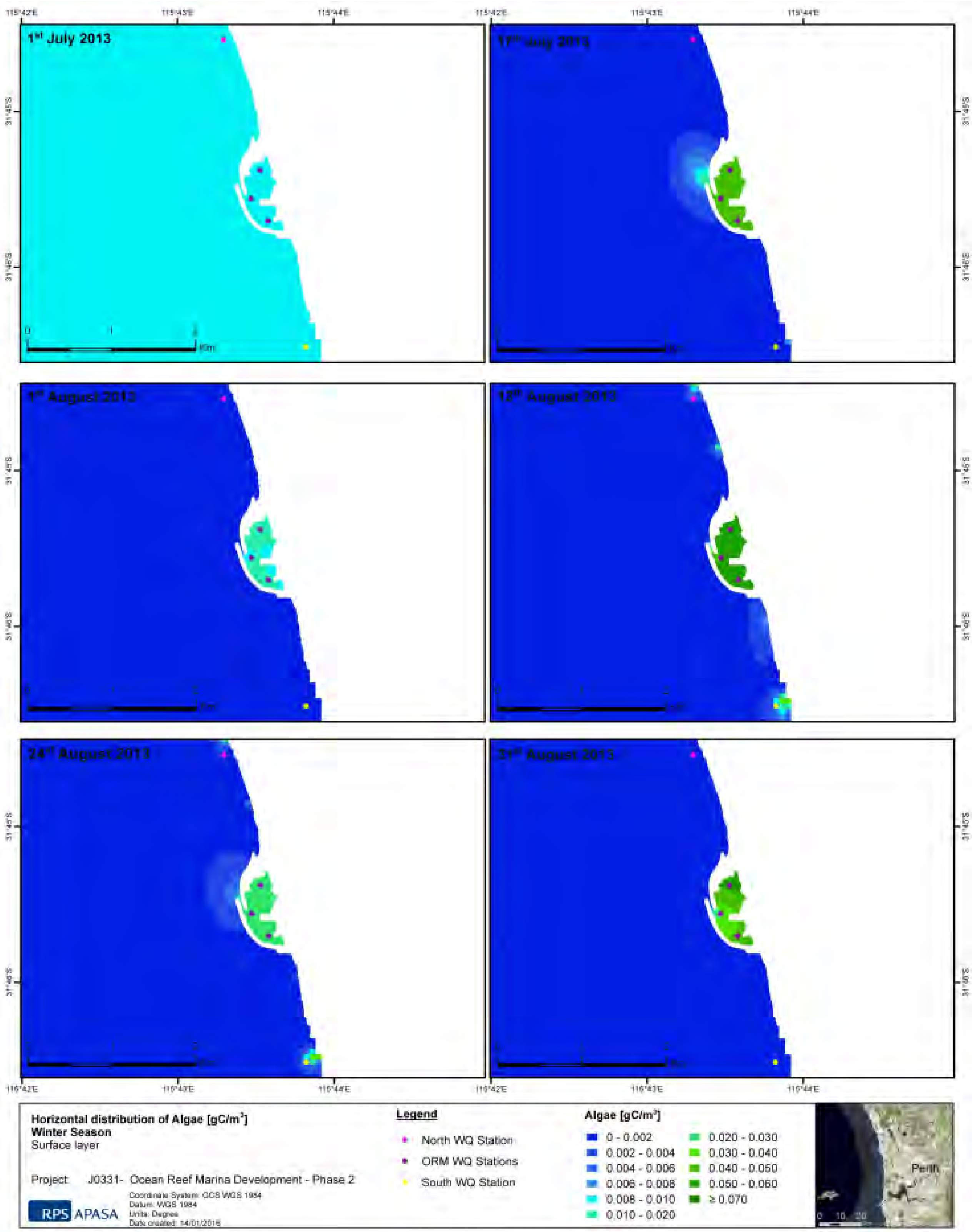


Figure 2.3 **Maps showing spatial variations in surface layer algal concentrations at selected time instances for the <u>winter</u> season scenario (RPS APASA 2016)**

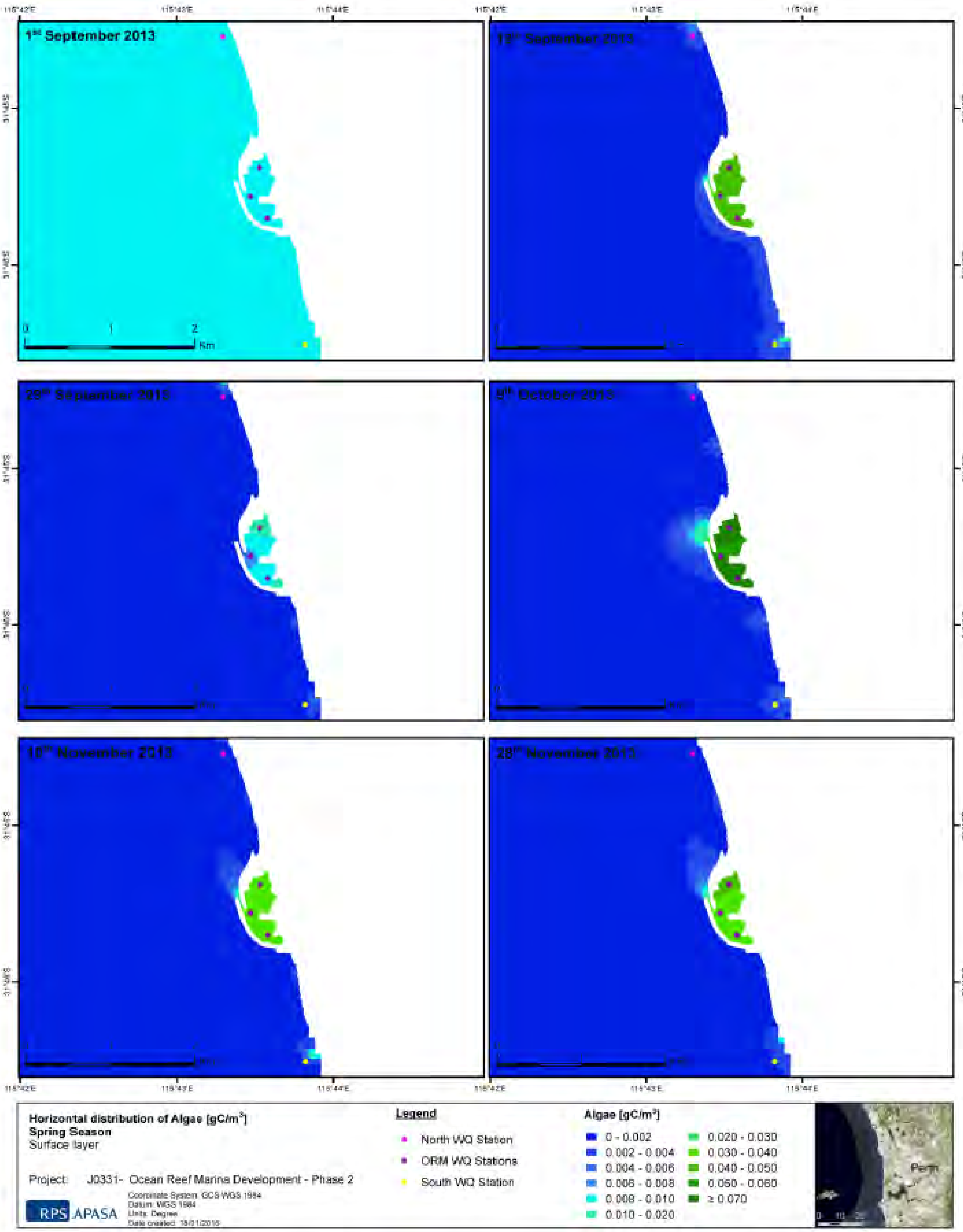


Figure 2.4 Maps showing spatial variations in surface layer algal concentrations at selected time instances for the spring season scenario (RPS APASA 2016)

2.1.2 Toxicants in water and sediment

The marine environment outside the marina is in a 'slightly disturbed' condition or better in accordance with ANZECC & ARMCANZ (2000) definition. In recognition of this a high level of ecological protection has been assigned to these areas. The EQG for this level of protection should be implemented in accordance with the recommendations of ANZECC & ARMCANZ (2000) (and consistent with EPA 2015b) as follows:

- The recommended 99% species protection guideline trigger levels for toxicants in water will apply
- The ISQG-low guideline trigger levels for toxicants in sediments.

Within the marina is considered to be 'moderately to highly disturbed' and shall be designated a MEPA and should be assessed separately. The EQG for moderate ecological protection should be implemented in accordance with the recommendations of ANZECC & ARMCANZ (2000) (and consistent with EPA 2015b) as follows:

- Application of the default 90% species protection guideline trigger levels for toxicants in water;
- The ISQG-low guideline trigger levels for toxicants in sediments;

While the methodology for developing EQC for all moderate ecological protection areas should be consistent, it may be appropriate to monitor a subset of indicators for the marina depending on potential threats to environmental quality and the benthic habitats.

2.2 Fishing and Aquaculture

To protect the EV of Fishing and Aquaculture the EQOs (EPA 2015a) are:

- Seafood (caught or grown) is of a quality safe for eating.
- Water quality is suitable for aquaculture purposes.

The stressor-response relationships potentially impacting on Fishing and Aquaculture values were identified in the marine environmental quality risk matrix (Attachment A) and conceptual models for construction (Figure 1.2) and operation (Figure 1.3) as follows:

- Nutrient release during marina construction and operation causing toxic algal production and seafood contamination
- Chemical contaminant release during marina construction and operation causing seafood contamination
- Biological (faeces) release during marina operation causing seafood contamination

2.2.1 Seafood safe for consumption

As per EPA (2015b), the EQC for this EQO shall set a level of environmental quality that will ensure there is a low risk of any effect on the health of human consumers of seafood:

> "*For filter feeding shellfish, except scallops and pearl oysters, any assessment against the EQO must be using data that are collected from a comprehensive monitoring program consistent with the requirements of the WASQAP Manual. The primary threats to human consumers of seafood relate to contamination of filter feeding shellfish by faecal pathogens (e.g. bacteria), the accumulation of biotoxins from toxic algae and/or the accumulation of toxic chemicals in the flesh of the shellfish. Filter feeding shellfish need to filter large quantities of water to obtain their food and in the process they can potentially accumulate significant*

quantities of pathogens and other contaminants that can cause serious illness in humans. However, for other species of seafood and for those shellfish where only the adductor muscle is eaten (e.g. scallops and pearl oysters) the DoH advises that there is only a low risk of potential impacts on human health and therefore monitoring programs do not need to be as comprehensive as required in the WASQAP Manual and may not need to consider faecal bacteria or toxic algae."

Where:

"*The two primary reference documents for development of the environmental quality guidelines and standards for this objective are the Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH, 2011) and the Australia New Zealand Food Standards Code (http://www.foodstandards.gov.au/foodstandards/foodstandardscode.cfm), developed and administered by Food Standards Australia New Zealand (FSANZ). Both documents are regularly updated and users should check the latest versions to determine whether the relevant EQC provided in this document have been revised. The WASQAP Manual can be located on the Department of Health (DoH) WA website* <www.public.health.wa.gov.au>."

The EQC (including EQG and EQS) specified in EPA (2015b) for biological and chemical contaminants are expected to be applicable to this Project.

2.2.2 Aquaculture production

There are no aquaculture operations within proximity of the Project. Should future aquaculture operations be approved within the vicinity of the Project, then EQC may need to be developed to ensure that water quality is sufficient for those operations. Compliance with EQC to protect the EV of Ecosystem Health should serve as a proxy to maintain water quality suitable for aquaculture operations.

2.3 Recreation and Aesthetics

To protect the EV of Recreation and Aesthetics the EQOs (EPA 2015a) are:

- Water quality is safe for primary contact recreation (e.g. swimming and diving).
- Water quality is safe for secondary contact recreation (e.g. fishing and boating).
- Aesthetic values of the marine environment are protected.

The stressor-response relationships potentially impacting on Recreation and Aesthetic values were identified in the marine environmental quality risk matrix (Attachment A) and conceptual models for construction (Figure 1.2) and operation (Figure 1.3) as follows:

- Breakwater construction and dredging causing turbid plume and water clarity outside marina to be not suitable for primary contact recreation
- Nutrient release during:
  - marina construction causing toxic algal production and water to be not suitable for primary or secondary contact recreation outside marina
  - operation of marina causing toxic algal production and water to be not suitable for primary or secondary contact recreation inside marina
- Chemical contaminant release during construction or operation of marina causing water to be not suitable for primary or secondary contact recreation
- Biological (faeces) contaminant release during operation of marina causing water to be not suitable for primary or secondary contact recreation

2.3.1 Primary contact recreation (swimming)

As per EPA (2015b), the EQC for this EQO are intended to "protect people from ill effects caused by poor water quality when undertaking recreational activities where the participant comes into frequent direct contact with the water, either as part of the activity or accidentally (e.g. swimming, water skiing, wind surfing or diving)."

The EQC (including EQG and EQS) specified in EPA (2015b) for faecal pathogens, toxic algae, water clarity and toxic chemicals are expected to be applicable to this Project.

2.3.2 Secondary contact recreation (boating)

As per EPA (2015b), the EQC for this EQO are intended to "protect people from ill effects caused by poor water quality when undertaking recreational activities in which the participant comes into direct contact with the water infrequently, either as part of the activity or accidentally (e.g. boating, canoeing or fishing).

The EQC (including EQG and EQS) specified in EPA (2015b) for faecal pathogens, toxic algae, water clarity and toxic chemicals are expected to be applicable to this Project.

2.3.3 Aesthetics

Project-specific EQC for visual water quality derived from EPA (2015b) should be developed including semi-quantitative observations of:

- Nuisance organisms:
- Faunal deaths:
- Water clarity
- Colour
- Surface films
- Surface debris
- Odour

Further, EPA (2015b) provides guidelines for fish tainting substances based on levels of contaminants that may make water or edible marine life unpalatable (but not toxic) to people. The EQC (including EQG and EQS) specified in EPA (2015b) for fish tainting are expected to be applicable to this Project.

2.4 Industrial Water Supply

To protect the EV of Industrial Water Supply the EQO is to ensure "*Water quality is suitable for industrial use*" (EPA 2015a).

There are no industrial water intakes within proximity of the Project. Should future industrial intakes be approved within the vicinity of the Project, then EQC may need to be developed to ensure that water quality is sufficient for those industrial requirements. Compliance with EQC to protect the EV of Ecosystem Health should serve as a proxy to maintain water quality suitable for industrial water intake.

2.5 Cultural and Spiritual

The EQO for this EV is simply to protect cultural and spiritual values of the marine environment (EPA 2015a).

Cultural and spiritual values of Indigenous Australians connected to marine and coastal environments may relate to a range of uses and issues including animals and plants associated with water, spiritual relationships, customary use, recreational activities and significant sites in the landscape (Collings 2012). Similar to Indigenous Australians, many non-indigenous Australians consider the coastal and marine environment to hold significant cultural and spiritual value; and their way of life of on the coastal fringe helps define their identity (Webler and Lord 2010).

Specific guidelines for marine water quality to protect cultural and spiritual values of Indigenous Australians are yet to be developed, and EPA (2015) does not denote EQC for the EQO to protect cultural and spiritual values. However, it is often deemed that the protection of ecosystem, recreational, fishing and aesthetic values of water bodies offers some assurance and a proxy towards protecting the fauna, flora, habitats and recreation values of cultural and spiritual importance (ANZECC & ARMCANZ 2000a).

3. Marmion Marine Park Ecological and Social Values

Under the Conservation and Land Management Act 1984 (CALM Act), marine parks and reserves (including Marmion Marine Park) are vested in the Marine Parks and Reserves Authority (MPRA). The MPRA has a statutory function under the CALM Act to prepare management plans for marine parks and reserves management plans, through the Department of Parks and Wildlife (DPaW), and to assess the implementation of these plans.

The MPRA (2012) conducted a 10-year audit of the Marmion Marine Park Management Plan (CALM 1992) in 2012; and the Project ESD requires that the EQP to consider MPRA's (2012) audit report findings.

Of particular relevance, the MPRA found that the Marmion Marine Park Management Plan (CALM 1992) "was not prepared with measurable outcome-based objectives"; and that, "in keeping with the outcome-based management plans that are now standard for marine park management in WA, management of Marmion Marine Park is reported in the…audit against a set of performance indicators developed for nearby Shoalwater Islands Marine Park and adapted by the operational [DPaW] district staff."

The set of indicators, those considered to be KPIs, and their relevant [ecological and social] values are shown in Table 3.1 and Table 3.2 below.

The ecological and social values adopted for the Marmion Marine Park under the CALM Act (MPRA 2012; Table 3.1, Table 3.2) are analogous to the EVs adopted EPA's environmental quality management framework (EQMF, Section 1); and the KPIs established by MPRA (2012) are similar in intent to the EQOs of the EQMF. Notwithstanding, MPRA/DPaW's mandate in the management of marine parks is contextually different to the EPA's broader role in protection of WA's marine environmental quality. As such, it is useful to consider the alignment of the MPRA's (2012) KPIs for ecological and social values of Marmion Marine Park, with the EQOs and EVs specified under the EQMF for the Project.

Ocean Reef Marina is excised from, but surrounded by, Marmion Marine Park (Figure 3.1). Most of the Park is zoned for 'General Use', with three small 'Sanctuary' zones in the centre of the Park, and 'The Lumps Sanctuary Zone' being the closest (~2.5 km) to Ocean Reef Marina. The targets for marine park zones under the CALM Act and the equivalent levels of ecological protection from the EPA's EQMF are presented in Table 3.1.

Given that the location of Marmion Marine Park is within 5 km of major development area, a high level of ecological protection is required to align with the MPRA’s long-term targets for marine environmental quality. Since the marine environmental quality of all areas beyond the Development Envelope boundary are not anticipated to change as a result of Project, the MPRA’s long-term targets are unlikely to be compromised by activities related to operation of the Marina.

Table 3.1 Long-term management targets for ecological values in Marmion Marine Park (MPRA 2012)

Ecological Value	Long-term management target for value
Finfish (KPI) – *A diverse finfish fauna contributes significantly to the biodiversity of the marine park.*	No loss of finfish diversity or non-targeted finfish species biomass as a result of human activity in the marine park. Abundance and size composition of finfish species in sanctuary zones and special purpose zones and non-targeted finfish species in other zones to be at natural[a] levels.
Seagrass Communities (KPI) – *Sea grass is an important primary producer and the extensive and diverse perennial seagrass meadows are important habitats for invertebrates and finfish.*	No loss of seagrass species diversity or perennial seagrass biomass[b] as a result of human activity in the marine park.
Invertebrates - *A high diversity and abundance of invertebrate fauna in the marine park forms a critical component of the food web that supports the variety of marine animals including sea and shorebirds and finfish.*	No loss of invertebrate diversity or non-targeted invertebrate species biomass[b] as a result of human activities in the marine park. Abundance and size composition of invertebrate species in sanctuary zones and non-targeted invertebrate species in other zones to be at natural[a] levels. Management targets for targeted invertebrate species to be determined in consultation with DoF and stakeholders.
Intertidal Reef Communities (KPI) – *Intertidal reef communities provide shelter for a variety of intertidal organisms, which in turn are a valuable food source*	No loss of intertidal reef species diversity or community biomass[b] as a result of human activity in the marine park.
Macroalgal (subtidal reef) Communities (KPI) – *Subtidal reefs support an extensive macroalgae community that has a high floral diversity. The macroalgae communities are important primary producers, which in turn are important refuge areas for a diverse range of finfish and invertebrates.*	No loss of subtidal macroalgal species diversity or community biomass[b] as a result of human activity in the marine park.
Subtidal Soft-bottom Communities – *These habitats support a variety of invertebrate species both in and on the sediments*	No loss of subtidal soft-bottom species diversity or community biomass[b] as a result of human activity in the marine park.
Australian Sea-Lion (KPI) – *The Australian sea lion* (Neophoca cinerea) *is a threatened species endemic to Australia and specially protected under the* Wildlife Conservation Act. *It uses the marine park waters to feed and the islands and rocks as haul-out sites.*	No loss in abundance[b] of Australian sea lions as a result of human activity in the marine park.
Sea and Shorebirds – *The marine park and adjacent nature reserves are important nesting and foraging areas for at least 14 species of sea and shorebirds*	No loss of seabird or shorebird diversity or abundance[b] as a result of human activity in the marine park.
Cetaceans – *Cetaceans are of special conservation status and five species have been observed in the marine park.*	No loss of cetacean abundance[b] as a result of human activity in the marine park
Water and Sediment Quality (KPI) – *The maintenance of good water and sediment quality is essential for a healthy marine ecosystem*	Maintain water and sediment quality at the current high[c] level, except for designated area where a different level of acceptable change is approved by the appropriate Government regulatory authority.
Geomorphology – *A complex seabed and coastal topography consisting of islands, limestone ridges and reef platforms, protected inshore areas and deeper basins, sandbars and beaches*	In sanctuary zones: no change in seabed structural complexity and coastal landforms as a result of human activity in the marine park In general use zone: no change in seabed structural complexity or coastal landforms, except in designated areas where some level of acceptable change is approved by the appropriate Government regulatory authorities.

[a] In this context '*natural*' refers to the abundance that would occur in areas that are undisturbed and/or unexploited by human activities.

[b] In this context a loss or change in '*abundance*' or '*biomass*' excludes losses of a minor, transient or accidental nature.
[c] A *high* level of protection has been defined for the marine park as set out in Perth's coastal Waters Environmental Values and Objectives (EPA 2000).

Table 3.2 Management objectives for social values in Marmion Marine Park (MPRA 2012)

Social Value	Management Objectives
Seascapes (KPI) – *Panoramic vistas of azure waters, offshore islands, reefs and beaches are major aesthetic attractions of the marine park*	Ensure the aesthetic values of the marine park are not degraded by human activities and minimize visual intrusions on seascape and coastal vistas in and adjacent to the marine park with no reduction in the spatial extent of the major seascape qualities and no significant loss of aesthetic values as a result of human activity in the marine park.
Aboriginal Heritage – *The area has significant Aboriginal heritage value, including oral recall of fish trap usage, possibly at Mettams Pool.*	Ensure that, in collaboration with local Aboriginal people and the relevant management authorities, human activities do not significantly impact sites of significance to Aboriginal people in the marine park. Involve local aboriginal people in the management of the marine park and raise awareness and knowledge of Aboriginal relationships with the marine environment.
Maritime Heritage – *The marine park has a significant maritime heritage and at least one historic shipwreck (the Centaur, wrecked 1874) is located in the marine park.*	In collaboration with the Western Australian Maritime Museum, ensure that human activities do not significantly impact historical sites or shipwrecks in the marine park and increase awareness of the maritime heritage within the local community and among visitors
Marine Nature-based tourism – *The marine offers a wide range of attractions and opportunities for visitors to the area, which support a marine nature-based tourism industry.*	Manage marine nature-based tourism in a manner that is consistent with maintaining the marine park's values and maintain the ecological and social values of the marine park that are important to the marine nature-based tourism industry.
Commercial Fishing – *The marine park is important for commercial fishers targeting rock lobster, abalone, and a variety of fish species through beach seine netting.*	In collaboration with the industry and DoF, ensure that commercial fishing activities in the marine park are managed in a manner consistent with maintaining the marine park's values and to maintain the ecological values of the marine park that are important to commercial fisheries.
Recreational Fishing – *Line fishing, netting and spearfishing methods target a variety of pelagic and reef finfish species, crabs, rock lobster and other invertebrates*	In collaboration with the industry and DoF, ensure that recreational fishing activities in the marine park are managed in a manner consistent with maintaining the marine park's values and to maintain ecological values of the marine park that are important for maintaining quality recreation fishing opportunities.
Recreational Water Sports – *The location, scenery, wildlife and marine environment makes the marine park a popular location for a range of activities including boating, diving and surface water sports.*	Ensure recreational water sports are managed in a manner that is consistent with maintaining the marine park's ecological and social values and minimizes conflict between users.
Coastal and Island Use – *The coastline (including beaches, dunes and rocky shorelines) in and adjacent to the marine park provides for a range of recreational uses.*	Ensure that coastal uses are managed in a manner that is consistent with maintaining the marine park's ecological and social values and ensure integration of marine, coastal and terrestrial management.
Scientific Research – *The diversity of the flora and fauna, combined with the range of human activities which occur in the marine park, provide opportunities for ecological and social research.*	Provide access and opportunities for ecological and social research and to ensure ecological and social research is ethical and ecologically sustainable in the marine park
Education – *The unique array or ecological and social values in the marine park combines with the ease of access and the close proximity of the marine park to the Perth metropolitan area provides opportunities for community education about the marine environment.*	Promote and facilitate the use of the marine park for marine education, ensure that the educational programs are ethical and ecologically sustainable and maintain the ecological values of the marine park that are important for marine education.

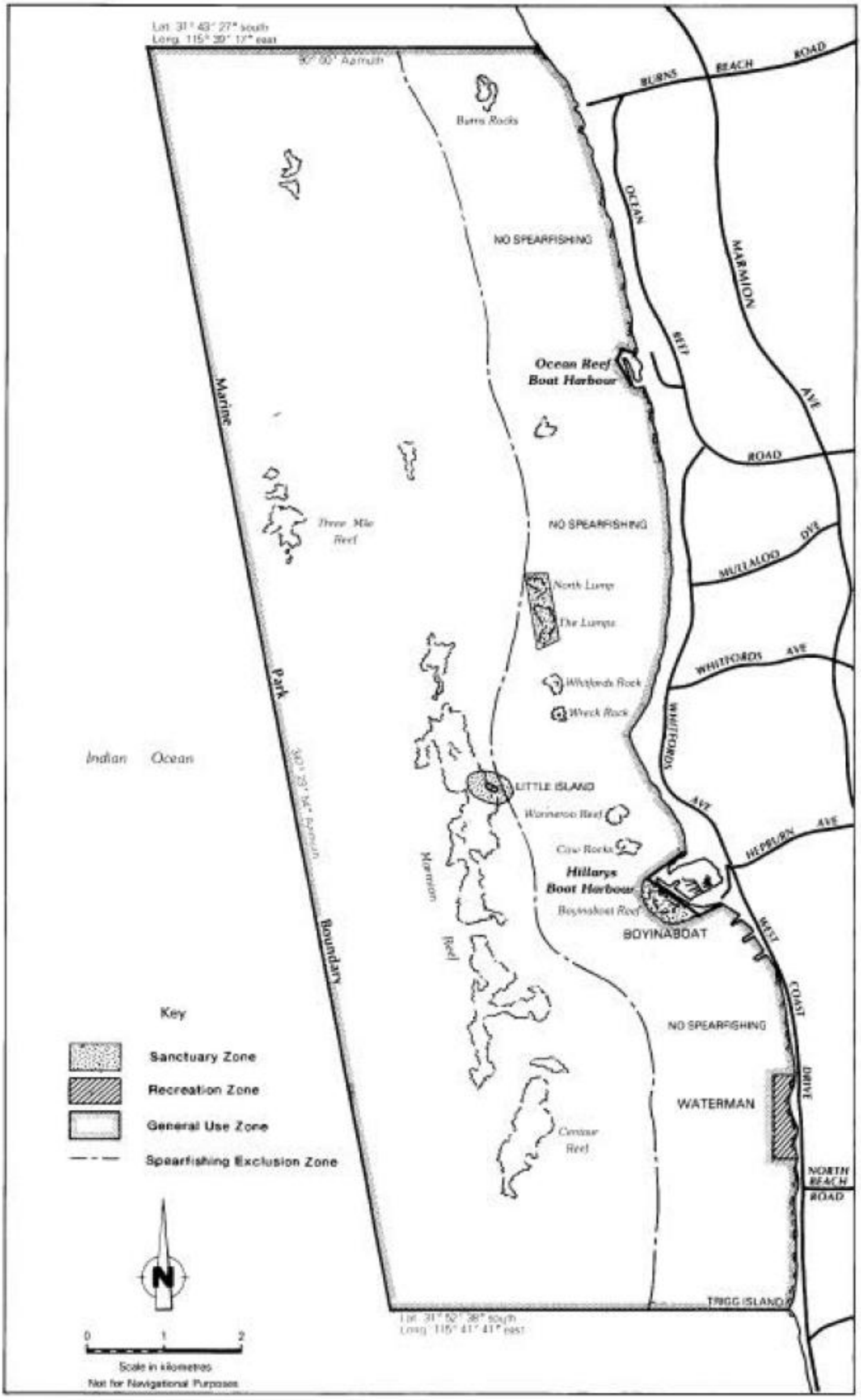


Figure 3.1 Zoning Plan for the Marmion Marine Park (CALM 1992)

Table 3.3 Targets from marine park management plans and the equivalent levels of ecological protection from the EPA's EQMF

Marine Park Zone	CALM Act Management Plan Targets for Marine Environmental Quality	EPA's Level of Protection
Sanctuary zone	No change from background levels, as a result of human activity in the marine park.	Maximum, unless within 5 km of major development area, where high may be considered (i.e. HEPA in Marmion MP)
Recreation zone	No change from background levels, as a result of human activity in the marine park	Maximum, unless within 5 km of major development area, where high may be considered (i.e. HEPA in Marmion MP)
General use zone	No change from background levels except in areas where some level of change is approved by the appropriate government regulatory authority. The area of change is not to exceed 1% (by area) of these zones. The level of change allowed in the 1% (by area) should not cuase the management objectives and targets for any other zones in the marine park to be compromised	Maximum, except in areas approved (where a government regulatory authority may approve a high, moderate or low level of ecological protection) (i.e. HEPA in Marmion MP)

4. Environmental Quality Plan

Provide an Environmental Quality Plan (EQP, i.e. a map) that spatially defines the Environmental Values (EVs, both ecological and social), Environmental Quality Objectives (EQOs) and Levels of Ecological Protection (LEPs) that currently apply to the area. The EQP should consider the Marine Parks and Reserves Authority's 10 year audit of the implementation Marmion Marine Park Management Plan 2002-2012."

Under the EPA's (2015) EQMF, all EVs and EQO are applicable within the EQP. Implementation of EQC shall be as follows for EVs and EQOs of:

- **Ecosystem Health**
  - Maintenance of ecosystem integrity
    - MEPA - inside marina and ZoHI (EQC for phytoplankton and toxicants)
    - HEPA - outside ZoHI and marina (EQC for phytoplankton and toxicants)

- **Fishing and Aquaculture**
  - Seafood safe for consumption (EQC for biological/chemical contaminants)
  - Water quality suitable for aquaculture (future operations protected by proxy - compliance with other EQC)

- **Recreation and Aesthetics**
  - Primary contact recreation (EQC for faecal contamination, toxic algae, water clarity, chemical contaminants)
  - Secondary contact recreation (EQC faecal contamination, toxic algae, chemical contaminants)
  - Aesthetics (EQC for visual aspects and fish tainting)

- **Industrial Water Supply**
  - Water quality suitable for aquaculture (future operations protected by proxy - compliance with other EQC)

- **Cultural and Spiritual**
  - (protected by proxy - compliance with other EQC)

A map shall be compiled to demonstrate the EQP described above, for inclusion within the MCMMP and MEQMP.

Protection of the EVs depicted in the EQP, will also protect MPRA (2012) ecological and social values of Marmion Marine Park.

5. Guidance for assessment of potential impacts on BPPH, Abalone and Western Rock Lobster

5.1 Predicted zones of influence and impact on BPPH

When applying the EQMF in EIA, another key marine EAG that also needs to be considered in the context of environmental quality is EAG 7 - Marine Dredging Proposals (EPA 2015). EAG 15 is the EQMF is "*focussed on the monitoring and management of longer term, more chronic effects on environmental quality*", whereas EAG 7 is an "activity-based guidance" that "considers impacts over the limited time frames associated with individual projects" (EPA 2015).

In the context of the Project, the framework described by EAG 7 for conducting EIA of potential shorter-term construction and dredging impacts, is particularly relevant to assessment of indirect loss of seagrass due to shading and sedimentation from turbid plumes during construction

The EPA requires that the extent, severity and duration of impacts on benthic habitat and associated biota be defined in accordance with Environmental Assessment Guideline No. 7 Environmental Assessment Guideline for Marine Dredging Proposals (EAG 7; EPA 2011) using spatially-defined zones as follows:

- **Zone of Influence (ZoI)** - the area where changes in environmental quality associated with dredge plumes were predicted, but these changes were not expected to result in a detectible impact on benthic biota. The ZoI represents the predicted maximum extent of the dredge plumes, and beyond it there should be no dredge-generated plumes discernible from background conditions at any stage during the dredging campaign. EAG 7 (EPA 2011) notes that the ZoI can be large, but at any point in time the dredge plumes are likely to be restricted to a relatively small portion of the ZoI. Reference sites for monitoring natural variability are ideally located outside of the Zone of Influence of the dredging activities.
- **Zone of Moderate Impact (ZoMI)** - the area where predicted impacts on seagrass and benthic organisms were expected to be sub-lethal, and/or the impacts were recoverable within a period of five years following completion of the dredging activities.
- **Zone of High Impact (ZoHI)** - the area where impacts on seagrass meadows and associated benthic organisms were predicted to be irreversible (defined as lacking a capacity to return or recover to a pre-dredging state within a timeframe of five years or less).

In accordance with EAG 7 (EPA 2011) zones shall be conservatively derived as follows:

- **Zone of Influence (ZoI)** - the outer boundary of the ZoI was defined using the 100th percentile of the area where a TSS threshold of 2 mg/L above background was exceeded, representing the maximum extent of the visible plume (see Figure 5.1)
- **Zone of Moderate Impact (ZoMI)** – defined as coincident with the ZoHI (conservative modelling results for both TSS (see Section 3.1.1) and sedimentation (see Section 3.1.2) implied an outer boundary of the ZoMI that coincided with the outer boundary of the ZoHI.
- **Zone of High Impact (ZoHI)** - comprising direct and indirect losses due to the development footprint, as follows:
  - direct losses due to the breakwaters and reclamation areas; and
  - indirect loss due to a 50 m halo effect around the breakwaters.

It is recommended that a map is prepared depicting these zones.

Figure 5.1 Conservative depiction of the Zone of Influence - i.e. potential extent of the area where visible plumes may occur during the full construction period. Analysis based on TSS elevation of 2 mg/L above background occurring during construction at any time (100th percentile) and at any level in the water column. (Source: RPS APASA 2016)

5.1.1 Tolerance of seagrass to shading

The time taken for 'irreversible' loss to occur is noted for the following species:

- *Posidonia sinuosa* (perennial species) - 3 to 6 months shading below minimum light requirements
- *Amphibolis griffithii* (perennial species) - 3 months shading below minimum light requirements
- *Halophila ovalis* (ephemeral species) - 21 days shading below minimum light requirements
- *Zostera marina* (ephemeral species) - 18 days shading below minimum light requirements (Collier 2006; McMahon and Lavery 2008; Collier et al. 2009 and references contained therein).

Water quality modelling indicated total suspended solids elevations of 2 mg/L or less (conservative proxy for shading) occurring outside the ZoHI for 1% of the time over the duration of:

- Breakwater reclamation/construction (6 months) for a period of less than 2 days, in patches within 50 m of the breakwater/construction footprint (Figure 5.2)
- Dredging (7 months) for a period of 0 days (i.e. suspended sediments shall be contained within the marina; Figure 5.3)
- The entire construction/dredging period (13 months) for a period of 0 days (i.e. isolated patches within the ZoHI, incorporating the 50 m halo, occurred for a period of less than 4 days) (Figure 5.4).

5.1.2 Tolerance of seagrass to sedimentation

Most BPPH communities are expected to persist through a level of 3 cm sedimentation (Fremantle Ports 2009).

Modelling of the degree of sedimentation at the end of the entire construction period showed highly localised effects within a very short distance of the dredge area, with no significant degree of sediment deposition (> 1 cm) outside the ZoHI (Figure 5.5).

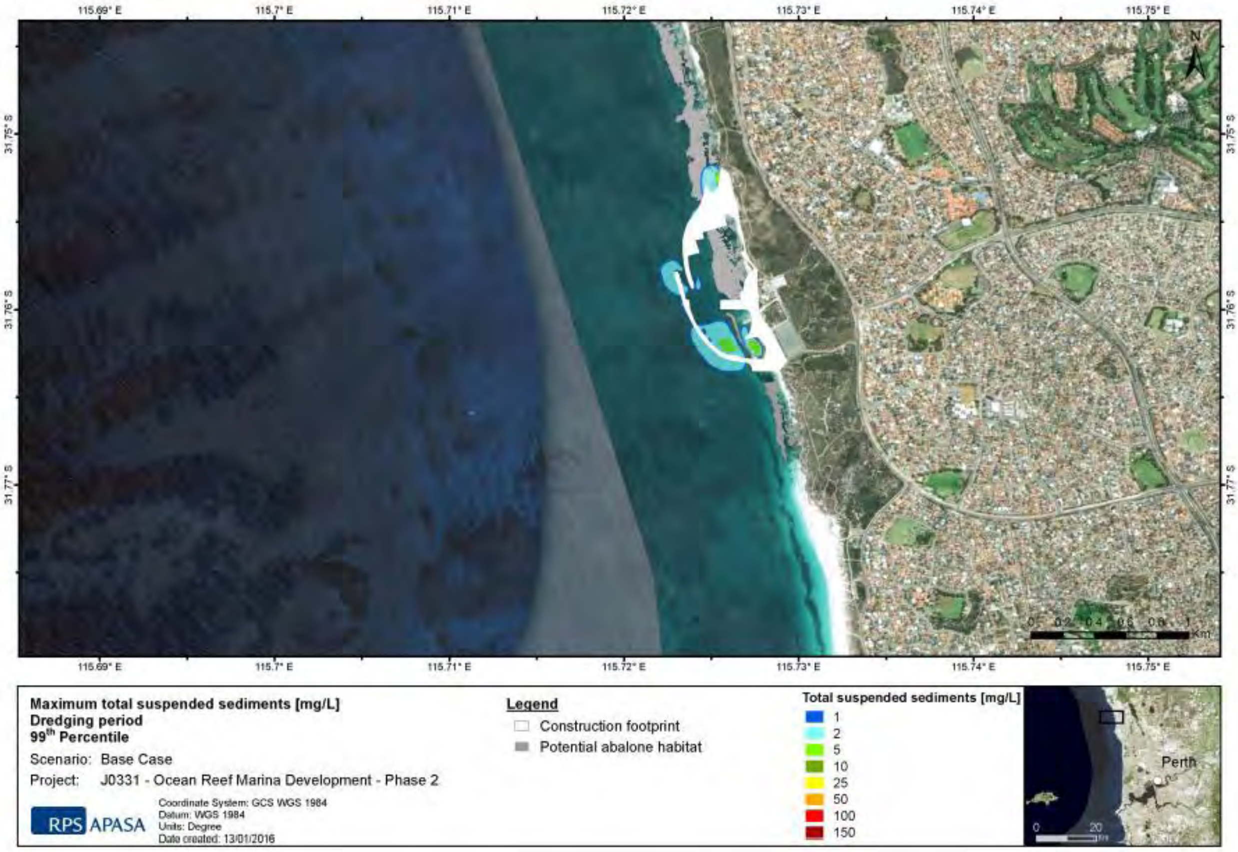


Figure 5.2 Map of the 99th percentile of maximum TSS concentrations during the breakwater/reclamation construction period (first 6 months). provide detail of the level of effect that is predicted to be exceeded 1% of the time or less. In terms of the 6- month analysis period, 1% of the time equates to less than 2 days, and less than 8 hours over any month. (Source: RPS APASA 2016)

Figure 5.3 **Map of the 99th percentile of maximum TSS concentrations during the dredging period (final 7 months). The results show that the discharge of any significant concentration of suspended sediment is expected to occur less than 1% of the time, with the sediment expected to be contained within the marina. (Source: RPS APASA 2016)**

Figure 5.4 Map of the 99th percentile of maximum TSS concentrations during the entire construction period. This figure highlights the localised levels that are expected to be exceeded 1% or less over the full 13 month period, which equates to approximately 4 days in total. (Source: RPS APASA 2016)

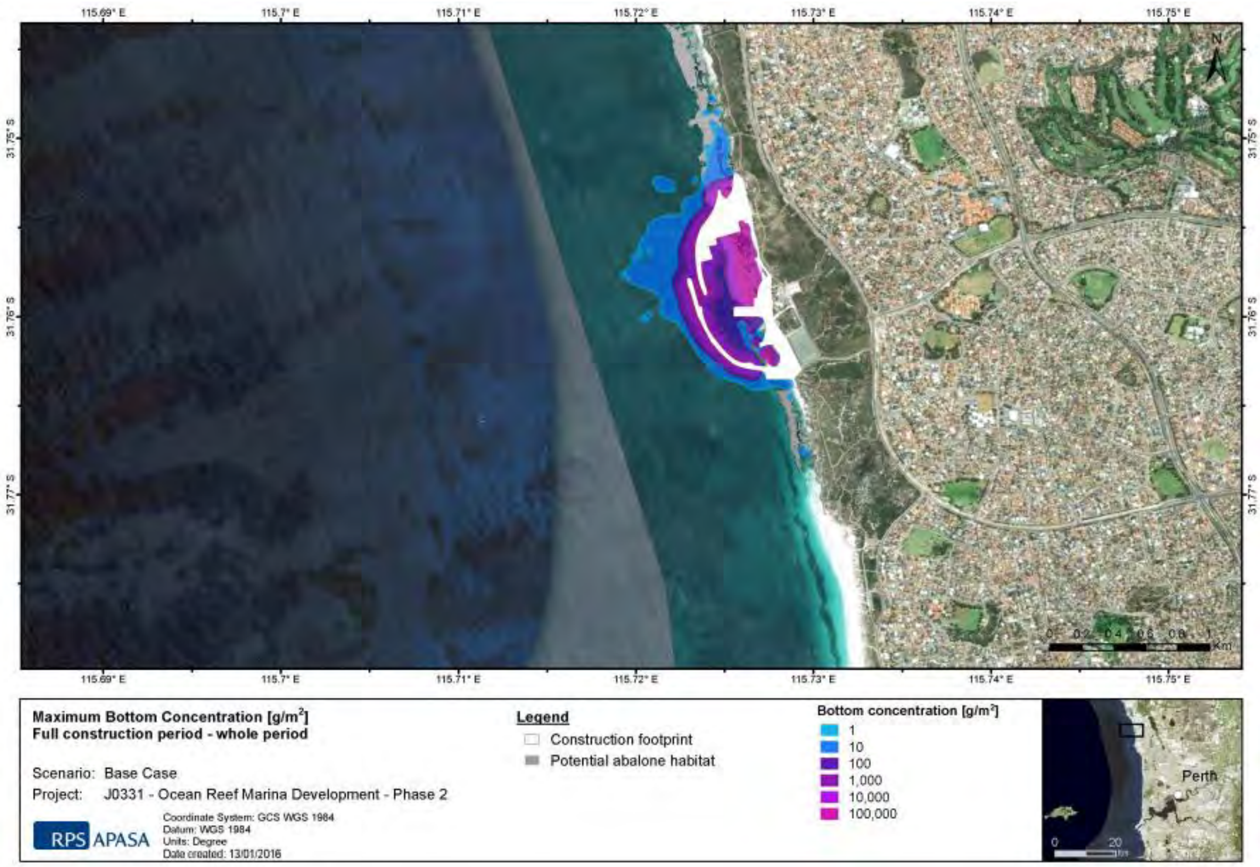


Figure 5.5 Map of the potential extent of the area where bottom deposition above model thresholds is expected to occur during the entire construction period. Analysis based on bottom concentration above background occurring at any time regardless of persistence. N.B. The contour of 1000 g/m^2 equates to a deposited thickness of approximately 1 cm. (Source: RPS APASA 2016)

5.2 Roe's Abalone EIA

5.2.1 Parameters which may influence abalone distribution

Direct loss of habitat from construction

Direct loss of Roe's abalone (*Haliotis roei*) habitat from the construction of the marina infrastructure and a potential 50 m halo effect has been estimated at 11.8 ha (BMT Oceanica 2016a).

Indirect loss from construction or operation

When considering potential environmental sensitivities of Roe's abalone (BMT Oceanica 2016b), construction and operation of the marina may potentially introduce multiple changes affecting abalone populations on Burns Beach Reef. These include: changes in hydrodynamics at the reef scale, sediment deposition, increases in nutrients in seawater, and changes in seawater temperature.

Reef scale hydrodynamics

Modelling shows that changes in current speed and residual currents will occur mainly north of the proposed development. The affect is most pronounced in summer, when peak instantaneous absolute differences of current speed from modelling of the existing harbour versus the proposed marina were of the order 5-10 cm s^{-1} (Figure 5.6). Changes in current speeds may affect the particle sizes that can remain suspended in the water column, and potentially affect the amount and fractions of both sediments and wrack that will be supplied to the areas of abalone habitat. These changes can also modify the coastal processes that determine where the sediment and wrack will be deposited and eroded. Changes in the distribution of drift algae that can be utilised by the Roe's abalone as a food source will affect the population directly as drift algae is believed to be a significant portion of their diet. But, it is not possible to predict how the drift algae, generated from the breakdown of wrack, will be affected by the changes in wrack deposition and movement. Changes in the current speed and the subsequent reduction in flushing along Burns Beach Reef may also have an effect on the settling location of broadcast larvae along the reef which are dispersed in the water column and transported to the reef on the currents.

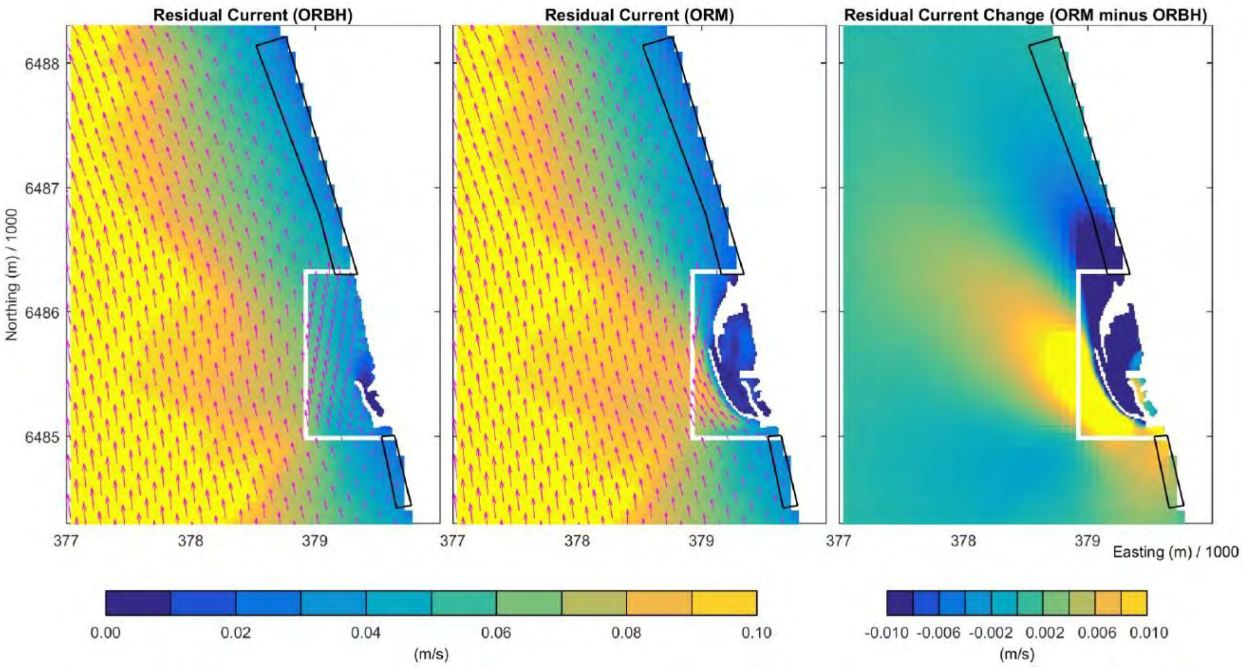


Figure 5.6 Maps of residual currents from a 15 day scenario commencing 9 January 2013 (greatest change scenario). Black boxes indicate the grid cells coinciding with abalone habitats north and south of proposed marina. Note the different scales on the two colour legends (Source: RPS APASA 2016)

Sediment deposition

Increased sediment deposition is predicted to occur up to a maximum thickness of 1 cm on the reef north of the proposed development (Figure 5.5). No deposition of sediment is expected on the reef south of the development as it is greater than 500 m from the development. It is not anticipated that this level of sedimentation will affect abalone health directly but, increased sediment deposition from construction activities (or changes in hydrodynamics after construction of marine infrastructure) may:

1. bury suitable protection (cryptic) sites for Roe's abalone. Inundation of sediments can result in the loss of safe habitat for juvenile and adult abalone due to cryptic sites and home scars becoming inundated with sediment, thus exposing abalone to predators. Large variations in mollusc abundance can occur when sand in-fills cracks and crevices and limits molluscs to bare ridges.
2. smothering and resultant death of non-geniculate coralline algae (NCAs). Sediment that builds up on crustose NCAs can quickly smother and kill the algae. This is significant as NCA are required habitats to trigger Roe's abalone larval settlement and metamorphosis and thus loss of NCAs may have an immediate negative effect on recruitment of Roe's abalone larvae.

A potential natural offset to increased sediment deposition on the reef and NCAs may be a subsequent removal of this sediment by large swells or storms along these high energy reefs.

The modelling results indicate that in this shallow water zone wave action will resuspend deposited sediments every 1 to 2 days (RPS APASA 2016).

Nutrient concentrations

Within the harbour, modelling shows a potential increase in nitrogen concentrations with a maximum P80 concentration reaching 0.57 mg L^{-1} for nitrogen and 0.0037 mg L^{-1} for phosphorus (see Section 2.1.1). Subsequent modelling of the influence of outflows from the marina indicated that the maximum concentration that would reach the abalone habitat to the north would be 15.1% of the concentration in the marina. Assuming a worst case scenario of 0.57 mg L^{-1} for nitrogen and a 15.1% concentration reaching the nearest northern abalone habitat this would result in a concentration increase of 0.086 mg L^{-1} for nitrogen. Baseline concentrations measured along Burns Beach Reef and the area immediately within the proposed marina development ranged from 0.1-0.16 mg L^{-1} (BMT Oceanica 2015). An increase of 0.086 mg L^{-1} for nitrogen would result in a total concentration of 0.19-0.25 mg L^{-1} for nitrogen compared to background water quality concentrations of 0.14-0.47 mg L^{-1} recorded for the Perth's northern waters (Buckee et al. 1994). Increases in nutrients are thus expected to be relatively small compared to background.

If significant nutrient shifts (e.g. increased nitrogen) were sourced from seawater, groundwater and/or sediments this may favour certain algal community species (i.e. *Ulva* spp.) within the abalone populated zones on the reef, which may increase total canopy cover. Rapid increases in nutrients could result in increased foliose and filamentous turfing algae, which can reduce NCA coverage. This occurs as the turfing algae increases sedimentation due to baffling effects, and can lead to smothering of NCA. Increases in nutrients and sedimentation favours growth of turf algae, compared to the present algal communities in the zones that support abalone. Nutrient inputs can have six times the effect on increasing turfing algae compared to sediment alone.

Although increased nutrient inputs may increase turfing algae and potentially decrease abalone population recruitment success, the community of grazers present may be able to consume the excess turf algae and ameliorate the effect. Resulting increases in filamentous turfing algae may be eaten by mollusc grazing, but a more robust and taller species may move into the cleared spaces. The effect of these other opportunistic species is not known in relation to the abalone ecology on the localised reef.

Seawater temperature

Seawater temperature ranges are not expected to differ from natural background temperatures during construction or operation of the marina. Seawater temperature has been shown to affect growth rates of abalone, the success of larvae and regional recruitment success, result in mass mortalities and worsen the effect of pathogens on a population. A complete mortality event was inferred to be due to a single two-month-long elevated temperature event of up to 3ºC.

5.2.2 Area of potential effect on abalone habitat

An area of potential effect on abalone may be inferred from consideration of substantial geographical changes introduced by the marina on: (i) reef scale hydrodynamics, (ii) sediment deposition, (iii) nutrient concentrations and/or (iv) seawater temperature. Although it is not possible to definitively state what effect these changes will have on the abalone population of Burns Beach Reef it is assumed that some negative response may occur within the area of potential effect.

Reef scale hydrodynamics

The construction of the proposed development will alter the current speed and flushing rate of the coastal margin along Burns Beach Reef (RPS APASA 2016). However, modelling of surface wave height showed very little change in wave heights after development of the marina and wave energy will be assumed to be equivalent to the wave energy experienced by the reef now.

Modelling showed changes in current speed resulting in a:

- reduction in current of 40-60% for < 500 m north of the marina
- reduction in current of 20% for 500-1500 m north of the marina
- and no detectable change in current at distances > 1500 m north of the marina.

South of the marina there was no substantial change in current speed over abalone habitat which is at a distance is >500 m from the marina, mainly since the current is dominated by northward flow for most of the year.

A reduction in flushing of the northern coastal margin was modelled due to the reduction of current speed along the northern reef. The time take it took for a tracer concentration to fall below 2% of its initial release concentration (surrogate of mixing) was reduced from 1 hour (before) to 7.5 hours (after) installation of the marina. The reduced rate of coastal flushing is indicative of reef-scale hydrodynamic changes that are predicted to occur to the north along Burns Beach Reef.

Sediment deposition

Modelling results indicated that potential seabed sediment deposition comprised a maximum concentration of:

- <100 g m^{-2} (i.e. 0.1 mm of thickness) at distances <500 m from the marina
- <1 g m^{-2} (or negligible) at distances >500 m from the marina.

In the shallow zones (2-6 m water depth) that abalone inhabit, the finer sediment that is able to be dispersed over larger distances from the source location tends to be resuspended due to wave action. Modelling results for the construction period predict that this is likely to occur, resulting in episodic deposition and then resuspension every 1 to 2 days (RPS APASA 2016).

Considering the conservative values of sediment deposition presented above represent a minimal threat to macroalgae communities or abalone individuals, coupled with the episodic deposition regime, any impact of sediment deposition on abalone is expected be minimal and limited to less than 500 m from the source location of the marina.

Nutrient concentrations

If an increase in nitrogen is experienced amongst abalone habitat a potential shift in macroalgae community (i.e. increase in turf algae) could occur. Ecological modelling of surface algae response concentrations due to nutrient flushing (RPS APASA 2016) showed that the algae attributable to the ORM source would be difficult to detect within a few hundred meters of the entrance (see Section 2.1.1; and Figure 2.1 to Figure 2.4). Surface algae concentrations are highly sensitive to nutrient inputs where the macroalgae community on Burns Beach Reef will be relatively resistant to change. Short term increases in surface algae concentrations are not expected to affect abalone populations, but may represent an early indicator of change in nutrients.

The macroalgae habitat associated with the Roe's abalone habitat is not likely to be affected at by increased nutrients along Burns Beach reef as these low (near background) nutrient concentrations. Coupled with continual coastal margin flushing, nutrient-related shifts in the macroalgae community structure of Burns Beach Reef are not expected. As a conservative estimate, it is anticipated that any nutrient related impacts on abalone will be minimal and limited to <500 m north of the marina.

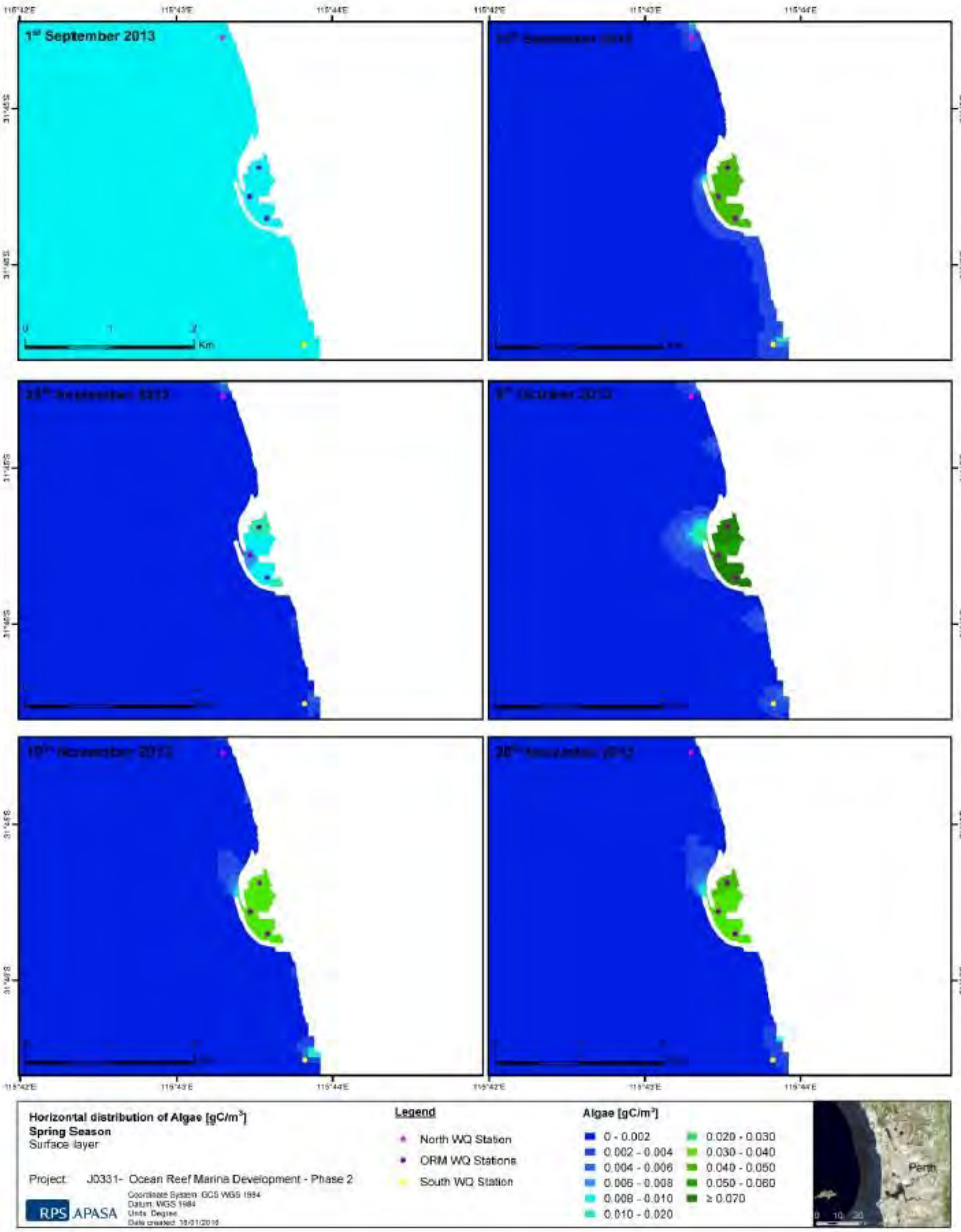


Figure 5.7 Surface layer concentrations of algae at selected time instances for the spring season. Coloured dots indicate the location of virtual observation stations, as indicated in the legend. (source RPS APASA 2016)

Seawater temperature

Seawater temperature was not modelled as it is unlikely to be affected by the development. As such no impact is predicted from changes in seawater temperature due to the proposed development.

5.2.3 Boundaries for Roe's abalone area of potential effect along Burns Beach Reef north of the proposed marina

The environmental parameters subject to substantial change from marina development and potentially affecting abalone populations on Burns Beach Reef are listed in Table 5.1, together with a spatial estimate of the corresponding change in each parameter to the north of the marina. In summary, the expected area of Roe's abalone habitat along Burns Beach Reef that may be affected by environmental parameters were:

- Reef scale hydrodynamics have the potential to alter sedimentation, and the distribution of drift algae and abalone larvae, along the reef for up to 1500 m north of the marina; however beyond 500 m north of the marina, current speeds are reduced by <20%.
- Sediment deposition would be minimal and limited to <500 m north from the source location of the marina.
- Increases in nutrients are expected to be minimal and any subsequent impact to macroalgae community associated with Roe's abalone is expected to be limited to <500 m north from the marina
- No impact from seawater temperature change is expected.

It is recommended that the zone of potential effect for Roe's abalone is presented on a map of the existing Roe's abalone habitat.

Table 5.1 Environmental parameters subject to substantial change from marina development and potentially affecting abalone populations on Burns Beach Reef, including spatial estimates of the corresponding change in each parameter to the north of the marina

Parameter modelled to have substantial changes	Potential changes to natural reef system	Change in parameter based on distance north of the Development along Burns Beach Reef		
		0-500 m	500-1500 m	>1500 m
Reef scale hydrodynamics	Shift in distribution of: • Sediment deposition • Wrack deposition • Drift algae load • Abalone larvae dispersion	Reduction of current speed by 40-60%	Reduction of current speed by 20%	None
Sediment deposition	Loss of cryptic microhabitats for abalone Smothering of non-geniculate coralline algae	seabed deposition <100 g m^{-2} (i.e. 0.1 mm of thickness)	None	None
Nitrogen concentration	Shift in algae community structure Increased growth of turfing algae Seawater surface layer concentrations of algae	An increase of 0.086 mg L^{-1} for nitrogen	Minimal surface algae response detectable for up to 1000 m	None

5.3 Western Rock Lobster EIA

The western rock lobster (WRL; *Panulirus cygnus*) is endemic to the state of Western Australia, and inhabits shelf waters between North-West Cape to Cape Leeuwin. Juvenile WRL inhabit nearshore reefs and seagrass habitats until they develop into 'white' lobsters, and undertake a mass migration offshore. Nearshore habitats of the Marmion Marine Park are typical of those inhabited by WRL. Western rock lobsters are omnivorous feeders which may prefer meat over plants but rely on a wider variety of benthic foods including coralline algae (which is likely consumed to assist with mineralisation of the exoskeloton), gastropods, crabs, seagrass and numerous algae (MacArthur et al.2007). Each year it is estimated that up to 20% of the entire biomass of WRL are harvested each year by commercial fishermen in Western Australia (MacArthur et al.2007).

5.3.1 Lifecycle of the western rock lobster

The WRL has a five stage life history. This includes both pelagic (living in the open ocean) and benthic (living on the seafloor) stages. These stages can be simplified to include the phyllosoma, puerulus, post-puerulus juveniles, juvenile whites, adult reds. Full development from larvae to sexual maturity takes between 4.5 and 6 years. Post-puerulus juveniles, juvenile whites and adult reds may inhabit areas of the MMP.

5.3.2 Phyllosoma

Western rock lobsters hatch on the continental shelf as planktonic, zoeal larva called phyllosoma between December and March (Phillip 1986) and are morphologically different to adult WRL (McWilliam & Phillips 2007). The phyllosoma larvae are transported offshore in wind-driven currents. These larvae have been caught as far as 1500 km offshore of the Western Australia mainland. The larvae feed on zooplankton and develop via a series of moults, resulting in a progressive increase in size (McWilliam & Phillips 2007). Between May and October the offshore wind-driven currents decrease in velocity and the phyllosoma vertically migrate deeper into the water column where they are transported shoreward by deep water easterly currents. After 9-11 months offshore as the phyllosoma larvae phase, the final larva stage metamorphoses at near the edge of the continental shelf into a morphologically distinct puerulus (Jernakoff et al. 1990).

5.3.3 Puerulus

The puerulus phase is a brief transitional stage (3–4 weeks long) that connects the planktonic and benthic life cycle phases. Unlike the phyllosoma larval phase, puerulus (postlarva) can actively swim and migrate the distances of 40–60 km to the coastal shelf regions where they settle (Phillips 1986). Puerulus have been known settle on reefs at least 30 m deep but they generally occupy shallow reef habitats at <12 m depth (Jernakoff et al. 1990). Settlement of the larvae can occur throughout the year; however, peak settlement occurs between August and February (Phillips 1986; Caputi 2008). The puerulus stage does not feed or moult during the migration to coastal regions.

5.3.4 Post-puerulus juveniles

After settlement in the coastal regions, the pueruli develops a dark pigmentation in the exoskeleton and moults within a few days into the post-puerulus juveniles which are 7–9 mm long (Jernakoff et al. 1990). The duration of the post-puerulus phase after settlement is about six months. In the initial stages of this phase, the post-pueruli are solitary animals living in small cracks and crevices in caves and on faces of limestone reefs which have a coverage of seagrass and/or macroalgae. During this stage post-puerulus juveniles do not leave the protection of the immediate reef.

5.3.5 Juvenile (whites)

When the post-pueruli are 16–20 mm in carapace length, they become gregarious, mix with other individuals and migrate into a juvenile habitat of caves and ledges of limestone patch reefs (Jernakoff et al. 1994). The duration of the juvenile phase is generally 3–4 years (Phillips 1983). A characteristic moult occurs during October or November whereby the old red exoskeleton is shed and replaced by a pale pink exoskeleton, referred to as the adolescent 'white' phase. After moulting, the white colouration gradually changes to the characteristic red over the ensuing two months (MacArthur et al. 2008). These freshly moulted juveniles aged 4–5 years with a carapace length of ~50-80 mm migrate offshore to lobster spawning habitats (Phillips 1983). Migration to offshore waters occurs between November and January. During this westerly to north westerly migration the WRL may travel up to 600 m per day and travel as far as 40-60 km to reach breeding grounds in 30-150 m deep waters.

5.3.6 Adult (reds)

The habitat of mature WRL occurs between the outer edge of coastal lagoons and the edge of the continental shelf in a depth range of 30 m to 150 m (Jernakoff et al. 1994). Western rock lobsters predominantly occupy limestone reefs habitats but may also live in seagrass and macroalgae communities during migrations. Females reach sexual maturity at a carapace length between 65-88 mm, while males reach sexual maturity at carapace lengths of 72–95 mm (Melville-Smith & de Lestang 2006). Mating typically occurs between the months of July and August at depths between 40–80 m. Male WRL affix a sperm packet (spermatophores), also known as a 'tar spot', to the females' chest (pleopods). This sperm packet remains intact for a period of about 69 days, after which fertilisation occurs. Spawning occurs during November to February (Caputi 2008). Up to 600,000 eggs develop on the underside of the female; females in this condition are commonly referred to as 'berried'. Eggs are attached the females for a period between 19-68 days with hatching occurring by the end of February or March.

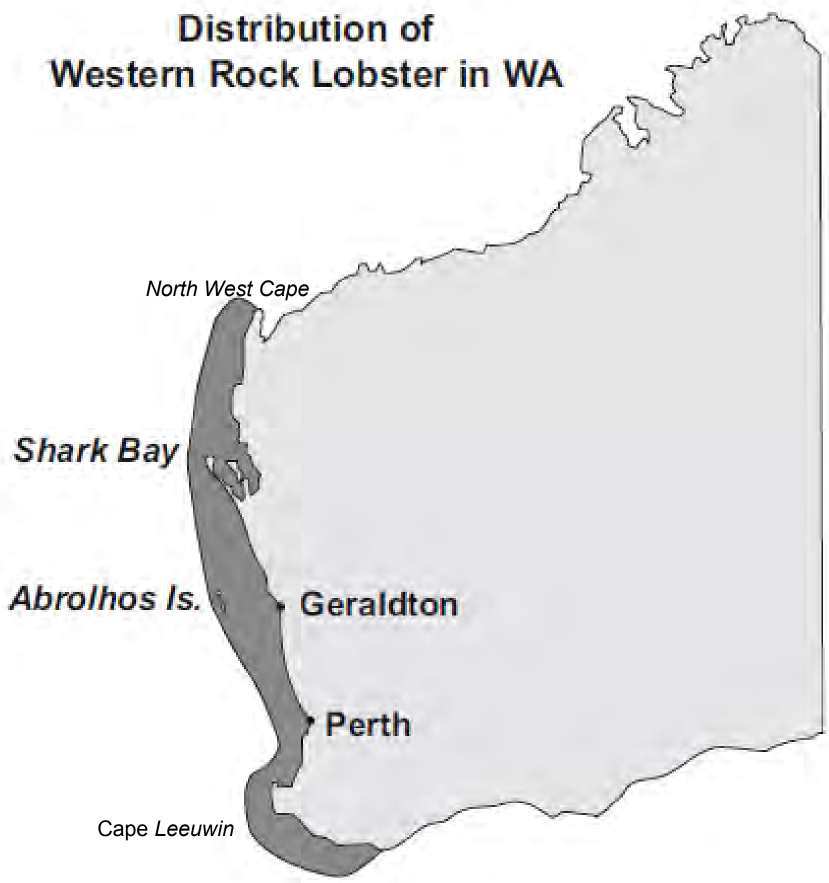
5.4 Distribution and habitat of the western rock lobster

5.4.1 Distribution

WRL are endemic to the state of Western Australia. They inhabit the clear, well-oxygenated shelf waters along the coast, from North-West Cape (21°45'S) to Cape Leeuwin (34°22'S) (Chittleborough 1975; Figure 5.8). The distribution of WRL can extend up to at least 1,500 km offshore in its phyllosoma stage but, rock lobsters are typically observed by humans inhabiting nearshore and continental shelf reef structures as juvenile and adults.

5.4.2 Habitat

Post-puerulus WRL (<25 mm carapace length) typically inhabit small holes in the face of coastal limestone reefs, as well as within ledges and caves. The addition of cover, such as that provided by seagrass or macroalgae, is preferred to bare reef (Jernakoff 1990). Smaller juvenile lobsters tend to inhabit the reef face, while larger individuals (25-45 mm) are common within caves, under ledges and in larger holes in the reef (Jernakoff et al. 1994, MacArthur et al. 2007). Western rock lobsters >25 mm will forage on reef covered in algal turf or *Amphibolis* spp seagrass but will also travel at night into adjacent seagrass beds to feed. Although WRL travel significant distances (hundreds of meters) in a night they remain within 50 m of the protection of the reef (MacArthur et al. 2007). Offshore larger WRL individuals may be associated with sponge communities with smaller individuals being more likely to be associated with the presence of *Ecklonia* sp. algal communities (Bellchambers et al. 2010). Western rock lobsters are often associated with sponge fields, sea squirts, kelps, seaweeds and seagrasses (MacArthur et al. 2007).



Source: Fletcher et al. (2005)

Figure 5.8 Distribution of Western Rock Lobster within Western Australia

5.4.3 Habitat types of the Marmion Marine Park

The inshore area coastal lagoon of the Marmion Marine Park (MMP) is characterised by regular high energy waves breaking across the reef which has a significant effect on the macro algal community which may be present. Inshore reef systems and seagrass beds provide hides and micro-habitats for WRL juveniles and adults. These habitats are important during different stages of the WRL lifecycle. Post-puerulus, juvenile and adult WRL typically inhabit the shallow reefs, and will forage for food at night over several hundreds of meters. The large sand flats (offshore mobile sand habitat) beyond the inshore reefs are important areas for juvenile (white) WRL during their migration offshore.

Inshore reefs within the MMP which are potential habitat for juvenile and adult WRL tend to be 'high' relief reef with macroalgal assemblages.

For the purpose of delineating a potential habitat map for WRL the visual assessment of high relief was determined to be >1 m. LiDAR data was used to attribute the MMP habitat map and thus the 'high' relief habitat was determined by algorithms in the software. Determinations of high relief by software were validated by referring to visual assessments to confirm the relief attribute. Although high relief has been designated as the potential WRL habitat, it is noted that low relief reef with sufficient 'gullies' may provide some habitat for juvenile stages.

The areas immediately adjacent to the proposed development would be considered adequate for early stage juvenile settlement and growth but an earlier study showed that the habitat at Ocean Reef (within a 3 km radius of the existing marina) is not a significant nursery area for juvenile lobsters, which may reflect upon seasonal differences in recruitment (although lobsters > 56 mm were encountered in larger numbers) (Meagher and LeProvost 1975 in Bellchamber et al. 2012). Regionally, the Sorrento area has been shown to support high densities of juvenile rock lobsters, due to the extensive availability of preferred habitats, such as reefs and limestone pavement (Bellchamber et al. 2012).

No designated potential adult WRL habitat is located within the area of direct loss of habitat (i.e. the project footprint), nor in the zone of potential influence, based on the present habitat mapping study (Figure 5.9). No juvenile habitat has been recognised within 3 km of the existing marina, based on an earlier study (Bellchamber et al. 2012). Marina construction and operational activities are not expected to result in significant WRL habitat loss .

It is recommended that a map is prepared depicting the maximum footprint of the visual plume (i.e. Figure 5.1) overlaid on the 'potential Western Rock Lobster habitat' map (Figure 5.9).

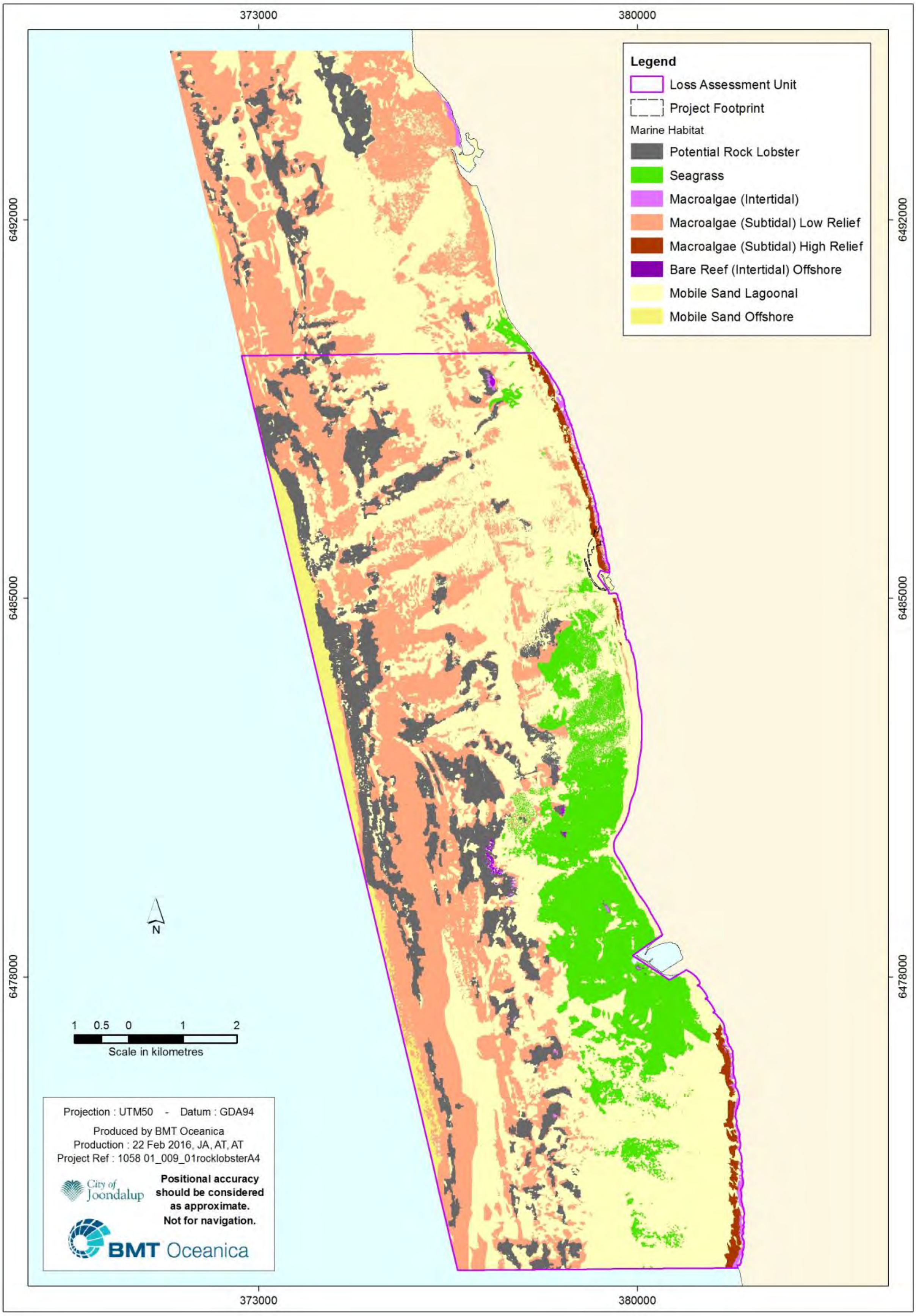


Figure 5.9 **Potential juvenile and adult Western Rock Lobster habitat in Marmion Marine Park**

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Attachment A

Project Environmental Risk Matrices for Relevant Environmental Factors

Table A.1 Environmental Factor: Marine Environmental Quality – Construction of Marina

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during breakwater construction and dredging	Causes water contamination	MEPA – Inside Marina	**Possible**	**Minor**	**Rating: Moderate** **Rationale:** Water quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during construction	**Intent:** Verify no water contamination **Tier 1 indicator (EQG):** Toxicants in water for MEPA (EPA 2015) – Table 2a – Environmental quality criteria for protecting the marine ecosystem from the effects of toxicants in marine waters and sediment pore waters – EQG for Moderate Protection 95th percentile of the sample concentrations from a single site or a defined area should not exceed the EQG *EQG at Moderate Protection* Metals Cadmium: 14 µg/L Chromium III: 49 µg/L Chromium IV: 20 µg/L Cobalt: 14 µg/L Copper: 3 µg/L Lead: 6.6 µg/L Mercury (inorganic): 0.7 µg/L Nickel: 200 µg/L Silver: 1.8 µg/L Vanadium: 160 µg/L Zinc: 23 µg/L Organics Benzene 900 µg/L Napthalene: 90 µg/L Pentachlorophenol: 33 µg/L **Monitoring sites:** Water sampling at 3 sites in the MEPA **Monitoring frequency** Not required during breakwater construction Fortnightly during dredging and reclamation **Contingency Management:** If EQG exceeded, monitor EQS Visual check for source of contamination such as hydrocarbon leaks/spills	**Intent:** Verify no water contamination **Tier 2 indicator (EQS):** Toxicants in water for MEPA (EPA 2015) – Table 2a – EQS for Moderate Protection *EQS Moderate Protection* Bioavailable measures (EPA 2015 Table 2a) Indirect biological measures (EPA 2015 Table 2a) **Monitoring sites:** Water sampling at 3 sites in the MEPA **Monitoring frequency:** Triggered by EQG Continue until in compliance with EQG **Contingency Management:** If EQS exceeded: Investigate source of contamination Reduce dredging	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during breakwater construction and dredging	Causes water contamination	HEPA – Outside Marina	**Possible**	**Minor**	**Rating: Moderate** **Rationale:** Water quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during construction	**Intent:** Verify no water contamination **Tier 1 indicator (EQG):** Toxicants in water for HEPA (EPA 2015) – Table 2a – Environmental quality criteria for protecting the marine ecosystem from the effects of toxicants in marine waters and sediment pore waters. 95th percentile of the sample concentrations from a single site or a defined area should not exceed the EQG *EQG at ZoMI/ZoI boundary* Metals Cadmium: 0.7 µg/L Chromium III: 7.7 µg/L Chromium IV: 0.14 µg/L Cobalt: 1 µg/L Copper: 0.3 µg/L Lead: 2.2 µg/L Mercury (inorganic): 0.1 µg/L Nickel: 0.8 µg/L Silver: 0.8 µg/L Vanadium: 50 µg/L Zinc: 7 µg/L Organics Benzene 500 µg/L Napthalene: 50 µg/L Pentachlorophenol: 11 µg/L **Monitoring sites:** Water sampling at 3 sites on ZoMI/ZoI boundary **Monitoring frequency:** Fortnightly during construction **Contingency Management:** If EQG exceeded, monitor EQS Water sampling at 3 reference sites outside ZoI Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Visual check for source of contamination such as hydrocarbon leaks/spills	**Intent:** Verify no water contamination **Tier 2 indicator (EQS):** Toxicants in water for HEPA (EPA 2015) – Table 2a – Environmental quality criteria for protecting the marine ecosystem from the effects of toxicants in marine waters and sediment pore waters. *EQS High Protection* Bioavailable measures (EPA 2015 Table 2a) Indirect biological measures (EPA 2015 Table 2a) **Monitoring sites:** Water sampling at 3 sites on ZoMI/ZoI boundary **Contingency Management:** If EQS exceeded: Establish EQG sites on ZoI boundary Visual check for source of contamination such as hydrocarbon leaks/spills Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	Contaminants of concern only – the list of contaminants may be rationalised
Ecosystem Health	Maintenance of	Toxicant release	Causes sediment	MEPA – Inside	**Possible**	**Moderate**	**Rating: Moderate**	**Intent:**	**Intent:**	Contaminants

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
	ecosystem integrity	during breakwater construction and dredging	contamination	Marina			**Rationale:** Sediment quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during construction	Verify no sediment contamination **Tier 1 indicator (EQG):** Toxicants in sediments for moderate protection (EPA 2015; Table 3) - Median total contaminant concentration in sediments from a single site or a defined sampling area should not exceed the environmental EQG values below: Metals Antimony: 2 mg/kg dry wt Arsenic: 20 mg/kg dry wt Cadmium: 1.5 mg/kg dry wt Chromium: 80 mg/kg dry wt Copper: 65 mg/kg dry wt Lead: 50 mg/kg dry wt Mercury (inorganic): 0.15 mg/kg dry wt Nickel: 21 mg/kg dry wt Silver: 1 mg/kg dry wt Zinc: 200 mg/kg dry wt Organometals TBT: 5 µg Sn/kg dry wt **Monitoring sites:** 3 sites in MEPA **Monitoring frequency:** Not required during breakwater construction Fortnightly during dredging and reclamation **Contingency Management:** If EQG exceeded, monitor EQS Visual check for source of contamination such as hydrocarbon leaks/spills	Verify no sediment contamination **Tier 2 indicator (EQS):** EQS for moderate protection Bioavailable measures (EPA 2015 Table 3) Porewater measures (EPA 2015 Table 3) Indirect biological measures (EPA 2015 Table 3) **Monitoring sites:** 3 sites in MEPA **Contingency Management:** If EQS exceeded: Investigate source of contamination Reduce dredging	of concern only – the list of contaminants may be rationalised
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during breakwater construction and dredging	Causes sediment contamination	HEPA – Outside Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Sediment quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during construction	**Intent:** Verify no sediment contamination **Tier 1 indicator (EQG):** Toxicants in sediments for high protection (EPA 2015; Table 3) - Median total contaminant concentration in sediments from a single site or a defined sampling area should not exceed the environmental EQG values below:	**Intent:** Verify no sediment contamination **Tier 2 indicator (EQS):** EQS for moderate protection Bioavailable measures (EPA 2015 Table 3) Porewater measures (EPA 2015 Table 3) Indirect biological measures (EPA 2015 Table 3)	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								Metals Antimony: 2 mg/kg dry wt Arsenic: 20 mg/kg dry wt Cadmium: 1.5 mg/kg dry wt Chromium: 80 mg/kg dry wt Copper: 65 mg/kg dry wt Lead: 50 mg/kg dry wt Mercury (inorganic): 0.15 mg/kg dry wt Nickel: 21 mg/kg dry wt Silver: 1 mg/kg dry wt Zinc: 200 mg/kg dry wt Organometals TBT: 5 µg Sn/kg dry wt **Monitoring sites:** Sediment sampling at 3 sites on ZoMI/ZoI boundary **Monitoring frequency:** Fortnightly during construction **Contingency Management:** If EQG exceeded, monitor EQS Sediment sampling at 3 reference sites outside ZoI Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Visual check for source of contamination such as hydrocarbon leaks/spills	**Monitoring sites:** Sediment sampling at 3 sites on ZoMI/ZoI boundary **Contingency Management:** If EQS exceeded: Establish EQG sites on ZoI boundary Visual check for source of contamination such as hydrocarbon leaks/spills Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	
Fishing and Aquaculture	Maintenance of aquatic life for human consumption	Biological (faeces) contaminant release during breakwater construction and dredging	Causes seafood contamination	Inside and Outside of Marina	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** No significant sources of biological contaminants (faeces) during construction			
Fishing and Aquaculture	Maintenance of aquatic life for human consumption	Chemical contaminant release during breakwater construction and dredging	Causes seafood contamination	Outside of Marina (assume no fishing inside of Marina during construction)	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Potential sources of chemical contaminants during construction, including minor spills and leaks	**Intent:** Verify no seafood contamination **Tier 1 indicator (EQG):** Ecosystem health monitoring for water and sediment **Monitoring sites:** Ecosystem health monitoring for water and sediment **Contingency Management:**	**Intent:** Verify no seafood contamination **Tier 2 indicator (EQS):** EQG for chemicals in seafood flesh (EPA 2015; Table 4). Median chemical concentration in the flesh of seafood should not exceed the EQG for seafood contamination in flesh: Copper:	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								If EQG exceeded, monitor EQS	Crustacea: 20 mg/kg Fish: 2 mg/kg Molluscs: 30 mg/kg Selenium: Crustacea/molluscs: 1 mg/kg Fish: 2 mg/kg Zinc: Crustacea: 40 mg/kg Fish: 15 mg/kg Oysters: 290 mg/kg **Monitoring sites:** Opportunistic collection of crustacean (crabs & lobsters), fish, molluscs and oysters within ZoMI. **Contingency Management:** If EQG for seafood contamination in flesh exceeded, monitor EQS for seafood contamination in flesh: Arsenic Crustacea and fish: 2 mg/kg Molluscs: 1 mg/kg Cadmium Molluscs: 2 mg/kg Lead Fish: 0.5 mg/kg Molluscs: 2.0 mg/kg Mercury Crustacea, molluscs, fish: 0.5 mg/kg (mean level) Visual check for source of contamination such as hydrocarbon leaks/spills Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	
Fishing and Aquaculture	Maintenance of aquaculture	There are no aquaculture operations within proximity of the Project.	Should future aquaculture operations be approved within the vicinity of the Project, then EQC may need to be developed to ensure that water quality is sufficient for those	Outside of Marina (no aquaculture operations inside of Marina)	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** Compliance with EQC to protect the EV of Ecosystem Health serves as a proxy to maintain water quality suitable for aquaculture operations.			

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
			operations.							
Recreation and Aesthetics	Maintenance of primary contact recreation values	Breakwater construction and dredging causing turbid plumes	Causes decrease in water clarity unsuitable for primary contact recreation	Outside of Marina (assume no primary contact recreation inside of Marina during construction)	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** TSS modelling does not predict impacts of turbid plume on primary contact areas outside of the Marina	**Intent:** Verify TSS model – monitor TSS at ZoMI/ZoI boundary **Tier 1 indicator (EQG):** Refer to Ecosystem Health monitoring for water quality (TSS) **Monitoring sites:** Refer to Ecosystem Health monitoring for water quality (TSS) **Contingency Management:** If EQG Ecosystem Health monitoring for water quality (TSS) exceeded, monitor EQS	**Intent:** Monitor water clarity at ZoMI/ZoI boundary and primary contact areas **Tier 2 indicator (EQS):** Secchi depth must exceed 1.6 m (EPA 2015; Table 6) **Monitoring sites:** 3 sites on ZoMI/ZoI boundary **Contingency Management:** If EQS exceeded: Monitor sites on ZoI boundary Monitor sites in proximity to recreational beaches Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	
Recreation and Aesthetics	Maintenance of primary and secondary contact recreation values	Biological (faeces) or chemical contaminant release during breakwater construction and dredging	Causes water not suitable for primary or secondary contact recreation	Outside of Marina (assume no primary or secondary contact recreation inside of Marina during construction)	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** No significant sources of biological contaminants (faeces) during construction			
Recreation and Aesthetics	Maintenance of primary contact recreation values	Chemical contaminant release during breakwater construction and dredging	Causes water not suitable for primary contact recreation	Outside of Marina (assume no primary contact recreation inside of Marina during construction)	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Potential sources of chemical contaminants during construction, including minor spills and leaks	**Intent:** Verify no water contamination **Tier 1 indicator (EQG):** Contaminants of concern in water (EPA 2015; Table 6 – Toxic Chemicals) The 95th percentile of the sample concentrations from the area of concern (either from one sample run or from a single site over an agreed period of time) should not exceed the EQG values below: Antimony: 30 µg/L Arsenic: 70 µg/L Barium: 7000 µg/L Boron: 40 000 µg/L	**Intent:** Verify no water contamination **Tier 2 indicator (EQS):** EQS from EPA 2015 for primary contact; Table 6G. DoH should be consulted for advice on setting an appropriate EQS that protects recreational users and any further investigations that would be necessary **Contingency Management:** **If EQS exceeded:** Monitor sites in proximity to recreational beaches Visual check of silt curtain for plume	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								Bromate: 200 µg/L Cadmium: 20 µg/L Chlorite: 3000 µg/L Chromium: 500 µg/L Copper: 20 000 µg/L Cyanide: 800 µg/L Fluorine: 15 000 µg/L Iodine: 1000 µg/L Lead: 100 µg/L Managanese: 5000 µg/L Mercury: 10 µg/L Molybdenum: 500 µg/L Monochloramine: 30 000 µg/L Nickel: 200 µg/L Nitrate: 500 000 µg/L Nitrite: 30 000 µg/L Selenium: 100 µg/L Sulfate: 5 000 000 µg/L **Monitoring sites:** 3 sites at ZoMI/ZoI boundary **Frequency**: Fortnightly during construction **Contingency Management:** If EQG exceeded, monitor EQS	Visual check of seawall for plume Review rock washing efficacy Reduce dredging	
Recreation and Aesthetics	Maintenance of secondary contact recreation values	Chemical contaminant release during breakwater construction and dredging	Causes water not suitable for secondary contact recreation	Outside of Marina (assume no secondary contact recreation inside of Marina during construction)	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Potential sources of chemical contaminants during construction, including minor spills and leaks	**Intent:** Verify no water contamination **Tier 1 indicator (EQG):** Contaminants of concern in water (EPA 2015; Table 7 – Toxic Chemicals) Water should contain no chemicals at concentrations that can irritate the skin of the human body **Monitoring sites:** Monitor reports from public **Frequency**: As reported by public **Contingency Management:** If EQG exceeded, monitor EQS	**Intent:** Verify no water contamination **Tier 2 indicator (EQS):** The Health Department of WA should be consulted for advice on setting an appropriate EQS that protects recreational users and any further investigations that would be necessary **Contingency Management:** If EQS exceeded: Monitor sites in proximity to recreational beaches Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	Contaminants of concern only – the list of contaminants may be rationalised
Recreation and Aesthetics	Maintenance of aesthetic values	Breakwater construction and dredging activities	Visual impacts from TSS plume or minor spills and leaks unsuitable for aesthetic values	Outside of Marina (assume aesthetic values relaxed inside of Marina during construction)	**Possible**	**Minor**	**Rating: Moderate** **Rationale:** Potential sources of chemical contaminants during construction, including minor spills	**Intent:** Verify visual TSS plume and potential other aesthetic impacts not greater than predicted **Tier 1 indicator (EQG):**	**Intent:** Verify visual TSS plume and potential other aesthetic impacts not greater than predicted **Tier 2 indicator (EQS):**	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
							and leaks	TSS (Ecosystem Health) – refer above Nuisance organisms: macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae and sewage, should not be present in excessive amounts Faunal deaths: there should be no reported incidents of large scale deaths of marine organisms relating from unnatural cuases Water clarity: the natural visual clarity of the water should not be reduced by more than 20% Colour: the natural hue of the water should not be changes by more than ten points on the Munsell scale Surface films: oil and petrochemicals should not be noticeable as a visual film on the water or detectable by odour Surface debris: water surfaces should be free of floating debris, dust and other objectional matter including substances that cause foaming Odour: there should be no objectional odours Concentrations of contaminants will not exceed the EQG for tainting substances (EPA 2015; Table 8J) **Monitoring sites:** Three sites on ZoMI/ZoI boundary **Frequency:** Fortnightly during construction **Contingency Management:** If EQG exceeded, monitor EQS	TSS (Ecosystems Health) – refer above There should be no overall decrease in the aesthetic water quality values using direct measures of the communities perception of aesthetic value for the factors: Nuisance organisms: Faunal deaths: Water clarity Colour Surface films Surface debris Odour There should be no detectable tainting of edible fish harvested **Monitoring sites:** Three sites on ZoMI/ZoI boundary **Frequency:** When triggered **Contingency Management:** **If EQS exceeded:** Visual check for source of contamination such as hydrocarbon leaks/spills Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	
Cultural and Spiritual	Maintenance of cultural and spiritual values	Breakwater construction and dredging activities	It is deemed that the protection of ecosystem, recreational, fishing and aesthetic values offers assurance and a proxy towards protecting the fauna, flora, habitats and	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Compliance with EQC to protect the EVs of Ecosystem Health, Fishing, Recreation and Aesthetics serves as a proxy to maintain water			

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
			recreation values of cultural and spiritual importance				quality suitable to protect cultural and spiritual values.			
Industrial Water Supply	Maintenance of industrial water supply values	There are no industrial water uses within proximity of the Project	Should future industrial water uses be approved within the vicinity of the Project, then EQC may need to be developed to ensure that water quality is sufficient for those uses.	Inside and Ouside of Marina	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** Compliance with EQC to protect the EV of Ecosystem Health serves as a proxy to maintain water quality suitable for aquaculture operations.			

Reference:

EPA (2015) Environmental quality criteria reference document for Cockburn Sound. Environmental Protection Authority, Perth, Western Australia, March 2015.

Note:

* - See Attachment B for explanation of the Project environmental risk assessment framework, and approach to development of Tier 1 (EQG) and Tier 2 (EQS) indicators, monitoring and management.

Table A.2 Environmental Factor: Marine Environmental Quality – Operation of Marina

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
Ecosystem Health	Maintenance of ecosystem integrity	Operation of marina causing nutrient release (eutrophication)	Causes algal growth, collapse and anoxia	MEPA – Inside Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Ecological modelling does not suggest impacts of algal plume on DO inside harbour	**Intent:** Verify ecological model – monitor dissolved oxygen (DO) in MEPA **Tier 1 indicator (EQG):** EQG for DO concentration (EPA 2015; Table 1b) The median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 80% (moderate protection) **Monitoring sites:** Three sites in MEPA **Monitoring Frequency:** Immediately after breakwater construction, monthly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQS	**Intent:** Verify ecological model – monitor dissolved oxygen (DO) in MEPA **Tier 2 indicator (EQS):** EQS for DO concentration (EPA 2015; Table 1aD) The median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 60% (moderate protection) **Monitoring sites:** Three sites in MEPA **Monitoring Frequency:** When triggered **Contingency Management:** Contact OEPA Management response required in relation to potential ecosystem health decline – management of anoxia required	
Ecosystem Health	Maintenance of ecosystem integrity	Operation of marina causing nutrient release (eutrophication)	Causes algal growth, collapse and anoxia	HEPA – Outside Marina	**Unlikely**	**Moderate**	**Rating: Moderate** **Rationale:** Ecological modelling does not suggest impacts of algal plume on DO outside harbour	**Intent:** Verify ecological model – monitor dissolved oxygen (DO) in HEPA **Tier 1 indicator (EQG):** EQG for DO concentration (EPA 2015; Table 1b) The median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 90% (high protection) **Monitoring sites:** Three sites on HEPA-MEPA boundary **Monitoring Frequency:** Immediately after breakwater construction, monthly for 2 years **Contingency Management:** If EQG exceeded:	**Intent:** Verify ecological model – monitor dissolved oxygen (DO) in MEPA **Tier 2 indicator (EQS):** EQS for DO concentration (EPA 2015; Table 1aD) The median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 60% (high protection) **Monitoring sites:** Three sites on HEPA-MEPA boundary **Monitoring Frequency:** When triggered **Contingency Management:**	

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								Monitor EQS	Contact OEPA Management response required in relation to potential ecosystem health decline – management of anoxia required	
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during marina operation	Causes water contamination	MEPA – Inside Marina	**Possible**	**Minor**	**Rating: Moderate** **Rationale:** Water quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during operations	**Intent:** Verify no water contamination Tier 1 indicator (EQG): Toxicants in water for MEPA (EPA 2015) – Table 2a – Environmental quality criteria for protecting the marine ecosystem from the effects of toxicants in marine waters and sediment pore waters – EQG for Moderate Protection 95th percentile of the sample concentrations from a single site or a defined area should not exceed the EQG *EQG at Moderate Protection* Metals Cadmium: 14 µg/L Chromium III: 49 µg/L Chromium IV: 20 µg/L Cobalt: 14 µg/L Copper: 3 µg/L Lead: 6.6 µg/L Mercury (inorganic): 0.7 µg/L Nickel: 200 µg/L Silver: 1.8 µg/L Vanadium: 160 µg/L Zinc: 23 µg/L Organics Benzene 900 µg/L Napthalene: 90 µg/L Pentachlorophenol: 33 µg/L **Monitoring sites:** Water sampling at 3 sites in the MEPA **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:**	**Intent:** Verify no water contamination **Tier 2 indicator (EQS):** Toxicants in water for MEPA (EPA 2015) – Table 2a – EQS for Moderate Protection *EQS Moderate Protection* Bioavailable measures (EPA 2015 Table 2a) Indirect biological measures (EPA 2015 Table 2a) **Monitoring sites:** Water sampling at 3 sites in the MEPA **Monitoring frequency:** Triggered by EQG Continue until in compliance with EQG **Contingency Management:** If EQS exceeded: Investigate source of contamination	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								If EQG exceeded, monitor EQS Visual check for source of contamination such as hydrocarbon leaks/spills		
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during marina operation	Causes water contamination	HEPA – Outside Marina	**Possible**	**Minor**	**Rating: Moderate** **Rationale:** Water quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during operations	**Intent:** Verify no water contamination **Tier 1 indicator (EQG):** Toxicants in water for HEPA (EPA 2015) – Table 2a – Environmental quality criteria for protecting the marine ecosystem from the effects of toxicants in marine waters and sediment pore waters. 95th percentile of the sample concentrations from a single site or a defined area should not exceed the EQG *EQG at High Protection* Metals Cadmium: 0.7 µg/L Chromium III: 7.7 µg/L Chromium IV: 0.14 µg/L Cobalt: 1 µg/L Copper: 0.3 µg/L Lead: 2.2 µg/L Mercury (inorganic): 0.1 µg/L Nickel: 0.8 µg/L Silver: 0.8 µg/L Vanadium: 50 µg/L Zinc: 7 µg/L Organics Benzene 500 µg/L Napthalene: 50 µg/L Pentachlorophenol: 11 µg/L **Monitoring sites:** Water sampling at 3 sites on the HEPA-MEPA boundary **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded, monitor EQS Water sampling at 3 reference sites outside ZoI	**Intent:** Verify no water contamination **Tier 2 indicator (EQS):** Toxicants in water for HEPA (EPA 2015) – Table 2a – Environmental quality criteria for protecting the marine ecosystem from the effects of toxicants in marine waters and sediment pore waters. *EQS at High Protection* Bioavailable measures (EPA 2015 Table 2a) Indirect biological measures (EPA 2015 Table 2a) **Monitoring sites:** Water sampling at 3 sites on the HEPA-MEPA boundary **Contingency Management**: If EQS exceeded: Investigate source of contamination	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								Visual check of seawall for plume Visual check for source of contamination such as hydrocarbon leaks/spills		
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during marina operation	Causes sediment contamination	MEPA – Inside Marina	**Possible**	**Major**	**Rating: Moderate** **Rationale:** Sediment quality EIA suggests toxicants within acceptable limits Best practice stormwater management Risk of minor spills and leaks during operations	**Intent:** Verify no sediment contamination **Tier 1 indicator (EQG):** Toxicants in sediments for moderate protection (EPA 2015; Table 3) - Median total contaminant concentration in sediments from a single site or a defined sampling area should not exceed the environmental EQG values below: Metals Antimony: 2 mg/kg dry wt Arsenic: 20 mg/kg dry wt Cadmium: 1.5 mg/kg dry wt Chromium: 80 mg/kg dry wt Copper: 65 mg/kg dry wt Lead: 50 mg/kg dry wt Mercury (inorganic): 0.15 mg/kg dry wt Nickel: 21 mg/kg dry wt Silver: 1 mg/kg dry wt Zinc: 200 mg/kg dry wt Organometals TBT: 5 µg Sn/kg dry wt **Monitoring sites:** 3 sites in MEPA **Monitoring frequency:** Immediately after breakwater construction, annually for 2 years **Contingency Management:** If EQG exceeded, monitor EQS Visual check for source of contamination such as hydrocarbon leaks/spills	**Intent:** Verify no sediment contamination **Tier 2 indicator (EQS):** EQS for moderate protection Bioavailable measures (EPA 2015 Table 3) Porewater measures (EPA 2015 Table 3) Indirect biological measures (EPA 2015 Table 3) **Monitoring sites:** 3 sites in MEPA **Contingency Management:** If EQS exceeded: Investigate source of contamination	Contaminants of concern only – the list of contaminants may be rationalised
Ecosystem Health	Maintenance of ecosystem integrity	Toxicant release during marina operation	Causes sediment contamination	HEPA – Outside Marina	**Possible**	**Major**	**Rating: Moderate** **Rationale:** Sediment quality EIA suggests toxicants within acceptable limits	**Intent:** Verify no sediment contamination **Tier 1 indicator (EQG):** Toxicants in sediments for high protection (EPA 2015; Table 3) -	**Intent:** Verify no sediment contamination **Tier 2 indicator (EQS):** EQS for moderate protection Bioavailable measures (EPA	Contaminants of concern only – the list of contaminants may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
							Best practice stormwater management Risk of minor spills and leaks during operations	Median total contaminant concentration in sediments from a single site or a defined sampling area should not exceed the environmental EQG values below: Metals Antimony: 2 mg/kg dry wt Arsenic: 20 mg/kg dry wt Cadmium: 1.5 mg/kg dry wt Chromium: 80 mg/kg dry wt Copper: 65 mg/kg dry wt Lead: 50 mg/kg dry wt Mercury (inorganic): 0.15 mg/kg dry wt Nickel: 21 mg/kg dry wt Silver: 1 mg/kg dry wt Zinc: 200 mg/kg dry wt Organometals TBT: 5 µg Sn/kg dry wt **Monitoring sites:** Sediment sampling at 3 sites on HEPA-MEPA boundary **Monitoring frequency:** Immediately after breakwater construction, annually for 2 years **Contingency Management:** If EQG exceeded, monitor EQS Sediment sampling at 3 reference sites outside ZoI Visual check of seawall for plume Visual check for source of contamination such as hydrocarbon leaks/spills	2015 Table 3) Porewater measures (EPA 2015 Table 3) Indirect biological measures (EPA 2015 Table 3) **Monitoring sites:** Sediment sampling at 3 sites on HEPA-MEPA boundary **Contingency Management:** If EQS exceeded: Establish EQG sites on ZoI boundary Investigate source of contamination	
Fishing and Aquaculture	Maintenance of aquatic life for human consumption	Operation of marina causing nutrient release (eutrophication)	Causes algal growth of toxic species and seafood contamination	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** No history of problematic toxic algal blooms Ecological modelling does not suggest impacts of algal plume outside or inside harbour	**Intent:** Monitor algal toxins inside the Marina **Tier 1 indicator (EQG):** Concentrations of toxic algae should not exceed the following environmental quality guideline values in any samples (EPA 2015, Table 4) Alexandrium : 100 cells/L (*A. acatenella, A. catenella, A. cohorticula, A.fundyense,*	**Intent:** Monitor algal toxins inside and outside the Marina **Tier 2 indicator (EQS):** Toxin concentration in seafood should not exceed the following environmental quality standards in any samples (EPA 2015, Table 4) Paralytic shellfish poison (PSP): 0.8 mg Saxitoxin eq./kg	Species and toxicants of concern only – the list may be rationalised

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								*A.lusitanucum, A. minitum, A. ostenfeldii, A. tamiyavanachi, A. tamarense***)** Dinophysis: 500 cells/L (*D. acuta, D. fortii, D. norvegica*) (*Dinophysis acuminate*: 30000 cells/L) Prorocentrum: 500 cells/L (*P. lima*) Gymnodinium: 1000 cells/L *(G. catenatum)* Karenia: 1000 cells/L (*K. brevis, K. brevis-like, K. mikimotoi*) Pseudonitzchia: 250,000 cells/L (*P. australis, P. pungens, P. turgidula, P. fraudulenta, P. delicatissima, P. pseudodelicatissima*) *Gonyaulax cf. Spinifera*: 100 cells/L *Protoceratium reticulatum (Gonyaulax grindley)*: 500 cells/L **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	Diarrhoetic shellfish poison (DSP): 0.2 mg/kg Neurotoxic shellfish poison (NSP): 200 mouse units/kg Amnesic shellfish poison (ASP) (domoic acid): 20 mg/kg Yessotoxins: 1 mg Yessotoxin eq./kg **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	
Fishing and Aquaculture	Maintenance of aquatic life for human consumption	Biological (faeces) contaminant release during operation of Marina (e.g. swimming and boat sullage)	Causes seafood contamination	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Human use of Marina, including swimming and boat sullage may introduce biological (faecal) contaminants	**Intent:** Monitor biological (faecal) contaminants inside the Marina **Tier 1 indicator (EQG)** From Table 4 of EPA (2015): The median or geometric mean faecal coliform concentration in	**Intent:** Monitor biological (faecal) contaminants inside and outside the Marina **Tier 2 indicator (EQS):** From Table 4 of EPA (2015): The median or geometric	

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								samples from a single sitemust not exceed 14 CFU/100mL and the estimated 90th percentile must not exceed 21 CFU/100 mL measured using the membrane filtration method. or The median or geometric mean faecal coliform concentration in samples from a single site must not exceed 14 MPN/100 mL and the estimated 90th percentile must not exceed 43 MPN/100 mL measured using a 5 tube decimal dilution test, or 49 MPN/100 mL measured using a 3 tube decimal dilution test. or The median or geometric mean total coliform concentration in samples from a single site must not exceed 70 MPN/100 mL and the estimated 90th percentile must not exceed 230 MPN/100 mL measured using a 5 tube decimal dilution test, or 330 MPN/100 mL measured using a 3 tube decimal dilution test. **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after commissioning, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at 3 sites outside the Marina Monitor EQS	mean faecal coliform concentration in samples from a single site must not exceed 70 CFU/100 mL and the estimated 90th percentile must not exceed 85 CFU/100 mL measured using the membrane filtration method. or The median or geometric mean faecal coliform concentration in samples from a single site must not exceed 88 MPN/100 mL and the estimated 90th percentile must not exceed 260 MPN/100 mLmeasured using a 5 tube decimal dilution test, or 300 MPN/100 mL measured using a 3 tube decimal dilution test. or The median or geometric mean total coliform concentration in samples from a single site must not exceed 700 MPN/100 mL and the estimated 90th percentile must not exceed 2300 MPN/100 mL measured using a 5 tube decimal dilution test, or 3300 MPN/100 mL measured using a 3 tube decimal dilution test. **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** **If EQS exceeded:** Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	
Recreation and Aesthetics	Maintenance of primary contact recreation values	Operation of marina causing nutrient release (eutrophication)	Causes algal growth of toxic species and water to be not suitable for primary	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** No history of problematic	**Intent:** Monitor algal toxins inside the Marina	**Intent:** Monitor algal toxins inside and outside the Marina	* Phytoplankton cell counts include cyanobacteria

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
			contact recreation				toxic algal blooms Ecological modelling does not suggest impacts of algal plume outside or inside harbour	**Tier 1 indicator (EQG)** From Table 6 of EPA (2015): The phytoplankton cell count* from a single site, should not: – exceed 10 000 cells/mL; or – detect DoH watch list species or exceed their trigger levels. # There should be no reports of skin, eye or respiratory irritation or potential algal poisoning of recreational users considered by a medical practitioner as potentially resulting from toxic algae when less than 10 000 cells/mL is present in the water column. **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	**Tier 2 indicator (EQS)** From Table 6 of EPA (2015): The phytoplankton cell count* from a single site, should not: – exceed 50 000 cells/mL; or – detect or exceed DoH watch list action levels. There should be no visual presence of algal scums† or relatively widespread visible presence of Lyngbya majuscula filaments (NHMRC 2008). There should be no confirmed incidences by report from a medical practitioner, of skin, eye or respiratory irritation, caused by toxic algae or of algal poisoning of recreational users. **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** **If EQS exceeded:** Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	and eukaryotic organisms. # Detection or exceedance of DOHWA watchlist trigger levels should trigger re-sampling and a visual assessment of the site within 48 hours for assessment against EQS B and C. † Algal scums are defined as dense accumulations of algal cells at or near the surface of the water forming a layer of distinct discolouration (green, blue, brown or red) (Gov QLD, 2002).
Recreation and Aesthetics	Maintenance of secondary contact recreation values	Operation of marina causing nutrient release (eutrophication)	Causes algal growth of toxic species and water to be not suitable for secondary contact recreation	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** No history of problematic toxic algal blooms Ecological modelling does not suggest impacts of algal plume outside or inside harbour	**Intent:** Monitor algal toxins inside the Marina **Tier 1 indicator (EQG)** From Table 7 of EPA (2015): The median phytoplankton cell count* for a defined sampling area (either from one sampling run or from a single site over an agreed period of time) should not exceed 25 000 cells/mL.	**Intent:** Monitor algal toxins inside and outside the Marina **Tier 2 indicator (EQS)** From Table 7 of EPA (2015): There should be no confirmed incidences, by report from a medical practitioner, of skin, eye or respiratory irritation or poisoning in secondary contact recreational users caused by toxic algae or chemical	* Phytoplankton cell counts include cyanobacteria and eukaryotic organisms.

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								There should be no reports of skin, eye or respiratory irritation or potential algal poisoning of recreational users considered by a medical practitioner as potentially resulting from toxic algae when less than 25 000 cells/mL is present in the water. **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	contaminants. **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	
Recreation and Aesthetics	Maintenance of primary contact recreation values	Biological (faeces) contaminant release during operation of Marina (e.g. swimming and boat sullage)	Causes water to be not suitable for primary contact recreation	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Human use of Marina, including swimming and boat sullage may introduce biological (faecal) contaminants	**Intent:** Monitor biological (faecal) contaminants inside the Marina **Tier 1 indicator (EQG)** From Table 6 of EPA (2015): The 95th percentile bacterial content of marine waters should not exceed 200 enterococci/100 mL. **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	**Intent:** Monitor biological (faecal) contaminants inside and outside the Marina **Tier 2 indicator (EQS)** From Table 6 of EPA (2015): The 95th percentile bacterial content of marine waters should not exceed 500 enterococci/100 mL. **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	
Recreation and Aesthetics	Maintenance of secondary contact recreation values	Biological (faeces) contaminant release during operation of	Causes water to be not suitable for secondary contact	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:**	**Intent:** Monitor biological (faecal) contaminants inside the Marina	**Intent:** Monitor biological (faecal) contaminants inside and	

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
		Marina (e.g. swimming and boat sullage)	recreation				Human use of Marina, including swimming and boat sullage may introduce biological (faecal) contaminants	**Tier 1 indicator (EQG)** From Table 7 of EPA (2015): The 95th percentile bacterial content of marine waters should not exceed 2 000 enterococci/100 mL. **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	outside the Marina **Tier 2 indicator (EQS)** From Table 7 of EPA (2015): The 95th percentile bacterial content of marine waters should not exceed 5 000 enterococci/100 mL. **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	
Recreation and Aesthetics	Maintenance of primary contact recreation values	Chemical contaminant release during operation of Marina, including minor spills and leaks	Causes water to be not suitable for primary contact recreation	Inside and Outside of Marina	**Possible**	**Moderate**	Rating**: Moderate** **Rationale:** Potential sources of chemical contaminants during operation of Marina, including minor spills and leaks	**Intent:** Monitor chemical contaminants inside the Marina **Tier 1 indicator (EQG)** From Table 6 of EPA (2015): The 95th percentile of the sample concentrations from the area of concern (either from one sampling run or from a single site over an agreed period of time) should not exceed the environmental quality guideline values provided below. Antimony: 30 µg/L Arsenic: 70 µg/L Barium: 7000 µg/L Boron: 40 000 µg/L Bromate: 200 µg/L Cadmium: 20 µg/L Chlorite: 3000 µg/L Chromium: 500 µg/L Copper: 20 000 µg/L Cyanide: 800 µg/L Fluorine: 15 000 µg/L Iodine: 1000 µg/L	**Intent:** Monitor chemical contaminants inside and outside the Marina **Tier 2 indicator (EQS)** From Table 6 of EPA (2015): DoH should be consulted for advice on setting an appropriate environmental quality standard that protects recreational users and any further investigations that would be necessary. **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then	

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
								Lead: 100 µg/L Managanese: 5000 µg/L Mercury: 10 µg/L Molybdenum: 500 µg/L Monochloramine: 30 000 µg/L Nickel: 200 µg/L Nitrate: 500 000 µg/L Nitrite: 30 000 µg/L Selenium: 100 µg/L Sulfate: 5 000 000 µg/L **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	contact DoH; Management response required in relation to potential risk to public health	
Recreation and Aesthetics	Maintenance of secondary contact recreation values	Chemical contaminant release during operation of Marina, including minor spills and leaks	Causes water to be not suitable for secondary contact recreation	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Potential sources of chemical contaminants during operation of Marina, including minor spills and leaks	**Intent:** Monitor chemical contaminants inside the Marina **Tier 1 indicator (EQG)** From Table 7 of EPA (2015): Water should contain no chemicals at concentrations that can irritate the skin of the human body. **Monitoring sites:** 3 sites inside the Marina **Monitoring frequency:** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	**Intent:** Monitor chemical contaminants inside and outside the Marina **Tier 2 indicator (EQS)** From Table 7 of EPA (2015) Same as EQG **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Contact DoH; Management response required in relation to potential risk to public health Outside marina, compare to EQS; if exceeded, then contact DoH; Management response required in relation to potential risk to public health	
Recreation and Aesthetics	Maintenance of aesthetic values	Marina operations	Visual impacts from minor spills and leaks unsuitable for aesthetic values	Inside and outside of Marina	**Possible**	**Minor**	**Rating: Moderate** **Rationale:** Potential sources of	**Intent:** Verify visual aesthetic impacts not greater than predicted inside the Marina	**Intent:** Verify visual TSS plume and potential other aesthetic impacts not greater than	

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
							minor spills and leaks during operation of Marina	Nuisance organisms: macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae and sewage, should not be present in excessive amounts Faunal deaths: there should be no reported incidents of large scale deaths of marine organisms relating from unnatural causes Water clarity: the natural visual clarity of the water should not be reduced by more than 20% Colour: the natural hue of the water should not be changes by more than ten points on the Munsell scale Surface films: oil and petrochemicals should not be noticeable as a visual film on the water or detectable by odour Surface debris: water surfaces should be free of floating debris, dust and other objectional matter including substances that cause foaming Odour: there should be no objectional odours Concentrations of contaminants will not exceed the EQG for tainting substances (EPA 2015; Table 8J) **Monitoring sites:** Three sites inside of Marina **Frequency** Immediately after breakwater construction, quarterly for 2 years **Contingency Management:** If EQG exceeded: Monitor EQG at sites outside the Marina Monitor EQS	predicted There should be no overall decrease in the aesthetic water quality values using direct measures of the communities perception of aesthetic value for the factors: Nuisance organisms: Faunal deaths: Water clarity Colour Surface films Surface debris Odour There should be no detectable tainting of edible fish harvested **Monitoring sites:** 3 sites inside the Marina 3 sites outside Marina (compare against EQG) **Contingency Management:** If EQS exceeded: Investigate source of aesthetic decrease and manage as appropriate	
Cultural and Spiritual	Maintenance of cultural and spiritual values	Marina operations	It is deemed that the protection of ecosystem, recreational, fishing and aesthetic values	Inside and Outside of Marina	**Possible**	**Moderate**	**Rating: Moderate** **Rationale:** Compliance with EQC to protect the EVs of			

Environmental Value	Environmental Quality Objective	Project Element/Stressor	Potential Environmental Impact/Response	LEP (MEPA – Inside Marina; HEPA Outside Marina)	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 / EQG Monitoring and Management Strategy*	Tier 2 / EQS Monitoring and Management Strategy*	Notes
			offers assurance and a proxy towards protecting the fauna, flora, habitats and recreation values of cultural and spiritual importance				Ecosystem Health, Fishing, Recreation and Aesthetics serves as a proxy to maintain water quality suitable for aquaculture operations			
Industrial Water Supply	Maintenance of industrial water supply values	Marina operations	Should future industrial water uses be approved within the vicinity of the Project, then EQC may need to be developed to ensure that water quality is sufficient for those uses.	Inside and Ouside of Marina	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** Compliance with EQC to protect the EV of Ecosystem Health serves as a proxy to maintain water quality suitable for aquaculture operations.			

<u>Reference:</u>

EPA (2015) Environmental quality criteria reference document for Cockburn Sound. Environmental Protection Authority, Perth, Western Australia, March 2015.

<u>Note</u>:

* - See Attachment B for explanation of the Project environmental risk assessment framework, and approach to development of Tier 1 (EQG) and Tier 2 (EQS) indicators, monitoring and management.

Table A.3 Environmental Factor: Benthic Communities and Habitats

Project Phase	Project Element/Stressor	Potential Environmental Impact/Response	Inside or Outside Marina	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 Monitoring and Management Strategy*	Tier 2 Monitoring and Management Strategy *	Notes
Construction	Breakwater construction and dredging	Causes turbid plume and sedimentation, leading to indirect BPPH loss	Outside Marina	**Unlikely**	**Major**	**Rating: Moderate** **Rationale:** TSS modelling does not predict impacts of turbid plume on BPPH outside of the ZoHI/ZoMI	**Intent:** Verify TSS model – monitor TSS at ZoMI/ZoI boundary **Tier 1 indicator (EQG):** TSS ≤2 mg/L (above background) rolling average (14 days) **Monitoring sites:** Turbidity loggers at 3 sites on ZoMI/ZoI boundary. Turbidity loggers at 3 reference sites outside ZoI Monitoring Frequency: Logging turbidity and downloading at fortnightly intervals **Contingency Management:** If EQG exceeded, monitor EQS Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy	**Intent:** Monitor TSS at BPPH sites **Tier 2 indicator (EQS):** TSS ≤2 mg/L (above background) rolling average (14 days) **Monitoring sites:** Turbidity loggers at 3 sites in ZoI where BPPH is present (i.e. seagrass on habitat map). Turbidity loggers at 3 reference sites outside ZoI **Contingency Management:** If EQS exceeded: Monitor BPPH health Visual check of silt curtain for plume Visual check of seawall for plume Review rock washing efficacy Reduce dredging	Turbidity logger will need to be calibrated against TSS in the field and/or laboratory.
Construction	Breakwater construction and dredging	Causes turbid plume and sedimentation, leading to indirect BPPH loss	Inside Marina	**Likely**	**Major**	**Rating: High** **Rationale:** Assume BPPH Zone of Loss within ZoHI/ZoMI	**Intent:** Verify BPPH survey **Tier 1 indicator:** Engineering survey confirms as-built Marina footprint same as that detailed in BPPH survey **Monitoring sites:** Marina footprint **Contingency Management:** If Tier 1 exceeded, monitor Tier 2	**Intent:** BPPH survey of halo area **Tier 2 indicator:** BPPH survey of halo areas **Monitoring sites:** Breakwater halo of BPPH **Contingency Management:** If Tier 2 exceeded: BPPH survey of broader area	
Operation	Operation of marina causing nutrient release (eutrophication)	Causes algal growth, shading and BPPH loss	Outside Marina	**Unlikely**	**Major**	**Rating: Moderate** **Rationale:** Ecological modelling does not predict impacts of algal plume on BPPH outside of the ZoHI/ZoMI	**Intent:** Verify ecological model – monitor algal concentration at HEPA-MEPA boundary **Tier 1 indicator (EQG):** Algal concentration ≤0.01 mgC/m3 at HEPA/MEPA boundary **Monitoring sites:** 3 sites on HEPA-MEPA boundary **Monitoring frequency:** Immediately after breakwater construction, monthly for 2 years.	**Intent:** Monitor algal concentration at BPPH sites **Tier 2 indicator (EQS):** Algal concentration ≤0.01 mgC/m3 in ZoI **Monitoring sites:** In ZoI where BPPH is present (i.e. seagrass on habitat map). **Contingency Management:** If EQS exceeded: Monitor BPPH health	

							Contingency Management: If EQG exceeded: Monitor EQS		
Operation	Operation of marina causing nutrient release (eutrophication)	Causes algal growth, shading and BPPH loss	Inside Marina	**Likely**	**Major**	**Rating: High** **Rationale:** Assume BPPH Zone of Loss within ZoHI/ZoMI	**Intent:** Verify BPPH survey **Tier 1 indicator:** Engineering survey confirms as-built Marina footprint same as that detailed in BPPH survey **Monitoring sites:** Marina footprint **Contingency Management:** If Tier 1 exceeded, monitor Tier 2	**Intent:** BPPH survey of halo area **Tier 2 indicator:** BPPH survey of halo areas **Monitoring sites:** Breakwater halo of BPPH **Contingency Management:** If Tier 2 exceeded: BPPH survey of broader area	
Operation	Marina footprint	Causes direct loss of BPPH	Inside and Outside Marina	**Likely**	**Major**	**Rating: High** **Rationale:** BPPH survey indicates minor direct BPPH loss	**Intent:** Verify BPPH survey **Tier 1 indicator:** Engineering survey confirms as-built Marina footprint same as that detailed in BPPH survey **Monitoring sites:** Marina footprint **Contingency Management:** If Tier 1 exceeded, monitor Tier 2	**Intent:** BPPH survey of halo area **Tier 2 indicator:** BPPH survey of halo areas **Monitoring sites:** Breakwater halo of BPPH **Contingency Management:** If Tier 2 exceeded: BPPH survey of broader area	
Operation	Marina footprint	Causes 50 m halo of indirect loss around breakwaters	Outside Marina	**Likely**	**Major**	**Rating: Major** **Rationale:** BPPH survey indicates minor halo BPPH loss	**Intent:** Verify BPPH survey **Tier 1 indicator:** Post-construction BPPH survey of halo area **Monitoring sites:** Breakwater halo of BPPH **Contingency Management:** If Tier 1 exceeded, monitor Tier 2	**Intent:** BPPH survey of broader area **Tier 2 indicator:** BPPH survey of broader area **Monitoring sites:** Broader area **Contingency Management:** If Tier 2 exceeded: Monitor BPPH recovery	

Note:
* - See Attachment B for explanation of the Project environmental risk assessment framework, and approach to development of Tier 1 (EQG) and Tier 2 (EQS) indicators, monitoring and management.

Table A.4 Environmental Factor: Marine Fauna

Project Phase	Project Element/Stressor	Potential Environmental Impact/Response	Inside or Outside Marina	Likelihood*	Consequence*	Risk rating of impact and rationale*	Tier 1 Monitoring and Management Strategy*	Tier 2 Monitoring and Management Strategy *	Notes
Construction	Breakwater construction and dredging	Causes interference or collision with marine fauna	Outside Marina	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** Marine fauna EIA suggests risks to marine fauna from construction activities are not significant			Marine fauna observer may be required during construction activities to ensureno impact on marine fauna
Operation	Marina operations	Causes interference or collision with marine fauna	Inside and Outside Marina	**Rare**	**Moderate**	**Rating: Negligible** **Rationale:** Marine fauna EIA suggests risks to marine fauna from operational activities are not significant			

Note:
* - See Attachment B for explanation of the Project environmental risk assessment framework, and approach to development of Tier 1 (EQG) and Tier 2 (EQS) indicators, monitoring and management.

Attachment B

Project Environmental Risk Assessment Framework and Approach to Development of Monitoring and Management Measures

Environmental Risk Assessment Framework and Approach to Development of Monitoring and Management Measures

Environmental Risk Assessment Framework

A standardised approach to environmental risk assessment was applied to the overall Ocean Reef Marina Project proposal, i.e. considering both construction and operational phases, to define key risks to the environmental factors of Marine Environmental Quality, Benthic Communities and Habitats and Marine Fauna. The environmental risk assessment enabled identification of appropriate measures to monitor, manage and/or mitigate risks to acceptable levels.

The method of risk assessment and attribution of appropriate monitoring and management measures for the Project was aligned with the procedures in Environmental Risk Management – Principles and Process Handbook 203:2012 (SASNZ 2012) and Risk Management Guidelines Handbook 436:2004 (SASNZ 2004b) as per Australian Standard/New Zealand Standard ISO 31000:2009 Risk Management (SASNZ 2009).

The environmental risk model was defined by the following:

- Consequence of the risk event (Table B.1);
- Likelihood of the risk event occurring (Table B.2); and
- Risk severity and rating (arising from the combined likelihood and consequence of the risk event; Table B.3).

'Consequence' may generally be defined as the outcome or impact of an event (SASNZ 2009). The definitions and generic descriptors of consequence defined in Table B.1 were adopted from AS/NZ ISO 31000:2009 (SASNZ 2009) and consider the level of ecosystem effect and potential for recovery following a risk event. Specific descriptors were also developed to rate the potential consequences of risk events upon explicit, relevant components of the environment (i.e. benthic primary producer habitat and marine fauna; see Table B.1).

'Likelihood' is a general description of the probability or frequency that an event may occur (SASNZ 2009). Table B.2 provides the various descriptors of likelihood for risk events occurring, as adapted from AS/NZS IS0 31000:2009 (SASNZ 2009) and Environmental Risk Management Handbook 203:2012 (SASNZ 2012), but with descriptions slightly modified to be applicable to the life cycle of the Project. The indicative frequencies outlined in Table 6.2 were not fixed but rather provided a suggestive tool to aid classification of the likely occurrence of Project risk events.

This severity of a risk event was determined by considering the matrix of likelihood versus consequence, as per Table B.3. The risk rating of severity incorporated a numbering system that ensured that the risk assessment was conservative and included credible worst case scenarios (i.e. it was tailored to suit the potential impacts, duration and sensitivities of the Project).

The risk assessment presumed that monitoring, management and mitigation measures identified in Attachment A shall be in place for the Project, such that the consequence, likelihood and risk severity rating represent 'residual' risk (i.e. not 'inherent' risk, without monitoring and management/mitigation emplaced). Potential impacts with a 'negligible' residual risk rating did not require development of monitoring and management measures, whereas potential impacts with a 'moderate' residual risk rating will require the monitoring and management measures identified in Attachment A to be emplaced. The only potential impacts identified for the Project that had a residual risk rating of high were for direct impacts on bentic communities and habitats

(Table A.3) where the EPA's (2009) cumulative loss guideline is expected to be marginally exceeded. No potential impacts identified for the Project had a residual risk rating of 'unacceptable'.

Approach to Development of Monitoring and Management Measures

Tier 1 (EQG) and Tier 2 (EQS) monitoring indicators and management measures were developed in accordance with the:

- Environmental Assessment Guideline for Protecting the Quality of Western Australia's Marine Environment (EAG 15; EPA 2015a)
- Environmental Quality Criteria Reference Document for Cockburn Sound – A Supporting Document to the State Environmental (Cockburn Sound) Policy 2015 (EPA 2015b)

Tier 1 indicators (EQG) are closer to the stress end of the stress-response relationships outlined in Tables A.1 to A.4, and provide an early warning of a potential problem. If Tier 1 (EQG) are exceeded, then the contingency management response is to further investigate the potential problem, including by monitoring Tier 2 indicators (EQS). Tier 2 indicators (EQS) are closer to the response end of the stress-response-relationship (outlined in Tables A.1 to A.4) and provide an indication of an impact occurring that requires a management response to restore environmental quality to within acceptable levels. The EPA (2015a,b) illustrate the application of Tier 1 (EQG) and Tier 2 (EQS) indicators and management responses as shown in Figure B.1.

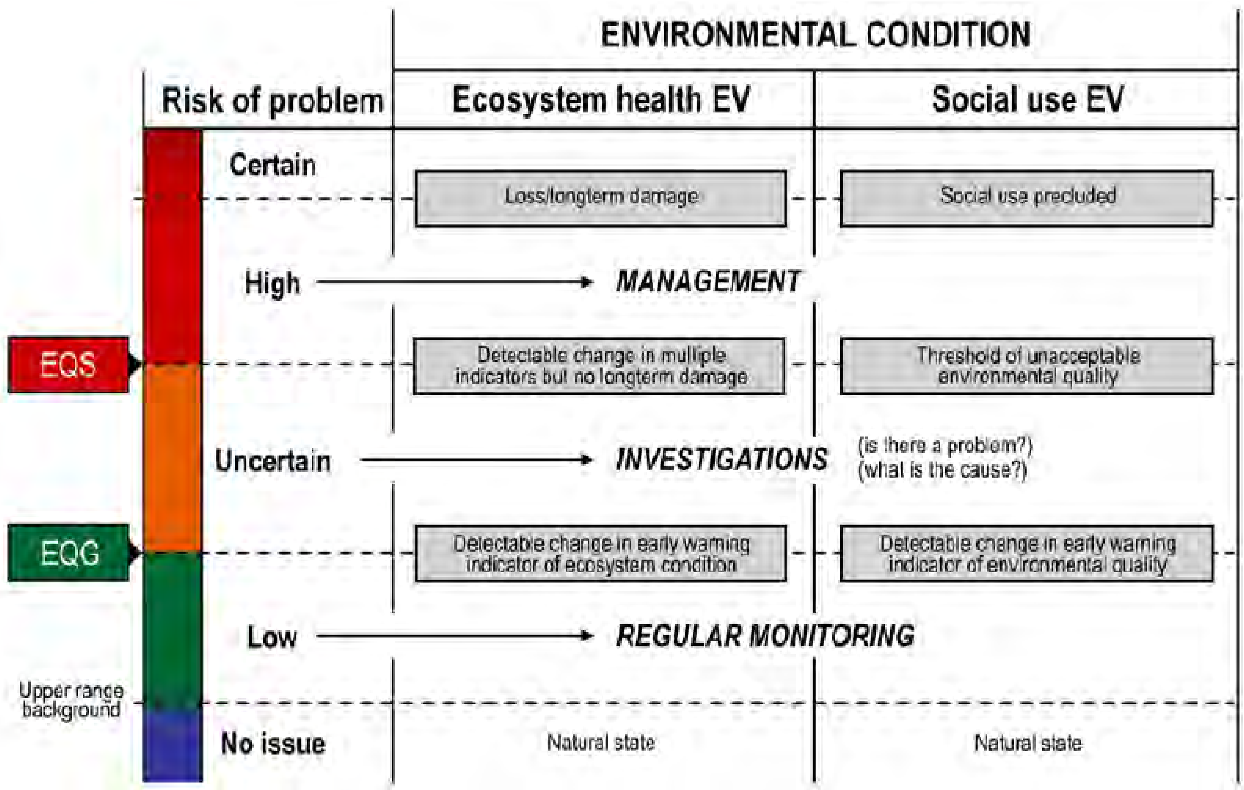

Figure B.1 Conceptual diagram showing the relationship between Tier 1 (EQG) and Tier 2 (EQS) indicators on the left hand side with the associated environmental condition and management response on the right hand side (EPA 2015a,b)

Table B.1 Classification of the consequences of risk events

Value	Description AS/NZS ISO 31000 and HB 203:2012	Generic Descriptors - Natural Environment (Impact on ecosystem &/or specific species or communities, recovery, remediation)	Specific Descriptors - Marine Fauna (Individuals) Impact on Protected Marine Fauna Individuals	Specific Descriptors - Marine Fauna (Populations) Impact on Protected Marine Fauna Populations	Specific Descriptors - BPPH Impact on Benthic Primary Producer Habitat
5	Catastrophic	Massive impacts with significant remediation required. Irreversible alteration to ecosystem functioning or damage to public health Long term environmental recovery that may take decades or longer. (For example, loss of an ecosystem, extinction of a species, multiple loss of human life or irreversible disability)	Behaviour, physiology, and well-being severely (or mortally) affected with individual reproductive success greatly reduced or ceased.	Effects initiate substantial population decline; possible mass mortality.	BPPH loss exceeds EPA (2009) Guideline Cumulative Loss Guideline (CLG - for relevant category of ecosystem protection and management unit). Large-scale remediation of BPPH and or offsets required.
4	Major	Major impacts with considerable remediation required. Major alteration to ecosystem or damage to public health Recovery period measured in years to decades. (For example, irreversible damage to part of an ecosystem, loss of single human life or permanent disability to one or two individuals)	Behaviour, physiology, and well-being substantially affected with reduction in individual reproductive success.	Effects are biologically significant with key demographic parameters adversely affected; population in slow/moderate decline.	BPPH loss exceeds CLG. Moderate remediation of BPPH and or offsets required.
3	Moderate	Moderate impacts with some management required. Moderate alteration to ecosystems or damage to public health. Recovery period measured in months to years. (For example, short term dip in ecosystem functioning, recovery of an actual injury following suitable medical treatment)	Behaviour, physiology, and well-being affected to a degree that individual reproductive success is reduced.	Effects detectable for demographic factors at population-level but not biologically sufficient to unless effect is sustained.	BPPH loss approaches (but does not exceed) CLG. Some management required.
2	Minor	Minor impacts with minimal management required. Minor alteration to ecosystems, not affecting function, no lasting effect on public health. Recovery period measured in weeks to months. (For example, pollution spill cleaned up immediately, minor medical incident)	Behaviour, physiology, and well-being affected to a degree that minimally influences individual reproductive success.	Effects potentially observable at population-level but insufficient to be biologically significant.	Some BBPH loss, but not approaching CLG. Some management required.
1	Insignificant	Negligible impact with no management required. No alteration to ecosystems or public health.	Behaviour, physiology, and well-being barely or weakly affected.	Effects not observable at population-level; no effect of biological significance.	No loss of BPPH. Minor and/or temporary impact on primary producer health.

Table B.2 Classification of the likelihood of risk events

Value	Descriptor	Description AS/NZS ISO 31000 and HB 203:2012 (modified)	Indicative Frequency (Expectation to occur)
5	Almost Certain	Is expected to occur in most circumstances during the life cycle of the proposed Project	e.g. daily to monthly
4	Likely	Will probably occur in most normal circumstances during the life cycle of the proposed Project	e.g. quarterly to annually
3	Possible	Could occur at some time during the life cycle of the proposed Project	e.g. few times per decade
2	Unlikely	Not expected, but could occur during the life cycle of the proposed Project	e.g. once per decade
1	Rare	May occur only under exceptional circumstances during the life cycle of the proposed Project.	e.g. once per century

Table B.3 Risk rating and severity matrix

Likelihood	**Consequence**				
	Insignificant 1	**Minor 2**	**Moderate 3**	**Major 4**	**Catastrophic 5**
Almost Certain 5	Moderate 5	Moderate 10	High 15	Unacceptable 20	Unacceptable 25
Likely 4	Negligible 4	Moderate 8	High 12	High 16	Unacceptable 20
Possible 3	Negligible 3	Moderate 6	Moderate 9	High 12	High 15
Unlikely 2	Negligible 2	Negligible 4	Moderate 6	Moderate 8	Moderate 10
Rare 1	Negligible 1	Negligible 2	Negligible 3	Negligible 4	Moderate 5

Risk Severity	Negligible 1 to 4	Moderate 5 to 10	High 11 to 19	Unacceptable 20 to 25

BMT Oceanica

Ocean Reef Benthic Habitat Map Report

1058_01_002/1_Rev6

August 2016

Ocean Reef Benthic Habitat Map Report

Prepared for

Strategen Environmental Consultants Pty Ltd

Prepared by

BMT Oceanica Pty Ltd

August 2016

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Quality Assurance

BMT Oceanica Pty Ltd has prepared this report in accordance with our Health Safety Environment Quality Management System, certified to OHSAS 18001, AS/NZS 4801, ISO 14004 and ISO 9001: 2008.

Status

This report is 'Draft' until approved for final release, as indicated below by inclusion of signatures from: (i) the author and (ii) a Director of BMT Oceanica Pty Ltd or their authorised delegate. A Draft report may be issued for review with intent to generate a 'Final' version, but must not be used for any other purpose.

Approved for final release:

Author
Date: 04/03/2016

Director (or delegate)
Date: 04/03/2016

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1. Introduction

1.1 Background

The City of Joondalup is proposing to construct a new marina and related infrastructure at the existing Ocean Reef Boat Harbour site (Figure 1.1). The key characteristics of the proposal include:

- construction and maintenance of two new outer breakwaters
- removal of the existing breakwaters and other marine infrastructure from the boat launching harbour
- dredging of sand and rock inside the harbour
- disposal of dredge spoil into land reclamation areas inside the breakwaters
- construction of jetties to support piled boat mooring pens
- operation and maintenance of the marina (EPA 2014).

In accordance with the Environmental Assessment Guideline EAG 8 (*Environmental factors and objectives*) (EPA 2013), the key environmental factors for the proposal include:

- marine environmental quality
- benthic communities and habitat
- marine fauna
- coastal processes
- integrating factors – offsets.

1.2 Scope of work

The Environmental Protection Authority's (EPA's) objective for benthic communities and habitat is "to maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scale". As such, the Environmental Scoping Document (ESD) (EPA 2014) states that it is necessary to characterise the environment by designing and conducting a benthic communities and habitat survey to accurately map the spatial extent of benthic habitats.

"*Characterise the environment by designing and conducting a benthic communities and habitat survey to accurately map the spatial extent of benthic habitats. Based on the findings of the surveys, produce georeferenced maps showing the extent and distribution of the different benthic communities and habitats and present these at the appropriate scale. Mapping is to extend to the outer boundary of the area where both reversible and irreversible effects of biota are predicted to occur and into the zone of influence and for appropriate reference sites. Surveys should be conducted to a standard such that the results can be used as a baseline for future monitoring both during construction and operation of the proposal. Mapping techniques and habitat classification should be consistent with those used by the Department of Parks and Wildlife for marine reserve management. The habitat map for Marmion Marine Park (Department of Environment and Conservation, 2002) is to be assessed for its accuracy within the predicted zone of influence. Where the map is deemed inaccurate it is to be updated, through methods that may include ground truthing, in consultation with the Department of Parks and Wildlife*."

The purpose of this document is to report the results of a benthic habitat survey conducted by BMT Oceanica Pty Ltd (BMT Oceanica) in the Marmion Marine Park (MMP), which focussed on the Ocean Reef region.

1.2.1 Objectives

The objective of this scope is to meet the requirements of the ESD and includes the following elements:

1. Design and conduct a benthic communities and habitat survey to accurately map the spatial extent of benthic habitats.
2. Produce georeferenced maps showing the extent and distribution of the different benthic communities and habitats and present at an appropriate scale.
3. Map to the extent of the outer boundary where both reversible and irreversible effects of biota are predicted to occur. This was conservatively scoped to be within 3 km of the proposed marina.
4. Map the zone of influence and appropriate reference sites.
5. Survey to be conducted to a standard such that the results can be used as a baseline for future monitoring.
6. Mapping techniques and habitat classification to be consistent with those used by Department of Parks and Wildlife (DPaW).
7. The MMP habitat map is to be assessed for its accuracy with the predicted zone of influence, and where deemed inaccurate it is to be updated using methods that may include ground truthing.
8. Define an appropriate local assessment unit (LAU).

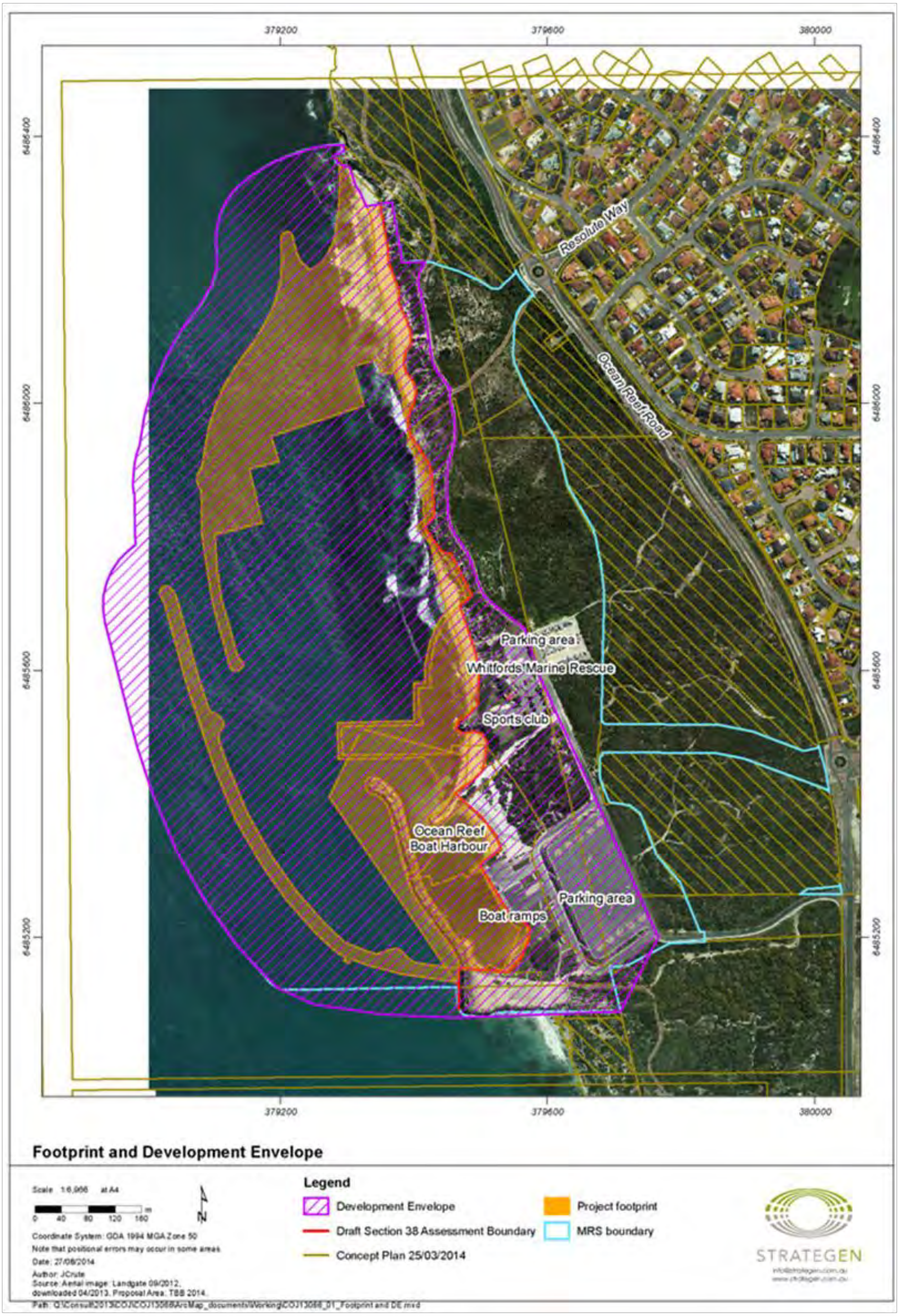

Figure 1.1 Footprint of the proposed Ocean Reef Marina Development

2. Methods

2.1 Local Assessment Unit

The Environmental Assessment Guideline EAG 3 (*Protection of benthic primary producer habitats in Western Australia's marine environment*) (EPA 2009) recommends a Local Assessment Unit (LAU) area to be ~50 km^2, but can be altered where a unit can be practically outlined. For this proposal the boundaries of the Marmion Marine Park (MMP) were used as the LAU following the recommendation of the EPA in the ESD. The LAU also includes the existing Ocean Reef Boat Harbour and Hillarys Boat Harbour for assessment of historical habitat loss as recommended in the ESD.

2.2 Pre-existing data for Ocean Reef area

A recent benthic habitat classification was completed by Water Corporation of Western Australia (Water Corporation) in 2013 (Water Corporation, unpublished data). This work used a March 2013 satellite image and ground truthing data which covered sections of the MMP near Ocean Reef Boat Harbour. A data sharing agreement was completed between the Water Corporation and City of Joondalup to allow use of this work for the current study. Data and imagery for the remaining area of the MMP and the northern extension area was sourced from the Marine Habitats of Western Australia dataset which consists of polygons delineating the broad-scale regional marine habitats for the MMP area (DEC 2003).

2.3 Study Area

The habitat map includes the MMP as this area has been designated as the LAU for the purpose of the Public Environmental Review (PER). An extended study area to the north of MMP is shown due to the availability of Department of Environment and Conservation (DEC) mapping in this area and as context for the habitats described in the MMP. To ensure adequate accuracy within the local area of the proposed development a ground truthing survey was completed in 2014 to a standard such that the results can be used as a baseline for future monitoring and to develop a detailed map for accurate assessment of benthic habitat areas where both reversible and irreversible effects of biota may occur. The area of the 2014 ground truthing survey is the Intensive Study Area which encompassed an area within a 3 km radius of Ocean Reef Boat Harbour.

2.4 Assembling the habitat map

Assembling of the current habitat map was completed by using the 2003 DEC dataset and imagery as a 'base' map for the MMP and northern extension area, updating it with the 2013 Water Corporation dataset, ground truthing and satellite imagery and then adding an Intensive Study Area (3 km radius of Ocean Reef Boat Harbour) which was intensively ground truthed in 2014 to update the map again (Figure 2.1). The latest available 2009 LiDAR dataset was also applied to the entire map to improve attributions to refine relief characteristics.

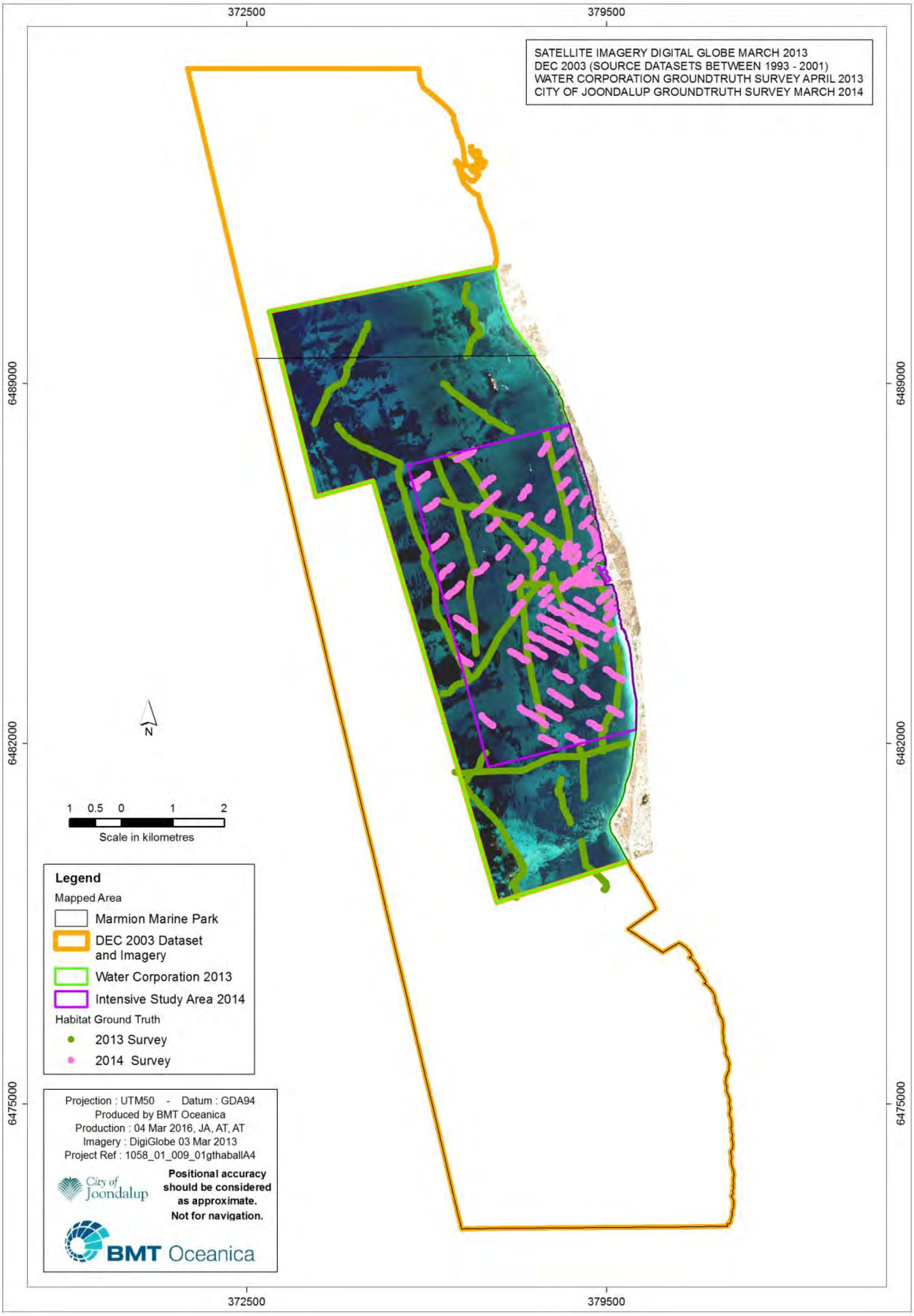

Figure 2.1 **Areas of habitat map designated based on the dataset, imagery source and timing of work completed.**

2.5 Towed video ground truthing and analysis

Ground truth data during the current study were collected using towed video camera surveys between 24 and 25 March 2014. Sixty-five towed video transects were undertaken in a 1953 ha area surrounding the Ocean Reef Boat Harbour within the Intensive Study Area (Appendix A). Transects covered a range of depths and habitat types and each video frame covered a ~2–3 m wide band of substrate. Garmin global positioning system (GPS) units with Ozi-Explorer mapping software were used to record the vessel position while towing. The vessel position was linked to the video footage using a timestamp. All times were set to Greenwich Mean Time (GMT).

Office based analysis of the towed video footage was undertaken using TransectMeasure software (SeaGIS 2013), using the categories shown in Table 2.1. At the start of each video a dominant and subdominant habitat category was assigned based on the habitat present. When a change in either the dominant or subdominant habitat category was detected, a new dominant and subdominant habitat category was assigned based on the habitat present. Dominance was defined as the habitat category which had the greatest percentage cover. Subdominance was defined as the habitat category which had the second greatest percentage cover (10-50%).

Table 2.1 TransectMeasure habitat classification categories

Category
Amphibolis
Halophila
Posidonia
Seagrass other
Algae
Low relief reef
High relief reef
Wrack
Sand
Unknown

Office based habitat classification was aligned with the benthic habitat categories by combining dominance and subdominance into the habitat classification (Table 2.2). Note that if a biota classification (macroalgae or seagrass) was subdominant to sand or reef it was classified as the biota if the biota was >10% cover.

Table 2.2 Video analysis substrate classification scheme and the subsequent benthic habitat category alignment over the 2014 Intensive Study Area

Dominant	Subdominant	2014 habitat classification
Amphibolis	*Amphibolis*	Seagrass
	Posidonia	Seagrass
	Halophila	Seagrass
	Algae	Seagrass
	Sand	Seagrass
	Low relief reef	Seagrass
	Wrack	Seagrass
Halophila	*Halophila*	Seagrass
	Posidonia	Seagrass
	Amphibolis	Seagrass
	Seagrass other	Seagrass
	Algae	Seagrass
	Sand	Seagrass

Dominant	Subdominant	2014 habitat classification
	Low relief reef	Seagrass
Posidonia	*Posidonia*	Seagrass
	Amphibolis	Seagrass
	Halophila	Seagrass
	Algae	Seagrass
	Sand	Seagrass
	Low relief reef	Seagrass
	Wrack	Seagrass
Seagrass other	*Halophila*	Seagrass
	Sand	Seagrass
Algae	Algae	Macroalgae
	Posidonia	Macroalgae
	Amphibolis	Macroalgae
	Halophila	Macroalgae
	Seagrass other	Macroalgae
	Sand	Macroalgae
Low relief reef	*Posidonia*	Seagrass[1]
	Halophila	Seagrass[1]
	Algae	Macroalgae[1]
	Sand	Sand[2]
	Wrack	Sand[2]
High relief reef	Algae	Macroalgae
Wrack	Wrack	Sand
	Sand	Sand
	Low relief reef	Sand[2]
Sand	Sand	Sand
	Posidonia	Seagrass[1]
	Amphibolis	Seagrass[1]
	Halophila	Seagrass[1]
	Seagrass other	Seagrass[1]
	Algae	Macroalgae[1]
	Low relief reef	Sand[2]
	Wrack	Sand
Unknown	Unknown	Not classified

Notes:

1. Designated as biota if biota cover was greater than 10%
2. Low relief reef not sub-dominated by biota was associated with sand due to rapid changes in sediment depths from longshore currents

During the office based analysis, reef with relief greater than ~1 m was designated as high relief reef. This designation was based on the practical ability of the office personnel to distinguish a significant change from a low 'flat' relief to 'high' relief which presented a significantly different habitat. Following classification of habitats, the time versus classification log was merged with the position versus time log to provide a single file with a classification for every position where valid video footage was obtained.

2.6 Habitat classifications and spatial analysis

To create an improved benthic habitat classification, the existing Water Corporation classification from 2013 was updated within the Intensive Study Area using towed video ground truthing data collected in 2014. The ground truthing was split into 70% to redefine areas in the 2013 classification shapefile, and 30% to validate the classification (Congalton 2001). Using the 70% ground truth data, polygons in the shapefile showing evident discrepancy between the classification and the ground truthing were modified to reflect actual benthic categories. Redefining of the polygons was performed through visual assessment using ArcGIS 10.2.

Subsequently, a number of bathymetric variables (depth, slope, aspect) were extracted from a 2009 LiDAR bathymetry dataset using ArcGIS 10.2 to correlate with the DPaW classification scheme's relief categories (Bancroft 2003, Appendix B). The variables were assessed to determine areas of high and low relief. In particular, the depth layer was used to create an object-based segmentation in ERDAS IMAGINE 14.0 to extract high and low relief areas within the macroalgae category. This process involved splitting the depth layer into segments or objects outlining features in the bathymetry based on shape, size, colour and textural attributes. Depth differences of greater than ~2 m between neighbouring segments were used as an indicator of high relief. The derived slope and aspect layers were used as secondary inputs to support and verify areas where the relief was difficult to define from the depth layer using visual assessment only. These approaches allowed for a successful extraction of relief features to combine with the existing benthic cover information. In addition, a threshold of -1.61 m AHD was used as the criteria to define subtidal and intertidal areas, which were also integrated into the benthic cover categories. The tidal and relief information was subsequently intersected with the benthic cover information of the 2014 habitat classification over the Intensive Study Area to reflect the DPaW classification scheme categories (Table 2.3). In addition, for macroalgae high and low relief reef in the subtidal zone these categories were further split into offshore or shoreline. Shoreline was designated to macroalgae subtidal zones if they occurred adjacent to intertidal areas (i.e. into shoreline reefs that occur along the mainland coast and around islands and emergent rocks - "shoreline") and designated as offshore for those that do not. This additional division of macroalgae subtidal zones was to provide a higher resolution of classification of the different reef complexes within Marmion Marine Park.

Table 2.3 Integration of 2014 habitat classifications with relief and tidal attributes over the Intensive Study Area to develop DPaW classification scheme categories

2014 habitat classification	Relief attribute	Tidal attribute	Final habitat class
Macroalgae	High Relief	Intertidal	Macroalgae (intertidal)
Macroalgae	Low Relief	Intertidal	Macroalgae (intertidal)
Macroalgae	High Relief	Sub-tidal	Macroalgae (subtidal) high relief offshore
Macroalgae	High Relief	Sub-tidal	Macroalgae (subtidal) high relief shoreline
Macroalgae	Low Relief	Sub-tidal	Macroalgae (subtidal) low relief offshore
Macroalgae	Low Relief	Sub-tidal	Macroalgae (subtidal) low relief shoreline
Sand	Lagoonal	Sub-tidal	Mobile sand lagoonal
Seagrass	Unclassified	Sub-tidal	Seagrass

In addition, the tidal and relief information was used to correct inconsistencies in the existing DPaW classification's tidal and relief information. The relief intersected habitat layer was then merged into the spatially larger and updated DPaW habitat layer to create a final habitat layer over the MMP extent consisting of the following categories (as defined in Appendix B):

- Seagrass

- Macroalgae (intertidal)
- Macroalgae (subtidal) low relief offshore
- Macroalgae (subtidal) low relief shoreline
- Macroalgae (subtidal) high relief offshore
- Macroalgae (subtidal) high relief shoreline
- Bare reef (intertidal) offshore
- Mobile sand lagoonal
- Mobile sand offshore.

2.7 Benthic primary producer habitat classification and loss calculations

Habitat classification units were designated into benthic primary producer habitat (BPPH) types for calculation of BPPH loss (Table 2.4). For the purposes of EAG3, BPPH are defined as seabed communities within which algae (e.g. macroalgae, turf and benthic microalgae), seagrass, mangroves, corals or mixtures of these groups are prominent components (EPA 2009). The BPPH types chosen here have combined the habitat units with similar broadscale functional ecological communities. The BPPH types chosen were based on functional designations of groups within the loss assessment unit to determine risk to ecological integrity from loss or serious damage caused by human activities on a practicable scale.

Table 2.4 Designation of habitat classification units into benthic primary producer habitat (BPPH) types for calculation of BPPH loss

Habitat classification units	BPPH type
Seagrass	Seagrass
Macroalgae (intertidal) Macroalgae (subtidal) low relief shoreline Macroalgae (subtidal) low relief offshore Macroalgae (subtidal) high relief shoreline Macroalgae (subtidal) high relief offshore	Macroalgae
Mobile sand lagoonal Mobile sand offshore Bare reef (intertidal) offshore	Mobile sand

The five macroalgae classification units have been combined into one macroalgae type for identification of BPPH calculations and estimations of loss, but it is noted that an ecologically distinctive habitat for Roe’s abalone is present at Burns Beach Reef. To investigate this distinctive nearshore macroalgae habitat at an appropriate scale, an additional study has been dedicated to the Burns Beach Reef Roe’s abalone habitat and abundance (BMT Oceanica 2016a). Similar abalone habitat is located south of Hillarys Boat Harbour and north of Mindarie Marina (outside of LAU).

2.8 Proposed development and designated disturbance footprint

The area of each BPPH type within the project footprint was calculated from the final habitat layer. Calculations have been completed of habitat within the project footprint to represent direct loss from construction. But to be conservative, the potential footprint related BPPH loss (direct and indirect) has been calculated on the entire area within the proposed marina development (i.e. the project footprint including the internal area that may not be directly disturbed by construction). An additional 70 m of ‘halo’ disturbance footprint was added to the exterior of the design footprint based on post construction halo monitoring completed at Hillarys Boat Harbour which is of similar size and depth (Oceanica 2008). The 70 m halo has been added as an estimate of indirect loss which may cause damage to habitat, or loss after construction, due to changes in wave or current action resulting in altered sedimentation around infrastructure and is calculated as part of potential footprint related BPPH loss (direct and indirect).

2.9 Benthic primary producer types

Summaries of the benthic communities within the BPPH types are listed below, these are not exhaustive lists of all species present within each unit, but represent the dominate components. The three BPPH types chosen for the interpretation of EAG3 were:

1. Seagrass
2. Macroalgae
3. Mobile Sand.

2.9.1 Seagrass

The seagrass habitat classification includes both perennial and ephemeral species found during the ground truthing surveys for loss assessment determinations. This conservative approach designated any area with seagrass cover >10% as 'seagrass'.

Perennial

Seagrass species are found on both sandy and limestone pavement habitats (CALM 1992). Many species of perennial seagrass are present throughout the MMP (including *Syringodium* sp) but, seagrass within the intensive study area were predominantly *Posidonia* spp. and *Amphibolis antarctica.*

Ephemeral

In general, ephemeral seagrass communities were relatively sparse and often directly associated with perennial species forming mixed communities. *Halophila ovalis* was the most common ephemeral species found during the ground truthing survey.

2.9.2 Macroalgae

Macroalgae habitat from intertidal, subtidal low relief and subtidal high relief were all designated as 'macroalgae' for loss assessment determinations. It is noted however, that macroalgae communities can differ significantly over these areas and the unique macroalgae habitats and communities associated with the nearshore reefs are recognised in a separate study (BMT Oceanica 2016a).

Major macroalgae taxa of the Marmion Lagoon have been recorded as *Ecklonia radiata*, *Lobophora variegate*, *Sargassum* spp., *Amphiroa anceps*, *Chauviniella corifolia*, *Dictymenia sonderi*, *Heterodoxia denticulata*, *Jeannerattia pedicellata*, *Pterocladia lucida* and *Rhodymenia sonderi* (Kendrick et al 1999). Dominant macroalgae species vary with water depth and substrate. Subtidal pavements are dominated by *E. radiata*, *Sargassum* spp. and *Caulerpa* spp. with a sub-canopy of encrusting red algae (CALM 1992). Nearshore and interidal reefs are dominated by red algae (*D. sonderi*, *Hypnea episcopalis*, and *Vidalia spiralis*) and brown algae (*E. radiata*, *Lobospira bicuspidata*) and may have a sub-canopy of encrusting red algae.

Nearshore reef (abalone habitat)

It is noted that within the MMP and the area adjacent to the proposed development, there are nearshore reefs with unique macroalgae benthic habitats that support *Haliotis roei* (Roe's abalone). The extent of *H. roei* habitat has been investigated in a field survey conducted in 2015 (BMT Oceanica 2016a). In summary, these reefs can be divided into four separate zones; the subtidal habitat, outer platform, middle platform, and inner platform. These zones, used to subdivide the cross-shore distribution of Roe's abalone, are common habitat delineations in the literature describing invertebrate distributions on the Perth limestone reef platforms (Hancock 2004, Wells et al 2007). Macrophytes, such as *C. cactoides, E. radiata, Sargassum* spp., and *H. episcopalis* dominate subtidal habitats, with a sub-canopy of encrusting red algae (CALM 1992, Hancock 2004). Crustose coralline algae and bare rock dominate the seaward edge of the reef platform (Hancock 2004). These crustose coralline algae are known to be important for the settlement and metamorphosis of *H. roei* (BMT Oceanica 2016b). The middle platform forms a transition zone of mixed *Sargassum* spp. and *E. radiata,* with both crustose and corraline filamentous algae present (Hancock 2004). Nearest the shore, the inner platform can be dominated by large red macroalgae (*D. sonderi*, *H. episcopalis*, and *V. spiralis*) and brown algae *(E. radiata, Sargassum spp, Lobospira bicuspidata*) (CALM 1992).

2.9.3 Mobile sand

Mobile sand lagoonal, mobile sand offshore and bare reef (intertidal) offshore were designated as 'mobile sand' for loss assessment determinations. The bare reef (intertidal) offshore habitat may not correlate well with the mobile sand classification and these areas are not able to support seagrass or macroalgae species but as bare reef (intertidal) offshore habitat made up only <0.07% of habitat it was placed in 'mobile sand'. Mobile sand is considered as 'potential' BPPH as ephemeral seagrass communities and perennial seagrass communities are known to have measureable spatial variability in their meadows over several years to decades. The predominant substratum in this currently unvegetated habitat consists of calcareous sand plains, interspersed with areas of bare sand and limestone pavement (CALM 1992). These areas may be potential seagrass habitat for areas in 2-47 m depth for both perennial and ephemeral species (Kirkmann 1997).

Filter feeder communities

Filter feeders on reefs and in seagrass beds likely play a key role in detrital food webs and nitrogen cycling in nearshore ecosystems in Western Australia due to the high rates of filtration (Keesing 2011). Although it is recognised that these communities are an important component of the benthic communities, and within sand dominated areas, it was not practicable to separate out these communities for the determination of habitat loss as only minor components of these communities are present within the area adjacent to the development.

3. Results

3.1 Accuracy assessment

Accuracy assessments were performed over the Intensive Study Area using the 30% ground truthing validation dataset in ERDAS IMAGINE 14.0. Two assessments within the Intensive Study Area were completed:

1. Overall accuracy of DPaW classifications versus 2014 validation ground truthing
2. Overall accuracy of 2014 map versus 2014 validation ground truthing.

The validation data was used to perform an accuracy assessment over the DPaW classification (DEC 2003) covering the Intensive Study Area, achieving an overall classification accuracy of 58.1% with a Kappa value of 0.434 (Table 3.1). An overall classification accuracy of 72.9% with a Kappa value of 0.635 was achieved for the 2014 revised habitat map (current study) over the same area reflecting a significant improvement (Table 3.2). Areas in the MMP outside of the Intensive Study Area were not validated, as no ground truthing was available over the surrounding area to enable a validation.

The tables reflect those categories existing within the Intensive Study Area. It should be noted that because of potential spatial discrepancies in the validation data, some areas that may have been classified correctly may have been labelled as incorrect due to the spatial shift between the validation data and the classified image. Therefore, it can be expected that the overall classification accuracy may be slightly higher than reported.

Table 3.1 DPaW habitat classification accuracy assessment results

Classified data	Reference data						
	Macroalgae			Seagrass	Sand	Total	Users accuracy[2] (%)
	(intertidal)	(subtidal) low relief	(subtidal) high relief				
Macroalgae (intertidal)	0	0	0	0	2	2	NA
Macroalgae (subtidal) low relief	0	636	230	47	57	970	65.57
Macroalgae (subtidal) high relief	0	19	301	25	52	397	75.82
Seagrass	0	265	8	757	175	1205	62.82
Mobile sand lagoonal	0	395	125	222	555	1297	42.79
Total	0	1315	664	1051	841	3871	-
Producers accuracy[1] (%)	-	48.37	45.33	72.03	65.99	-	Overall: 58.10
Overall Kappa Statistics							0.4337

Notes:

1. Producer's accuracy indicates the probability of a reference pixel being correctly classified, i.e. it lets the "producer" of the classification know how well a certain area can be classified (error of omission). It is calculated by dividing the total number of correct pixels in a class by the total number of pixels of that class as derived from the reference data.
2. User's accuracy, or reliability, indicates the probability that a pixel classified in the image actually represents that class on the ground (error of commission). It is calculated by dividing the total number of correct pixels in a class by the total number of pixels that were classified in that class (Congalton 2001).

Table 3.2 2014 revised habitat classification accuracy assessment results

Classified data	Reference data						
	Macroalgae			Seagrass	Sand	Total	Users accuracy[2] (%)
	(intertidal)	(subtidal) low relief	(subtidal) high relief				
Macroalgae (intertidal)	0	0	4	0	0	4	NA
Macroalgae (subtidal) low relief	0	855	5	45	60	965	88.60
Macroalgae (subtidal) high relief	0	0	553	16	10	579	95.51
Seagrass	0	241	0	803	160	1204	66.69
Mobile sand lagoonal	0	219	102	187	611	1119	54.60
Total	0	1315	664	1051	841	3871	-
Producer's accuracy[1] (%)	-	65.02	83.28	76.40	72.65	-	Overall: 72.90
Overall Kappa Statistics							0.63503

Notes:

1. Producer's accuracy indicates the probability of a reference pixel being correctly classified, i.e. it lets the "producer" of the classification know how well a certain area can be classified (error of omission). It is calculated by dividing the total number of correct pixels in a class by the total number of pixels of that class as derived from the reference data.
2. User's accuracy, or reliability, indicates the probability that a pixel classified in the image actually represents that class on the ground (error of commission). It is calculated by dividing the total number of correct pixels in a class by the total number of pixels that were classified in that class (Congalton 2001).

3.2 Spatial extent of benthic habitat units in the Marmion Marine Park

A total of 9492 ha of benthic habitat was identified within the MMP (Table 3.3) in the current study. The majority of the benthic habitat in the MMP was 'Mobile sand lagoonal'. 'Macroalgae (subtidal) low relief' was the next most common, followed by 'Macroalgae (subtidal) high relief' and 'Seagrass'. The remaining ~3% of benthic habitat in the MMP was comprised of, 'Mobile sand offshore', 'Macroalgae (intertidal)', and 'Bare reef (intertidal) offshore'.

Table 3.3 Area of benthic habitat units within the Marmion Marine Park in 2014

Benthic habitat type	Hectares (ha)	Percentage of habitat
Mobile sand lagoonal	4474	47.1
Macroalgae (subtidal) low relief offshore	2286	24.1
Macroalgae (subtidal) low relief shoreline	14.5	0.15
Macroalgae (subtidal) high relief offshore	1146	12.1
Macroalgae (subtidal) high relief shoreline	126	1.32
Seagrass perennial	1159	12.2
Mobile sand offshore	239	2.52
Macroalgae (intertidal)	40.7	0.43
Bare reef (intertidal) offshore	6.52	0.07
Total	**9492**	**100**

Note:

1. * Percentage does not add up to 100 due to rounding of hectare values

3.2.1 BPPH classification type

The area of BPPH was dominated by mobile sand (50%) and macroalgae (38%) while seagrass made up a significant portion (12%) (Table 3.4).

Table 3.4 Area of benthic primary producer habitat type within the Marmion Marine Park in 2014

Benthic habitat type	Area (ha)	Percentage of habitat
Seagrass	1159	12
Macroalgae	3613	38
Mobile sand[1]	4721	50
Total	**9492**	**100**

Note:

1. Includes bare reef (intertidal) offshore

3.3 Benthic habitat map for Marmion Marine Park and LAU

The resulting georeferenced benthic habitat map for the MMP, and thus the LAU, is presented in Figure 3.1. The majority of the offshore habitat was dominated by 'Macroalgae (subtidal) low relief' and 'Macroalgae (subtidal) high relief' reefs, whereas the intermediate and inshore habitat was dominated by 'Mobile sand lagoonal' and 'Seagrass'. The distribution of 'Seagrass' was concentrated between an area just south of the Ocean Reef ocean outlet diffuser to an area just south of the Hillarys Boat Harbour. Nearshore reef habitat supporting *H. Roei* abalone populations is located immediately north of the existing Ocean Reef Boat Harbour, and south of Hillarys Boat Harbour, and was comprised of macroalgae ('Macroalgae (intertidal)', 'Macroalgae (subtidal) high relief', 'Macroalgae (subtidal) low relief'). 'Mobile sand offshore' was restricted to the western seaward edge of the MMP.

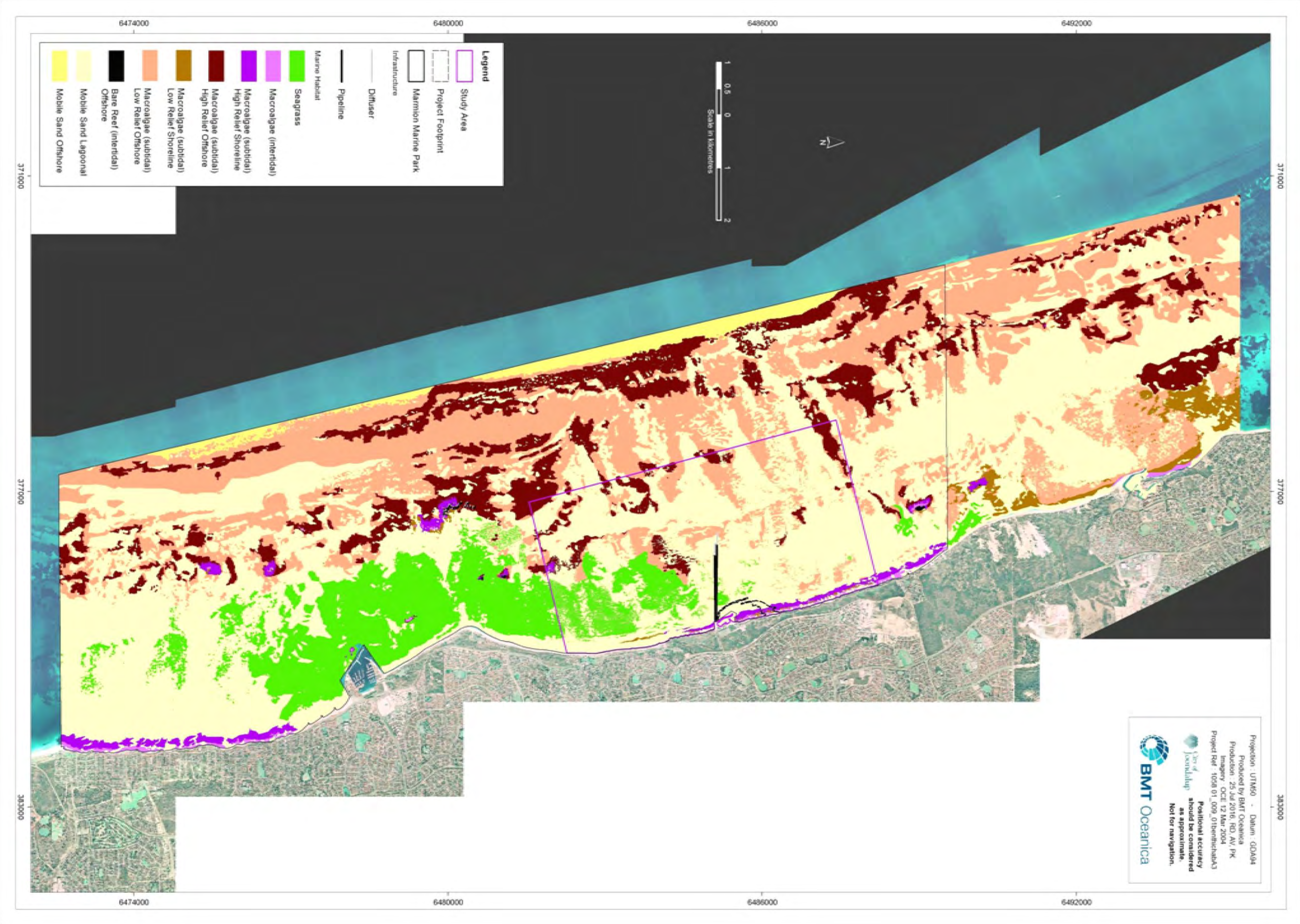

Figure 3.1 Benthic habitat distribution within the Marmion Marine Park and extended northern area

3.4 Benthic habitat loss

The area of benthic habitat in the project footprint and the potential footprint related BPPH loss (direct and indirect) (including a 70 m halo) was 8.63 ha and 47.58 ha, respectively (Table 3.5 and Table 3.6). 'Mobile sand lagoonal' was the most common habitat unit, comprising ~72% of both the project footprint and potential footprint related BPPH loss (direct and indirect). Macroalgae ('Macroalgae (intertidal)', 'Macroalgae (subtidal) low relief shoreline', 'Macroalgae (subtidal) high relief shoreline') was the next most common benthic habitat unit in both the project footprint and potential footprint related BPPH loss (direct and indirect). 'Seagrass' comprised ~0.01% of the benthic habitat in the potential footprint related BPPH loss (direct and indirect), but it was not present in the direct project footprint.

Table 3.5 Benthic habitat units within the project footprint and the potential footprint related habitat loss (direct and indirect)

Benthic habitat unit	Project footprint (ha)	Potential footprint related BPPH loss (direct and indirect) (ha)
Seagrass	0	0.62
Macroalgae (intertidal)	0.46	2.92
Macroalgae (subtidal) low relief shoreline	0.52	1.48
Macroalgae (subtidal) high relief shoreline	1.73	8.16
Mobile sand lagoonal	5.92	34.40
Total	**8.63**	**47.58**

Note:

1. BPPH = benthic primary producer habitat

Table 3.6 Benthic primary producer habitat (BPPH) types within project footprint and the potential footprint related BPPH loss (direct and indirect)

Benthic primary producer habitat type	Project footprint (ha)	Potential footprint related BPPH loss (direct and indirect) (ha)
Seagrass	0	0.62
Macroalgae	2.71	12.56
Mobile sand	5.92	34.40
Total	**8.63**	**47.58**

3.4.1 Potential loss of BPPH from development

According to the Environmental Assessment Guideline EAG 3 (EPA 2009), the MMP would be considered a 'High Protection Area' (i.e. Category B), whereby the cumulative loss guideline for BPPH within the LAU is 1%. Direct loss of benthic habitat from construction within the project footprint is presented in Table 3.7; additionally a more conservative measurement of loss from potential footprint related BPPH loss (direct and indirect) (assuming complete loss within the footprint, marina development and including a 70 m halo) is also presented. The loss of benthic habitat within the project footprint and potential footprint related BPPH loss (direct and indirect) is estimated to be <1% for any of the BPPH types.

Table 3.7 Percent loss of benthic primary producer habitat (BPPH) from the project footprint and potential footprint related BPPH loss (direct and indirect)

Benthic habitat type	Current habitat area (ha)	Loss from project footprint (ha)	Loss from project footprint (%)	Loss from potential footprint related BPPH loss (direct and indirect) (ha)	Loss from potential footprint related BPPH loss (direct and indirect) (%)
Seagrass	1159	0	0	0.62	0.05
Macroalgae	3613	2.71	0.07	13.13	0.36
Mobile sand	4721	5.92	0.13	33.83	0.72

3.4.2 Cumulative loss

The existing BPPH is considered to be a realistic estimate of the spatial extent of each BPPH that existed in the LAU prior to European habitation, with the exception of the loss from the development of the existing Ocean Reef Boat Harbour, Hillarys Boat Harbour and the two Ocean Reef ocean outfall disturbance footprints. The existing Ocean Reef Boat Harbour disturbance footprint is accounted for in the potential footprint related BPPH loss (direct and indirect) estimates (Table 3.7), but Hillarys Boat Harbour, which was built in 1986, has a total footprint of approximately 35 ha and has contributed to the cumulative loss for the chosen LAU. The installation of the Ocean Reef ocean outfall pipelines in 1978 (Outlet A) and 1992 (Outlet B) has also contributed to some historical loss of BPPH in the LAU. Actual hectares loss of BPPH from the Hillarys Boat Harbour development are not accurately known, but estimates of expected total area to be disturbed were 38 ha, with 13 ha being subtidal sand assembly and 25 ha seagrass meadow assembly (Scott and Furphy 1984). Surveys were not completed to ground truth the existing habitats prior to the development so the actual habitat areas cannot be verified. No post-development surveys occurred either, so it is not known how much of the seagrass habitat was permanently lost, but it was noted in the five year (1986-1991) post-development monitoring program that divers recorded that “the harbour bottom continued to flourish and that the harbour floor had experienced colonisation by a variety of marine flora and fauna” (DMH 1991). The actual loss numbers for the ocean outfall pipeline installations is also not known and is further complicated by recovery of these habitats and the creation of new habitat for macroalgae assemblages. However, estimates for seagrass can be qualitatively drawn from the position of existing seagrass habitat relative to the existing pipelines and inferring some loss due to the pipelines being in place (Table 3.8).

Table 3.8 Cumulative loss of benthic primary producer habitat (BPPH) from the potential footprint related BPPH loss (direct and indirect) and estimates from Hillarys Boat Harbour and ocean outfalls

Benthic habitat type	Current habitat area (ha)	Estimated loss from Hillarys Boat Harbour (ha)	Estimated loss from ocean outfalls (ha)	Historical loss (%)	Predicted loss from Proposal (ha)	Predicted loss from Proposal (%)	Estimated cumulative loss in LAU (%)
Seagrass	1159	25	0.1	2.16	0.62	0.05	2.21
Macroalgae	3613	0	0	0	13.13	0.36	0.36
Mobile sand	4721	13	0.3	0.28	33.83	0.72	1.00

Estimated cumulative loss for the seagrass and mobile sand BPPHs do exceed the designated 1% threshold for the LAU. Section 8.3 of the ten year audit of the MMP Management Plan (MPRA 2012) recommends that "a study should be undertaken with a view to extending the MMP to the north, perhaps as far as Two Rocks". If this is the case and the MMP boundaries are extended, the loss percentages presented in Table 3.8 will likely be reduced due to the increased area of habitat within the MMP.

4. Discussion

The boundary of the MMP, with the inclusion of the existing Ocean Reef and Hillary Boat Harbours, was used to designate the LAU and an updated georeferenced benthic habitat map was created that characterised the spatial extent of benthic habitats in the MMP and the area above the northern boundary to the extent of available DPaW data (DEC 2003). The benthic habitat map was verified from the existing 2013 Water Corporation map using a combination of ground truthed data, LiDAR bathymetry data and updating the DPaW 2006 benthic habitat map to such a standard that the results can be used as a baseline for future monitoring. The MMP habitat map was assessed for its accuracy within the predicted zone of influence (Intensive Study Area) and updated.

4.1 Assessment of MMP habitat map accuracy

An accuracy assessment of the DPaW 2006 benthic habitat classification (DEC 2003) was completed which showed 58.1% accuracy contrary to an accuracy of 72.9% for the 2014 habitat classification map over the same area. As the DPaW map was created on a 'broadscale', while the Intensive Study Area (3 km radius of Ocean Reef Boat Harbour) was intensively surveyed, the overall accuracy of 58.1% is considered a moderate result compared to the improved accuracy of the 2014 habitat classification over the same area. In addition, the Kappa statistic of 0.43 represents moderate agreement between the classification and the validation datasets (Congalton 2001). The benthic habitat classification in the Intensive Study Area represents a more accurate and up to date benthic habitat classification than the area in the MMP outside of the Intensive Study Area. Following the correction of relief and tidal areas in the DPaW mapped area outside the Intensive Study Area, the DPaW habitat map represents a baseline for assessment of reference areas and the area of potential influence. Any remaining inconsistencies in the DPaW map outside the Intensive Study Area should not represent any changes in the value or significance for these habitats. The assessment of the accuracy of the DPaW map (DEC 2003) was undertaken as a more detailed assessment of habitats within the predicted zone of influence was required to accurately assess any loss of habitat during the construction and post construction of the proposed development.

4.2 Benthic habitat types within and adjacent to the project footprint

The benthic habitat designations within the project footprint, and directly adjacent to the development area, are presented in Figure 4.1. Areas of benthic habitat adjacent to the development have been identified as areas A-F and these areas have been described in additional detail below.

Area A

This benthic habitat area is ~ 500 m northwest of the existing marina in 8–10 m water depth. It has been designated as seagrass as it contains perennial seagrass cover estimated to be 10–15%. Much of the area is low relief limestone reef with a sand veneer cover in places. Mixed assemblages of seagrass and macroalgae are on this reef area, with *Halophila* sp in sand areas in between. Limited patches of *Posidonia sinuosa* and *P. coriacea* exist in sandy areas.

Area B

This benthic habitat area is ~300 m west of the existing marina in 8–10 m water depth. It has been conservatively designated as seagrass although it only contains perennial seagrass cover estimated to be in the order of 5–10%. Much of the area is low relief reef with patches of *Halophila* sp and *P. coriacea* in the sand areas. Near the pipeline some of the area contains *Amphibolus* sp. meadows and *Halophila* sp is interspersed with macroalgae around the pipeline.

Area C

This benthic habitat area is ~650 m southwest of the existing marina in 8–10 m water depth. Sparse meadows of perennial seagrass have significant cover in patches visually estimated to be in the order of 30%. Additionally, sections also contain sparse *P. coriacea* meadows with bare sand patches.

Area D

This benthic habitat area is ~1000 m west of the existing marina in 10–12 m water depth. The north and northwest sections of this area contains a low relief reef system with accumulations of wrack and macroalgae assemblages with intermittent sponges. Large seagrass meadow areas have seagrass species including *Amphibolus* sp, *Halophila* sp and some *P. sinuosa* and *P. coriacea*. Cover of perennial seagrass species visually estimated to be 10%.

Area E

The nearest high relief reef with macroalgae cover is located ~1200 m southwest of the existing marina in 6-10 m water depth. This area is potential juvenile and adult Western Rock Lobster habitat with ledges and caves throughout the area. The macroalgae benthic habitat community is typical of inshore reefs in the MMP and is generally described in Section 2.9.2.

Area F

The nearshore reef located ~200 m north of the existing harbour is identified as *H. roei* abalone habitat. This is Burns Beach Reef and it is located in 1–6 m of water depth and can be as close as 50 m to shore. The reef continues north of the existing harbour ~ 3000 m. The benthic habitat community is described in Section 2.9.2.

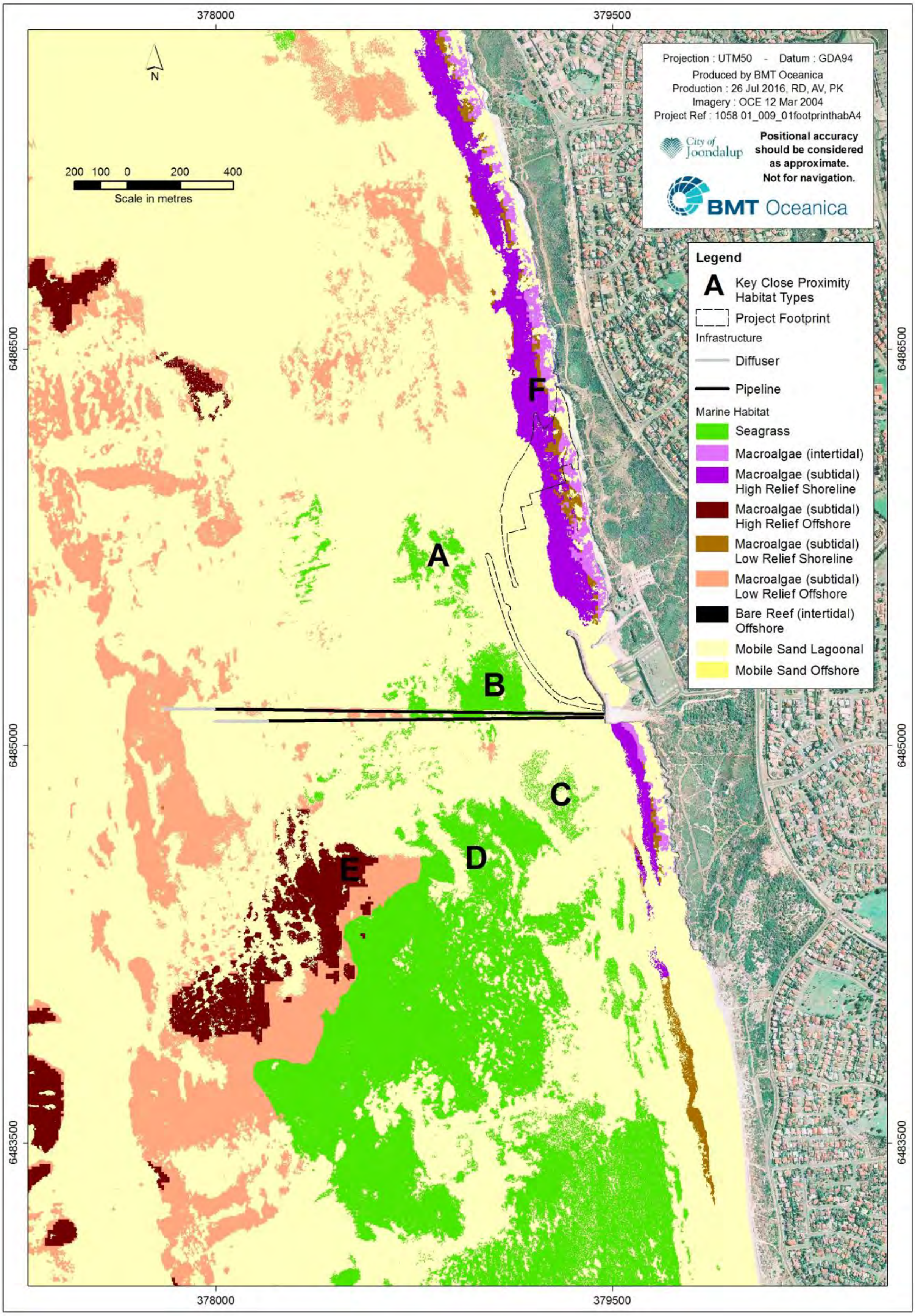

Figure 4.1 **Benthic habitat distribution within and adjacent to the proposed project footprint. Letters correspond to areas with habitat community descriptions.**

4.3 Potential BPPH loss

The development of the proposed Ocean Reef Marina will result in a direct loss of benthic habitat within the project footprint of no seagrass and 0.07% macroalgae loss from the LAU. Conservatively, the potential footprint related BPPH loss (direct and indirect), assuming total loss of benthic habitat within the project footprint and including a 70 m halo, would be ~ 0.05% of the LAU seagrass, 0.36% of the LAU macroalgae and 1.0 % of the LAU mobile sand. A conservative estimate of cumulative loss of seagrass and macroalgae within the LAU would be 2.2 and 0.36% respectively. The conservative and unverified historical seagrass loss estimate from the Hillarys Boat Harbour accounts for 98% of the cumulative loss (of 2.2% total) in the LAU, with seagrass loss for the proposed Development only contributing 0.62 ha or 2% of the estimated cumulative loss. Although the macroalgae BPPH unit is well below the 1% loss threshold it has been identified that the nearshore macroalgae habitat at Burns Beach Reef is ecologically significant for *H. roei* abalone and thus, an additional study has been dedicated to the Burns Beach Reef Roe's abalone habitat and abundance (BMT Oceanica 2016a).

5. Summary

The footprint of the proposed Ocean Reef Marina will result in a loss from the LAU of 0.36% (13.13 ha) macroalgae, and there is a potential to lose 0.05% (0.62 ha) of the LAU’s seagrass and 1% of the LAU's mobile sand habitats due to indirect BPPH loss from a 70 m halo effect from the introduced marina infrastructure. These estimates do not include any potential indirect loss from effects of construction or operation of the proposed marina development. The macroalgae habitat loss is significant as this nearshore reef area supports a *H. roei* abalone population that is a popular recreational and commercial fishery. The adjacent seagrass areas may be important habitat, but they are relative sparse seagrass meadows intermixed with low relief reef areas covered with typical macroalgae communities.

6. References

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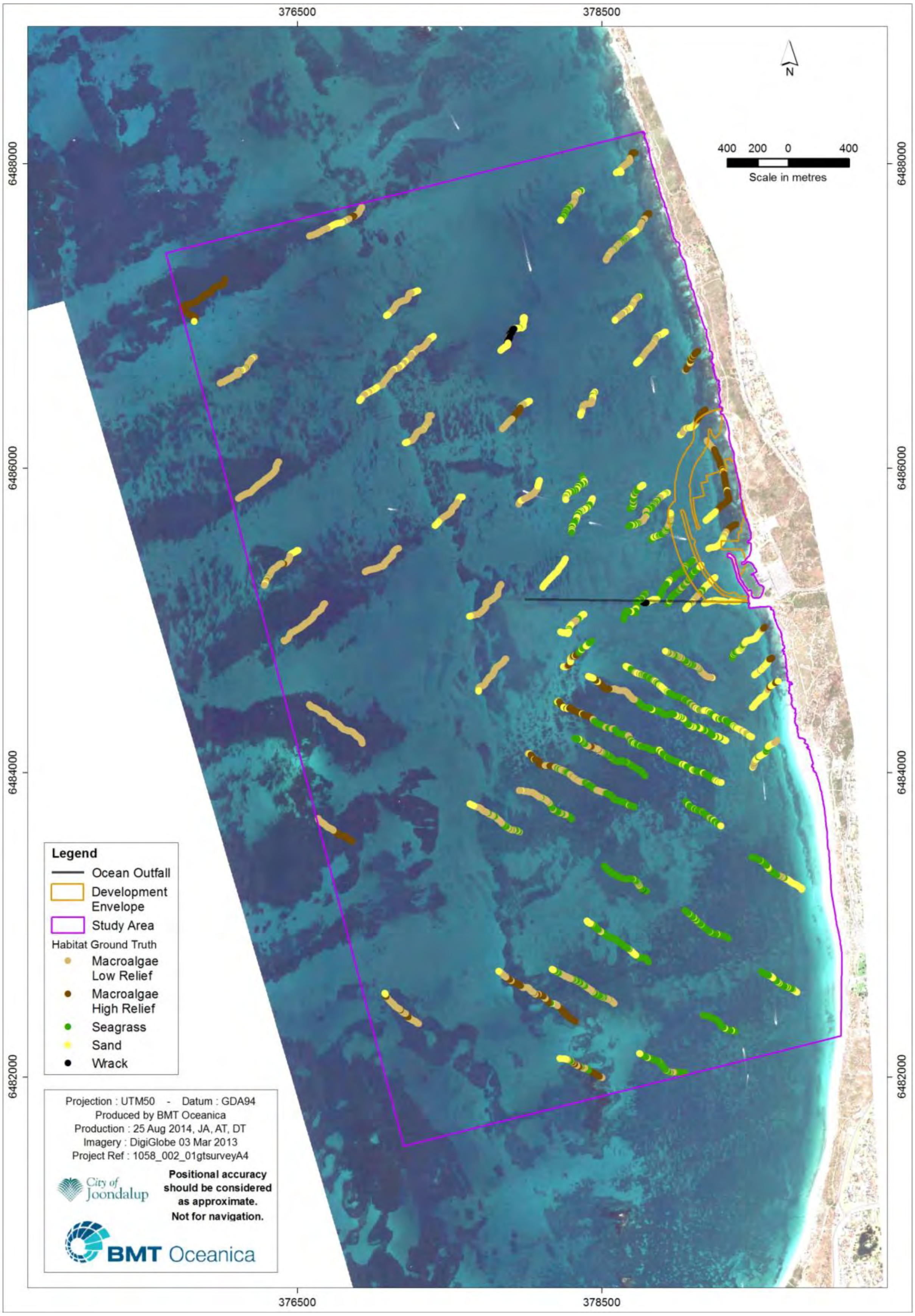
Appendix A

Towed video transects



Towed video transects used for ground-truthing

Appendix B

Standardised classification scheme

Bancroft, K.P. (2003). A standardised classification scheme for the mapping of shallow-water marine habitats of Western Australia. Report MCB-05/2003. June 2003. Marine Conservation Branch, Department of Conservation and Land Management. Fremantle, WA, Australia.

Tidal range	Community	Description
Intertidal	BARE REEF (intertidal)	The *bare reef (intertidal)* habitat is located in the intertidal zone (between the LAT and HAT) and may be offshore or contiguous to the coast. This habitat includes low cliffs (<5 m high), high cliffs (>5 m high), boulders (>25.6 cm particle size), or pavement of igneous (granite/basalt), metamorphic (gneiss/schists), or sedimentary (limestone/sandstone) substratum. The *bare reef (intertidal)* is typically unvegetated but may have algal turfs present. This habitat may contain a variety of mollusc species including oysters (eg. *Saccostrea* spp.), abalone (eg. *Haliotis* spp.) nerites (eg. *Nerita* spp. *Nodolittorina* spp., *Littoraria* spp.), chitons (eg. *Ischnochiton* spp.) and barnacles (eg. *Tetraclita porosa*). Rock crabs (*F. Grapsidae*) also inhabit this habitat.
	CORAL REEF (intertidal)	The *coral reef (intertidal)* habitat is located in the intertidal or shallow regions (<1 m LAT) on a limestone substrate. This habitat includes the reef crest, shallow reef fronts, reef flats and shallow back reef zones (see Veron, 2000). Live coral cover varies greatly and some areas have a high proportion of coral rubble. Macroalgae, sand, reef rubble or pavement also may be present. Hard corals (eg. *Acropora* spp.) and soft corals (eg. *Sinularia* spp.) are typical of the fauna present in these habitats. Parts of this habitat typically support a high diversity and abundance of fish and invertebrate fauna.
	MACROALGAE (intertidal)	The *macroalgae (intertidal)* habitat is typically located in the lower intertidal or shallow subtidal zones (<1 m below LAT). This habitat occurs on low relief reef platforms, boulder (>64 mm) or high relief reef of limestone, igneous or metamorphic substratum. *Macroalgae (intertidal)* habitat typically supports turf algae (eg. *Laurencia* sp., *Ulva* sp., *Halimeda* sp., *Enteromorpha* sp., *Padina* sp.) or fleshy macroalgae (eg. *Ecklonia* sp., *Cystophora* spp. or *Sargassum* spp.) and invertebrates such as gastropods (eg. *Tridacna* spp. clams), seastars (eg. *Patiriella* spp.), sea urchins (eg. *Heliocidaris* sp., *Nudechinus* sp.), and isolated soft and hard coral communities.
	SANDY BEACH	The *sandy beach* habitat is located in the upper intertidal zone and typically consists of unconsolidated carbonate or siliceous sands (62.5 µm to 2 mm). *Sandy beach* habitats are dynamic exposed environments, which are typically exposed to strong water action such as tides and waves. The *sandy beach* habitat is mostly unvegetated however flora such as spinifex (*Spinifex longifolius*) may be present above HAT. Infauna such as bivalves (eg. *Katelysia* spp., *Tellina* spp.) may also be present. In the tropics, ghost crabs (*Ocypode* spp.) and mole crabs (*Hippida* spp.) are conspicuous in this habitat particularly at night.
	SANDSHOAL	The *sandshoal* habitat is located in the lower intertidal zone, generally seaward of the shoreline habitats and are typically found in macrotidal (>2 m tidal range) areas where strong currents and wave action create offshore banks and shoals. These banks and shoals can also be connected to islands or the mainland. The *sandshoal* habitat consists of mobile fine (62.5 µm to 500 µm) or coarse (500 µm to 2 mm) carbonate sand, and typically is unvegetated and supports a low diversity of infauna.
	GRAVEL/RUBBLE (intertidal)	The *gravel/rubble (intertidal)* habitat is located in the lower intertidal zone and is typically found in high water motion areas such as areas where strong currents or wave action occur. The *gravel/rubble (intertidal)* habitat typically is bare with some macrophyte attached and a low diversity of infauna. The substratum of this habitat may comprise of pebble (particle size of 2 mm to 64 mm), cobble (particle size of 7.5 cm to 25 cm), or rubble (which is generally comprised of coral fragments) or shell which is technically a pebble however has been differentiated to highlight the material source.
	MUDFLAT	The *mudflat* habitat is located in the lower intertidal zone and generally consists of terrigenous mud, silt or clay (<62.5 µm) sediments. Anaerobic conditions often exist under the surface and typically have a high organic

		content. *Mudflats* are typically broad and occur in areas of low energy and high deposition such as the areas seaward of *mangals*. *Mudflat* habitats are typically bare of vegetation, but supports a high diversity of gastropods (eg. *Cerinthium* sp.), crabs (eg. *Uca* sp., *Macrophthalmus* sp.) and invertebrate infauna.
	SALTMARSH	The *saltmarsh* habitat describes areas of low relief located in the upper intertidal zone of low energy coastlines. The substratum consists of muddy or silty terrigenous sediment. *Saltmarsh* habitats often occur landward of mangals, tidal creeks and estuaries, and typically supports vegetation such as the saltwater couch (*Sporobolus virginicus*) and blue-green algal mats (eg. *Microcoleus chthonoplastes*, *Oscillotoria* sp., *Phoridium* sp.), but can also occur as unvegetated coastal saline flats. In the tropics, burrowing crabs (*Uca* sp.), soldier crabs (*Mictyris* sp.) and *Cerinthium* spp. gastropods are conspicuous fauna in this habitat. In temperate areas, the glassswort *Sarcocornia quinqueflora* and *Sporobolus virginicus* are conspicuous flora in this habitat.
	MANGAL	The *mangal* habitat describes areas of mangrove forest greater than 0.05 ha and typically is located in the upper intertidal zone. The substratum of this habitat is typically comprised of mud and silt; however some mangrove species do occur on intertidal rocky shores. In Western Australia, the most common mangrove species are *Rhizophora stylosa* and *Avicennia marina*, the latter occurring as far south as Bunbury. Mangrove roots provide a substratum for many gastropods (eg. *Natica* sp., *Cerithium* sp., *Strombus* spp.) and other invertebrates, such as the mangrove crab (*Scylla serrata* and *Scylla olivacea*) and fiddler crab (*Uca* sp.)are often present. *Mangals* are an important habitat for birds such as the mangrove whistler (*Pachycephala melanura*) and brahminy kite (*Haliastur indus*).
Subtidal	BARE REEF (subtidal)	*Bare reef (subtidal)* is located in subtidal areas with either sedimentary (eg. limestone, sandstone), igneous (eg. granite, granophyre) or metamorphic (eg. schist, gneiss) substratum, either as pavement or boulder (>25 cm) fields. This habitat typically includes areas covered by mobile sand veneers, and is located in deep water offshore or in subtidal lagoonal areas. *Bare reef (subtidal)* habitats are typically bare but may have vegetation (eg. *Thalassodendron* spp., *Padina* spp.), or have sparse cover sessile invertebrates such as sponges (eg. *Cymbastella* spp., *Carteriospongia* spp.), octocorals, soft corals and ascidians.
	CORAL REEF (subtidal)	The *coral reef (subtidal)* habitat is located in the subtidal zone and often has high live coral cover with macroalgal turf and coralline algae covering areas of reef not occupied by living corals. Sand patches, bare pavement and rubble may also be present. This habitat is used to describe the upper seaward reef slope, sheltered back reef, deep lagoonal reef (Veron, 2000) and bommie clusters. Typically, areas of high coral cover are generally restricted to water depths of less than 15 m depth. Offshore, the *coral reef (subtidal)* habitats are dominated by the faster growing coral species such as *Acropora* (eg. *A. hyacinthus*) and *Pocillopora* (eg. *P. verrucosa*). This habitat typically supports a high diversity and abundance of fish and other coral reef fauna such as crabs (Families Xanthidae and Portunidae) and snapping shrimp (*Alpheus* spp.).
	FILTER FEEDERS (subtidal)	The *filter feeders (subtidal)* habitat is located in the subtidal zone and often has a high diversity of sessile invertebrates such as sponges, ascidians, gorgonians and seawhips (octocorals), bryozoans, sea pens, soft corals and hard corals. Macroalgal turf and coralline algae may be present in areas of reef not occupied by the filter feeder community. Sand patches and bare reef pavement may also be present. The *filter feeders (subtidal)* habitat typically occurs in areas, which experience high water motion where the habitat is exposed to large volumes of water. This habitat typically supports a high diversity and abundance of fish, molluscs and other mobile invertebrates such as sea cucumbers and feather stars.
	MACROALGAE (subtidal)	The *macroalgae (subtidal)* habitat is subtidal areas with sedimentary, igneous or metamorphic substratum of low or high relief. This habitat is found in deep and shallow-waters and also may incorporate mobile sand patches, and scattered isolated hard and soft corals. This habitat

		generally is covered in large fleshy macroalgae (eg. *Sargassum* spp., *Cystophora* spp., *Ecklonia* spp.) or macroalgal turf (thallus height <100mm) comprised of red (eg. *Laurencia* spp.*)*, green (eg. *Enteromorpha* spp., *Ulva* spp. *Caulerpa* spp.) and brown (eg. *Padina* spp., *Turbinaria* spp.) algae. A wide range of invertebrate life such as sponges, ascidians, gastropods, seastars, brittle stars, sea urchins and soft corals, are associated with this habitat. Crustaceans such as the western rock lobster (*Panulirus cygnus*), painted rock lobster (*P. vericolor*), ornate rock lobster (*P. ornatus*) and the southern rock lobster (*Janus edwardsii*) are often found in *macroalgae (subtidal)* habitats.
	MOBILE SAND (subtidal)	The *mobile sand (subtidal)* habitat is defined as subtidal habitats that have predominantly white carbonate sands (0.1-2 mm grain size) as a substrate, which is constantly being moved by currents or wave action. However, the sand may overlay reef platform or have patches of other habitats present. *Mobile sand (subtidal)* habitats typically are bare, and may have seasonal vegetation or permanent patches of seagrass or macroalgae. Invertebrate infauna such as scallops (eg. *Pecten* spp.) seastars (eg. *Astropecten* spp.), and sea urchins (eg. *Brissus* spp., *Echinocardium* spp.), may also be present.
	GRAVEL/RUBBLE (subtidal)	The *gravel/rubble (subtidal)* habitat is located below the LAT and is typically found in areas of high water motion such as areas where strong currents or wave action occur. The *gravel/rubble (subtidal)* habitat typically is bare with some macrophyte or sessile invertebrate fauna attached and has a low diversity of infauna. Rhodoliths, nodules of calcareous red algae, which may or may not be encrusting shell fragments or small pebbles, are also included in this class. The substratum of this habitat may be comprised of pebble (particle size of 2 mm to 64 mm), cobble (particle size of 7.5 cm to 25 cm), or rubble (which is generally comprised of coral fragments). Shell and rhodoliths, which are technically pebbles, are included to highlight the particular material source.
	SEAGRASS	*Seagrass* habitat is subtidal areas typically of unconsolidated substratum, however some species (eg. *Thalassodendron* sp., *Halophila* sp.) may occur on consolidated substratum. This habitat is found in shallow waters to depths of up to 50 m in clear temperate waters. There are many species of seagrasses, which are perennial (eg. *Posidonia* spp, *Amphibolis* spp. *Thalassodendron* spp. *Syringodium* sp.) or ephemeral (eg. *Halophila* spp., *Heterozostera tasmanica*). *Seagrass* meadows are important nursery areas for many fish species and important food source for marine wildlife such as dugong (*Dugong dugon*) and green turtles (*Chelonia mydas*). *Seagrass* habitats support a high diversity of invertebrates such as crustaceans (eg. *Penaeus* spp., *Metapenaeus* spp. *Portunus* spp.), gastropods (eg. *Thalotia conica*, *Phasionella australis*), bivalves (eg. *Pinna* spp.), ascidians (eg. *Botrylloides* spp., *Pyura* spp., *Polycarpa* spp.), sea urchins (eg. *Amblypneustes* spp., *Temnoplurus michaelseni*) and brittle stars (eg. *Comatula purpurea*).
	SILT	The *silt* habitat is located in subtidal areas with mud or silt (<0.1 mm grain size) substratum and typically comprises either calcareous or terrigenous fractions, with significant organic matter. *Silt* habitat occurs in the sheltered unexposed areas (eg. embayments), is usually unvegetated and typically has low water visibility due to the high level of silt particles in the water column. *Silt* habitats support a rich variety of infauna such as sea pens (eg. *Sarcoptilus* spp., *Cavernularia* spp.), molluscs (eg. Tellina spp.) and crustaceans (eg. *Paneus* spp.).
	ALGAL MAT (subtidal)	The *algal mat (subtidal)* habitat is defined as a blue-green algal mat covered soft sediment, which typically is silt (<0.1 mm particle size). A tough surface layer of blue green algae dominates the *algal mat (subtidal)* habitat, which usually is void of infauna, as anaerobic conditions typically occur under the mat.
	PELAGIC	The *pelagic* habitat is defined as habitats with greater than 50 m depth. The *pelagic* habitat is dominated by the life in the water column, which include pelagic fish, pelagic invertebrates, zooplankton and phytoplankton. Contemporary acoustic mapping techniques have been

		able to discern hardness (soft and hard) and relief (smooth and rough) which may be used for local scale habitat mapping (Penrose & Siwabessy, 2001; Siwabessy *et al*., 1999).

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Ocean Reef Baseline Studies – Abalone Habitat and Abundance at Burns Beach Reef

1058_01_002/2_Rev1

February 2016

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Prepared by

BMT Oceanica Pty Ltd

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C	J Anderson	M. Brook	Strategen Pty Ltd	1 x pdf	16/07/2015
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Status

This report is 'Draft' until approved for final release, as indicated below by inclusion of signatures from: (i) the author and (ii) a Director of BMT Oceanica Pty Ltd or their authorised delegate. A Draft report may be issued for review with intent to generate a 'Final' version, but must not be used for any other purpose.

Approved for final release:

Author
Date: 22/02/2016

Director (or delegate)
Date: 22/02/2016

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1. Introduction

1.1 Proposed development background

The City of Joondalup proposes to upgrade and expand the existing marine facilities at the Ocean Reef Boat Harbour, hereafter referred to as the Ocean Reef Marina Proposal. The Ocean Reef Marina Proposal is located in the Ocean Reef locality, ~29 km north of the Perth central area, Western Australia (WA), and lies adjacent to Marmion Marine Park (MMP) (Figure 1.1).

The Ocean Reef Marina Proposal includes (Strategen 2014):

- construction of two new outer breakwaters
- removal of the existing breakwaters from the boat launching harbour
- dredging of sand and rock inside the harbour
- disposal of dredge spoil into land reclamations inside the breakwaters
- construction of jetties to support piled boat mooring pens
- operation and maintenance of the marina.

The existing Ocean Reef Boat Harbour is located outside the boundaries of the MMP. However, the Ocean Reef Marina Proposal Development Envelope will extend into the boundaries of the MMP (Figure 1.1). The Development Envelope extends 100 m from the project footprint and encompasses the proposed area to be annexed from the MMP. The actual Ocean Reef Marina Proposal project footprint is approximately 8.6 ha while potential footprint related BPPH loss (direct and indirect) is estimated to encapsulate ~42 ha, this includes a 50 m halo and all the area encompassed by the project footprint.

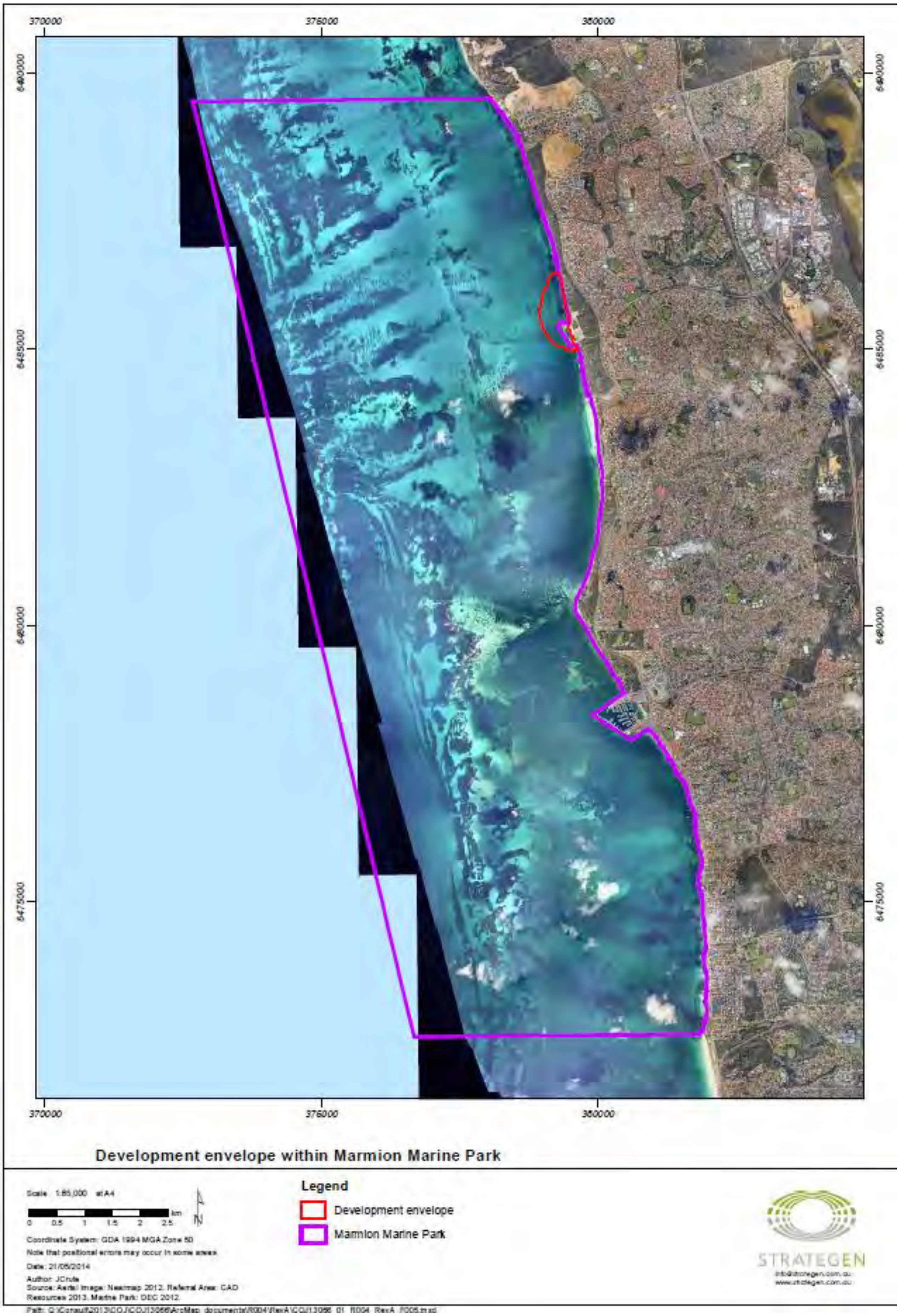
The Ocean Reef Marina Proposal is being assessed by the Environmental Protection Authority (EPA) under Part IV of the *Environmental Protection Act (1986)* (EP Act) at the level of Public Environmental Review (PER). The Environmental Scoping Document (ESD) (EPA 2014), approved in consultation with the proponent by the EPA, states that the key environmental factors for the Ocean Reef Marina Proposal include:

- marine environmental quality
- benthic communities and habitat
- marine fauna
- coastal processes
- integrating factors – offsets.

1.2 Environmental Scoping Document requirements for abalone survey

This report provides a summary of abalone habitat and abundance adjacent to the existing Ocean Reef Boat Harbour to fulfil requirements of the ESD. The scope of work for the assessment of abalone is stated in Section 3 (Table 2) of the ESD with respect to two of the key environmental factors identified for the Ocean Reef Marina Proposal, as follows:

1. **Benthic communities and habitat** - "assess the values and significance of benthic communities and habitats within the proposal and adjacent areas and describe these values in a local and regional context. This assessment must also specifically address the values and significance of benthic communities and habitats in the context of Marmion Marine Park and for abalone and western rock lobster habitat" ('Required work', point 2).



Source: Strategen (2014)

Figure 1.1 Ocean Reef Marina Development Envelope and Marmion Marine Park footprint

2. **Marine fauna** - "assess the values and significance of marine fauna in the proximity of the proposal and describe these values in a local, regional and State context. This assessment must also specifically address the values and significance of conservation significant marine fauna in the context of Marmion Marine Park and for abalone, finfish and western rock lobster in the context of fisheries" ('Required work', point 4).

1.3 Purpose of this document

The purpose of this document is to satisfy the required work specified by the ESD (Section 1.2) in relation to abalone and abalone habitat, by meeting the following objectives:

- Provide a summary of the existing environment and information on the local population of abalone adjacent to the Ocean Reef Boat Harbour.
- Design and conduct a survey for abalone to identify significant habitat and to estimate abundance where this may be affected by the proposal (in consultation with DoF).
- Identify the significance of abalone communities and habitat in the context of the MMP.

2. Existing Environment and Information

2.1 Regional setting of project

Marmion Marine Park lies between Trigg Island and Burns Rock and comprises the regional setting of the Ocean Reef Marina Proposal. The MMP was reserved on 13 March 1987 as an 'A' class reserve, under the *Conservation and Land Management Act 1984* (CALM Act 1984). The purpose of the Marine Park is "to fulfil so much of the demand for recreation by members of the public as is consistent with the proper maintenance and restoration of the natural environment, the protection of indigenous flora and fauna" (CALM Act 1984).

Marmion Marine Park is comprised of three zones:

1. General Use Zone: provides for commercial and recreational uses consistent with the conservation of natural resources (CALM 1992). Commercial and recreational fishing are permitted in this zone under the *Fish Resources Management Act 1994*
2. Waterman's Observation Zone: provides for recreational uses that are consistent with conservation of natural resources (CALM 1992). In this zone, commercial fishing is not permitted, while recreational fishing is permitted, under the *Fish Resources Management Act 1994*
3. Sanctuary Zone: provides for the protection of environmental values and the exclusion of any human activities likely to damage the environment (CALM 1992). Commercial and recreational fishing are not permitted in this zone

The Ocean Reef Marina Proposal is located within and adjacent to the General Use Zone.

2.2 Burns Beach Reef and benthic habitat map

Burns Beach Reef is located within and immediately north of the Ocean Reef Marina Proposal. It is a nearshore reef habitat which supports a significant population of Roe's abalone. BMT Oceanica (2016a) developed a benthic habitat map which describes the benthic primary producer habitats within the proposed Ocean Reef Marina Proposal and surrounding areas. During the benthic habitat map survey, abalone habitat was preliminarily described along the nearshore macroalgae reefs of Burns Beach Reef and south of Hillarys Boat Harbour (from Sorrento Beach to Trigg Island) within the MMP.

The section of nearshore reef which is habitat for the Roe's abalone along Burns Beach Reef is oriented roughly north to south, running parallel to the shore, and is approximately 3 km long and 100 m wide, although the width is inconsistent along the reef. The nearshore reef ranges from the shoreline out to approximately 300 m offshore to a depth of approximately 4-6 m. There are two distinct abalone habitats on the nearshore reef: the platform and sub-tidal. The platform section is <2 m deep and is generally the recreational abalone fishery portion; while the sub-tidal section is typically 2-6 m deep and is the commercial fishery portion (see Section 2.4). Burns Beach Reef is the most popular Roe's abalone recreational fishery in the Perth metropolitan area and the fishing activities annually attract media attention.

During the BMT Oceanica (2016a) survey it was noted that additional survey work was required to delineate the extent of abalone along Burns Beach Reef.

2.3 Abalone background information

Abalone are a family of reef-dwelling marine snails. In Western Australia, abalone have become a significant commercial fishery target due to their high export value. The abalone recreational fishery is also highly prized and has one of the shortest fishing seasons in Australia. There are 11 species of abalone in Western Australia, however only three species are large enough in size to be fished (Hart et al. 2013):

- Brownlip abalone (*Haliotis conicopora*)
- Greenlip abalone (*Haliotis laevigata*)
- Roe's abalone (*Haliotis roei*).

Abalone are widely distributed across tropical and temperate coastal areas. Roe's abalone is the only species to inhabit Burns Beach Reef. Roe's abalone mostly inhabit shallow nearshore limestone reefs (Scheibling 1994; Hancock 2004) and can be found as far north as Shark Bay in Western Australia around to Victoria.

2.4 Roe's abalone fishery

The Roe's abalone fishery of Western Australia is a dive and wade fishery (Fletcher & Santoro 2014). Within the General Use Zone of Marmion Marine Park, commercial and recreational fishing of abalone is permitted but all other shellfish species are protected (CALM 1992). The commercial fishery harvest method is a single diver using a hookah (surface-supplied breathing apparatus) and an abalone 'iron' to prise the shellfish off rocks (Fletcher & Santoro 2014). The recreational fishery harvest method is primarily wading and snorkelling, with the main area of focus for the fishery being the Perth metropolitan stocks (Fletcher & Santoro 2014). Marmion Marine Park is a well known and very productive target area for the recreational Roe's abalone season which had a bag limit of 15 per person in 2014/2015.

The reef platforms comprising Roe's abalone habitat in the Perth metropolitan area are exposed during low tide, making the recreational fishery very accessible for large numbers of people wading out to collect abalone; while commercial divers target abalone in sub-tidal water. Roe's abalone catch numbers in the Perth metropolitan area and Western Australia statewide are listed in Table 2.1.

Table 2.1 Roe's abalone catch numbers (tonnes) in Perth metropolitan area and Western Australia statewide

Fishing season – catch (tonnes)		2012/2013	2013/2014
Western Australia	Commercial	67	73
	Recreational	32	34
	Total	**99**	**107**
Perth metropolitan	Commercial	28	36
	Recreational	18	20
	Total	**46**	**56**

Sources: (Hart et al. 2013; Hart et al.2014)

The percentage of the statewide catch that was from the Perth metropolitan fishery was 47% during the 2012/2013 season and 52% during the 2013/2014 season. Recreational catch made up 32% of the total catch statewide during 2012/2013 and 2013/2014 seasons. Recreational catch made up 39% of the Perth metropolitan catch during 2012/2013 season and 36% during 2013/2014 season. The 2013/2014 Roe's Abalone Fishery Status Report assessed the Stock level as adequate and the fishing level as acceptable in the Perth Metropolitan fishery (Hart et al. 2014).

In terms of catch, the fishery is divided into large areas spanning hundreds of kilometres. Areas 6, 7 and 8 comprise the main Roe's abalone fishery in Western Australia (Hart et al. 2014). The main regional areas are:

- Area 6 is the Cape Leeuwin to Cape Bouvard
- Area 7 is from Cape Bouvard to Moore River and includes the Perth region (see above)
- Area 8 is from Moore River to the Western Australian/Northern Territory border.

Hancock (2004) and Hart (2014) divided the abalone fishery into 10 nm sections. Area 7 is regarded as the Perth metropolitan area and comprises:

- Moore River (Section 36)
- Yanchep (Section 37)
- Mindarie Keys, Burns Beach/Ocean Reef Boat Harbour, Hillarys Boat Harbour (Section 38)
- Trigg Island (Section 39)
- Carnac Island, Cottesloe (Section 40)
- Garden Island, Point Peron (Section 41)
- Rockingham to Mandurah (Section 42)
- Mandurah to Cape Bouvard (Section 43)

Burns Beach Reef is located within Section 38 of Area 7. The level of interaction between reefs appears to be low. Hancock (2004) noted high levels of gene flow across 3000 km sampled, but the area of complete genetic mixing was estimated to be less than 13 km which indicated a number of discrete stocks in the metropolitan area. Within Section 38, the Burns Beach Reef population (just north of Ocean Reef Boat Harbour) is approximately 7 km to the surrounding abalone populations at Mindarie Keys and 11 km to the reef just south of Hillarys Boat Harbour. Although these populations are within estimated distances for genetic mixing there is potential for discrete stocks to exist within kilometres of each other if coastal barriers, such as headlands or lagoons exist which limit current flow.

2.5 Existing Roe's abalone information at Burns Beach Reef

Substantial research has been completed on the Roe's abalone in the Perth metropolitan area during the past 20 years due to the increasing popularity and value of the commercial and recreational fisheries. This work has included:

- The population characteristics of the abalone on intertidal platforms (Wells and Keesing 1990).
- A PhD thesis focussed on the fishery with a significant amount of the research completed at Burns Beach Reef (Hancock 2004).
- Permanent transect based size and density surveys conducted at sites around the Perth metropolitan area since 1996 by the Department of Fisheries (DoF; WA Fisheries and Marine Research Laboratories, Mollusc Research team). Three of these sites (Beaumaris, Shenton Avenue and Burns Beach) are within Burns Beach Reef and a fourth site is located immediately north of Mindarie Marina.

2.6 Need for Roe's abalone abundance baseline survey

As part of the ESD requirements for the Ocean Reef Marina Proposal, BMT Oceanica (2015) completed a separate desktop review which identified potential marine fauna species that may occur within the Ocean Reef Marina Proposal area. Roe's abalone was identified as a marine fauna species that may potentially be directly affected by the Ocean Reef Marina Proposal.

While comprehensive work and research has been completed on the fisheries aspect of Roe's abalone and relevant habitat has been preliminarily mapped, it was identified that additional information is required to understand the abundance of and distribution of Roe's abalone along Burns Beach Reef.

A survey was therefore designed in consultation with DoF and the West Coast Abalone Divers Association to collect additional data on the relative abundance of abalone along the known habitat at Burns Beach Reef to better understand the south to north distribution along the reef. The methods, results and a discussion of the findings of this survey are described in the sections that follow.

3. Methods

Survey methods were developed in consultation with the DoF Mollusc Research Team. Every attempt was made to replicate the DoF survey methodology which is based on the methods used in Hancock 2004. After substantial stakeholder consultation and a number of knowledge sharing field trips the abalone abundance surveys were completed on 12 and 13 March 2015.

3.1 Stakeholder consultation

3.1.1 West Coast Abalone Divers Association

Members (John Brindle and Wayne Spencer) of the West Coast Abalone Divers Association (WCADA) were consulted about the abalone abundance survey methods during knowledge sharing meetings on 18 August and 24 November 2014. BMT Oceanica's survey field lead also spent a day (19 December 2014) at Burns Beach Reef with Wayne Spencer (local commercial Roe's abalone fisherman with 20 years experience) to scout out appropriate survey areas and learn about the local abalone distribution and challenges of finding small hidden juvenile abalone.

3.1.2 Department of Fisheries

The DoF Mollusc Research Team was repeatedly consulted for advice and knowledge to help develop appropriate methods. Members of the team gave advice on method design, accompanied the BMT Oceanica survey field lead on 26 February 2015 to scout appropriate survey areas and provide informal training on survey methods, use of equipment and data collection.

The proponent and the DoF also entered into a data sharing agreement on 23 March 2015 which allows the publication of the DoF data from 2015 surveys for the Beaumaris, Shenton Avenue, Burns Beach and Mindarie sites in this report. Data from this report may also be shared with the DoF for their use.

3.2 Survey site locations and habitat ground-truthing

Four sites (AB1, AB2, AB3A and AB4) were established to collect abalone abundance counts, in addition to three existing DoF annual monitoring sites (Beaumaris, Shenton Avenue and Burns Beach), which together allow for good spatial coverage of Burns Beach Reef (Figure 3.1). An additional site just north of Mindarie, which is annually monitored by the DoF was also included as a control site (i.e. similar habitat but not potentially impacted by the Ocean Reef Marina Proposal). Survey site coordinates are listed in Appendix A.

Confirmation of the presence of abalone at each site during the survey, as well as during scouting surveys (Section 3.1), allowed for ground-truthing of the BMT Oceanica (2016a) benthic habitat map and specification of the areal extent of abalone habitat.

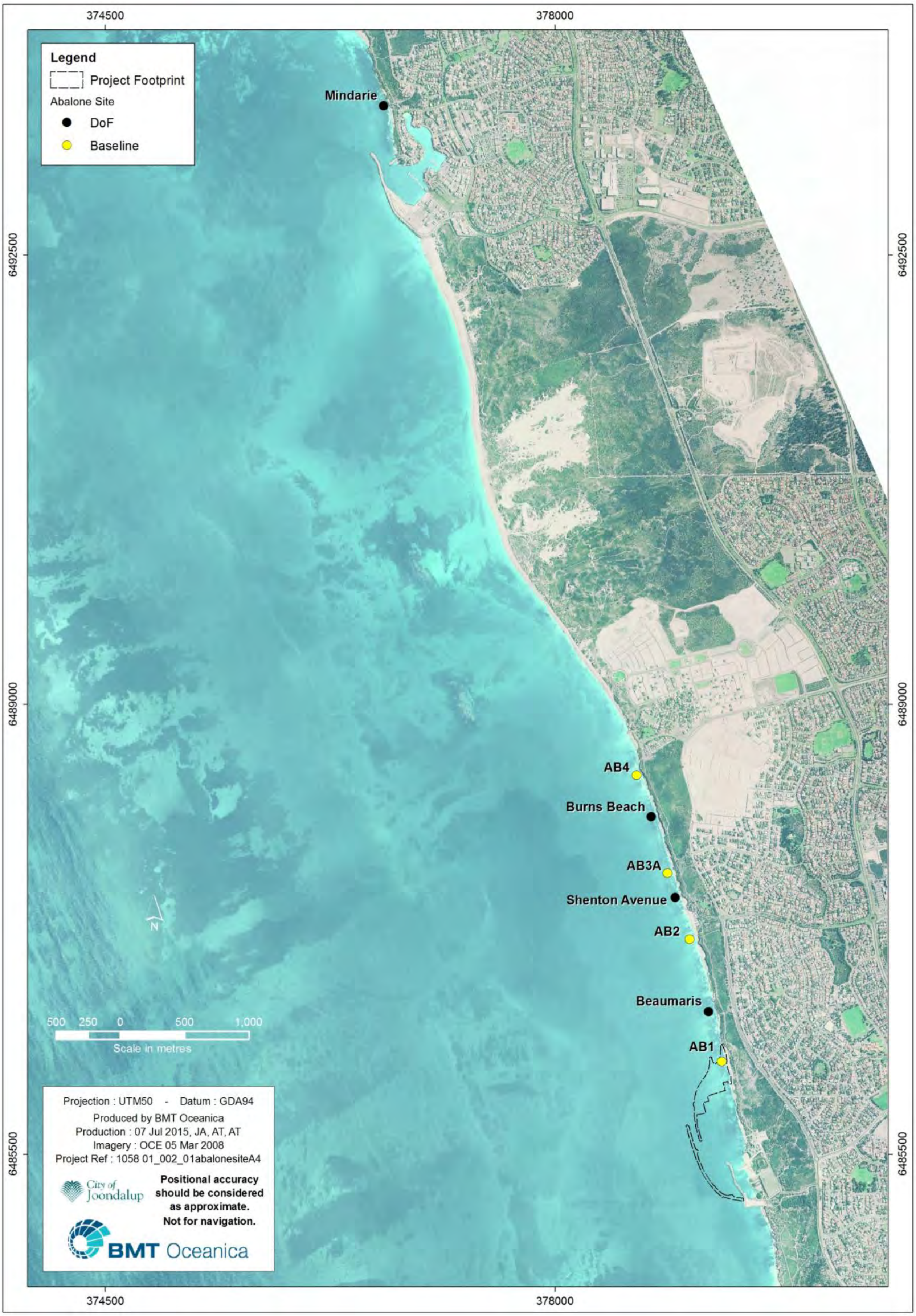


Figure 3.1 Survey site locations at Burns Beach Reef and the Mindarie site

3.3 Survey design and implementation

The surveys were completed by commercial scientific divers utilising surface supplied breathing apparatus (SSBA) equipment diving to AS/NZS 2299.1: 2007. Special weighting equipment was used by the platform diver to assist keeping the diver stable during measurements. The survey design is based on the methods used by DoF which in turn are based on the methods of Hancock (2004), as summarised below.

3.3.1 Transect placement

Surveys were conducted on both the reef platform and sub-tidal reef at each of the four sites. At the starting point of each transect a flat circular weight was placed with a surface buoy attached. The transect tape was attached to this weight and adjusted to start at the edge of the platform reef; however, for the sub-tidal reef the 0 m mark was considered to be at the edge of the weight. On the platform portion of the reef a transect was laid to the extent of abalone presence (or a maximum of 20 m) and the bearing was recorded for both transects. At the completion of each site a waypoint was taken of this location as the starting point for the site and the marker buoy was removed, but the weight was left for possible future surveys.

3.3.2 Quadrat placement

Quadrat size and placement was different for the different sections of reef. Ten quadrats of 0.25 m^2 were placed at regular intervals along the platform section of the reef. Within the sub-tidal reef area a total of nine 0.5 m^2 quadrats were placed with: three on reef top sections, three on sloping reef and three along bottom reef sections. Site diagrams with placements of quadrats and transect bearings are provided in Appendix B. Within each of the quadrats, abalone which had the tip of their swirl within the frame were considered to be 'in' the quadrat and were measured for maximum length. A photo was taken of each quadrat to support the quality assurance and control process (Section 3.6).

3.4 Data collection

Divers recorded on waterproof paper the maximum length of each abalone within each quadrat of each site. The length of abalone greater than 5 mm was measured using either callipers or equivalent measuring equipment. Platform and sub-tidal reef abalone count data were collected and processed individually by separate divers.

3.5 Data processing

Collected data were separately processed for the platform and sub-tidal reef section to determine:

- total Roe's abalone count per quadrat and transect
- abalone density (m^2) (converted from counts per quadrat)
- size classes and designated age classes (Hancock 2004) and legal and sublegal classifications (based on the length of each abalone)
- total counts and percentage per age and per legal classification.

3.5.1 Age and legal classifications

Age classes were determined base on the abalone size using the maximum length size classes in Table 3.1.

Table 3.1 Roe's abalone age designation based on maximum length

Age (years)	Size (mm) range
<1	<17
1-2	17-32
2-3	33-50
3-4	51-60
4-5	61-70
5+	>70

The legal size limit for fishing Roe's abalone is 60 mm. Abalone <60 mm were designated as sub-legal and abalone 60 mm or greater were designated as legal size.

3.6 Quality control and assurance

Quality control and assurance was completed by:

- Commercial scientific divers were trained to AS2815.2 or AS2815.3 and hold a PhD, with one of the divers having significant experience in mollusc research.
- Divers also received additional informal training from DoF personnel in the field to ensure sampling methods were equivalent and directly comparable to DoF techniques.
- Photos of diver slates were taken prior to leaving bottom to ensure data was not accidently lost.
- Sea conditions were less than 1.0 m swell at the Rottnest Island buoy and winds were from an easterly directions and less than 10-15 knots.
- Speciality equipment was used to help stabilise the diver on the platform transect to ensure accurate measurements of abalone maximum length.

3.7 Statistical analysis

Summary statistics of the relevant abalone parameters minimum, maximum, mean and standard deviation were calculated for each reef section (platform or sub-tidal) for each site.

4. Results

The Roe's abalone abundance surveys were completed on 12 and 13 March 2015. Completion of the surveys at the four sites (AB1, AB2, AB3A and AB4) required approximately 18 hours of diver bottom time. Weather conditions for the survey were excellent with <1.0 m swell recorded at the Rottnest Wave Buoy and winds from the east <15 knots for both days.

4.1 Abalone habitat

Abalone habitat ground-truthing was verified during these surveys and during scouting field trips with the stakeholders. This allowed for the development of a map comprising a habitat category of 'nearshore reef with Roe's abalone' to be completed from the benthic primary producer habitat map (BMT Oceanica 2016a) (Figure 4.1).

4.1.1 Abalone habitat loss calculations

Within the Loss Assessment Unit (BMT Oceanica 2016a) it is estimated that approximately 131 ha nearshore reef is currently supporting populations of Roe's abalone. This 131 ha is located in two distinct areas, one being Burns Beach Reef and the other reef area about 1 km south of Hillarys Boat Harbour which extends to the MMP southern boundary. The benthic habitat mapping report (Oceanica 2016a) defined an area of potential footprint related BPPH loss (direct and indirect impacts) that included direct loss from the project footprint plus assumed loss of all habitats within the proposed Ocean Reef Marina, and also includes a 50 m halo effect around the project footprint. This area of abalone habitat within this potential footprint related BPPH loss area is 11.8 ha or 9% of the extent of this habitat in the MMP. The project footprint represents direct habitat loss resulting from construction of the Ocean Reef Marina infrastructure at 2.7 ha or 2.1% (Table 4.1)

Table 4.1 Potential loss of nearshore reef habitat supporting Roe's abalone within Marmion Marine Park

Current nearshore reef habitat area (ha)	Direct loss from project footprint (ha)	Direct loss from project footprint (%)	Loss from potential footprint related BPPH loss (direct and indirect) (ha)	Loss from potential footprint related BPPH loss (direct and indirect) (%)
131	2.7	2.1	11.8	9.0

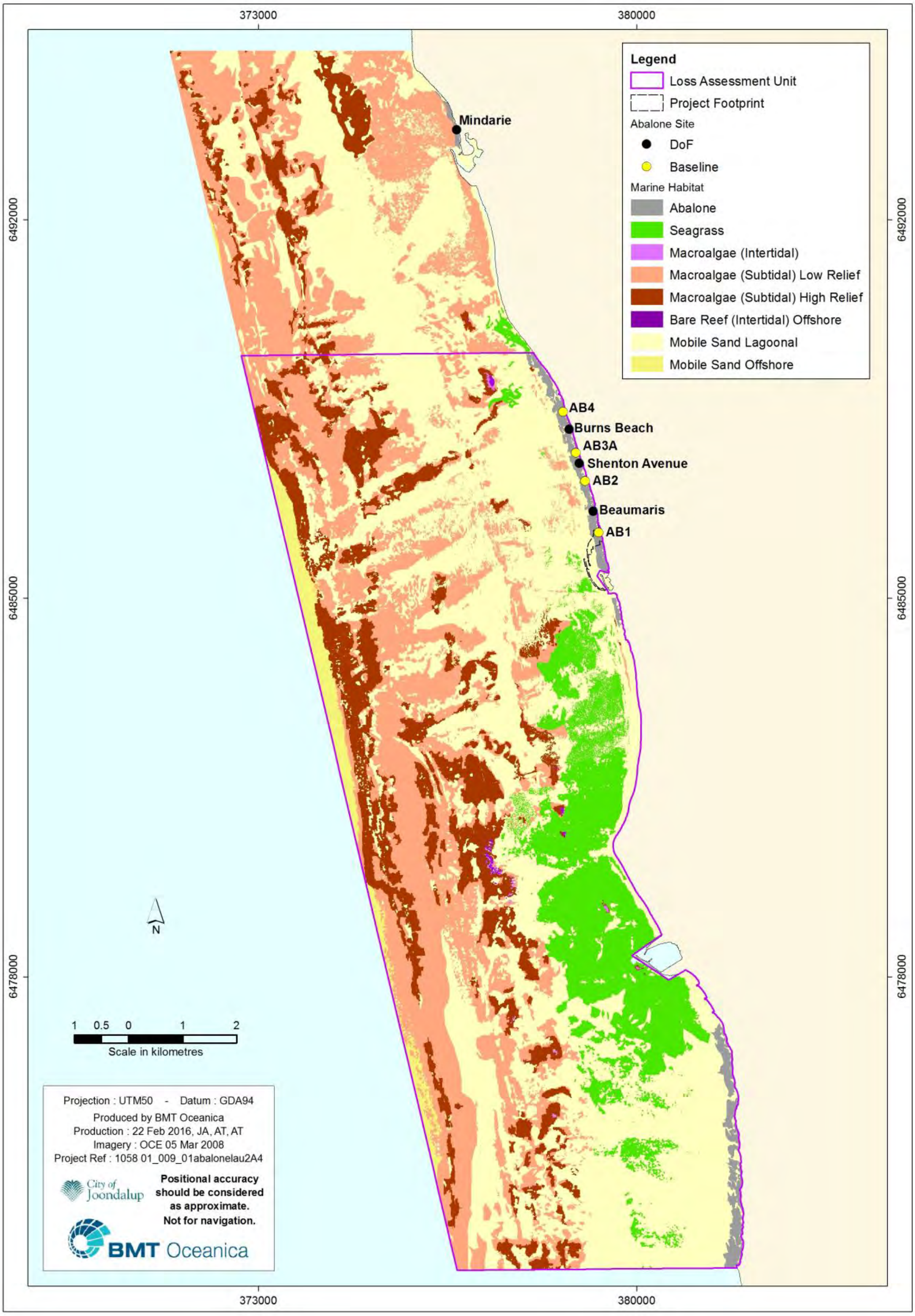


Figure 4.1 Abalone habitat at Burns Beach Reef and within the Loss Assessment Unit

4.2 Abalone densities

Roe's abalone densities were relatively high across all sites and typically greater on the platform compared to the sub-tidal reefs, except for sites Shenton Avenue and AB1. Distribution of abalone along the reef tended to be heterogeneous although continuous in large sections (i.e. 50-300 m distances). Summary statistics of Roe's abalone densities are shown in Table 4.2. Mean densities ranged from 6-113 abalone per m^2.

Along Burns Beach Reef, AB4 is the northernmost site and AB1 is the southernmost site. No clear trends in abalone densities are apparent, although Burns Beach, Shenton Avenue and AB2 had the highest densities and are located towards the centre of Burns Beach Reef. AB1 which is the site nearest the proposed Ocean Reef Marina development had the second lowest overall site density (the Mindarie site had the lowest).

Table 4.2 Summary statistics for Roe's abalone along Burns Beach Reef March 2015

Site	Reef section	Minimum density (m^2)	Maximum density (m^2)	Mean density (abalone m^2)	Standard Deviation
Mindarie	Platform	0	108	48	30
	Sub-tidal	0	22	6	8
AB4	Platform	16	132	75	42
	Sub-tidal	0	50	20	18
Burns Beach	Platform	54	200	113	51
	Sub-tidal	2	174	84	50
AB3A	Platform	8	88	49	30
	Sub-tidal	14	114	64	34
Shenton Avenue	Platform	24	204	87	57
	Sub-tidal	76	128	99	20
AB2	Platform	20	208	94	48
	Sub-tidal	20	90	56	20
Beaumaris	Platform	18	116	63	31
	Sub-tidal	4	50	15	14
AB1	Platform	8	48	31	15
	Sub-tidal	26	58	40	11

4.3 Age class distributions

Age class distributions as a percentage of total population are shown in Figure 4.2. Platform reef sections tended to have higher percentages of juvenile abalone (<4 years old) than sub-tidal sections (Appendix C). Conversely, sub-tidal reef sections had higher percentages of mature abalone (>4 years old) than platform sections. The majority of abalone (58-94%) at all sites were between 2-4 years old. The percentage <1 year old was <10% at all sites, except Burns Beach platform (29%) and Shenton Avenue platform (19%) reefs. Sites surveyed during this study (AB1-4) comprised cohorts of <1 year old at 0-7%, while DoF sites comprised < 1 year old cohorts of 0.3-28%. Overall, relatively similar distributions of age occurred amongst all sites. No clear trends in age distributions were apparent, but the proportion of abalone 4 years or older tended to be higher in the sub-tidal reef section than the platform section.

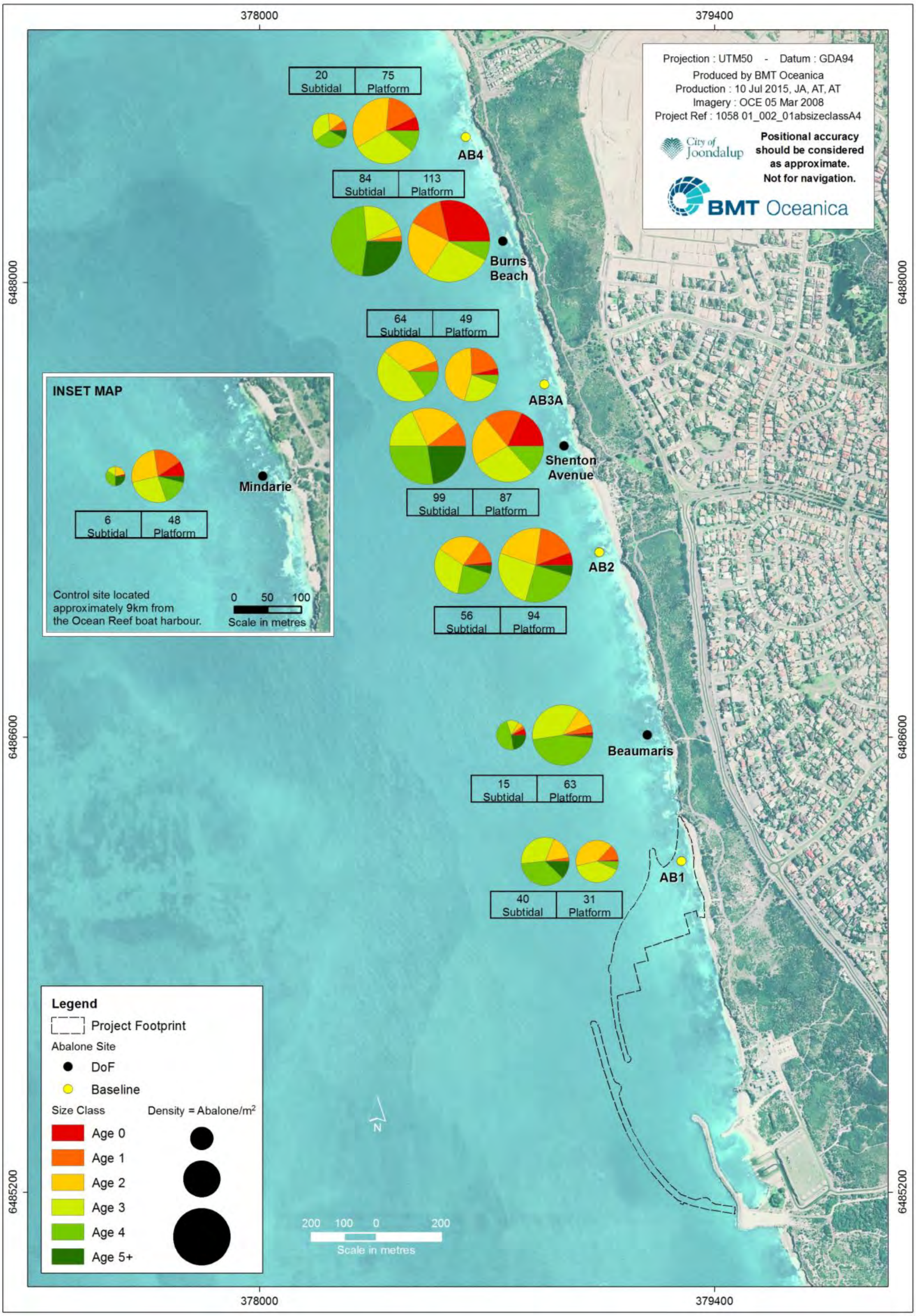


Figure 4.2 Mean densities of Roe's abalone and percentage of age class distribution of abalone at the Burns Beach Reef sites and Mindarie

4.4 Legal catch limit distribution

Roe's abalone over 60 mm are the legal catch size. The percentages of legal catch size versus sub legal sizes, per reef section, are shown in Figure 4.3. The percentage of legal sized abalone was greater on the sub-tidal reef (ranged from 15 to 77%) than the platform reef (ranged from 6 to 55%) (Appendix D). Of the eight sub-tidal reef sections, four sections had a greater percentage of legal sized abalone than sub legal (Mindarie, Burns Beach, Shenton Avenue and Beaumaris). Of the platform reef sections, only the Beaumaris section had a greater percentage of legal than sub legal abalone.

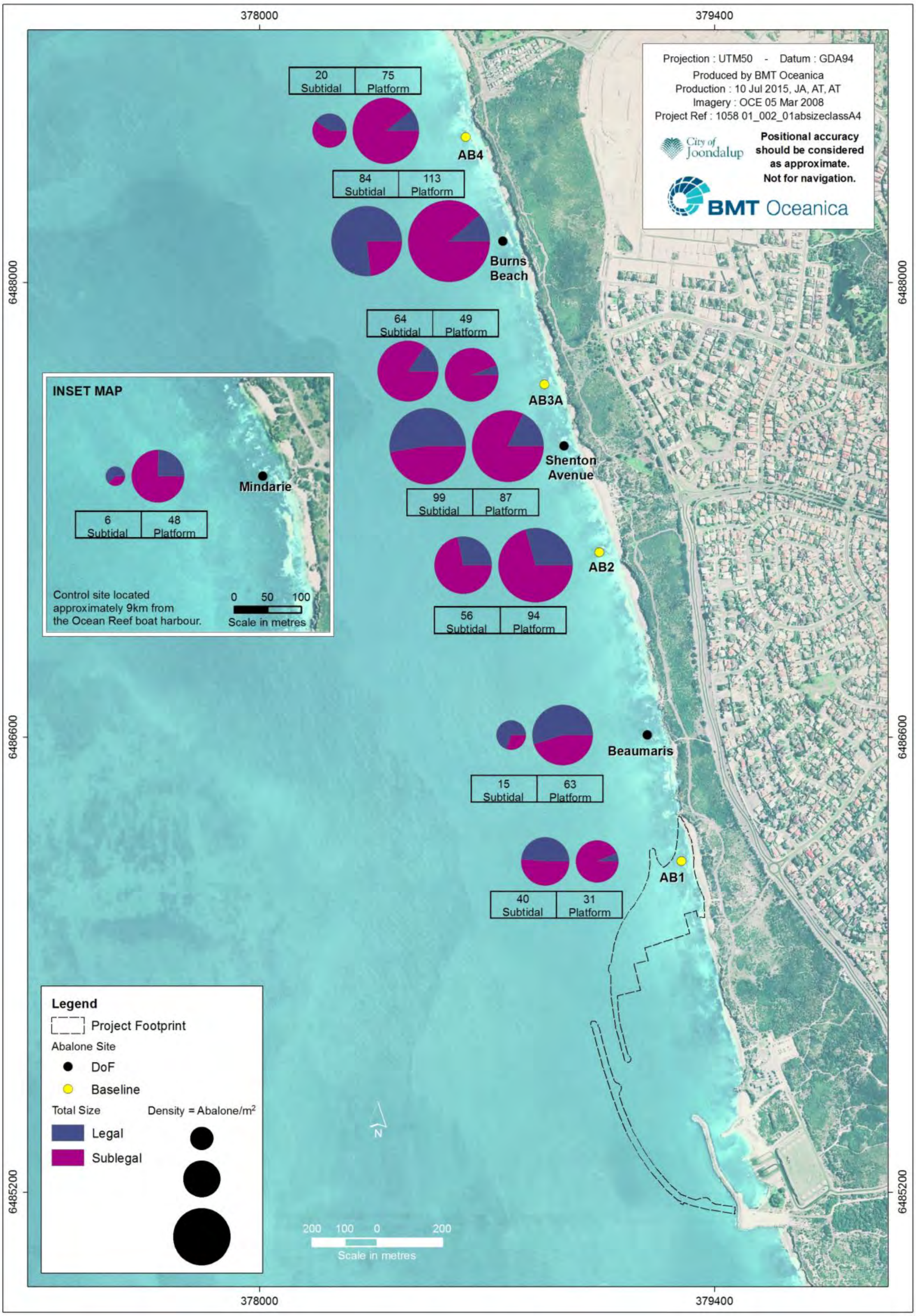


Figure 4.3 **Mean densities of Roe's abalone and percentage of abalone of legal catch size limit at the Burns Beach Reef sites and Mindarie**

5. Summary and Discussion

Following extensive consultation with the two key stakeholders, West Coast Abalone Divers Association and the DoF, a survey method design and sites were selected to increase the understanding of Roe's abalone habitat distribution and overall abundance along the Burns Beach Reef. In conjunction with DoF's existing site data, the results comprise a baseline data set to better inform future monitoring of the Roe's abalone population and/or management decisions in relation to the Ocean Reef Marina Proposal.

Two nearshore reefs which support Roe's abalone populations were identified in the Loss Assessment Unit during habitat surveys and mapping; one approximately 1 km south of Hillarys Boat Harbour (from Sorrento Beach to Trigg Island) and the other being Burns Beach Reef. Together these reefs are estimated to comprise 131 ha of abalone habitat. A direct loss of 2.1% abalone habitat will occur from the Ocean Reef Marina project footprint with an additional 6.9% habitat loss from indirect footprint related impacts including assumed total loss within the marina and a 50 m halo effect outside of the breakwaters

Abundance survey data showed that Roe's abalone densities were relatively high across all sites with densities typically greater on the platform versus the sub-tidal reef sections. No clear spatial trend in abalone density was apparent, although Burns Beach, Shenton Ave and AB2 sites had the highest densities and they are located towards the centre of Burns Beach Reef. Site AB1 which is nearest the proposed Ocean Reef Marina Proposal had the second lowest overall site density. It was also noted that distribution of abalone along the reef tended to be heterogeneous, although was continuous in large sections (i.e. 50-300 m areas).

Platform reef sections had a greater percentage of juvenile (<4 year old) populations than sub-tidal reef sections. Lower percentages of the <1 year old abalone cohort found during the current study (sites AB1-4) is possibly due to the lesser experience of the field survey divers (compared to DoF survey team members who have multiple years experience at finding abalone <17 mm in size). As such, the <1 year old counts are possibly an underestimate of the actual percentage of the population in that age group. The percentage of legal sized abalone (>60 mm) were greater on the sub-tidal reef section than the platform reef.

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Appendix A

Survey site coordinates

Site	E	N	Lat_DMS	Lon_DMS
Mindarie	376667.77	6493665.52	31° 41' 8.52" S	115° 41' 55.50" E
AB4	378635.76	6488448.48	31° 43' 58.68" S	115° 43' 7.90" E
Burns Beach	378750.46	6488128.42	31° 44' 9.12" S	115° 43' 12.12" E
AB3A	378877.40	6487686.97	31° 44' 23.50" S	115° 43' 16.75" E
Shenton Avenue	378937.90	6487496.84	31° 44' 29.70" S	115° 43' 18.96" E
AB2	379047.23	6487170.25	31° 44' 40.35" S	115° 43' 22.97" E
Beaumaris	379194.65	6486607.38	31° 44' 58.68" S	115° 43' 28.32" E
AB1	379299.67	6486218.11	31° 45' 11.36" S	115° 43' 32.14" E

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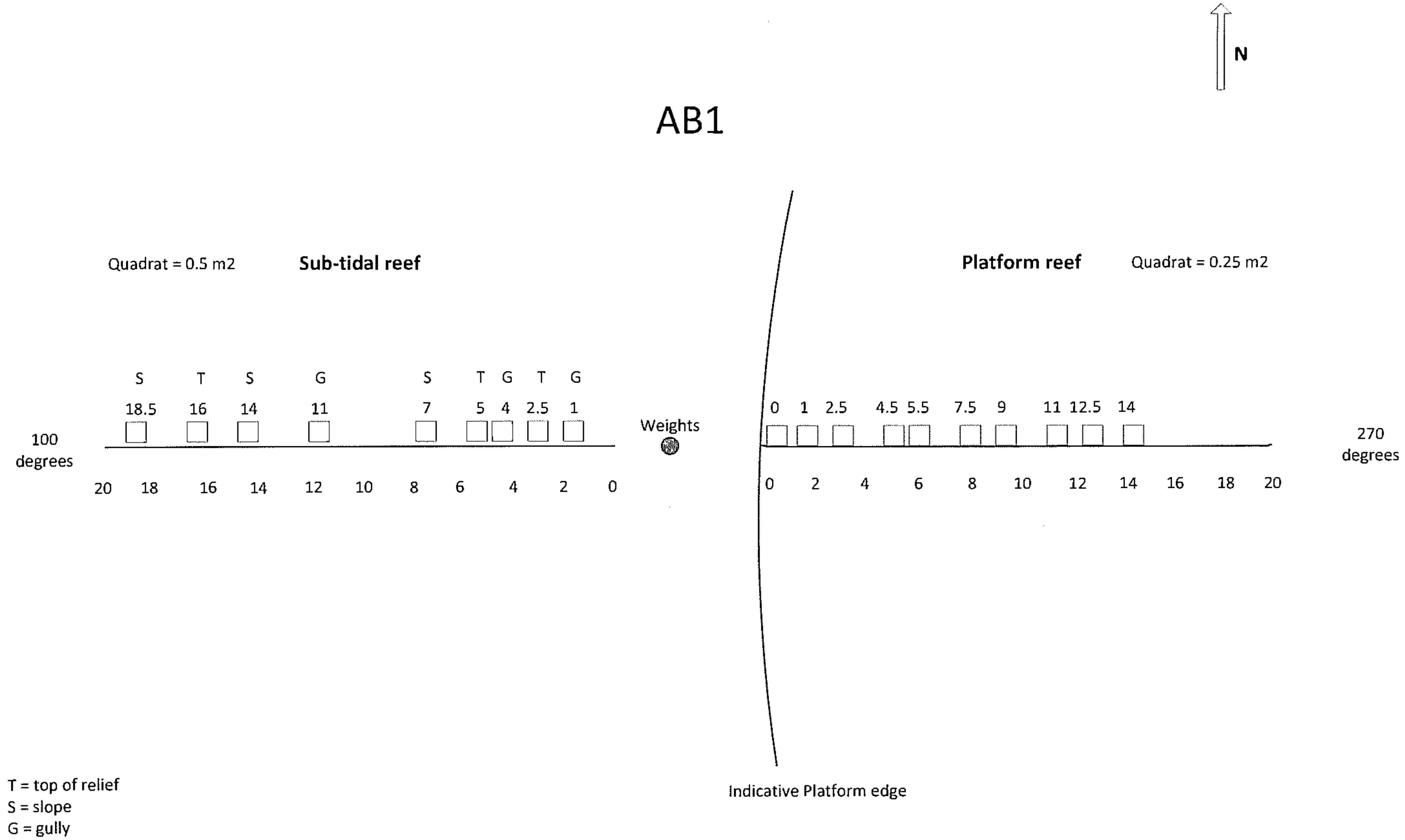
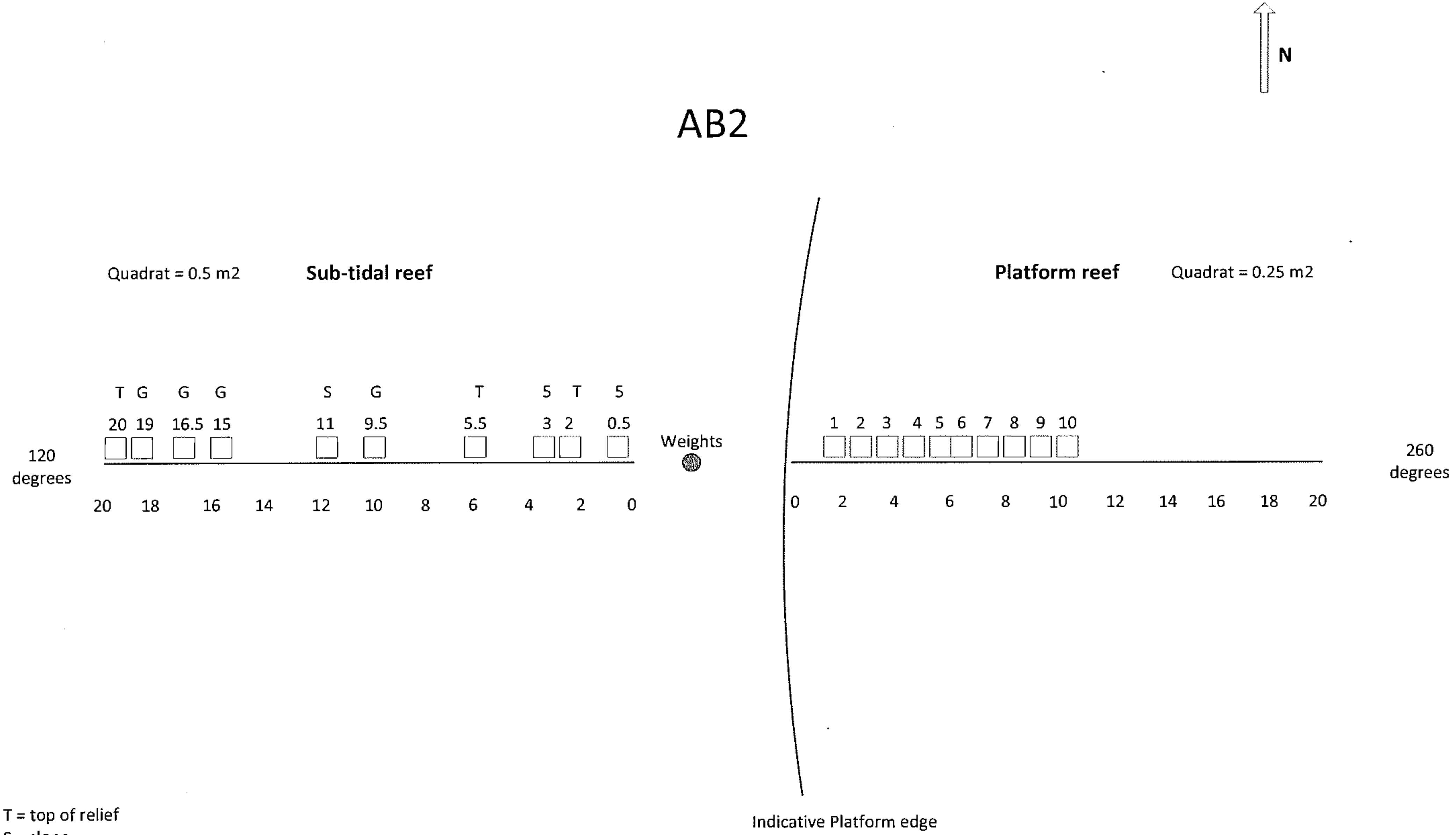
Appendix B

Survey site diagrams

AB1

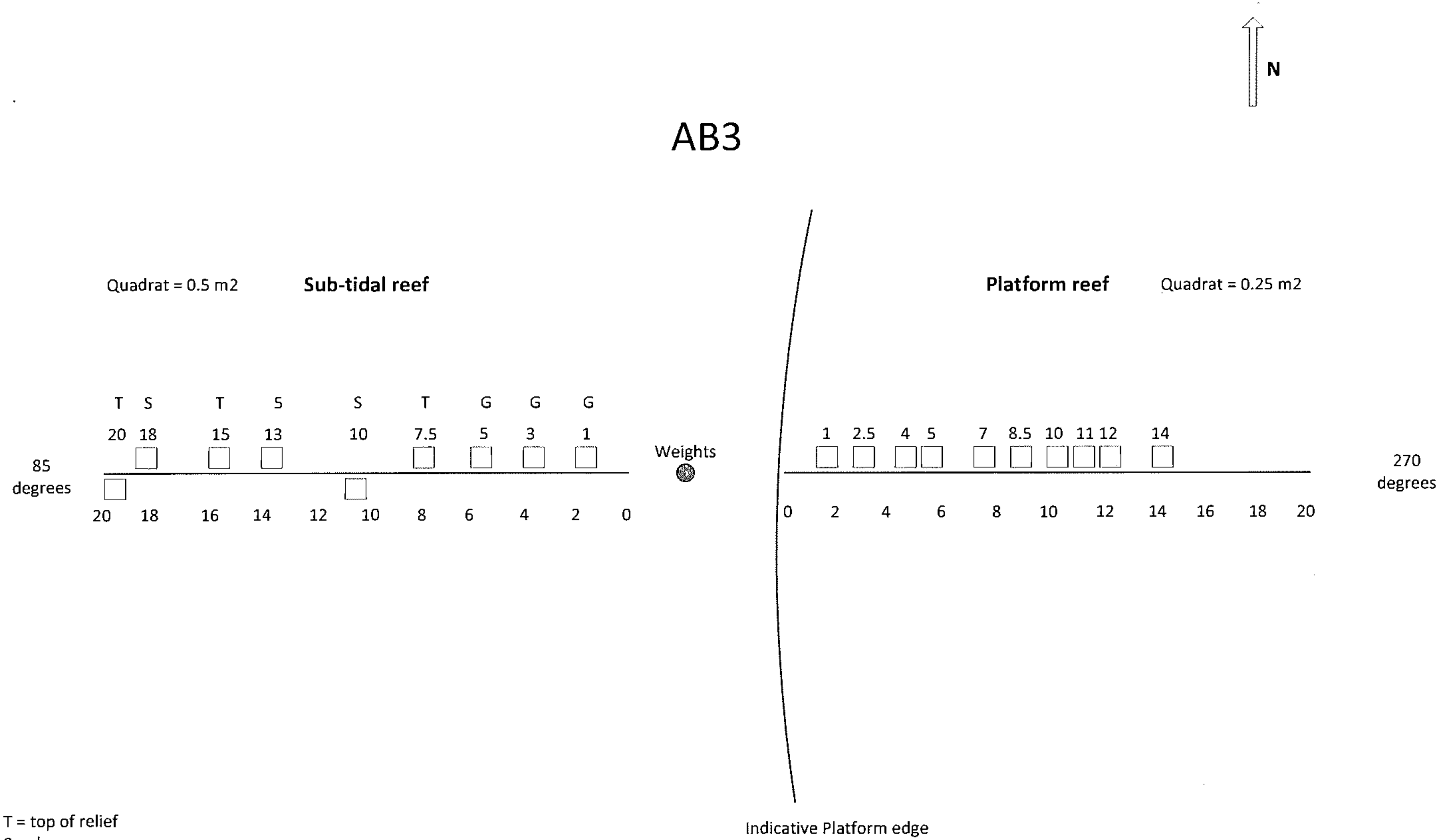

N
Quadrat = 0.5 m2
Sub-tidal reef
S T S G S T G T G
18.5 16 14 11 7 5 4 2.5 1
100 degrees
20 18 16 14 12 10 8 6 4 2 0
Weights
Platform reef
Quadrat = 0.25 m2
0 1 2.5 4.5 5.5 7.5 9 11 12.5 14
270 degrees
0 2 4 6 8 10 12 14 16 18 20
Indicative Platform edge
T = top of relief
S = slope
G = gully

AB2



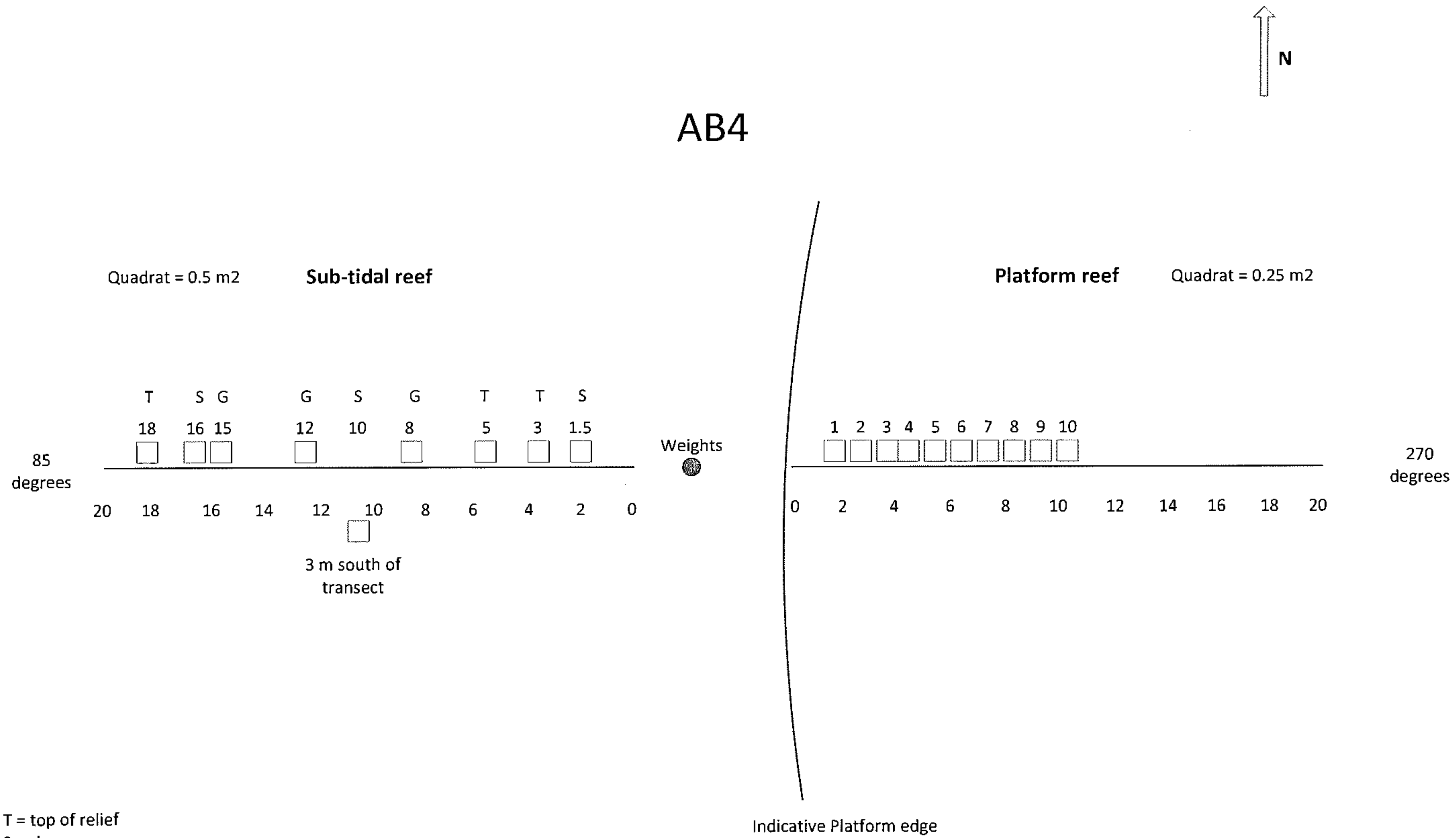
T = top of relief
S = slope
G = gully

AB3



T = top of relief
S = slope
G = gully

AB4



T = top of relief
S = slope
G = gully

Appendix C

Abalone age distributions

Population age distribution (as percentage) of Roe's Abalone along Burns Beach Reef and Mindarie

Site	Depth	0-1 years	1-2 years	2-3 years	3-4 years	4-5 years	5+ years	<4 years	4+ years	2-4 years
Mindarie	Platform	9.3	18.1	26.4	26.4	15.5	4.2	80.3	19.7	68.4
	Sub-tidal	3.1	0	21.9	15.6	34.4	25.0	40.6	59.4	71.9
AB4	Platform	7.0	16.6	34.8	31.0	10.7	0	89.3	10.7	76.5
	Sub-tidal	1.1	9.0	15.7	33.7	32.6	7.9	59.6	40.5	82.0
Burns Beach	Platform	28.6	13.9	23.1	26.8	7.7	0	92.3	7.7	57.5
	Sub-tidal	0.5	2.4	4.5	19.3	46.3	27.0	26.7	73.3	70.1
AB3A	Platform	4.1	21.3	45.1	23.8	5.7	0	94.3	5.7	74.6
	Sub-tidal	0	5.6	33.2	45.8	15.4	0	84.6	15.4	94.4
Shenton Avenue	Platform	18.6	17.2	22.3	28.4	13.2	0.3	86.5	13.5	63.9
	Sub-tidal	0.3	10.4	21.2	18.2	27.3	22.6	50.2	49.8	66.7
AB2	Platform	5.5	17.0	22.1	26.0	24.7	4.7	70.6	29.4	72.8
	Sub-tidal	1.8	13.5	25.2	31.6	23.1	5.0	72.0	28.0	79.8
Beaumaris	Platform	1.3	4.4	10.0	36.7	45.9	1.8	52.4	47.6	92.6
	Sub-tidal	7.5	3.0	6.0	13.4	47.8	22.3	29.9	70.2	67.2
AB1	Platform	1.3	11.7	40.3	40.3	6.5	0	93.5	6.5	87.0
	Sub-tidal	0	2.8	16.2	32.4	36.3	12.3	51.4	48.6	84.9

Appendix D

Abalone legal versus sub legal distributions

Population of legal catch size versus sub legal (as percentage) of Roe's Abalone along Burns Beach Reef and Mindarie

Site	Depth	Legal (>60 mm)	Sublegal (<60 mm)
Mindarie	Platform	24.9	75.1
	Sub-tidal	62.5	37.5
AB4	Platform	10.7	89.3
	Sub-tidal	40.5	59.6
Burns Beach	Platform	11.4	88.6
	Sub-tidal	76.7	23.3
AB3A	Platform	5.7	94.3
	Sub-tidal	15.4	84.6
Shenton Avenue	Platform	17.9	82.1
	Sub-tidal	52.5	47.5
AB2	Platform	29.4	70.6
	Sub-tidal	28.0	72.0
Beaumaris	Platform	55.0	45.0
	Sub-tidal	70.2	29.9
AB1	Platform	6.5	93.5
	Sub-tidal	48.6	51.4

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Roe's Abalone Environmental Sensitivity

1058_01_006/1_Rev0

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Roe's Abalone Environmental Sensitivity

Prepared for

Strategen Environmental Consultants Pty Ltd

Prepared by

BMT Oceanica Pty Ltd

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Review

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A	M. Westera	Technical review	22/09/15
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Acronyms

BPPH	Benthic primary producer habitat
DBL	Diffuse boundary layer
EP Act	*Environmental Protection Act (1986)*
EPA	Environmental Protection Authority
ESD	Environmental Scoping Document
ha	Hectares
LAU	Loss assessment unit
MMP	Marmion Marine Park
NCA	Non-geniculate coralline algae
PER	Public Environmental Review
WA	Western Australia

Executive Summary

Potential impacts on the Roe's abalone (*Haliotis roei*) local population along Burns Beach Reef (immediately north of the proposed Ocean Reef Marina Development; hereafter referred to as the Development) is an environmental issue of substantive public sensitivity associated with the proposed Development. This is due to the commercial fishery value and the importance of the reef to the popular and heavily utilised recreational fishery. Certain elements of the proposed Development such as sedimentation plumes, changes in hydrodynamics, changes in fresh water fluxes, and changes in wrack deposition may alter the population demography of abalone along Burns Beach Reef.

Roe's abalone is a relatively simple organism that inhabitants an ecosystem which is relatively harsh. Although the abalone do not appear to play a significant role in the trajectory of the ecosystem state or in direct competition with other trophic level species, changes in the ecosystem (such as vegetative community shifts) have been shown to dramatically affect abalone population success. In particular, Roe's abalone at Burns Beach Reef may be sensitive to certain changes in the physico-chemical environment at the reef level. Often a combined effect from multiple changes to the ecosystem can result in an alternative stable state. This could occur from significant changes in nutrients and sediments that may combine to produce algal community changes, including reductions in the required substratum (non-geniculated coralline algae) for larval recruitment. Often changes in nutrient and sediments occur from changes in hydrodynamics at the reef scale. The reef is in equilibrium within the variation of the hydrodynamics in place historically, and significant changes may affect the reef community and thus Roe's abalone in multiple ways – these include changes in the ability of the current to carry and deposit sediments and also drift algae, which is the key food source for Roe's abalone at Burns Beach Reef. Regional changes in sea temperature may also affect the abalone by altering growth rates, larval success, regional recruitment success and the effect of pathogens on a population.

Sediment and water quality are largely variable in the natural environment, and the ability of the reef to resist ecosystem changes will likely depend on the magnitude, duration and extent of the changes to these parameters. Although significant changes in the physico-chemical environment at Burns Beach Reef may have an impact on Roe's abalone, it is difficult to understand what the effects will be as the Burns Beach Reef ecosystem is a complex interactive system with many feedback mechanisms that may compensate for one change or multiply another.

1. Introduction

The City of Joondalup proposes to upgrade and expand the existing marine facilities at the Ocean Reef Boat Harbour, hereafter referred to as the Development. The Ocean Reef Marina Proposal is located in the Ocean Reef locality, ~29 km north of the Perth central area, Western Australia (WA), and lies adjacent to Marmion Marine Park (MMP) (Figure 1.1).

The Ocean Reef Marina Proposal includes (Strategen 2014):

- construction of two new outer breakwaters
- removal of the existing breakwaters from the boat launching harbour
- dredging of sand and rock inside the harbour
- disposal of dredge spoil into land reclamations inside the breakwaters
- construction of jetties to support piled boat mooring pens
- operation and maintenance of the marina.

The existing Ocean Reef Boat Harbour is located outside the boundaries of the MMP. However, the Ocean Reef Marina Proposal Development Envelope will extend into the boundaries of the MMP. The Development Envelope extends 100 m from the project footprint and encompasses the proposed area to be annexed from the MMP. The actual Ocean Reef Marina Proposal project footprint is ~8.6 ha while potential footprint-related benthic primary producer habitat (BPPH) loss (direct and indirect) is estimated to encapsulate ~42 ha, which includes a 50 m halo and all the area encompassed by the project footprint.

The Ocean Reef Marina Proposal is being assessed by the Environmental Protection Authority (EPA) under Part IV of the *Environmental Protection Act (1986)* (EP Act) at the level of Public Environmental Review (PER). The Environmental Scoping Document (ESD) (EPA 2014), approved in consultation with the proponent by the EPA, states that the key environmental factors for the Ocean Reef Marina Proposal include:

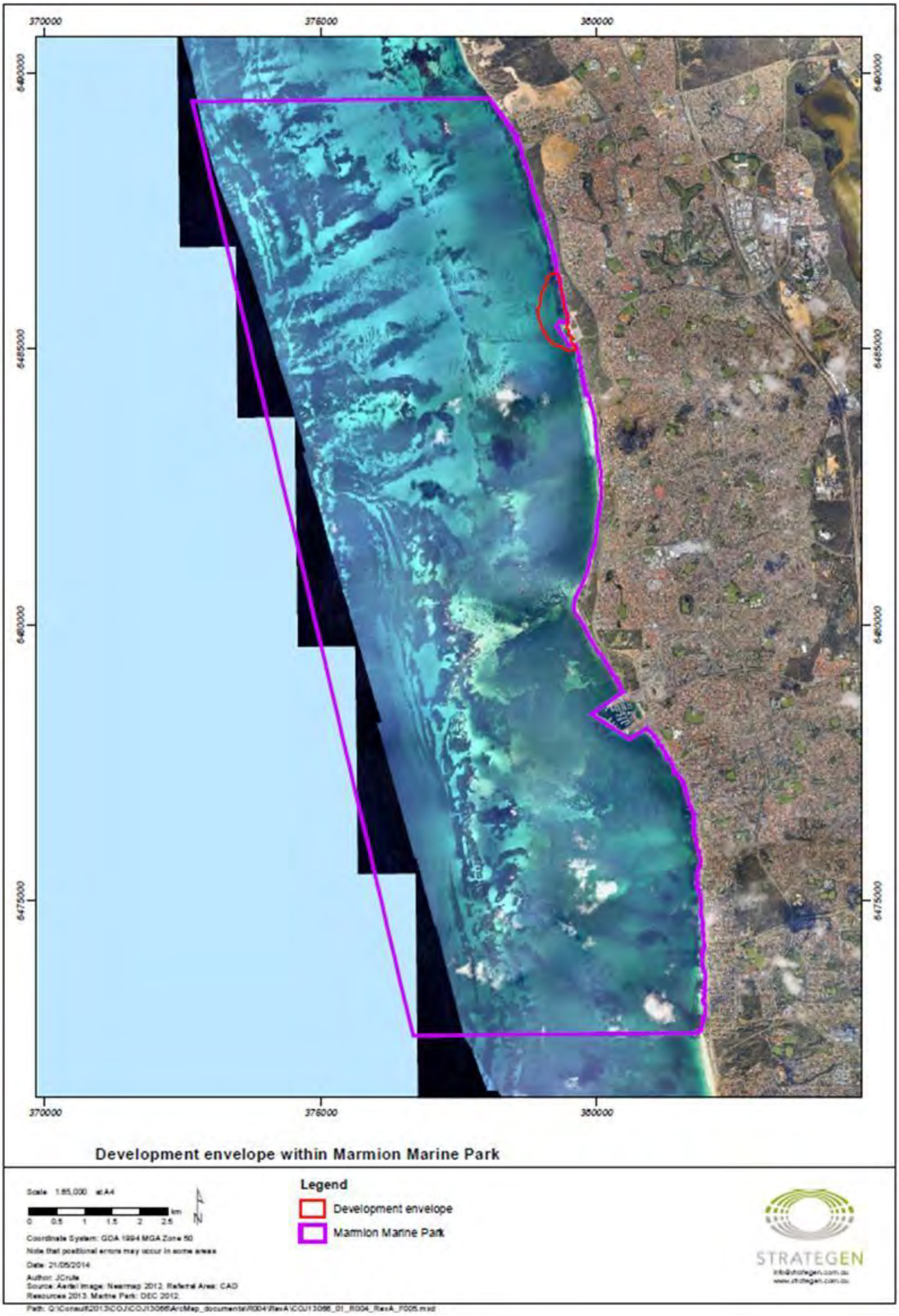
- marine environmental quality
- benthic communities and habitat
- marine fauna
- coastal processes
- integrating factors – offsets.

Potential impacts on the local Roe's abalone (*Haliotis roei*) population along Burns Beach Reef (immediately north of the proposed Development) is an environmental issue of substantive public sensitivity associated with the proposal. Burns Beach Reef contributes to the metropolitan commercial and recreational abalone fishery. Based on the high productivity and value of the metropolitan fishery, there will likely be significant attention paid to the future impact assessment and ongoing monitoring of the local abalone population on Burns Beach Reef.

This review of the Roe's abalone will assist in satisfying specific requirements of the Ocean Reef Marina Environmental Scoping Document (EPA 2014; Assessment Number 2012); i.e.:

"*elements of the proposal which may potentially affect marine fauna (Roe's Abalone), including both direct and indirect impacts and for both construction and operation"* and *"Impact predictions are to include both short- and long-term....predictions are to include how the proposal may change food availability as a result of a shadowing effect of the breakwaters and impacts resulting from changes to water quality during construction and operation*".

Certain elements of the proposed Development such as sedimentation plumes, changes in hydrodynamics, increased fresh water fluxes, and changes in wrack deposition may alter the population demography of abalone along Burns Beach Reef, but an understanding of the abalone's ecology is required to inform assessment potential impacts. This report compiles the available literature regarding abalone environmental sensitivity as a basis for environmental impact assessment of the Ocean Reef Marina Development.



Source: Strategen (2014)

Figure 1.1 Ocean Reef Marina Development Envelope and Marmion Marine Park footprint

1.1 Need for desktop review of Roe's abalone

During the development of the Ocean Reef marine baseline studies, a review of the marine fauna known or likely to occur in the proposed Development area identified the Roe's abalone population on Burns Beach Reef as likely to be affected by the Development (BMT Oceanica 2015a). A concurrent study on the benthic habitats and communities within the area identified the extent of the habitat supporting Roe's abalone on the Burns Beach Reef and other reefs supporting abalone within the loss assessment unit (LAU) (BMT Oceanica 2016a). A subsequent survey was completed to determine the habitat and abundance of Roe's abalone on Burns Beach Reef to improve the understanding of the extent of the population and its distribution along the reef (BMT Oceanica 2016b). Additional studies have been completed to characterise the water quality within the immediate area (BMT Oceanica 2014) and along the extent of Burns Beach Reef (BMT Oceanica 2015b). The close proximity of the Ocean Reef Marina Proposal to the Burns Beach Reef abalone population is shown in Figure 1.2.

An understanding of the environmental sensitivities of the abalone during its life cycle and the complex interactions within the shallow reef ecosystem are required for assessing the potential impacts from the Development. This review of existing knowledge will assist in identifying potential environmental sensitivities of the abalone to the proposed Development, particularly focusing on the local population of Roe's abalone along Burns Beach Reef.

In order to determine potential stressors from the proposed Development – for example, changes in water quality, wrack dynamics, sedimentation and hydrodynamics – a review of the Roe's abalone biology and ecology is required to assist in understanding potential sensitivities of this species.

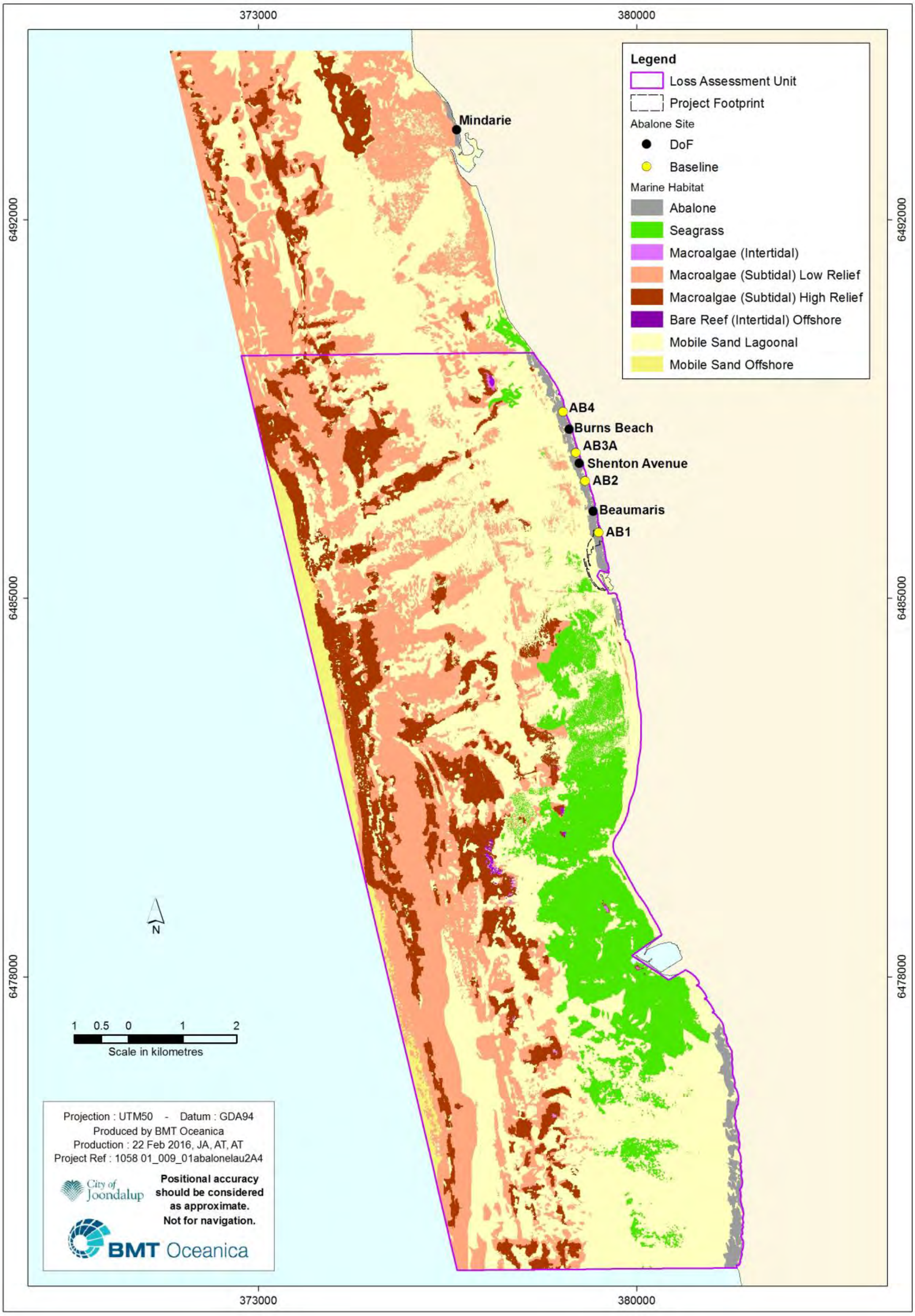


Figure 1.2 Abalone populations within the area of the Ocean Reef Marina Proposal

1.2 Existing studies on Roe's abalone

Fisheries-based research on Roe's abalone in WA has followed the extensive commercial and recreational fisheries that have developed since the 1960's. A significant portion (~42%) of the Roe's abalone catch is in the Perth metropolitan area. Substantial research has been completed on Roe's abalone in the Perth metropolitan area during the past 20 years due to the increasing popularity and value of both the commercial and recreational fisheries. Work specific to metropolitan reef ecosystems that is either directly related to Burns Beach Reef, or potentially linked to Burns Beach Reef via recruitment processes, has included:

- Studies on reproduction, feeding and growth of *H. roei* (Keesing & Wells 1989, Wells & Keesing 1989).
- Evaluation of population characteristics of *H. roei* on intertidal platforms (Wells & Keesing 1990).
- Research on molluscan grazing and macroalgal zonation on rocky intertidal platforms (Scheibling 1994).
- A PhD thesis focussed on the *H. roei* fishery, with a significant amount of the research completed at Burns Beach Reef (Hancock 2004).
- An assessment of invertebrate populations on intertidal platforms in the Perth metropolitan area (Trigg, Watermans Bay and Cottesloe; Wells et al. 2007). This was a comparison of data collected in 1982–1985 with data collected in 2007, with Roe's abalone as a significant focus of study.
- Annual surveys of *H. roei* size and density conducted along permanent transects at sites around the Perth metropolitan area since 1996 by the Department of Fisheries (DoF; WA Fisheries and Marine Research Laboratories, Mollusc Research team). Three of these sites (Beaumaris, Shenton Avenue and Burns Beach) are within Burns Beach Reef and a fourth site is located immediately north of Mindarie Marina (Figure 1.2).
- Western Australia Department of Fisheries annual fishery status reports (Hart et al. 2013) – these are a review of the catch and sustainability of the WA abalone fisheries both in the Perth metropolitan area and state-wide.

Although clearly well-researched as a fishery, details of the ecology of these molluscs are limited.

1.3 Purpose of document

The purpose of this document is to summarise the current state of knowledge about the relevant biology and ecology of Roe's abalone in the Perth metropolitan area in relation to potential sensitivities of the species to changes in environmental parameters.

1.3.1 Objectives

The objectives of this document are to present:

1. the known relevant biology, habitat requirements, behaviour and ecology of the Roe's abalone
2. information from previous literature regarding abalone population decline or collapse
3. potential environmental sensitivities of the Roe's abalone along Burns Beach Reef.

2. Physiology of Roe's Abalone

Abalone have been harvested as a food source for centuries. In the 4th century, Aristotle called abalone 'sea ears', from which the genus name *Haliotis* was derived (Shepherd & Edgar 2013). They were scientifically described by Gray (1826). Abalone are part of a primitive group of gastropods, and are a family of reef-dwelling marine snails. The full taxonomy of Roe's abalone is:

Kingdom – Animalia
Phylum – Mollllusca
Class – Gastropoda
Clade – Vetigastropoda
Family – Haliotidae
Genus – Haliotis
Species –- *Haliotis roei*

Eleven species of abalone are known in WA (DoF 2011). Five of these species, including Roe's abalone, exist in the southern temperature reef areas of WA (Shepherd and Edgar 2013). Three species are large enough in size to be fished (Hart et al. 2013):

- brownlip abalone (*Haliotis conicopora*)
- greenlip abalone (*Haliotis laevigata*)
- Roe’s abalone (*Haliotis roei*).

2.1 Physiological characteristics

The physiological characteristics of a species such as anatomy, mobility, life cycle, growth rates and mortality will determine the ability of that species to adapt or escape effects of disturbance.

2.1.1 Anatomy

Roe's abalone are the smallest of the abalone commercially harvested in WA, with a maximum size of ~110–120 mm shell length. Their shell is made from layers of calcium carbonate known as nacre or 'mother of pearl', which develops characteristic respiratory pore holes during the post larval growth stage (Koike 1978). These pores allow the passage of exhalant current after water has being through the gills. In this exhaled current, waste and reproduction products are also discharged (Shepherd & Edgar 2013). The shell grows from the peristome on the right hand side of the animal, and forms a relatively flat shell with a single apex. A 'foot' is attached to the shell with muscle tissue, and the abalone moves by contracting this muscle. An epipodium is found along the edge of the abalone foot. Epipodial tentacles line the epipodium, and these tentacles supply sensory organs for determining movement and obstacles. These tentacles tend to have distinctive colouration, on which many of the common abalone names (e.g. greenlip) are based.

Along the right side of the shell, a thin mantle extends from the muscle attachment. This mantle has glands that secrete the shell material. The internal organs are in a circle around the muscular foot and include digestive, respiratory, circulatory and reproductive systems. The head and mouth are near the most recently formed respiratory pore. The anus is at the end of the slit in the mantle under the last open hole. At the head, there is a mouth, a pair of oral tentacles, a pair of eyes and an internal radula. In the early growth stages, abalone graze the surface of the reef using the radula, which is a rasping tongue with rows of 'teeth' that collect and breakdown food. In the juvenile and adult stages, the mouth is used to collect drift algae.

The eyes are light sensitive, and the oral tentacles are used to sense the surrounding area. Gills are located behind the head on the left hand side under the respiratory pores. Within the area under the open pores, cilia create a constant flow through the head to the gills, past the anus and apex and out the pores. This supplies oxygenated water for the gills, removes waste products and also provides a mechanism to broadcast gametes during spawning. The reproductive organs (gonads) are on the opposite side of the animal from the pore holes. During spawning, the female and male abalone expel eggs and sperm, respectively. At the back of the abalone is an apex and heart. The apex is a digestive organ located under the apex of the shell, with the heart adjacent. Interestingly abalone do not have blood clotting abilities, and will therefore bleed to death if cut.

2.1.2 Mobility

Larval abalone develop bands of cilia for propulsion within 24 hours of hatching. As the abalone enters the veligar growth state it develops a velum, which is similar to fins or wings used for propulsion. During this stage the larvae will vertically traverse the water column until they become competent to settle (i.e. have developed a foot). Once settlement is complete and metamorphosis has occurred, post larval abalone will remain on the substratum where they originally settled. This substratum will be almost exclusively a non-geniculated coralline (NCA) alga (see Section 4.2). During this growth stage, the pre-juvenile abalone will travel using their foot to find diatoms and bacteria to eat. Juvenile and adult Roe's abalone tend to remain in their 'home scars' or other cryptic sites during the day to protect themselves from daytime predators, but at night they use their foot to move to the reef surface to position themselves to intercept drift algae passing in the current (Shepherd 1972). Once in position they partially prop their shell up on the incoming current side (by ~10 mm) to maximise catchment of drifting algae (Shepherd 1972). The abalone's foot is connected to the shell with a strong muscle that allows the abalone to clamp down on the substratum in case of danger.

2.2 Life cycle

2.2.1 Timing of biological development

A detailed account of the biological development of another abalone species, *H. tuberculata,* is presented in Kioke (1978). Although the development of Roe's abalone may be different, the development of *H. tuberculata* is summarised below to represent the potential timing of development prior to the juvenile stage. During the study by Kioke (1978), fertilized eggs occurred from the contact of eggs and sperm and measured 0.21 mm diameter. First division took place within 1 hour and 50 minutes of the egg being fertilized. At 10 hours (hatching), the larvae had reached the trochophore stage with cilia being present. At this point, the larvae sank to the bottom of the tank and then began swimming up and down within the water column. The abalone developed a shell during the larval veligar stage (~24 hours after hatching). Shortly after the shell developed, the foot also developed and was able to retract itself within 38 hours of hatching. At 2.5 days, epipodial tentacles and eyes were present. On day 3, settlement behaviour began and the abalone was competent to attach to the substratum with the foot. During days 4-5, the post larval abalone began to 'creep around'. Within 5–6 days, after settlement and metamorphosis was complete, the shell began to grow in the characteristic whirl shape from the peristomal shell edge on the right hand side of the animal. By day 6, complete mobility with the foot was noted. Within 30–40 days, the first respiratory pore developed and the spat measured 2.0 mm in length. A second respiratory pore developed by day 50, and spat was 2.5 mm in length. By day 85, the spat measured 3.2 mm long and had four open respiratory pores (the first respiratory pore had closed). The abalone was observed feeding on *Ulva*. On day 160, *H. tuberculata* measured 6.2 mm long.

Roe's abalone are assumed to be juvenile when they are ~5–10 mm long, as this is approximately the time they leave the NCA (where they originally settled) to find a cryptic location to remain during the daylight hours. At ~40 mm in length or 2–3 years old, abalone reach sexual maturity and become adults (Hart et al. 2013). Roe's abalone are believed to live for a maximum of ~10 years.

2.2.2 Spawning reproduction

Roe's abalone are broadcast spawners. Spawning occurs when females release eggs and male release sperm into the water at the same time. Animals tend to aggregate, as increasing distance apart reduces the fertilisation success rate (Shepherd & Edgar 2013). Spawning is triggered by sea temperature and food availability (DoF 2011). Roe's abalone in the metropolitan area have major spawning events in winter, but minor spawning event can also occur between winter and December (Wells & Keesing 1989).

Mature abalone are able to spawn at ~40 mm in length, with the 60 mm minimum catch size allowing a minimum of 1–2 years of breeding before harvest can occur (Hart et al. 2013). The number of eggs mature females can produce is correlated to overall length, as evaluated by Wells and Keesing (1989):

- 40 mm – 200 000 eggs
- 60 mm – 510 000 eggs
- 75 mm – 1 000 000 eggs
- 97 mm – 3 075 000 eggs
- 122 mm – 8 600 000 eggs.

2.2.3 Larval stage

Leighton (1974) recorded eleven stages of larval development from trochophore larvae to circular shell post larva. Once eggs are fertilized they divide and hatch out as larvae within 24 hours (DoF 2011). Trochophores have several bands of cilia for propulsion, and they either take up nutrients from the seawater or may eat phytoplankton. These trochophores develop into veliger larvae, which have velum that are similar to fins or wings used for propulsion. Overall, the larval planktonic stage lasts ~5-7 days (Shepherd & Edgar 2013).

While in the planktonic stage, larvae are dispersed by currents. The distance travelled by the larvae is dependent on current speed and tides, although they tend to settle near their natal reefs (Shepherd & Edgar 2013). Roe's abalone larvae may only travel up to 10 km and may return to their natal reefs, which results in isolated genetically differentiated populations (Hancock 2004).

As the larvae prepare to settle, the veliger develops a foot and is attracted to the substratum by chemical cues from NCA (See Section 3.4.2). Some evidence suggests that they may also be attracted to mucus trails from conspecifics (Shepherd & Turner 1985). Settlement and metamorphosis is the end of the larval stage (Leighton 1974).

2.2.4 Post larval stage

Once settled, the veliger is triggered to metamorphose by chemicals on the surface of NCA. The development of the post larvae begins with deposition of peristomal shell, and then through to formation of respiratory pores (Leighton 1974). Abalone of 0.5–1 mm in length were only found on NCA where they originally settled (Shepherd & Turner 1985), and remain there until ~5-10 mm in size. The colour of the newly growing shell will quickly become the same as the NCA they settled and developed on, as in addition to eating diatoms and bacteria, they consume the upper layer of the NCA which contains coloured pigments. This supplies excellent camouflage from visual predators.

2.2.5 Juvenile stage

Once post larval abalone have developed a shell and reach ~5 mm, they become juveniles or 'spat' (DoF 2011). These juvenile abalone still retain the colour of the surrounding NCA (which covers the majority of barren reef surfaces), with abalone <10 mm rarely taken by fish predators due to the colour camouflage and protection from topography on crustose NCA (Shepherd & Turner 1985).

2.2.6 Mature stage

Roe's abalone in the Perth metropolitan area are known to reach maturity at ~40 mm in length, which corresponds with an age of ~1 year at Watermans Bay (Wells & Keesing 1989) or 2–3 years at Burns Beach Reef (Hancock 2004) as dependent on local conditions. Maturity of species may be at different sizes based on different growth rates at different locations (Keesing & Wells 1989), and depend on the environmental stressors present.

2.3 Growth rates

Growth rates are hard to determine as they vary based on local conditions of food availability and temperature (Leighton 1974), amongst other potential environmental stressors. Along the Perth metropolitan reefs, availability of food appeared to control growth rate assuming no infestation of boring sponge was present (Keesing & Wells 1989). Overall, growth rates are likely to be affected by:

1. differences in temperature (Leighton 1974)
2. food availability
3. periods of reproductive activity (Keesing & Wells 1989).

At Watermans Bay, size was 40 mm at 1 year (maturity), 60 mm at 2 years (legal catch size), 74 mm at 3 years, and 120 mm (maximum size) at 5 years (Keesing & Wells 1989). At Burns Beach Reef, Hancock (2004) found only 20 mm growth in the first year (compared to the 40 mm of growth at Watermans Bay; Keesing & Wells 1989), which suggests early growth is highly variable between sites which were <10 km apart. At Burns Beach Reef, growth of 6–14 mm per year for a 40 mm animal was recorded (Hancock 2004), with an average maximum size of 89 mm (Hart et al. 2013). Roe's abalone may live two years on the platform section of the reef and then move to sub-tidal regions to achieve superior growth rates, likely due to greater access to drift algae (Keesing & Wells 1989).

2.4 Mortality

Comprehensive mortality data for natural populations are hard to estimate due to historical fishing, but natural mortality of adult Roe's abalone is between 12–16% per annum (Hart et al. 2013). Roe's abalone are thought to have natural mortality at ~10 years (DoF 2011).

3. Ecology of Roe's Abalone

3.1 Burns Beach Reef habitat

Roe's abalone live in narrow cervices or on intertidal reef platforms on exposed coasts in 3–5 m of water (Shepherd & Edgar 2013). They are a benthic species that inhabits shallow, high energy reef ecosystems in very specific algal zones. They occur in patchy populations within the platform and sub-tidal regions of the reef, and remain separated due to unsuitable habitats located between populations (Morgan & Shepherd 2006).

The section of nearshore reef that provides habitat for the Roe's abalone along Burns Beach Reef is oriented roughly north–south (parallel to the shore), ~3 km long and ~100 m wide (although the reef width is inconsistent). The nearshore reef ranges from the shoreline out to ~300 m offshore to a depth of ~4–6 m. There are two distinct abalone habitats on the nearshore reef: the platform and sub-tidal. The platform section is <2 m deep and is generally the recreational abalone fishery portion; the sub-tidal section is typically 2–6 m deep and is the commercial fishery portion (BMT Oceanica 2016b).

3.2 Distribution

Abalone are widely distributed across tropical and temperate coastal areas. Roe's abalone is the only species to inhabit Burns Beach Reef. Roe’s abalone mostly inhabit shallow nearshore limestone reefs (Scheibling 1994, Hancock 2004), and can be found from Shark Bay in WA to Victoria on the southeast coast of Australia (DoF 2011). On a regional scale, sea temperatures appear to limit the distribution of abalone species. A combination of local populations in a distinctive geographic region makes up a metapopulation (Shepherd & Edgar 2013). Local populations are linked by larval dispersal (Shepherd & Edgar 2013), which is often limited by headlands and bays (Shepherd & Rodda 2001). Hancock (2004) found distinct metapopulations at reefs within 10 km of each other in the Perth metropolitan area. Within populations, abalone occur in patchy abundance on reefs due to limited suitable habitats, mainly due to sand inundation. Chief determinants of abalone distribution and abundance on localised reefs are:

- suitable substrates
- shelter
- food availability
- water movement
- interactions with other fauna (i.e. competition and predators) (Shepherd 1972).

3.3 Recruitment

Recruitment success is one of the key parameters to maintaining viable abalone metapopulations (Sheppard & Rodda 2001). Fisheries research has demonstrated that when a population falls below a threshold (due to overfishing or disease) and recruitment is to the natal reef, there is not enough available mature abalone to produce the minimum number of successful larvae to supply the required recruitment within a metapopulation.. As the successful larvae are reduced, there tends to be a lag time based on the population dynamics (specifically the age to maturity) of the abalone species, which results in further declines until the population either reaches an alternative stable state or a complete collapse occurs.

Recruitment strength may be limited by maximum sea surface temperature anomalies. In South Australia, it was recorded that there were four times greater recruitment rates in warm summers compared to cool summers (Shepherd & Turner 1985).

It is possible that the larger abalone in sub-tidal reefs maintain high levels of recruitment for Perth metropolitan populations (Wells et al. 2007). Large females produce much greater numbers of eggs (see Section 2.2.2). Populations with females <80 mm only have 30% of the reproductive output compared to natural populations (Wells & Keesing 1989). Fishing pressures tend to reduce the number of large mature abalone and may reduce the recruitment capability of a population.

Recruitment is also heavily dependent on availability of suitable substratum for the larvae to settle on. It is known the abalone larvae are dependent on non-geniculated coralline algae species for successful settlement and metamorphosis (see Section 3.4.2). Specific inducing molecules on the NCA interact with stereo-chemical specific receptors on the larvae to provide a fail-safe mechanism for appropriate substratum recognition by the larvae (Morse & Morse 1984). Actual contact of larvae with the surface of the NCA must occur to trigger settlement and metamorphosis (Morse & Morse 1984), which greatly reduces the risk of predation. It is known that there is a contact requirement with the chemical on the surface as the specific molecule on the NCA, and not morphological characteristics (e.g. lumpy vs flat), is the trigger that encourages the larvae to settle. When the chemical is present, the larvae will even settle on glass substrates (Morse & Morse 1984).

Recruitment is greatly reduced when the NCA is either smothered by sediments, or overgrown with filamentous turfing algae. In an experiment in Japan, abalone recruitment was measured over one year and when crustose coralline algae were wholly covered with colloidal mud-like ephiphytes, no recruitment occurred (Saito 1981).

3.4 Habitat

3.4.1 Reefs ecosystems

Multiple biotic and abiotic factors of reef ecology influence successful reproduction of Roe's abalone, including:

- depth of site
- algal community present
- canopy cover within algae community
- source of abalone larvae
- substratum for inducing settlement and metamorphosis (i.e. NCA)
- food sources available for different life stages
- other grazers present to control stable state of algal zones
- timing of food source availability (e.g. seasonality)
- available microhabitats (i.e. cryptic sites and home scars).

There are typically two main sections of the reef ecosystems supporting Roe's abalone in the Perth metropolitan area: the platform and the sub-tidal. A summary of a typical intertidal platform reef in the Perth metropolitan area is presented in Wells et al. (2007).

Hancock (2004) found that abalone densities were highest on the outer edge of the platform, intermediate in the middle of the platform, and lowest on both the inner platform and the sub-tidal zones. Roe's abalone densities at Burns Beach Reef in 2015 were relatively high across all sampling sites and typically greater on the platform compared to the sub-tidal reefs, with a similar trend in the algal zones (BMT Oceanica 2016b).

Platform

The platform section is a shallow (<2 m deep), relatively flat and high energy section of the limestone reef with crevices, multiple channels and 'pot' marks. Three zones of algae support abalone populations on the platform (Wells et al. 2007):

1. inshore portion of platform
2. *Sargassum* zone
3. bare (or barren) zone.

At Watermans Bay platform reef, the inshore part of the platform consisted of arborescent coralline red algae, various filamentous red algae, patchy *Sargassum* spp. coverage, and green algae, with *Ulva* notably abundant in summer (Scheibling 1994). A barren zone was recorded along the offshore margin and was devoid of erect macroalgae. It was highly eroded, with heterogeneous topography and a thin veneer of crustose coralline algae covering most of the substratum (Scheibling 1994). These descriptions from Watermans Bay are very similar to habitat identified at the Burns Beach Reef.

At Burns Beach Reef, the seaward side of the platform section is a barren zone that is dominated by encrusting coralline red algae and bare rock. In the middle of the platform, an algal transition zone included *Sargassum* with crustose and filamentous coralline algae. The zone nearest the shore, where abalone abundance discontinued, contained larger macroalgae canopy of *Sargassum*, with *Ecklonia* and foliose red algae. As in many Perth metropolitan reefs, the Roe's abalone live in the seaward portion of the *Sargassum* zone (Hancock 2004, Wells et al. 2007). In Tasmania, canopy covering foliose red algae was negatively correlated with blacklip abalone abundance, highlighting the role canopy cover plays (Valentine et al. 2010).

In the Perth metropolitan area, abalone, limpets, and chitons are abundant in the barren zone of reefs but are limited to small restricted pits in the algal zone (Scheibling 1994). Other invertebrate grazers (such as sea urchins) are typically absent on the platforms (Scheibling 1994), as was the case at Burns Beach Reef. A herbivorous fish (western buffalo bream, *Kyphosus cornelii*) schools on the platform during summer (Scheibling 1994). Forty-eight species of mollusc were found within the Perth metropolitan reef ecosystem during a survey in 2007 (Wells et al. 2007). The bare zone of the platform has 10–15 species of molluscs (Wells et al. 2007), including the greatest density of Roe's abalone.

Subtidal

The sub-tidal section is deeper (2–6 m) and rises abruptly to the platform section. The topography is much more tortuous than the platform reef, with caves and deep ledges. It is dominated by large canopy forming algae such as *Ecklonia* and *Sargassum.* Wave energy is reduced in this section of the reef. *Ecklonia* movement is thought to increase NCA coverage because it shades out turf algae (which causes accumulation of sediments that smothers NCA; Daume 2013). Although overall, an increase in algal canopy cover resulted in a decrease in abalone (Scheibling 1994). The amount of algal canopy cover may be limited by limpets and chitons, as they eat spores and germlings of macroalgae and clean crustose coralline algae (Scheibling 1994).

3.4.2 Non-geniculated coralline algae

NCA induce settlement of invertebrate larvae such as soft octocorals, scleractinian corals, polychaetes, limpets, chitons, asteroids, sea urchins and abalone (Daume 2013). It has been shown that crustose coralline algae cover was positively correlated with abalone abundance (Valentine et al. 2010). In South Australia, newly metamorphosed larvae of Roe's abalone settled on *Lithothamnia,* and it was noted that at <10 mm size these abalone were the same colour as the settlement substratum (Shepherd 1972) – as indicated earlier (Section 2.2.4), this produces excellent camouflage from visually oriented predators. Macromolecule fractions from red algae induce settlement and metamorphosis. There are high levels of these macromolecules in many forms of red algae, but they are only available at the surface in NCA (Morse & Morse 1984) which allows for substratum species specific recruitment.

The surface micro-environment of the NCA (i.e. oxygen levels, microalgal growth, surface topography, water flow and pH) is critical for larval settlement and subsequent survival (Daume 2013). Grazing by limpets, chitons, gastropods and sea urchins removes filamentous algae, diatoms and bacteria from the coralline surface and keeps it clean (Daume 2013). Sea urchin grazing on NCA can have an adverse effect on NCA if they remove too much surface layer (Daume 2013). At Burns Beach Reef, sea urchins were not noted in the 2015 Roe's abalone survey.

The thickness of the oxygen diffuse boundary layer (DBL) will limit success of post larval invertebrates based on their size. The DBL can be adversely affected if there is inadequate water flow, a biofilm of detritus, substantial microalgal growth, a significant protozoa and/or bacteria accumulation or sedimentation present on the surface of the NCA. When this occurs, the DBL can become >1 mm and thus the 0.5 mm larvae can become oxygen stressed (Daume 2013). Grazing and adequate water flow reduces the DBL and improves conditions for post larvae (Daume 2013). Post larval abalone graze the biofilms, microalgae growth, diatoms and bacteria from the surface of the NCA.

3.5 Diet

All abalone species are herbivorous and show a strong preference for red algae (Shepherd & Edgar 2013). During the larval stage, the primary food source is the yolk sac, potentially supplemented with filtering nutrients out of the water column. During the post larval stage, they eat diatoms, bacteria and the upper layer of the NCA. As juveniles, they switch to eating mainly drift algae, as diatoms and bacteria do not contain enough energy to support the increase in growth although may remain as supplementary food. As adults, Roe's abalone feed mainly on drift algae (as recorded at Burns Beach Reef), but may also graze on turf algae and microalgae films. It has also been recorded that Roe's abalone may only be grazers (Shepherd 1972), but whether they graze or feed on drift algae may depend on food availability (Scheibling 1994). Striated rasping marks were noted around abalone home scars, which may represent grazing on filamentous turf algae and microalgal films (Scheibling 1994). At Perth metropolitan reefs, their chosen feeding mechanism is likely based on seasonal food availability (Wells & Keesing 1989). A wide variety of algae was eaten by Roe's abalone depending on the availability and seasonality (Wells & Keesing 1989).

Some of the leathery brown algae have high phenolic contents, which are chemical deterrents to grazers (Shepherd & Edgar 2013). Roe's abalone seem to be an exception, as they will feed on fucoids such as *Ecklonia* and *Sargassum* spp. (Shepherd & Steinburg 1992, Wells & Keesing 1989)

3.5.1 Feeding behaviours

In the Perth metropolitan area, Roe's abalone appear to prefer feeding on drift algae over grazing. There are three advantages to feeding on drift algae:

1. less foraging, as foraging exposes animals to predation
2. drift algae contains a high diversity of algae and seagrass species
3. animals are able to rest in protected or cryptic sites during the day and still feed (Shepherd & Edgar 2013).

To escape fish predators, Roe's abalone stayed in crevices during the day (Shepherd 1972), as did its main predator, the crab. Crabs became active from an hour before dusk to an hour after dusk. The abalone did not actively move around the boulders until an hour after dusk, when the crab discontinued its activity (Shepherd 1972). As juveniles, abalone >10 mm moved from settlement substratum to cryptic sites under boulders (Shepherd 1972), used as daytime hiding places. Adult abalone feed at night by grazing upper portions of the boulders on the reef (Shepherd 1972). The feeding activity of Roe's abalone recorded in the Perth metropolitan area over a 24 hour period was summarised by Wells and Keesing (1989) as:

- 0800–1600: abalone in resting position
- 1600: 10% of abalone in feeding position
- 1800 (at dusk): 40 % of abalone in feeding position
- 0200–0400: >90% of abalone in feeding position
- 0800: 4% of abalone in feeding position.

It is thought the Roe's abalone may live ~2 years on the platform before moving to the sub-tidal area to achieve superior growth rate. This increased growth rate is thought to be related to the greater amount of drift algae available to trap (Keesing & Wells 1989).

The seasonality of food availability in the Perth metropolitan area can be seen in abalone gut contents. Gut content volumes were at a minimum in January and remained low until April. Volumes increased from June to August (when at a maximum), and then slowly declined until January (Wells & Keesing 1989). Within the guts of Roe's abalone in the Perth metropolitan area, over 60 taxa of algae and seagrass were identified, although seagrass was only a minor component (Wells & Keesing 1989). *Sargassum* was the largest component of gut content, although Ulva was also a common component during spring and summer when it is naturally abundant (Wells and Keesing 1989).

3.6 Predators

Abalone have multiple predators depending on the life cycle stage. The larval stages are preyed upon by anemones (Shepherd & Edgar 2013), terebellid polychaetes, copepods and nematodes (Shepherd & Turner 1985). The post larval stages (<5 mm length) are preyed upon by flatworms, nemerteans, asteriods and crabs (Shepherd & Edgar 2013). As juveniles 5–20 mm in length, they are preyed upon by wrasses, fish, crabs, whelks and asteroids (Shepherd 1973, Shepherd & Edgar 2013). Larger abalone (>20 mm) are preyed up by stingrays, gropers, wrasses, lobsters, octopus and asteriods (DoF 2011, Shepherd & Edgar 2013). In South Australia, abalone predators consisted of banded sweep, sea sweep, cleft fronted shore crab, rough rock crab, spiny seaweed crab, hermit crab and annelids, with the main predator being crabs that could dislodge abalone <30 mm (Shepherd 1972). At Burn Beach Reef, significant predators of Roe's abalone likely include whelks, wrasses, crabs, octopus, and stingrays.

3.6.1 Protection mechanisms

An abalone senses for danger by protruding its tentacles and waving them about (Shepherd & Edgar 2013). When confronted by a predator (such as a sea star or whelk), an adult abalone may chose either fight or flight:

1. Once the predator is identified and within striking distance, the abalone 'mushrooms' by elevating its shell about 1 cm above stratum.
2. The abalone than twists its shell or uses a thrust behaviour in which it violently twists to ward off a seastar, or a uses a violent thrust to knock down a whelk.
3. If this fails, the abalone flees by elevating the forepart of the foot (Shepherd & Edgar 2013).

Larger Roe's abalone (>60 mm) no longer flee, and instead lock down to the reef by spreading their foot to increase adhesion and extend their sensory tentacles.

3.7 Parasites

Many of the different species of abalone in Australia have multiple known parasites. However, few appear to affect the Roe's abalone. Potential parasites in Roe's abalone in the Perth metropolitan area may include:

- shell boring polychaetes, sponges and bivalves (Jenkins 2004)
- boring whelks
- boring sponge *Cliona* spp. (Shepherd 1972)
- trematodes (1–8% of abalone had trematode infections in the gonads; Wells & Keesing 1989).

4. Interspecies Competition, Mutualism and Effect on Environment

In temperate intertidal reef ecosystems, abalone are regarded as megafauna. Fauna are classified by the following class sizes (Shepherd & Edgar 2013):

- meiofauna (1–2 mm)
- macrofauna (2–20 mm)
- megafauna (> 20 mm).

Amongst the invertebrates known to inhabit Burns Beach Reef, minimal competition for food or space is believed to occur between abalone and chitons, limpets and other gastropods. There is recognised mutualism of abalone larvae with non-geniculated coralline algae and the epizoic limpet *Patelloida nigrosulcata*, which lives on the shell of Roe's abalone. In complex reef habitats, macrofaunal gastropods can control filamentous algal growth and prevent smothering of NCA micro habitat (Shepherd & Edgar 2013). It has been shown that Roe's abalone grazing has some effect on its environment through the benefits to NCA, and thus itself; they also have a minor effect on growth of filamentous turf algae and algal spores. However overall, these effects are minor in terms of the ecosystem, as interactions of abalone in the reef ecosystem exist against a background of high natural variability (Jenkins 2004). Physical variability that may have significant influence on the state of the ecosystem includes:

- storms (particularly in the winter)
- regional changes in current speeds
- regional or seasonal temperature anomalies (Jenkins 2004).

These processes and the influence of other grazers may limit or mask the influence that Roe's abalone has on its surrounding environment.

4.1 Interspecies competition

Within the barren zone of the reef platform, invertebrate biomass is dominated by Roe's abalone (Wells et al. 2007). Abalone, limpets, and chitons are all found in the barren zone, but limited to small restricted pits in the algal zone (Scheibling 1994). Other invertebrate grazers, such as sea urchins, are absent on the reef platform (Scheibling 1994). A herbivorous fish (western buffalo bream, *Kyphosus cornelii*) schools in relatively large populations on the platform during summer (Scheibling 1994), and may compete for food availability. Although Roe's abalone dominate the biomass in the barren zones of the platform, they only accounted for 10% of variance in total algal cover (Scheibling 1994). In general, the relationship between abalone abundance and cover of algal understory is weak, and in Tasmania blacklip abalone did not contribute to variation in benthic community structure (Valentine et al. 2010). Intensive grazing by chitons and gastropods created gaps in algal beds that resulted in barren zones, with little effect from abalone. The NCA is able to persist despite grazing from the chitons and gastropods, as they are resistant to grazing (Scheibling 1994). In a Perth metropolitan study, the exclusion of either abalone or chiton/limpets from the ecosystem had no effect on each other (Scheibling 1994). Overall, it appears that interspecies competition on the reef is very low in relation to abalone.

4.2 Mutualism

4.2.1 Non-geniculated coralline algae

More than 17 species of abalone have mutualism with crustose NCA (Morse 1990, Kitting & Morse 1997). A diffuse co-evolution between abalone larvae and NCA is likely to have occurred, which supplies multiple benefits to both organisms (Morse & Morse 1984). These benefits include:

- the NCA is kept clean of the load of epibionts (sloughing of upper layer), which is digested by larvae
- larvae receive a biochemical inducer, which is absolutely required for settlement and metamorphosis
- contact induces settlement, and thus limits amount of time the larvae is at risk without shelter from predators
- NCA is a reliable source of nutrition – during the first 10 days post-settlement, the larvae feeds on the surface mucus, diatoms and bacteria; after that, the larvae will feed on epibionts and the upper layers of the NCA itself
- the larvae takes up the colour of the NCA due to ingestion of pigments, and is thus effectively camouflaged from predators
- the pitted topography of the NCA surface provides suitable microhabitats (Morse & Morse 1984).

Abalone <10 mm are rarely taken by fish predators due to colour camouflage provided by ingested NCA pigments, and protection supplied from the microhabitat on the crustose coralline algae (Shepherd & Turner 1985). In this mutualistic relationship, the NCA surface micro-environment is critical for larval settlement and survival. This micro environment includes: oxygen levels, microalgal growth, surface topography, water flow and pH (Daume 2013).

4.2.2 Epizoic limpet

In WA waters, the limpet *Patelloida nigrosulcata* lives only on the shells of the Roe's abalone and the patellid limpet (*Patella laticostata*). *P. nigrosulcata* was found on 18–95% of Roe's abalone in the barren zones of Peth metropolitan reefs (Scheibling et al. 1990). As this species is epizoic (meaning growing or living non-parasitically on the shell of the host), it does not adversely affect its host. Both species likely benefit from this arrangement, as the limpet has its own grazing area and the host is cleaned of erect macroalgae (Scheibling et al. 1990).

4.3 Effects of grazing of algal communities

Grazing of algal communities may result in or alter an existing stable state of the assemblage. In a study on intertidal platforms off Perth, the exclusion of abalone, chitons and limpets resulted in a marked increase in algal cover in the barren zone (Scheibling 1994). The Burns Beach Reef population has a comparable distribution of abalone, chiton and limpets. Abalone did not have an effect on algal cover when chitons and limpets were present, although they did limit algal cover and abundance when they were the only grazers (i.e. absence of chitons and limpets) (Scheibling 1994). The removal of chitons and limpets resulted in the following shifts in localised algal community in the barren zone:

- after a few days – brown film of diatoms evident
- after 1 week – turf or filamentous green algae present
- after 1 month – dense low lying canopy of *Ulva rigida* (Scheibling 1994).

Removal of chitons and limpets caused an increase in *Ulva*, which in turn accumulated sand and filled in cryptic locations suitable for abalone (Scheibling 1994). Limpets appeared to be the main factor limiting the algal cover distribution and abundance (Scheibling 1994). The subsequent increase in sand and filamentous algae decreased crustose NCA availability for settlement and decreased juvenile habitat, thus limiting the available area for colonisation (Scheibling 1994). In complex reef habitats, macrofaunal gastropods can also control the filamentous algal growth and prevent smothering of NCA (Shepherd & Edgar 2013). Abalone do have some effect on filamentous turf algae, as striated rasping marks were noted around abalone home scars and may represent grazing on filamentous turf algae and microalgal films (Scheibling 1994).

The importance of grazers in the maintenance of a stable state within a shallow reef ecosystem that supports abalone is highlighted in several experiments examining the effect of removing grazers from coralline habitat, and which resulted in an increase in filamentous turf algae. This turfing algae overgrew the NCA, trapped sediments and resulted in death of the NCA, with no recovery of the NCA after the reintroduction of grazers. The growth of ~5 mm of filamentous turf algae occurred during the 65 days in which grazing was excluded, which in turn caused the accumulation of sediments a few millimetres thick and resulted in the death of NCA. The subsequent reintroduction of grazers removed the turf algae within 7 days, but the dead NCA community never recovered (Daume 2013).

5. Population Dynamics of Roe's Abalone

Abalone interact with the reef ecosystem through multiple natural mechanisms including feeding, competition, commensalism, predation and parasitism (Jenkins 2004). These mechanisms were discussed in Sections 3 and 4, but the question remains – how do these mechanisms create stress on the abalone population and vice versa? Due to abalone being a highly sought commercial and recreational catch, and the geographic location of suitable habitat next to the Perth metropolitan area, Roe's abalone is susceptible to heavy fishing pressures and potential pollutants. In addition to this, the effects of elevated sea surface temperatures due to climate change may introduce further anthropogenic stressors on the Burns Beach Reef Roe's abalone population.

5.1 Historical changes to Roe's abalone habitat

Historically there have been small amounts of Roe's abalone habitat loss from the development and operation of the existing Ocean Reef, Mindarie and Hillary Boat Harbours. While it is difficult to determine the extent of actual habitat loss due to limited survey data, anecdotal evidence from commercial fishermen suggest the losses have reduced the extent of the spatially segregated populations in the areas adjacent to the Harbours. Some development of marine reserve areas which disallow fishing (such as Watermans Bay) have been created to stabilise and recover populations.

5.2 Current stressors on the Burns Beach Reef population

5.2.1 Roe's abalone fishery

The WA Roe's abalone fishery is a dive and wade fishery (Fletcher & Santoro 2014). Within the General Use Zone of MMP, commercial and recreational fishing of abalone is permitted but all other shellfish species are protected (CALM 1992). The commercial fishery, which was worth an estimated $2.1 million in 2012, is a harvest method with a single diver using a hookah (surface-supplied breathing apparatus) and an abalone 'iron' to prise the shellfish off rocks (Fletcher & Santoro 2014). The recreational fishery harvest method is primarily wading and snorkelling, with the main area of focus for the fishery being the Perth metropolitan stocks (Fletcher & Santoro 2014). MMP is a well known for being a very productive target area.

The reef platforms comprising Roe's abalone habitat in the Perth metropolitan area are exposed during low tide, making the recreational fishery highly accessible for large numbers of people wading out to collect abalone (while commercial divers target abalone in sub-tidal water). The recreational fishers are limited to the platform area, and to limit the competition between commercial and recreational fishers, they are not allowed to use diving equipment aids. Roe’s abalone catch numbers in the Perth metropolitan area and Western Australia statewide are listed in Table 5.1.

Table 5.1 Roe’s abalone catch numbers in Perth metropolitan area and Western Australia statewide

Fishing season – catch (tonnes)		2012/2013	2013/2014
Western Australia	Commercial	67	73
	Recreational	32	34
	Total	**99**	**107**
Perth metropolitan	Commercial	28	36
	Recreational	18	20
	Total	**46**	**56**

Sources: (Hart et al. 2013; Hart et al.2014)

The percentage of the statewide catch that was from the Perth metropolitan fishery was 47% during the 2012/2013 season and 52% during the 2013/2014 season. Recreational catch made up 32% of the total catch statewide during 2012/2013 and 2013/2014 seasons. Recreational catch made up 39% of the Perth metropolitan catch during 2012/2013 season and 36% during 2013/2014 season. The 2013/2014 Roe's Abalone Fishery Status Report assessed the Stock level as adequate and the fishing level as acceptable in the Perth Metropolitan fishery (Hart et al. 2014).

Recreational fishers

The crowds of recreational fishers are well known due to the media attention that the annual 5-day recreational abalone fishing season brings. The fishery in 2014/2015 was open from 0700–0800 on the first Sundays of November thru March only. During these times large numbers of fishers access the platform reefs and potentially cause damage to the Roe's abalone population through:

- trampling NCA and algae
- accidental death from damage to sub-legal abalone
- large number of fishers causing potential shock damage to reef (Jenkins 2004).

In 2012, there were 15 500 recreational licenses that allowed fishers to participate in the season (Hart et al. 2014). Burns Beach Reef is a focal point for these recreational fishers, with numbers increasing each year. It would be reasonable to assume this 1-hour of intensive fishing may cause substantial physical and biological damage to the reef ecosystem.

Commercial fishers

Commercial fishers do not have the fishing season restrictions imposed on recreational fishers, but are mainly limited to sub-tidal fishing by weather conditions. No direct damage is thought to be occurring to the Roe's abalone as the commercial fishers do not accidentally take sublegal abalone, but indirect effects may occur to algal communities. Effects on algal communities may be from hookah hoses, diver damage, trampling, dragging of abalone bags and potential habitat manipulation by fishers (Jenkins 2004). However, with only 26 vessels operating in WA's Roe's abalone industry and only a handful of abalone licensed divers to fish this area, the effects are likely to be minor.

5.2.2 Climate changes

Climate change has been linked to abalone *H. kamtschatkana* larvae survival and development (Crim et al. 2011). There was a 40% decrease in larval survival at elevated CO_2 levels (above 800 ppm) compared to ambient (400 ppm) levels. However CO_2 had no effect on the surviving larvae, which later metamorphosed. Larval shell abnormalities occurred to 40% of larvae at ~800 ppm CO_2, while almost all larvae (98%) had shell abnormalities or lacked a shell at 1800 ppm CO_2 (Crim et al. 2011). Ocean acidification, the ongoing decrease in the pH of the global ocean due to increased atmospheric CO_2 levels, will become a direct consequence of climate change for abalone. Increased water temperatures will also likely result from climate change, and this has been shown to compound the effects of some pathogens (e.g. withering syndrome) in abalone populations in California (Raimondi et al 2002).

5.3 Abalone population declines

Many abalone fisheries have collapsed in the last two decades due to overfishing, pollution and natural recruitment failure (Jenkins 2004). Many fisheries have experienced significant declines in abalone populations, including Tasmania and the red, pink and black abalone fisheries in California (Lafferty & Kuris 1993, Karpov et al. 2000, Raimondi et al. 2002). There have been significant population collapses in South Australia (Shepherd & Rodda 2001) and the California white abalone fishery, amongst others. In South Australia, local populations serially collapsed from upstream to downstream of larval source. This was caused by intensive fishing and a subsequent decline in recruitment, which could not be overcome through natural processes even after fishing sanctions were introduced (Shepherd & Rodda 2001). Many of the declining or collapsed fisheries have followed this same trajectory, although the declines may have also been compounded by disease (e.g. California withering syndrome).

5.3.1 Declines in Roe's abalone

From March 1981 through 31 July 1982 a temporary complete ban on taking of abalone and whelks was imposed in all WA waters between Cape Bouvard and the mouth of the Moore River. Additionally, the ban forbid taking any gastropod mollusc or sea urchin from the high water mark to 200 m seaward at any coastal locality from the southern end of Warnbro Sound to Burns Beach (Wells et al. 2007). At the time, it was believed that over collecting of abalone and other platform molluscs was due to the encroachment of recreational fishers into the commercial areas, thus adding to the fishing pressure while a new recreational interest in platform molluscs had concurrently developed (Wells et al. 2007). This temporary ban was followed by four years of research from WA Department of Fisheries and for the development of MMP from 1982–1986. A follow up study in 2007 found a lack of abalone >70 mm in fished areas, however the overall density, diversity, biomass and composition of molluscs at the three platform reef ecosystems were similar in 2007 when compared to the 1980s and within expected ranges (Wells et al. 2007).

5.3.2 Catastrophic loss of Roe's abalone

A catastrophic loss of Roe's abalone occurred in the Area 8 Roe's Abalone Fishery north of the Murchison River in WA. This complete mortality event is believed to be due to a single two-month long elevated temperature event of up to 3ºC during February and March 2011 (Pearce et al. 2011). The temperature anomaly was due to an extremely strong La Nina event, which resulted in a record strong Leeuwin Current event for that time of year (Pearce et al. 2011). The abalone kill occurred at the end of February after two months of elevated temperatures, discoloured water, poor visibility and algal blooms (Pearce et al. 2011). Additional sub-lethal events also occurred in the Area 7 fishery, which affected the >71 mm animals in the prediction for 2012/2013 (Fletcher & Santoro 2014). Restocking from translocation is currently being researched, as natural recruitment will likely not occur within the foreseeable future.

5.4 Effect of Roe's abalone on the reef ecosystem

There are components of the relationship between Roe's abalone and the other reef ecosystem processes that are not well understood. There appears to be three key relationships between abalone and its environment: grazing effects on algal communities; interspecies competition for food and habitat; and as a food source for predators. It has been shown that Roe's abalone do not play a significant role in controlling the key factor of algal canopy growth when chitons and limpets are also present, but abalone do appear to have an effect on algal establishment and turf algae growth in their absence (Section 4.3). The removal of abalone would apparently have no effect on the algal communities present, as other molluscs will complete the grazing on algal assemblages. It would also appear that Roe's abalone do not have direct competition with other algal grazers for food or space on these reefs, as most of their diet comes from drift algae (Section 4.1). There may be greater competition during the summer, when diets become reduced and food sources may be limited. Additionally, NCA are used as recruitment sites for many different species and there may be competition within this microhabitat, which has not yet been studied.

Few, if any, predator species have abalone as a significant portion of their diet (Jenkins 2004). At Burns Beach Reef, there may be a few fish and crabs that depend at least partially on abalone (at different stages of abalone growth) for their dietary intake. There may be a few species such as certain whelks that may feed only on abalone (Jenkins 2004) (Section 3.6), but these numbers are considered to be low. Potentially there may be parasites that only survive in Roe's abalone and which may be affected by the removal of the abalone, but these are yet to be documented (Section 3.7).

6. Potential Environmental Sensitivities

Abalone are megafauna with a relatively simply anatomy, but with a highly variable reproduction process that relies on water column conditions and suitable substrates for success of broadcast spawning. Competition may be low for food and space on the reef, and thus the main limitations of a successful abalone population at Burns Beach Reef may be:

1. A population of mature abalone (either at Burns Beach Reef, or another reef interconnected via water currents) that can produce sufficient numbers of fertilised eggs to survive the high variability of water column conditions prior to settlement and continue an adequate level of recruitment.
2. Sufficient cover of NCA to induce settlement and metamorphosis of larvae, while supplying a food source and protection from predators during the post larval stage.
3. Continued sources of incoming drift algae, coupled with potential supplemental food sourced on the reef (i.e. diatoms/bacteria, microalgae, filamentous turf algae).
4. A physico-chemical environment with the required microhabitats to supply protection from predators, adequate water quality (including necessary current speed) and free from pollution.

These limitations may be affected by increased deposition of sediment on the reef, increased nutrient loads, changes in temperature, alterations to hydrodynamics and fishing pressures.

6.1 Sediment deposition

Increases in sediment build up on Burns Beach Reef have two potential adverse impacts: smothering and resultant death of NCAs, and burial of suitable protection (cryptic) sites for abalone. Sediment that builds up on crustose coralline algae can quickly smother and kill the algae, and will have an immediate effect on recruitment as the NCAs are required for Roe's abalone larval settlement and metamorphosis. Inundation of sediments can result in the loss of safe habitat for juvenile and adult abalone due to cryptic sites and home scars becoming inundated with sediment, thus exposing abalone to predators. Large variations in mollusc abundance occurred when sand in-filled cracks and crevices, thus limiting molluscs to bare ridges (Wells et al. 2007). A potential offset to increased sediment deposition may be a subsequent removal by large swells or storms along these high energy reefs, as this is a natural process.

6.2 Nutrient concentrations

Nutrient shifts (e.g. increased nitrogen) sourced from either seawater, groundwater and/or sediments may favour certain algal community species (i.e. *Ulva* spp.) within the abalone populated zones on the reef, which may increase total canopy cover. Rapid increases in nutrients often result in increased foliose and filamentous turfing algae, which can reduce NCA coverage. This occurs as the turfing algae increases sedimentation due to baffling effects, and can lead to smothering of NCA. Increases in nutrients and sedimentation favours growth of turf algae (Shepherd & Edgar 2013), compared to the present algal communities in the zones that support abalone. Gorgula and Connell (2004) found that increased nutrients and increased sedimentation had an additive effect that increased turf algae by 77%. Nutrients had six times the effect on increasing turfing algae compared to sediment alone.

Although increased nutrient inputs may increase turfing algae and decrease abalone population success, the community of grazers present may be able to consume the excess turf algae and ameliorate the effect (Russell & Connell 2007). Russell and Connell (2005) completed a grazing effect study that was coupled with additions of nutrients into the system. The resulting increases in filamentous turfing algae were eaten by mollusc grazing (which they termed as bulldozing), but a more robust and taller species (*Cladosiphon filum*) moved into the cleared spaces. The effect of these other opportunistic species is not known in relation to the abalone ecology on the localised reef.

6.3 Seawater temperature

Seawater temperature has been shown to affect growth rates of abalone (Leighton 1974), the success of larvae and regional recruitment success (Shepherd & Turner 1985, Fletcher & Santoro 2014), result in mass mortalities (Pearce et al. 2011) and worsen the effect of pathogens on a population (Raimondi et al. 2002). As discussed in Section 5.3.2, a catastrophic loss of Roe's abalone occurred in the Area 8 Roe's Abalone Fishery north of the Murchison River in WA. This complete mortality event is believed to be due to a single two-month-long elevated temperature event of up to 3ºC during February and March 2011. Additional sub-lethal events also occurred in the Area 7 fishery, which affected the >71 mm animals in the prediction for 2012/2013 (Fletcher & Santoro 2014). In a Japan species of abalone, very cold water (3ºC) slowed growth compared to 8ºC (Saito 1981). Although these temperatures are not comparable with Burns Beach Reef it does highlight the importance temperature alone can have on the growth of abalone.

Increased temperatures can cause abnormal trochophore larva that do not survive, while cold temperatures can result in retardation or slowed growth (Leighton 1974). This trochophore stage of development may limit the temperature variation the abalone can successfully recruit in. Recruitment strength may be limited by maximum sea surface temperature anomalies (Shepherd & Turner 1985). In South Australia, there were four times greater recruitment rates in warm summers versus cool summers. Increased temperatures have been shown to compound the effects of some pathogens, causing additional pressure on a population in drastic decline (Raimondi et al. 2002).

6.4 Reef scale hydrodynamics

Changes in hydrodynamics at the reef scale may alter physico-chemical conditions in regions of the reef. Changes in current speeds may affect the particle sizes that can remain suspended in the water column, and potentially affect the amount and fractions of both sediments and wrack that will be supplied to the areas the abalone inhabit. These changes can also modify the coastal processes that determine where the sediment and wrack will be deposited and eroded. The effects of sedimentation are described in Section 6.1. It is not possible to predict how drift algae, generated from the breakdown of wrack, will be affected by the changes in wrack deposition and movement.

6.5 Fishing

The recreational and commercial fishing sectors at Burns Beach Reef are well known and continually studied, and are not a focus of this paper. However it should be noted that the management of the fishery has a very significant impact on the Roe's abalone population at Burns Beach Reef, and due to the scale of fishing is likely the largest single stressor on the population.

7. Summary and Conclusions

Roe's abalone at Burns Beach Reef may be susceptible to certain changes to the physico-chemical environment at the reef level. A combined effect from multiple changes to the ecosystem can result in an alternative stable state (Valentine et al. 2010), and recovery can often follow a different trajectory to the former state. If nutrients and sediments combine to produce algal community changes (i.e. increased turfing algae or changes in canopy structure), this may have adverse effect on NCA (Morse & Morse 1984, Shepherd et al. 1985, Daume et al. 1999, Valentine et al. 2010), which will in turn limit critical settlement habitat to abalone larvae during recruitment. Population loss may potentially reduce recruitment capabilities of larvae being returned to the natal reef. Sediment and water quality are largely variable in the natural environment, and the alibility of the reef to resist ecosystem changes will likely depend on the magnitude, duration and extent of the changes to these parameters.

As there is a lack of comprehensive understanding about the relationships between abalone and the other ecosystem components (e.g. competition), it is not possible to determine the effect that changes in a specific environmental parameter, or combination of changes in these parameters, will produce. The Burns Beach Reef ecosystem is a complex interactive system within which it is hard to define the potential impacts from changes in inputs, since there are many feedback mechanisms that may compensate for one change or multiply another.

Any reduction in the Roe's abalone population at Burns Beach Reef will have an effect on the fishery for both recreational and commercial license holders. If recruitment is affected, then the effect on abalone abundance may not be recognised immediately as there may be a time lag based on the population age structure. If recruitment fails, and the existing abalone population ages and declines, the process may become iterative (and potentially not capable of being reversed, leading to a complete collapse of the population). Alternately, a new steady state could occur with a similar or reduced, but stable, abalone population.

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Rockwater
PROPRIETARY LIMITED

OCEAN REEF MARINA

GROUNDWATER MODELLING TO ASSESS NUTRIENT LOADS IN GROUNDWATER DISCHARGING TO THE OCEAN AND MARINA

FEBRUARY 2015

REPORT FOR
M P ROGERS & ASSOCIATES

288-3/15/01

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1 BACKGROUND

M P Rogers and Associates is carrying out oceanographic modelling for the planned marina at Ocean Reef (Fig. 1). Rockwater was engaged by M P Rogers and Associates as a sub-consultant to provide calculated values of groundwater flows and nutrient loads, particularly in summer. These are required as an input to the oceanographic modelling.

Rockwater (2011) presented the results of flow and solute transport modelling, using nitrogen concentrations in the groundwater that were recorded in the Department of Water WIN database as source concentrations. It was noted that the nitrogen source concentrations were based on a few measurements in nearby bores that were made more than 20 years earlier, and that bores near the planned marina should be re-sampled if the nutrient loads were of concern. Sampling by Strategen (2015) indicated there were now higher nitrogen concentrations in groundwater in the area. Rockwater was requested to update the 2011 report and to:

- Recalibrate/validate the groundwater model;
- Incorporate the report on the impacts of climate change that was produced by Rockwater in 2013; and
- Use contemporary monitoring data to characterise the hydrogeology and groundwater flows into the planned marina as required by the EPA Scoping Document.

This report is an update of the 2011 report; it presents details of the groundwater modelling including groundwater flows and nutrient loads, and includes the additional information required as described above.

2 HYDROGEOLOGICAL SETTING

The planned Ocean Reef Marina is in an area of predominantly limestone and sand of the Tamala Limestone, with minor recent eolian sand of the Quindalup Dune System (Safety Bay Sand). The Safety Bay Sand consists of fine to medium grained quartz sand and shell fragments; it overlies calcareous sand and limestone of the Tamala Limestone. The Safety Bay Sand is generally unsaturated, and so the Tamala Limestone forms the Superficial aquifer inland of the marina site; with sand of the Tamala Limestone and Gnangara Sand to the east from Lake Joondalup.

The Tamala Limestone extends down to about -35 m AHD at the coast, and unconformably overlies the Osborne Formation or the Pinjar Member of the Leederville Formation, both of Cretaceous age.

The Tamala Limestone is karstic in nature, and has high permeability. Its groundwater is recharged by rainfall infiltration, and flows westwards with a water-table elevation decreasing from about 45 m AHD at Lake Mariginiup to sea-level at the coast. Groundwater flow in the Tamala Limestone is largely controlled by the location, and degree of interconnection, of solution channels within the limestone (Davidson, 1995). A study by Barber et al (1990) in an area near Ocean Reef indicated groundwater flow velocities of between 85 and 335 m/year.

Groundwater discharges to the ocean and by evaporation and transpiration from the lakes. It is extracted by bores for irrigation of parks, sporting grounds, public open space, and market gardens; and for public water supply (Whitfords and Quinns Rocks borefields).

The description of the hydrogeology in this section of the report forms the conceptual model on which the numerical groundwater model is based.

2.1 GROUNDWATER QUALITY

Groundwater salinity in the Tamala Limestone is about 500 mg/L TDS, increasing to around 1,000 mg/L TDS near the coast.

Background nutrient concentrations in the area were indicated in Davidson (1995, Plates 60 and 61) to be low: nitrate concentrations about 1 to 2 mg/L (as nitrate), and phosphorus concentrations around 0.03 mg/L. There are few nutrient data in the Department of Water (DoW) WIN (now WIR) database and those data are old (collected between 1971 and 1992) – the Total Nitrogen (TN) and Total Phosphorus (TP) concentrations are shown in Figures 1 and 2. Where there was a range of values, the highest value was used in preparing these maps. Nutrient concentrations for the bores near Ocean Reef (Table 1) indicated some elevated concentrations of TN of up to 7.1 mg/L. Also, TP concentrations were less than 0.1 mg/L with one exception (0.5 mg/L).

Table 1: Nitrogen and Phosphorus Concentrations, from WIR Database

Bore	mE	mN	TN Range	TP Range
JP4	380677	6483378	0.7-4.1	0.5
Production Bore	380790	6485260	0.9	0.08
WF1	380420	6486544	5.4-7.1	0.01
WF1 Shallow	380420	6486544	5.6	<0.01
WF13	380045	6486243	0.02-3.7	0.04-0.06
WF8	381623	6484349	0.5	0.09
WF8 Shallow	381623	6484349	3.6	0.01

There were between one and three measurements of TN and TP: where there is only one value given in the range there was generally only one measurement.

Bores installed for the marina project, and DoW bore GE5 (4931), were sampled on either one or three occasions by Strategen in 2014 (Strategen, 2015). The average nutrient concentrations are given in Table 2 and are shown in Figs. 3 and 4.

Table 2: Nitrogen and Phosphorus Concentrations Measured in 2014

Bore	Scaled Coordinates		No. of Analyses	TN	TP
	mE	mN	(2014)	(Average mg/L)	
MB01	379611	6486175	3	12.7	<0.05
MB02	379758	6485196	3	8.9	0.10
MB03	379646	6485157	3	3.0	0.05
GE5 (DoW 4931)	379910	6484989	3	4.8	0.29
CB01	379541	6485646	1	10.0	0.09
CB02	379561	6485650	1	9.0	0.06
CB03	379586	6485202	1	9.8	0.14
CB05	379685	6485140	1	7.1	0.12
CB06	379611	6485597	1	1.8	<0.05
CB07	379509	6485536	1	24.0	0.17

The results of the analyses indicate that TN concentrations in the area generally range from 2 to 13 mg/L, somewhat higher than the 1971 to 1992 values measured in other bores, as a result of fertiliser use and urbanisation at Ocean Reef and further inland. Bores CB03 and CB07 are close to septic tanks and leach drains at Ocean Reef Sports Club and the public toilets, and the high concentration at CB07 reflects its location and point-source contamination.

TP concentrations measured in 2014 ranged from <0.05 to 0.29 mg/L, a similar to slightly higher range than for the old values in the WIR database (except for the JP4 value). Strong adsorption by the Tamala Limestone will have kept concentrations low, counteracting the effects of urbanisation.

3 NUMERICAL GROUNDWATER MODEL

3.1 DESCRIPTION

The model is based on a portion of the Perth Regional Aquifer Modelling System (PRAMS) groundwater model that has been developed by the Water Corporation and the DoW. For this project the model is centred on Ocean Reef and covers an area of 19 km north–south and 19 km east–west, and uses the top two layers of the PRAMS model that compose the Superficial aquifer. Both layers represent the same aquifer, but only Layer 1 includes the ocean and wetlands – the division into two layers allows vertical components of groundwater flow to be simulated.

The model consists of a rectangular grid of 77 columns and 86 rows, and cell sizes range from 70 m by 70 m at the planned marina, to 280 m by 280 m over much of the model area (Fig. 5). It utilises Processing Modflow Pro version 8.0.42 (Simcore Software, 2010) that incorporates MODFLOW, finite-difference groundwater modelling software designed by the US Geological Survey (McDonald and Harbaugh, 1988).

Model stress periods were selected to alternate between 212 days of summer (October to April), and 153 days of winter (May to September). All of the recharge is assumed to occur during the winter and all evapotranspiration during summer.

The model was constructed with layer tops and bottoms as adopted in PRAMS (Davidson and Yu, 2008). The base of Layer 1 was then adjusted to be about 3 m below summer groundwater levels in 2010.

3.2 MODEL PARAMETERS AND BOUNDARY CONDITIONS

Values of vertical and horizontal hydraulic conductivity, specific yield and storage coefficient were initially as used previously in modelling another area immediately to the north. Values of horizontal hydraulic conductivity were varied during calibration of the model, as described in Section 3.3, below. The values adopted after calibration are given in Table 3.

Table 3: Aquifer Parameters Adopted In Model (Superficial Formations)

Parameter	Units	Tamala Limestone	Tamala/Gnangara Sands
Horizontal Hydraulic Conductivity	m/d	130 to 300	10 to 36
Vertical Hydraulic Conductivity	m/d	2	0.5
Specific Yield		0.2	0.2
Storage Coefficient (Layer 2)		0.001	0.001

The PRAMS model uses two recharge models coupled to the flow model to provide recharge rates. For a model covering an area immediately to the north, Chengchao Xu who developed the recharge models for PRAMS recommended using a recharge rate of 179 mm/a for most of the area, and this value was adopted as a starting point for the Ocean Reef model and varied in steady-state model calibration.

In the transient calibration, an annual factor was applied to the recharge values for each year modelled from 1987 to 2014 based on the rainfall each year compared to the 1944 to 2014 (Perth airport) average. The factors are a weighted percentage of rainfall above or below the average, as shown in Figure 6; they were derived to achieve calibration of a similar model of the Southern River area (Rockwater, 2005). The factors follow a curved rather than straight-line trend as there is proportionately more recharge in wet years, and proportionately less in dry years. The adopted recharge in an average rainfall year ranges from 197 mm to 255 mm per year over the modelled area.

There is a large number of groundwater licences in the modelled area, including those for Water Corporation bores. There are also many private garden-irrigation bores that are unlicensed and whose water use is unrecorded. Actual extraction rates were used for the Water Corporation bores and these were assumed to be spread evenly throughout each year. The licensed allocations of 100,000 kL/a or more were included in the model as given in the DoW Water Register and were applied in summer stress periods from the year the allocation was granted. Some very large allocations were reduced in the model where they were located close to the northern or southern model (no-flow) boundaries as modelling the full allocation would have resulted in unrealistically large declines in groundwater level. Smaller allocations were not included and were assumed to be accounted for in the (reduced) recharge rates.

Boundaries to the model include constant-head boundaries representing the ocean, and on the eastern side of the model to represent groundwater flow into the modelled area. Those representing the ocean are in Layer 1 only. The other boundaries are assumed to be no-flow boundaries as they are sub-parallel to the direction of groundwater flow; and there is assumed to be no flow into or out of the Superficial formations from the underlying Cretaceous sediments.

3.3 MODEL CALIBRATION

The model was first calibrated in steady state mode to water levels measured around mid 1987. Those levels were then used as initial groundwater levels in the model. The model was then calibrated to water-level changes measured from 1987 to 2014 in nine representative monitoring bores that have been monitored for an extended period and provide a good spread over the model area.

A comparison of model-calculated and observed groundwater levels for September–October 2014 after calibration of the model is given in Figure 7, and the comparisons of time-series plots for the nine monitoring bores are given in Figures 8 to 10. There is a close correspondence, considering the uncertainties in actual groundwater extraction in the area, and that the dates of measured and calculated groundwater levels vary by up to 50 days. Also, groundwater levels in the Tamala Limestone near the coast are affected by ocean tides.

The scaled root mean square (RMS) error for the September–October 2014 water levels is 4.63 percent; and for the time-series water levels ranges from 0.46 to 1.70 % except for 8.11 % for bore JP20C and 3.51 % for WM42. All these errors except for the time-series data for bore JP20C are below the maximum of 5 % recommended in Barnett et. al. (2012). The largest errors are for bore JP20B&C, WM42 and two other bores close to Lake Joondalup – the model doesn't well-represent the flattening of the water table through the lake, but this is irrelevant to groundwater flows to the coast and planned marina.

Post-2010 water-level monitoring data did not necessitate recalibration of the 2011 model and so validated that model. However, some recalibration was carried out to improve the RMS errors by including recent water allocations and adjusting water levels on the eastern model boundary.

The overall water balance error for the transient model is less than 0.01 %, well below the upper limit of 1 % recommended in Barnett et. al. (2012).

A scattergram of modelled groundwater levels versus groundwater levels is presented in Figure 11. Even though they are not for the same dates, there is a close correspondence for all the key bores except JP20B&C and to a lesser degree WM42 (where the data fall above the equivalence line). For the other bores, a similar number of points fall above and below the equivalence line showing that there is no significant systematic error.

3.4 SENSITIVITY ANALYSIS

Sensitivity analysis was carried out by varying the values of one parameter at a time and calculating water levels in the representative bores at the end of summer and end of winter in 2010 and comparing them with water levels from the calibrated model. The differences in water levels are given in Table 4.

Table 4: Results of Sensitivity Analysis

Parameter, And Variation	Changes In Representative Bore Water Levels (m)	
	End Of Summer	End Of Winter
Pumpage +15%	-0.05 to -0.01	-0.04 to -0.01
Recharge -15%	-0.37 to -0.04	-0.39 to -0.06
Evapotranspiration +15%	-0.22 to -0.01	-0.17 to 0.0
Horizontal Conductivity +15%	-0.31 to -0.02	-0.33 to -0.03
Vertical Conductivity +15%	-0.03 to 0.0	-0.03 to 0.0
Specific Yield +15%	0.02 to 0.13	0.0 to 0.05

The results show that the model is most sensitive to recharge rates, followed by horizontal hydraulic conductivities and evapotranspiration rates. The model is insensitive to pumping rates, vertical hydraulic conductivity and specific yield.

3.5 MODELLING RESULTS

The calibrated model was run to simulate groundwater flow with average rainfall and recharge over a 10-year period from 2014, with and without the planned marina. Model-calculated peak end-of-winter and minimum end-of-summer groundwater flows at the end of that period were applied to total nitrogen (TN) and total phosphorus (TP) concentrations that were distributed to model cells by kriging the 2014 data for the planned marina area and the WIR data for other areas, to determine nutrient loads in groundwater discharging to:

- The existing Ocean Reef harbour;
- The ocean along the section of coast that will be enclosed by the planned marina; and
- The planned marina.

Model-calculated groundwater flows for each of these cases are given in Table 5 and nutrient loads are given in Table 6.

Table 5: Calculated Groundwater Flows

Case Modelled	Groundwater Flow (kL/d)	
	End of Summer	End of Winter
To Existing Harbour	2149	3346
Existing Coast within Planned Marina	4851	7989
To Planned Marina	5022	8396

Table 6: Calculated Nutrient Loads

Case Modelled	TN Loads (kg/d)		TP Loads (kg/d)	
	End of Summer	End of Winter	End of Summer	End of Winter
To Existing Harbour	26.5	41.2	0.2	0.3
Existing Coast within Planned Marina	61.0	102.2	0.4	0.7
To Planned Marina	64.5	107.9	0.4	0.7

The calculated nitrogen loads are probably on the high side, as the elevated concentration in bore CB07 resulting from point contamination has resulted in some elevated TN concentrations in the model in the surrounding area after kriging of the monitoring data.

Groundwater will discharge to the marina and ocean through the sea bed. Sampling of sea-bed pore water by Bowman Bishaw Gorham (RPS Group) at Port Coogee indicated that most of the flow would be within 20 to 30 m of the shoreline (unless there are solution pipes in the limestone that “daylight” further off-shore).

The salinity of groundwater discharging in the planned marina is expected to be between 590 and 1,000 mg/L TDS, based on electrical conductivity measurements from bores MB01 to MB03 in 2014.

3.6 IMPACT OF ADDITIONAL CLIMATE CHANGE

The modelling described above is based on rainfalls and groundwater recharge continuing with a similar dry climate to that which has occurred since the 1970’s. The potential impacts on the planned marina of further climate change (less rainfall and higher ocean levels) are discussed below.

3.6.1 Impact of Reduced Rainfalls

Lower rainfalls would reduce groundwater levels, and hence groundwater throughflow and discharge to the ocean. They would be offset, at least in part, by increased infiltration to groundwater from runoff from roofs and roads with further urbanisation in the area inland of the marina, and reduced extraction of groundwater for irrigation of market gardens. Lowering of groundwater levels on the Gnangara Mound (upgradient of Ocean Reef) has resulted in the development of the Gnangara Sustainability Strategy (2009). Based on the strategy, the Government is planning reductions in private and public groundwater extraction, and the clearing of pine plantations that prevent groundwater recharge.

The future climate in Perth could be wetter, similar or drier than at present, although it has been widely predicted to be drier. For example, Sadler (2007) cited in DoW (2009) predicted that rainfall could decrease by 15 percent to 2030 compared to the 1980–1999 baseline, together with a -5% to -25% natural variability.

CSIRO (2009) has assessed groundwater availability in the South-West of Western Australia at year 2030 for a number of climate scenarios using 15 global climate models, including a dry extreme future climate scenario. The Perth Regional Aquifer Modelling System (PRAMS) was run to predict future groundwater levels for these scenarios, and for the dry extreme future climate case it was predicted that groundwater levels in 2030 would be similar (to those at present) near the coast at Ocean Reef and 3 m lower (than those at present) inland on the flanks of the Gnangara Mound. The modelling did not allow for the impacts of urbanisation, or for reductions in extraction and increased recharge to the Gnangara Mound.

The 2011 Rockwater model constructed for the Ocean Reef project was re-run with 20 percent lower recharge rates to give approximately 3 m lower groundwater levels inland of the planned marina. In that case, calculated flow rates to the planned new marina after 10 years with the drier climate were indicated to average 7,900 kL/d in winter and 4,600 kL/d in summer, i.e. 92 to 94 percent of the flows calculated for the current climatic conditions. The flows would continue to decline at a gradually decreasing rate until a new equilibrium was reached.

3.6.2 Impact of Higher Ocean Levels

Ocean levels are predicted to rise by 0.9 m by the Year 2110 (EPA, 2012). Higher ocean levels would change the configuration of the coastline and cause the coastal saltwater wedge in the aquifer to move further inland.

Groundwater levels will rise to match the rise in base level (ocean level) and so there will probably be only a small reduction in hydraulic gradients. As a result groundwater discharge rates will, therefore, also remain largely unchanged.

5 CONCLUSIONS

The Tamala Limestone forms the Superficial aquifer at and inland of the marina site. The limestone is karstic in nature, and has high permeability.

Groundwater salinity in the Tamala Limestone is about 500 mg/L TDS, increasing to around 1,000 mg/L TDS near the coast.

Nitrogen concentrations measured in 2014 in monitoring bores near the planned marina generally ranged from 2 to 13 mg/L, with one high value of 24 mg/L immediately down-gradient of the Ocean Reef Sports Club resulting from point-source contamination. The general concentrations are around double those recorded for other bores in the DoW WIR database that were measured more than 20 years ago. The higher concentrations have resulted from urbanisation and fertiliser use.

Total phosphorus concentrations ranged from <0.05 to 0.29 mg/L in the 2014 samples, similar to slightly higher than old measurements in the WIR database.

The results of numerical groundwater flow modelling indicate that groundwater flows to the planned marina will range from 5,000 to 8,400 kL/d. Most of the flow is likely to be within 20 m to 30 m of the shore.

Nutrient loads in groundwater discharging to the marina are calculated to range from 64.5 to 107.9 kg/d for total nitrogen, and 0.4 to 0.7 kg/d for total phosphorus, with the smaller loads (and groundwater flows) occurring in summer. The actual nitrogen loads are likely to be less than the calculated values, as the elevated value for bore CB07 has caused some higher modelled concentrations on kriging the monitoring data.

The modelling is partly based on the climate since the 1970's which has been drier than the climate in the long-term record. It is uncertain whether the climate will continue to become drier. On the basis of a drier future as predicted by CSIRO, the groundwater levels would decrease by about 3 m inland but remain at around current levels near the coast. Consequently, groundwater flow to the planned marina could decrease by up to 8% over the coming decade, and by more in subsequent decades.

Dated: 14 February 2015 **Rockwater Pty Ltd**

P H Wharton
Principal

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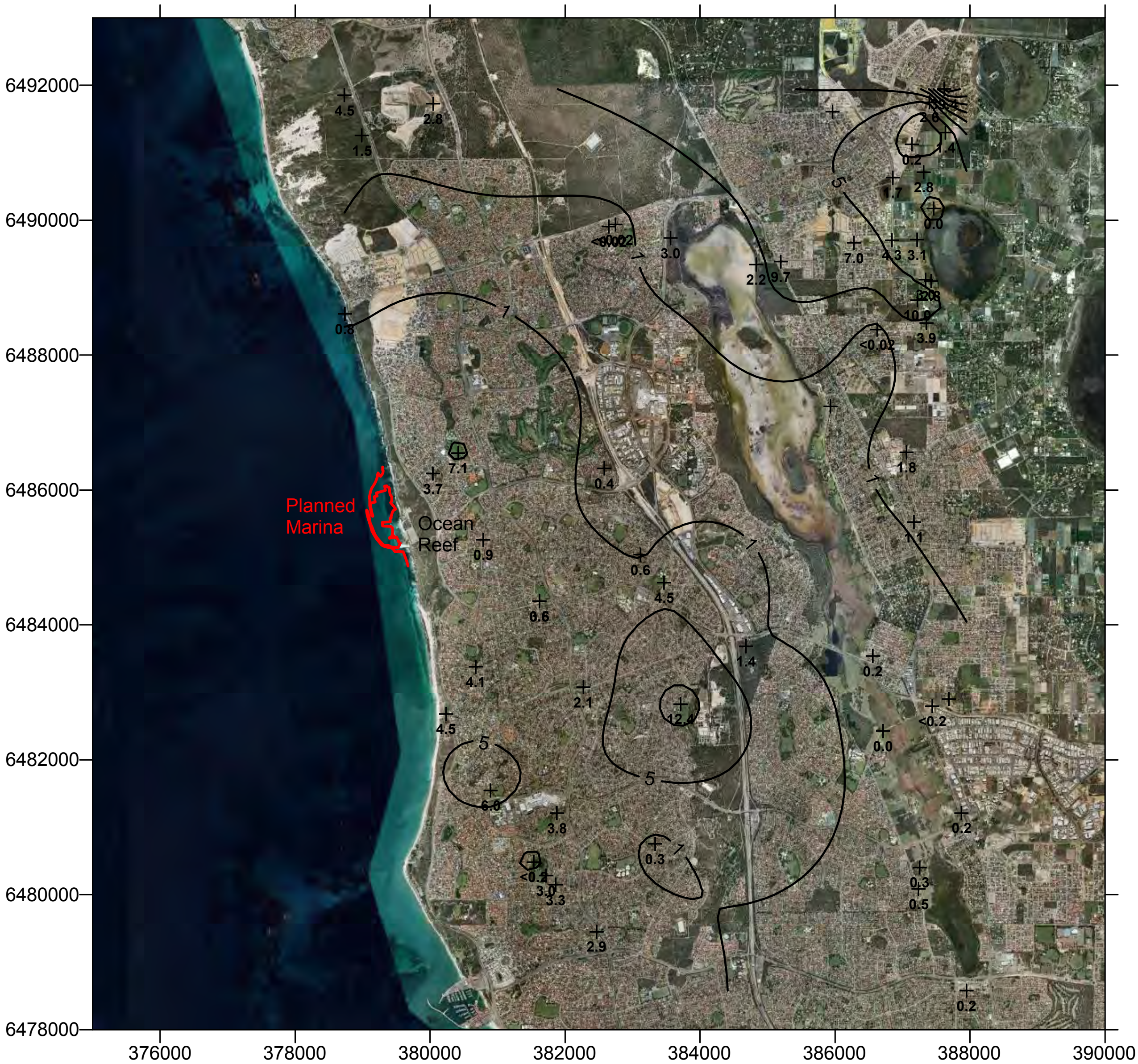
FIGURES

FIGURE 1



TN.srf

Note: highest value shown where there was more than one analysis

CLIENT: M P Rogers & Associates

PROJECT: Ocean Reef Marina

DATE: February 2015

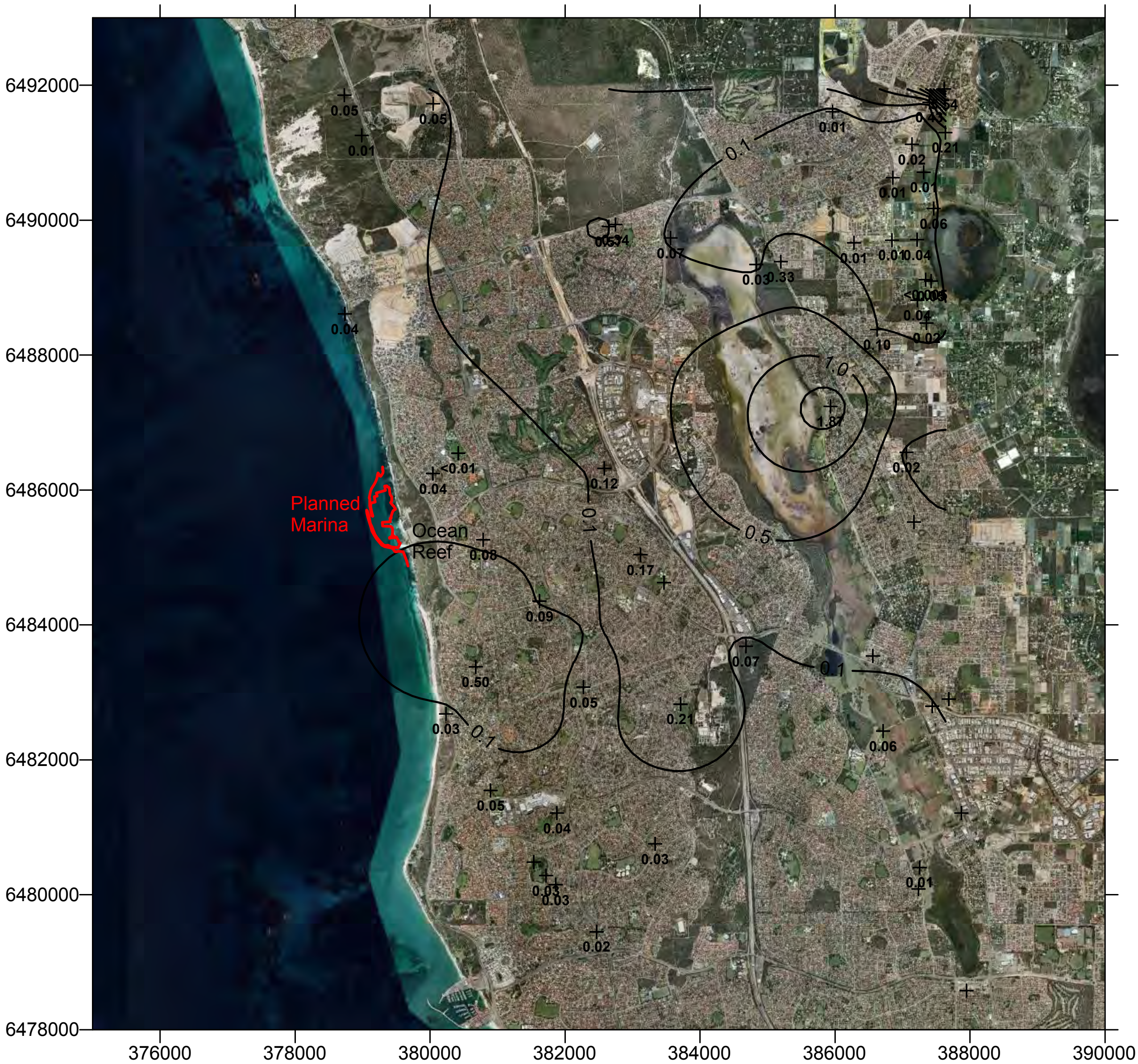
Dwg No: 288-3/15/1-1

TN CONCENTRATIONS (mg/L)

WIR DATABASE

Rockwater Pty Ltd

FIGURE 2



TP.srf

Note: highest value shown where there was more than one analysis

CLIENT: M P Rogers & Associates PROJECT: Ocean Reef Marina DATE: February 2015 Dwg No: 288-3/15/1-2	TP CONCENTRATIONS (mg/L) WIR DATABASE Rockwater Pty Ltd

FIGURE 3

TN New.srf

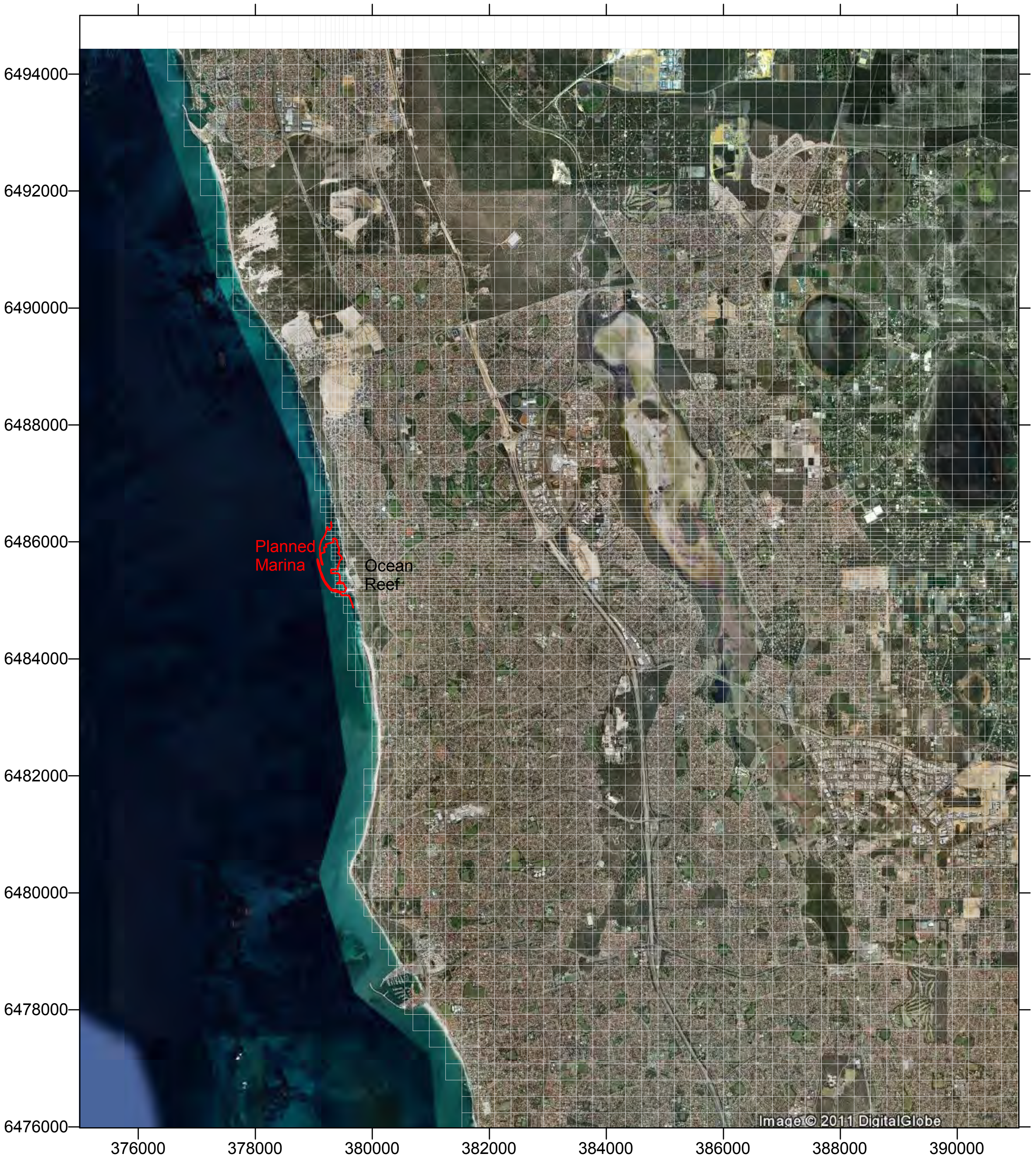
CLIENT: M P Rogers & Associates PROJECT: Ocean Reef Marina DATE: February 2015 Dwg No: 288-3/15/1-3	AVERAGE TN CONCENTRATIONS (mg/L) 2014 (STRATEGEN) Rockwater Pty Ltd

FIGURE 4

TP New.srf

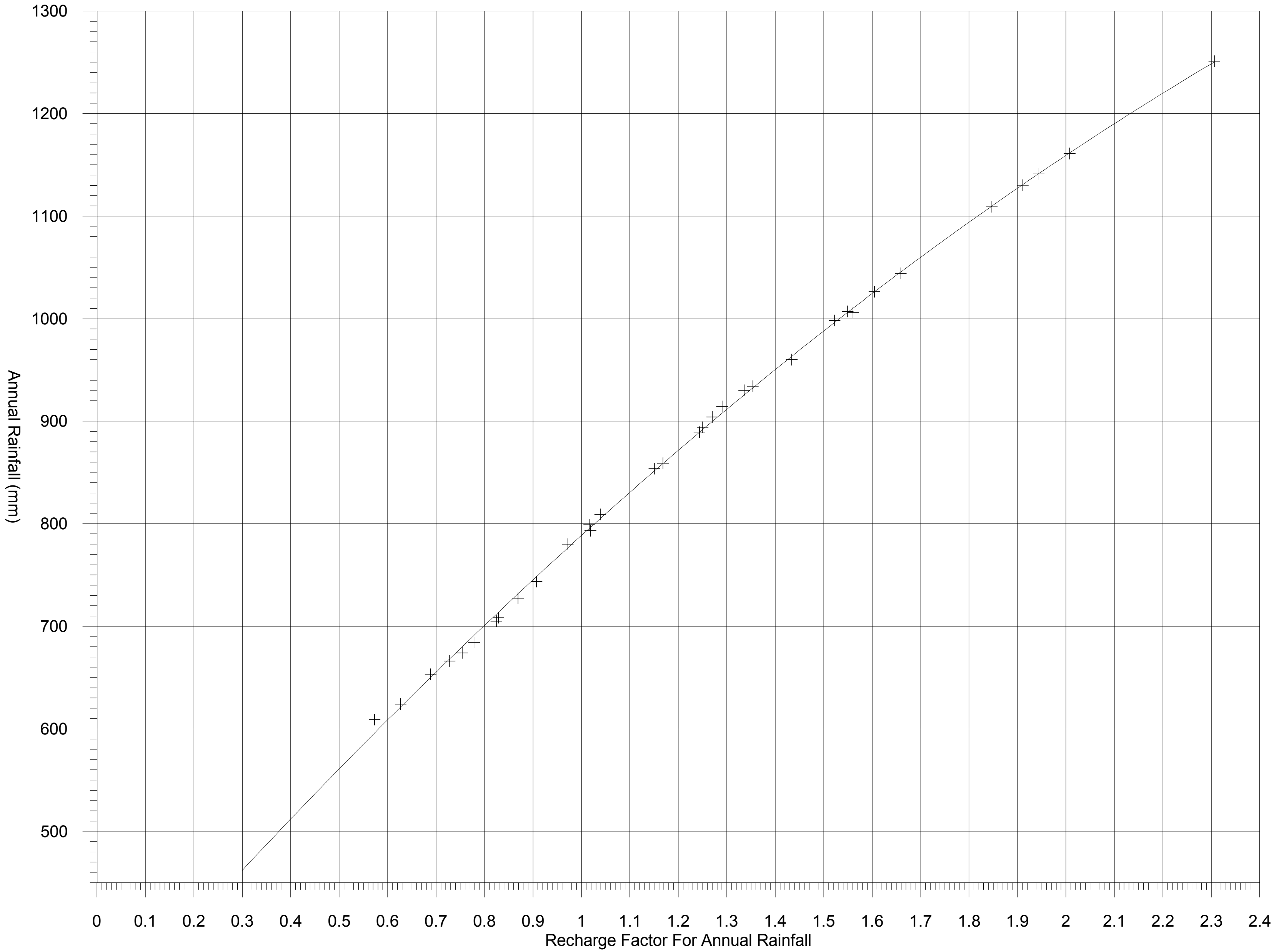
CLIENT: M P Rogers & Associates PROJECT: Ocean Reef Marina DATE: February 2015 Dwg No: 288-3/15/1-4	AVERAGE TP CONCENTRATIONS (mg/L) 2014 (STRATEGEN) Rockwater Pty Ltd

FIGURE 5



Model Grid.srf

CLIENT: M P Rogers & Associates PROJECT: Ocean Reef Marina DATE: February 2015 Dwg No: 288-3/15/1-5	EXTENT OF MODEL GRID (LAYER 1) Rockwater Pty Ltd



annual recharge multiplier.grf

Figure 6

Client: M P Rogers & Associates

Project : Ocean Reef Marina

Date : February 2015

Dwg. No: 288.3/15/1-6

RECHARGE FACTOR, FOR ANNUAL RAINFALL

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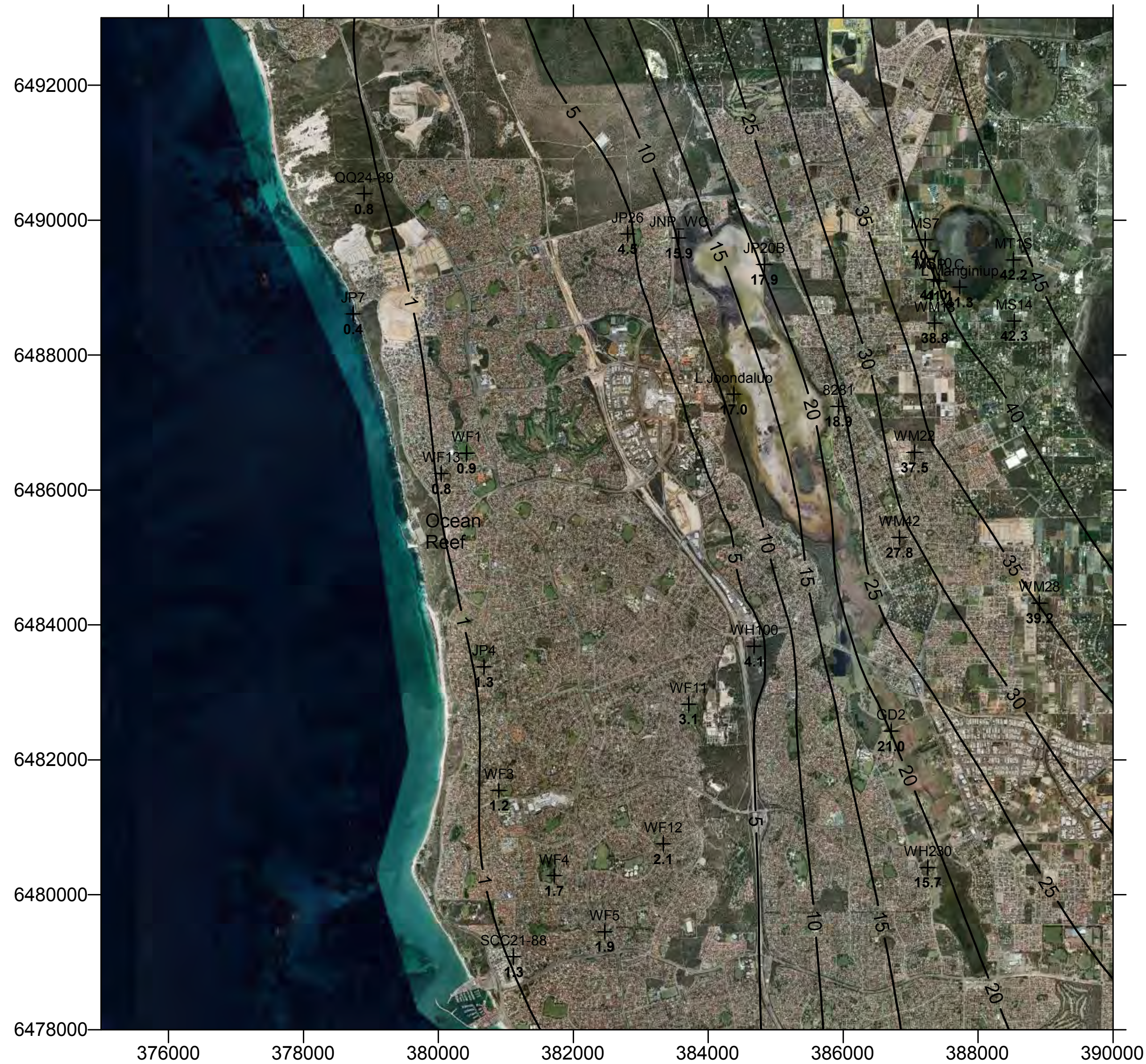
FIGURE 7



2014 wls comparison.srf

CLIENT: M P Rogers & Associates PROJECT: Ocean Reef Marina DATE: February 2015 Dwg No: 288-3/15/1-7	WATER LEVELS SEPT-OCT 2014 (POSTS, m AHD) AND MODEL-CALCULATED (CONTOURS) Rockwater Pty Ltd

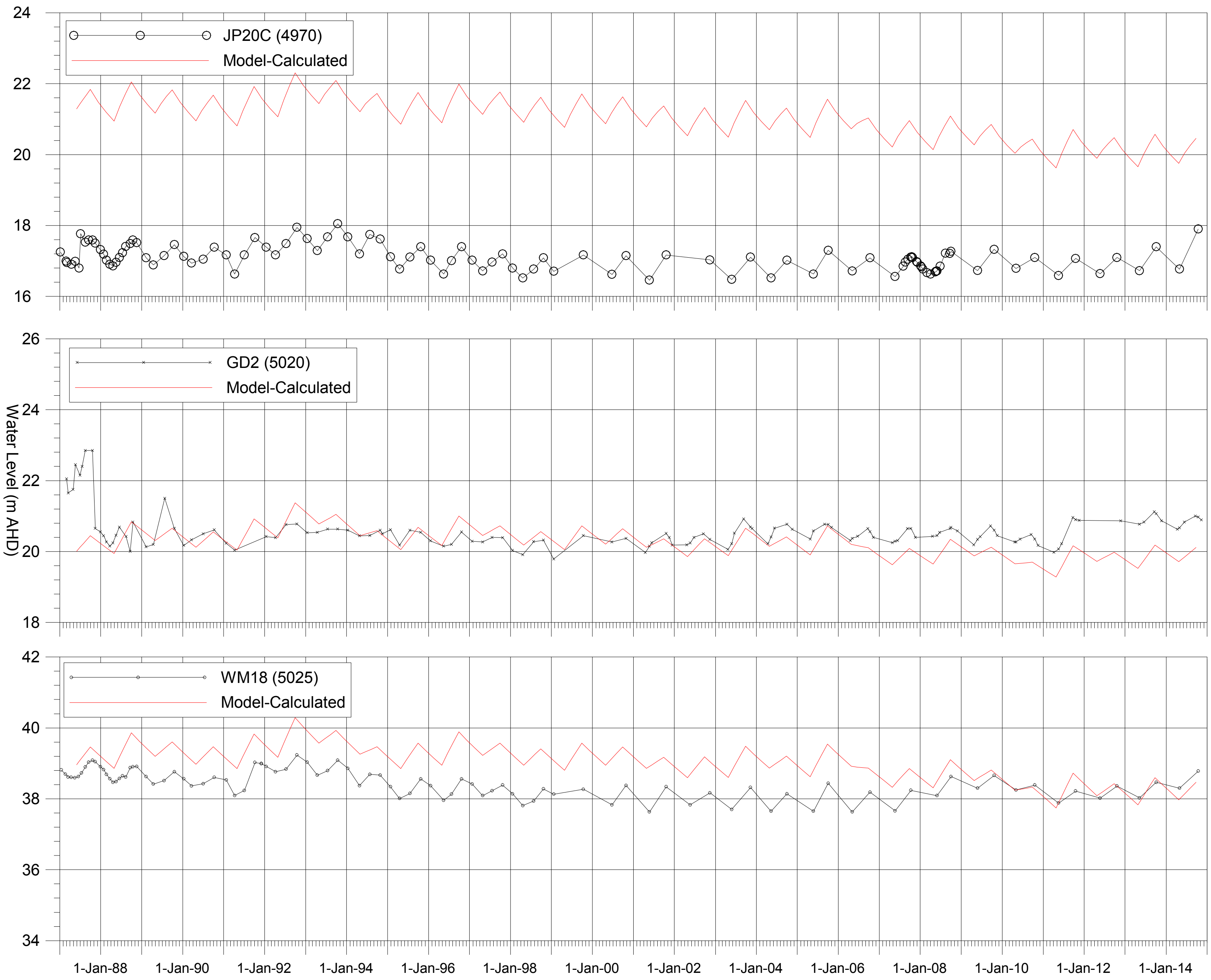


Figure 8

key wls1 calib.grf

Client: M P Rogers & Associates

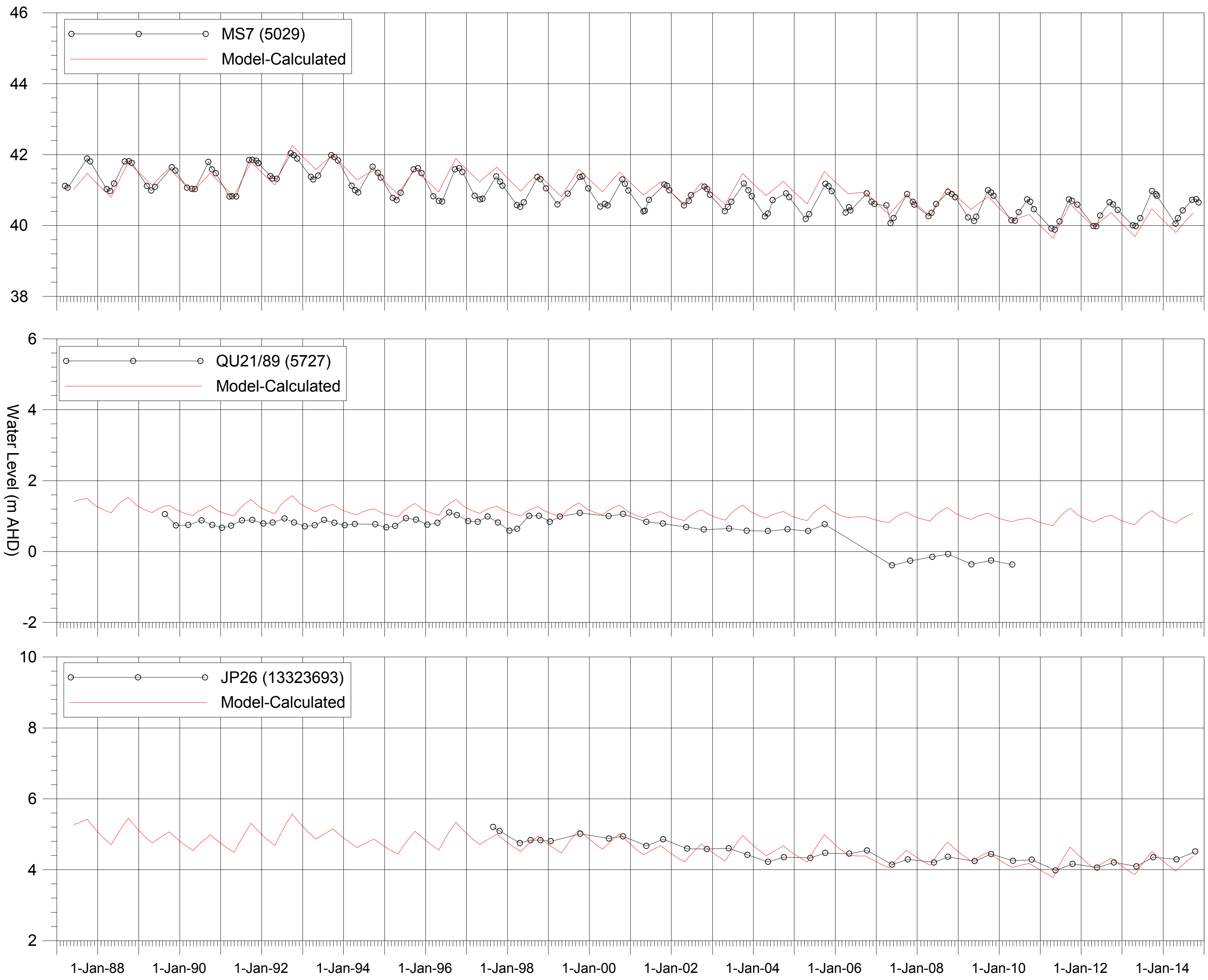
Project : Ocean Reef Marina Modelling

Date : January 2015

Dwg. No: 288-3/15/1-8

MEASURED AND MODEL-CALCULATED HYDROGRAPHS, BORES JP20C, GD2 & WM18

Rockwater Pty Ltd



key wls2 calib.grf

Client: M P Rogers & Associates

Project : Ocean Reef Marina Modelling

Date : January 2015

Dwg. No: 288-3/15/1-9

MEASURED AND MODEL-CALCULATED
HYDROGRAPHS, BORES MS7, QU21/89 & JP26

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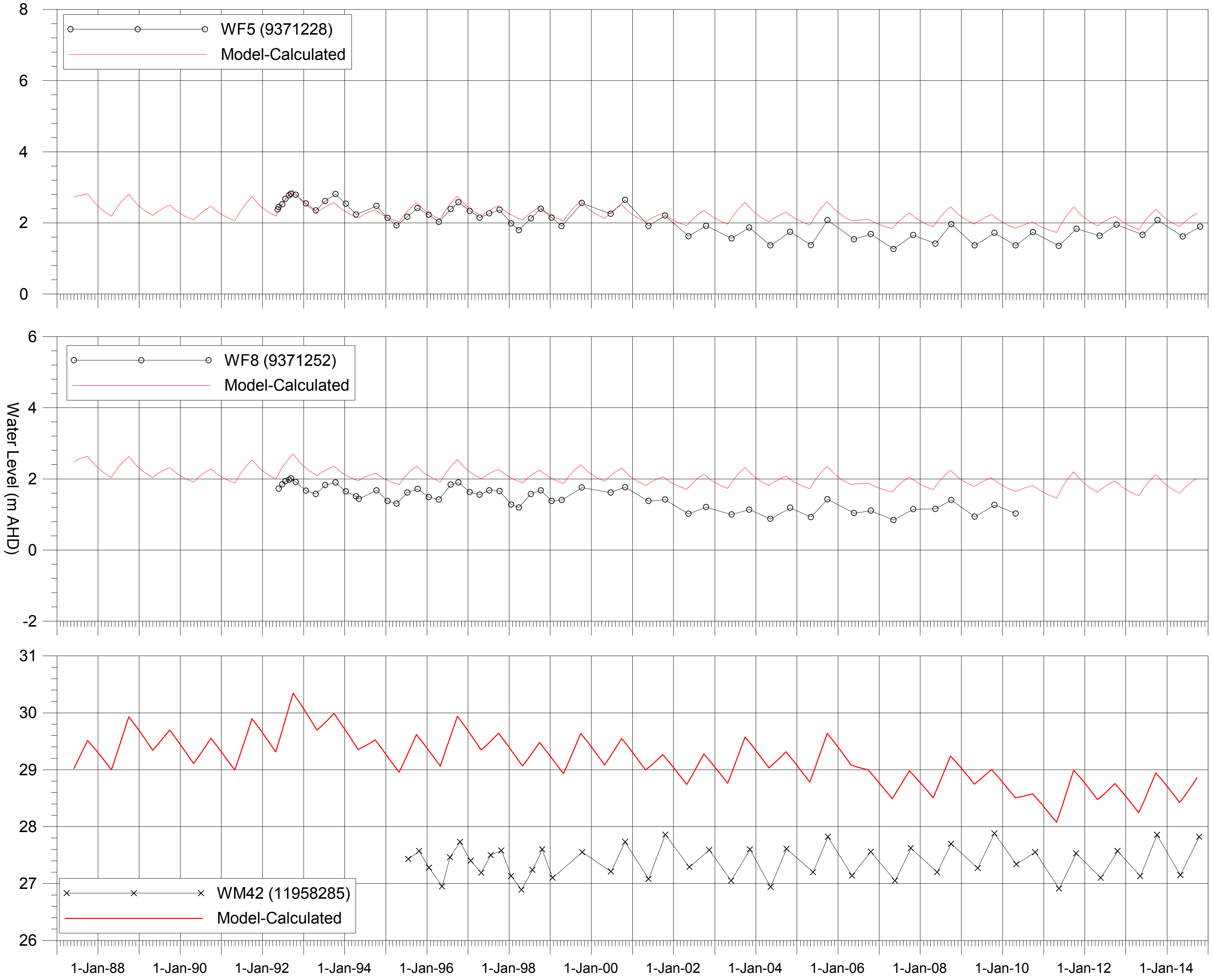
Figure 9



key wls3 calib.grf

Client: M P Rogers & Associates

Project : Ocean Reef Marina Modelling

Date : January 2015

Dwg. No: 288-3/15/1-10

MEASURED AND MODEL-CALCULATED HYDROGRAPHS, BORES WF5, WF8 & WM42

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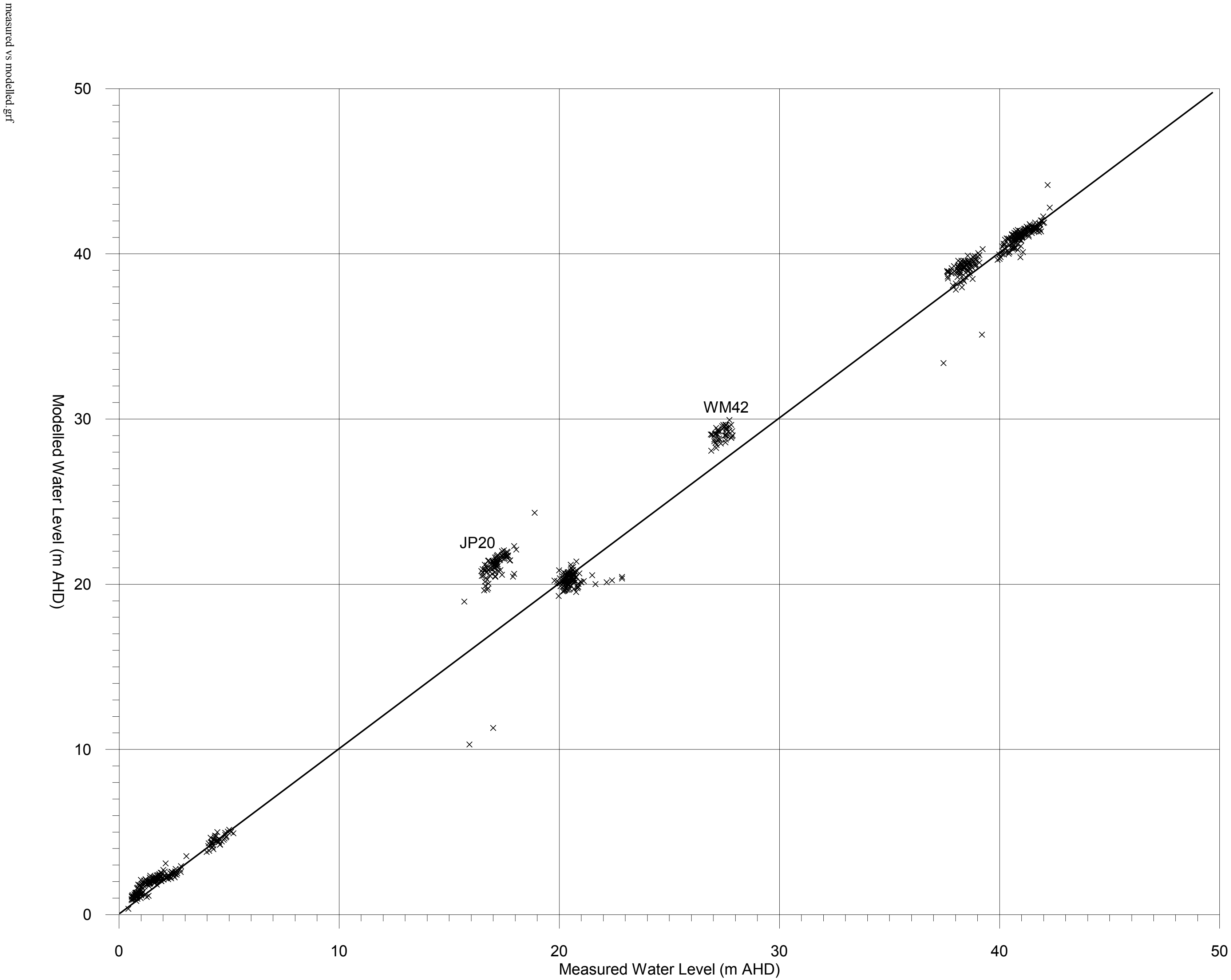
Figure 10

Figure 11



Client: M P Rogers & Associates
Project : Ocean Reef Marina Modelling
Date : February 2015
Dwg. No: 288.3/15/1-11

MODELLED VERSUS CALCULATED
GROUNDWATER LEVELS, ALL BORES

Rockwater Pty Ltd

RPS APASA

Ocean Reef Marina Development

Phase 2: Water Quality Modelling

1/08/2016

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Senior Coastal Engineer

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Rev 1	Issued for external review	R Alexander	S Langtry	29/1/2016
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Rev 3	Issued for client feedback	R Alexander	M Burling	18/4/2016
Rev 4	Issued for client feedback	R Alexander	M Burling	25/7/2016
Rev 5	Issued for client feedback	R Alexander	M Burling	1/8/2016

Approval for Issue

Name	Date
M Burling	1/8/2016

Contents

Tables

Figures

Executive Summary

The City of Joondalup is developing a concept plan for a marina development (ORM) at the site of the existing Ocean Reef Boat Harbour (ORBH). The concept plan is to be assessed by the Environment Protection Authority (EPA) under terms that have been detailed in the form of an Environmental Scoping Document (ESD).

RPS APASA has been engaged by M P Rogers & Associates (MPRA) on behalf of the City of Joondalup to address aspects of the ESD that concern water quality modelling and related outputs. This report does not make conclusions as to any ultimate effects of predicted water quality changes, but rather, provides input to a broader team who will assess potential effects based on this report together with other information.

This report first presents the set-up, calibration and validation of a model framework that provides the basis to the water quality modelling, and then the results of water quality modelling components are presented. The report doesn't address potential subsequent effects of any water quality changes, but rather prepares data for use by others in the overall assessment team. The key outcomes from the water quality modelling are as follows:

- The maximum natural flushing time for the proposed ORM was determined as 7.3 days, which occurred in autumn conditions. During other times of the year the median flushing times were typically of the order of 5 to 6 days.
- Nitrogen and phosphorus concentrations within the ORM are expected to be affected by continuous loading from groundwater discharge. The forecast 80th percentile nitrogen and phosphorus concentrations within ORM due to this mechanism were 0.57 mg/L and 0.0037 mg/L, respectively.
- Abalone habitat within 500 m of the ORM is forecast to experience reduced current speeds. Beyond 500 m of ORM and out to the 1.5 km range, the forecast differences were much less pronounced and peak differences in current speed were typically less than 5 cm/s. Abalone habitat south of ORM is generally less affected by changes.
- Outflows from the ORM that reach the abalone habitat 100 m north of ORM are likely to have undergone at least a 6-fold dilution. The shortest time taken for an outflow from ORM to reach the habitat 100 m to its north was 6 hours and the longest time taken was 216 hours. Abalone habitat south of ORM is generally unaffected by the outflows.
- The abalone habitat within 500 m north of the marina is forecast to experience slower flushing with the introduction of ORM to the coastline. The flushing time is forecast to increase from 1 hour to 7.5 hours in this region.
- The introduction of ORM to the coastline is not expected to cause changes to the local wave climate, at least for distances further than 100 m from the proposed breakwaters.
- During the breakwater construction phase, high suspended solids concentrations are likely to be very localised and short-lived. The highest concentrations outside of the direct footprint are expected to the immediate north, likely resulting from the initial core placement as part of the northern breakwater construction.
- During the dredging phase, the discharge suspended sediment from the marina is expected to occur less than 1% of the time, with most of the sediment expected to be contained within the marina. Suspended sediment will settle within the marina and would then be unlikely to be resuspended by natural processes
- The primary suspended solids impact to abalone habitat is predicted to occur during the initial month of construction when the construction of both breakwaters commences from the shoreline.
- Based on the notional thresholds used for plume visibility, the visible suspended sediment plume (above

background) is generally expected to be confined to the near vicinity of the construction site.

- Beyond the immediate vicinity of the marina, seabed deposition is expected to be less than 100 g/m^2 at any time, and less than 1 g/m^2 further than approximately 500 m away from the construction activities
- Ecological modelling of the potential for algal growth within ORM above normal background levels indicated algal concentrations within the marina are expected to be in the range of 0.2 to 0.6 µgChla/L above background. The standard for a Moderate Ecological Protection Area (MEPA) is not expected to be exceeded within the marina. The standard for a High Ecological Protection Area (HEPA) is not expected to be exceeded at the edge of a 70 m buffer zone around the marina.
- A climate change scenario for the year 2040 indicated that the maximum flushing times for ORM may increase by around 24 to 36 hours. The results for year 2115 scenario indicated maximum flushing times may increase by 2 to 3 days. In both cases, the increases in flushing times are attributable to higher sea level and reduced groundwater discharge.

1.1 Project Description

The City of Joondalup is undertaking the development and approval of a concept plan for Ocean Reef Marina (ORM). The concept plan involves significant expansion of the existing Ocean Reef Boat Harbour (ORBH) into a recreational, boating and tourism facility. The concept plan is to be assessed by the Environment Protection Authority (EPA) under Part IV of the *Environmental Protection Act 1986.* The EPA requirements for the assessment have been detailed in the form of an ESD (EPA 2014).

RPS APASA has been engaged by M P Rogers & Associates (MPRA) on behalf of the City of Joondalup to address aspects of the ESD that concern water quality modelling and related outputs. There are four principle issues raised in the ESD that will be addressed by the application of water quality modelling:

1) Determining the natural flushing characteristic of the proposed ORM.

2) Understanding the dispersion, deposition and accumulation of sediments and contaminants from marine-based construction and maintenance activities. In this context the potential contaminants include nutrients sourced from groundwater as well as generic contaminants that might be accidentally spilt within the marina.

3) Understanding the effect of outflows from the ORM on the water quality of the surrounding marine environment.

4) Ecological modelling to predict algal responses to changes in marine water quality within the marina, and the potential implications of any changes within the marina for the broader marine environment.

The various aspects of water quality modelling presented in this report will use input data from the same hydrodynamic model. The dredging and construction component of the study will also rely on input from a wave model, which will also be used for a part of the abalone habitat assessment. Specific post construction incident scenarios such as accidental contaminant discharge are not addressed by this study explicitly. However, the suite of results from the flushing modelling (i.e. conservative tracer study) will serve to provide a general but quantitative indication of expected flushing times in the event of a hypothetical contaminant release.

1.2 Background

An existing hydrodynamic model (Delft3D-FLOW) was constructed, calibrated and validated to suit a previous ORM modelling study undertaken in 2011 (APASA 2011). This model covered a region extending approximately 55 km to the north of ORBH and 85 km to the south. The model was composed of a relatively coarse outer grid (1 km), which was nested with progressively finer resolution sub-grids down to a resolution of 12 m in and around ORBH.

To accommodate the increased scope of the current study, the model set-up from the previous ORM study (APASA 2011) was updated and enhanced. The extents of the nested sub-grids were modified; in particular, the domain size of the 250 m sub-grid was increased significantly so that it extended 20 km to the north and south of ORBH. The opening of the ORBH entrance was resolved by at least three grid cells in the horizontal direction to ensure that inflow and outflow was appropriately calculated by the model. In addition to the grid modifications, the open ocean boundary forcing data was revised so that tidal sea level fluctuations were augmented with weather-induced sea level anomalies determined from a global ocean model. The bathymetry used for the model was also updated based on more recent LiDAR survey information.

The scope of this study necessitated the development of a wave model (Delft3D-SWAN) for water quality modelling purposes. The wave model developed for this study was customised in a manner appropriate for scope of the water quality modelling and was therefore independent of the wave model used by MP Rogers & Associates (MP Rogers) to investigate coastal processes component of the wider overall assessment. In particular, the spatial extent of the water quality wave model was designed to match the spatial extent of the hydrodynamic model grid and the internal grid resolution was comparatively coarse around the marina. The water quality wave model was used in the dredging and construction component of the study because of the potentially significant influence of waves on sediment settling and resuspension in shallow water. The wave model was also used to conduct a broad scale assessment of the potential for changes in wave climate near to abalone habitat.

1.3 Scope

This study presents modelling of several environmental water quality aspects that relate to either the development or the ongoing operation of the proposed ORM. The water quality modelling is all underpinned by a common hydrodynamic model framework.

Subsequent chapters will describe the set-up, calibration and validation of the hydrodynamic model framework as well as a wave model framework that is used to support some specific aspects of the water quality modelling. Following the introduction of these model frameworks, results are presented for five different water quality assessment components:

- Assessment of natural flushing rates within the proposed ORM together with a conservative assessment of the potential for accumulation of nutrients sourced from groundwater within the marina.
- The potential for changes to current circulation and flushing patterns due to the proposed ORM are assessed, particularly in relation to abalone habitat nearby to ORM.
- The fates of sediment plumes generated by the construction phase of the ORM development are assessed.
- Assessment of the potential for sustained algal growth within ORM due to the combination of its natural flushing time combined with external nutrient input.
- The potential effect of climate change scenarios on the natural flushing time of ORM.

2.0 Site Description

2.1 Location

The existing ORBH (31°45.66' S, 115°43.63' E) is located within Perth coastal waters, approximately 32 km north of the Fremantle Port (Figure 2.1). The ORBH lies within Whitfords Lagoon, which is a semi-enclosed lagoon, bounded by shallow regions at Mullaloo Point to the south and Burns beach to the north. The lagoon is part of the Marmion Marine Park (Figure 2.1), which is characterised by irregular submerged limestone reefs positioned among extensive areas of pavement reef covered by a sediment veneer that is irregular and changeable in thickness.

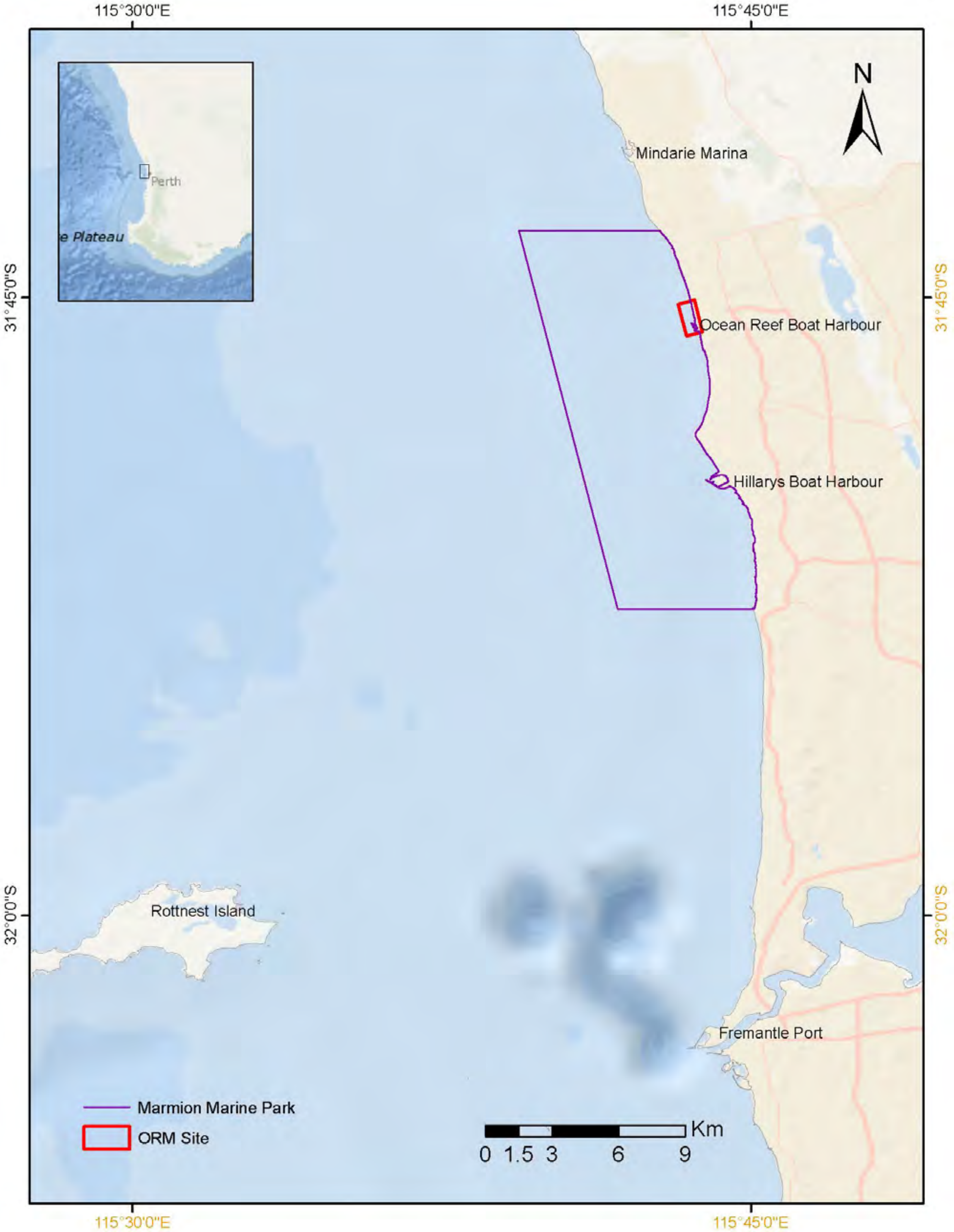

Figure 2.1: Location map indicating the site of the proposed Ocean Reef Marina (red) and the boundary of the Marmion Marine Park (purple).

2.2 Regional Metocean Conditions

2.2.1 Wind Climate

To give a broad overview of diurnal wind patterns, wind statistics prepared by the Bureau of Meteorology (BoM 2015) from data collected twice-daily (9:00 and 15:00) at Swanbourne Station, were reviewed for the period 1993 to 2010. These statistics are only available for some BoM stations, which is why the Swanbourne Station was selected as the most appropriate location for a general description (the actual wind forcing inputs used for modelling are discussed subsequently). The statistics indicate that the wind climate in the Perth Coastal area is characterised by significant seasonal and diurnal variability. Although twice-daily data doesn’t provide a comprehensive description of diurnal wind patterns for the Perth coastal region, the 9:00 measurement can be considered broadly representative of the early morning to midday period while the 15:00 measurement is representative of midday to late evening. Statistics for the period from midnight to early morning weren’t available in this format, but this period is generally considered to be a relatively calm transition period for wind speed and direction.

Morning mean wind speeds (at 9:00) are relatively consistent throughout the year within the range of 17 to 20 km/h, and are generally directed from the southeast quadrant in summer and the northeast quadrant in winter. The influence of a daily sea breeze directed from the south-west is most pronounced in summer months, causing mean wind speeds to increase in the afternoon (25 to 28 km/h). In winter months the influence of the sea breeze on wind speeds is weaker but a westerly shift in afternoon wind direction is still typical.

Although overall mean wind speeds are highest in summer months, the wind speed variability is highest in winter months. The highest speeds (>40 km/h) occur in the period from May to September in association with storm events. These winds are predominantly directed from the west, northwest or southwest. Light winds (<10 km/h) are most likely to occur regularly between May and August. Regardless of the month of year, calm conditions (~0 km/h) at either 9:00 or 15:00 are uncommon (i.e. <1% frequency).

2.2.2 Sea Level Variation

The magnitude of tidal variation in Perth coastal waters is relatively small. The tidal range is typically around 0.5 m, and ranges between 0.1 m and 0.9 m relative to the Lowest Astronomical Tide (LAT). The tides are predominantly diurnal, with the major diurnal constituents (K1 and O1) being 2-3 times the amplitude of the semi-diurnal M2 and S2 constituents.

The sea level in Perth coastal waters can also be influenced significantly by the passage of pressure systems and associated storm surges and other long period forcing, such as coastally-trapped shelf waves (DEP 1996). The sea level variations associated with these events are typically around 0.3 m but can be up to 0.9 m, which implies they can be of similar or greater magnitude to the tidal variations.

2.2.3 Currents

The nearshore currents within Perth coastal waters are considered to be primarily influenced by wind forcing rather than tidal forcing (Fandry *et al.* 2006). This influence is particularly evident in summer when the sea breeze is most active (Gallop *et al.* 2012). However, the relationship between the current and wind speed is known to deteriorate in deeper waters further offshore (Fandry *et al.* 2006).

The current regime offshore is dominated by both wind forcing and the warm southward flowing Leeuwin current, which is strongest in winter. In summer, the predominantly southerly wind forcing drives a relatively cool inshore counter current known as the Capes Current (Pearce and Pattiaratchi 1999). The Capes current weakens the Leeuwin Current and pushes it further offshore. The alongshore component of current speeds (monthly mean) in the Perth coastal region (~30 m depth) are generally in the range of 0-15 cm/s depending on the season (Pearce *et al.* 2006).

3.0 Model Descriptions

3.1 Hydrodynamic Model

Delft3D-FLOW is the hydrodynamic component of the Delft3D suite of modelling products (Deltares 2013). Delft3D-FLOW is a multidimensional (2D or 3D) hydrodynamic and transport model which calculates non-steady flow and transport phenomena resulting from tidal, meteorological and baroclinic forcing. The model can be implemented on a rectilinear or curvilinear grid system, and use either a sigma-coordinate (depth proportioned layer thickness) or z-coordinate (constant layer thickness) vertical layering approach. It solves the non-linear Reynolds-averaged Navier Stokes equations for fluid momentum and mass conservation, and can be used in either hydrostatic or non-hydrostatic mode.

Delft3D-FLOW has been used for a vast array of applications all over the world, and is considered to be a reliable and robust model for oceanic, coastal, estuarine, riverine and flooding applications. The model adheres to the International Association for Hydro-Environment Engineering and Research guidelines for documenting the validity of computational modelling software, closely replicating an array of analytical, laboratory, schematic and real-world data (Gerritsen *et al.* 2007).

3.2 Wave Model

The DELFT3D-SWAN model (SWAN) is a spectral phase-averaging wave model developed by the Delft University of Technology (Holthuijsen *et al.* 1997). SWAN is a numerical model for simulating realistic estimates of wave parameters in coastal areas for given wind, bottom and current conditions. The model is a third generation model based on a wave action balance equation.

SWAN includes algorithms for the following wave propagation processes: propagation through geographic space, refraction due to bottom and current variations, shoaling due to bottom and current variations, blocking and reflections by opposing currents, transmission through or blockage by obstacles. The model also accounts for the dissipation effects due to white-capping, bottom friction and wave breaking as well as non-linear wave-wave interactions. SWAN is fully spectral (in all directions and frequencies at the chosen resolutions) and computes the evolution of wind waves in coastal regions with shallow water depths and ambient currents.

3.3 Sediment Fate Model

Modelling of the dispersion of suspended sediment resulting from the various construction and dredging operations has been undertaken using an advanced sediment fate model SSFATE, operating within the ASA DREDGEMAP system. DREDGEMAP allows the three-dimensional prediction of suspended sediment concentrations and seabed sedimentation to be assessed against allowable exposure thresholds. Sedimentation thresholds often relate to burial depths or rates, while suspended sediment concentration (SSC) thresholds are usually more complicated, involving tiered exposure duration and intensities. As a result, assessing the project generated sediment distributions against these thresholds in both 3D space and time is a computationally intensive task.

SSFATE (Suspended Sediment FATE) is a computer model originally developed jointly by the U.S. Army Corps of Engineers Engineer Research and Development Center and Applied Science Associates (ASA) to estimate suspended sediment concentrations generated in the water column and deposition patterns generated due to dredging operations in a current-dominated environment, such as a river (Johnson *et al.* 2000, Swanson et. al. 2000, 2004). ASA has significantly enhanced the capability of SSFATE to allow the prediction of sediment fate in marine and coastal environments, where wave forcing becomes important for reworking the distribution of sediments (Swanson *et al.* 2007).

SSFATE is formulated to simulate far-field effects (i.e. ~25 m or larger scale relative to the location of the sediment source) in which the mean transport and turbulence associated with ambient currents are dominant over the initial turbulence generated at the discharge point. This far field scale is appropriate for considering the potential effect of sediments on sensitive environmental receptors external to the marina. The model computes the advection, dispersion, differential sinking, settlement and resuspension of sediment particles. The model can be used to represent inputs from a wide range of suspension sources, producing predictions of sediment fate both over the short-term (minutes to days following a discharge source) and longer term (days to years following a discharge source). SSFATE isn't designed to resolve sediment concentrations in the near-field (i.e. less than ~25 m) because this is generally unnecessary.

A five class particle-based model predicts the transport and dispersion of the suspended material. The classes include the 0 to 130 micron range of sediment sizes that typically result in plumes. Heavier sediments tend to settle very rapidly and are not relevant over the larger time and space scales of interest here. Table 3.1 shows the material classes used in SSFATE.

Table 3.1: Material size classes used in SSFATE

Material Class	Size Range
Clay	< 7 microns
Fine Silt	7 to 35 microns
Coarse Silt	35 to 75 microns
Fine Sand	75 to 130 microns
Coarse Sand	> 130 microns

Particle advection is based on the simple relationship that a particle moves linearly with a local velocity, obtained from the hydrodynamic model, for a specified model time step. Particle diffusion is assumed to follow a random walk process resulting in the stochastic spread of particles over time. The Lagrangian approach of calculating transport through a grid-less space removes limitations of grid resolution, artefacts due to grid boundaries and also maintains a high degree of mass conservation.

Following release into the model space, the sediment cloud is transformed according to the following processes:

- Advection due to the imposed three-dimensional current field.
- Diffusion by a random walk model with the mass diffusion rate specified ideally from measurements at the site. As particles represent an ensemble of real particles, each particle in the model has an associated Gaussian distribution, governed by particle age and the mass diffusion properties of the surrounding water.
- Settlement or sinking of the sediment due to buoyancy forces. Settlement rates are determined from the particle class sizes and include allowance for flocculation and other concentration dependent behaviour, following the model of Teeter (2001).

- Deposition of the sediment onto the seabed. Deposition is determined using a model that couples the deposition across particle classes (Teeter, 2001). The likelihood and rate of deposition depends on the shear stress at the bed. High shear inhibits deposition, and if large enough will prevent deposition all together, with sediment remaining in suspension. Shear stress at the seabed is calculated at each location and time step by the model based on local current speed (from the hydrodynamic model) and orbital velocity (from the wave model). The model allows for partial deposition of individual particles according to a practical deposition rate, thereby allowing the bulk sediment mass to be represented by fewer particles.

- Potential resuspension of material, governed by exceedance of required shear stress at the seabed due to the combined action of waves and currents. Different thresholds are applied for resuspension depending upon the duration that settled sediments have remained settled based on empirical studies that have demonstrated that newly settled sediments will have higher water content and are more easily resuspended by lower shear stresses (Swanson et al 2007). The resuspension flux calculation also accounts for armouring of fine particles within the interstitial spaces of larger particles. Thus, the model can indicate whether deposits will stabilise or continue to erode over time given the shear forces that occur at the site. Resuspended material is released back into the water column to be affected by all of the processes defined above.

SSFATE formulations and proof of performance have been documented in a series of USACE Dredging Operations and Environmental Research (DOER) Program technical notes (Johnson et al. 2000; Swanson *et al.* 2000), and published in peer-reviewed literature (Swanson *et al.,* 2004; Swanson *et al.,* 2007). SSFATE has been applied and validated by RPS APASA against observations of sedimentation and suspended sediments at multiple locations in Australia, notably Cockburn Sound for Fremantle Ports and Mermaid Sound for the Pluto dredging project. The model has been applied as part of the approvals studies for many other projects, including recent work for the proposed Mangles Bay Marina (Cockburn Sound) and the Elizabeth Quay development (Swan River).

3.4 Ecological Model

The Delft3D-Water Quality module (Delft3D-WAQ), developed by Deltares (2013) provides a framework for solving advection-diffusion-reaction equations for a wide range of water quality related substances. Delft3D-WAQ operates on a grid and flow field that is pre-defined by a hydrodynamic model framework (e.g. Delft3D-FLOW). Delft3D-WAQ allows flexibility in the selection of substances to be modelled and the related processes associated with each substance, which means that it can be customised as appropriate for a particular study.

The ecological modelling for this study focusses on algal growth and mortality. Algal growth and mortality were modelled using Monod-kinetics for the calculation of growth rates (Delft Hydraulics, 1989). An underlying assumption of Monod-kinetics is that algal growth may respond quickly to changes in nutrient loading, which is a conservative assumption. The Delft3D-WAQ submodule for simulating algal growth under Monod-kinetics is known as DYNAMO. DYNAMO is recommended for eutrophication reconnaissance studies focussing on nutrient mass balances and the primary effects of changes in nutrient loading. For this study, DYNAMO was configured so that algal growth responded to nutrient concentrations and day length. During daylight hours light was assumed non-limiting to algal growth. The temperature dependence of algal growth was not modelled explicitly but rather, was considered implicitly by the use of a conservative growth rate as described in Section 8.0.

4.0 Method

4.1 Modelling Approach Overview

Customised hydrodynamic and wave model frameworks were developed for this assessment. The calibration and validation of these models were performed independently (i.e. uncoupled) and over different periods in time in order to make best use of the available measured data. This section briefly clarifies how the different models were used for various components of this study.

The wave model framework used for this study was developed to address the specified scope of the water quality modelling. This scope did not include nearshore sediment transport because this component was addressed separately by MP Rogers. The wave model developed for this study was therefore independent of that developed by MP Rogers for the assessment of coastal processes. Wave modelling was used in this study primarily as an input to the sediment fates modelling of the dredging and construction period, and secondly, to provide a broad scale assessment of the potential for changes in wave climate near to the abalone habitat due to the proposed ORM. For the latter, the scope of the study didn't include assessment of waves near enough to the development to be affected by reflection and refraction from the ORM breakwaters (within ~100 m); this zone was assumed to within the range of abalone habitat that would be directly impacted by the development.

The flushing calculations, and associated assessments of the potential for nutrient accumulation within ORM, were all based on the use of passive tracers in the hydrodynamic model.

The ecological assessment of the potential for algal growth within ORM used the Delft3D-Water Quality module. This module was driven by a grid and flow field that was pre-generated by the hydrodynamic model. The water quality module was configured to simulate algal growth responding to changing nutrient concentrations. For the ecological component of the study the nutrients were treated as 'active' tracers, which contrasts with the more simplistic conservative tracer approach that is used to assess the potential for nutrient accumulation within ORM.

The abalone habitat assessment involved analysis of current fields generated by the hydrodynamic and wave models, and interrogation of the sediment fates modelling results.

4.1.1 Hydrodynamic Model

Delft3D-FLOW was configured in a 3-dimensional mode with five vertical (sigma) layers used throughout the entire domain. A nested grid approach was used to achieve an efficient balance between the high spatial resolution required around ORBH/ORM and an outer domain spanning over 100 km. The nesting scheme used by Delft3D-FLOW ensures two-way communication of momentum and water properties between the grids, with the restriction that all grids must share the same time step.

The outer boundaries of the hydrodynamic model were chosen to span a region large enough to allow the model to reproduce the wind driven drift and tidal currents along the Perth coastal margin. A nested grid with resolution of ~250 m was selected to adequately resolve shallow reef systems that are located within 20 km of ORBH. To appropriately resolve the dynamics of flow in and around ORBH, a minimum horizontal scale of 12.5 m was required. The requirement for the model to satisfy Courant-Friedrichs-Levy (CFL) criteria at the finest grid scale constrained the time step that had to be applied for all model grids to three seconds. This implied a peak Courant number of much less than one for grid cells at the ORBH entrance (peak horizontal current speed in this region was typically ~0.1 m/s).

The various sources of data that were used for the set-up, calibration and validation of the hydrodynamic model framework are presented in Section 4.2. A model calibration was performed over a time period from 1 February to 15 March 2013 when current and water level measurements were available from two instruments deployed within several kilometres of ORBH (AWAC-North and AWAC-West).

The calibrated model was validated over the period 2 July 2011 to 11 August 2011, based on comparison with current measurements from an instrument deployed within a few hundred meters of ORBH (AWAC-ORBH). Furthermore, the capacity of the model to simulate the flushing characteristics within ORBH was assessed against the results from a Rhodamine dye flushing experiment that was conducted in July 2011. This assessment was needed to confirm that the updated model framework matched or bettered the skill of the previously validated model framework (APASA 2011).

4.1.2 Wave Model

A regional wave model was established to allow prediction of wave-induced effects on the settlement and resuspension of sediments associated with planned dredging and construction activities. The same wave model was also used for a broad scale wave assessment of abalone habitat. The chosen wave model (SWAN) was configured with a grid scale that was adequate for the reef areas of interest but too large to resolve the nearshore areas. This implies that the model was not configured to resolve surf zone wave breaking processes, which are not considered relevant to transport processes related to sediment suspended by the dredging and construction nor to the broad scale nature of the abalone habitat assessment. Similarly, the model was not configured to resolves waves in and around the immediate vicinity of the marina (i.e. within ~100m of the breakwaters).

The SWAN model was developed to simulate spatially-varying wave conditions over a wide domain encompassing Perth coastal waters from Lancelin to Preston Beach. The large size of the wave model domain is required to ensure that both distant and local influences on wave generation can be adequately resolved.

The wave model framework had to balance conflicting requirements of high spatial resolution (needed to appropriately represent local variations) and practical computational efficiency (to cover the potential duration of the proposed activities). This was achieved by development and application of an unstructured grid mesh.

The wave model results were calibrated against available measured wave data near Cottesloe, Rottnest and near ORBH. The wave data at Rottnest is assumed to be representative of offshore conditions while the data measured near ORBH and Cottesloe are representative of nearshore conditions, with ORBH being site specific.

The model calibration was performed over a time period in which wave measurements near ORBH were available, from 1 June to 31 August 2011. Thus the wave measurements near ORBH were only available over a winter period. To validate the calibrated wave model and assess its performance over summer conditions, comparison was made to wave buoy data from Rottnest and Cottesloe that was measured over the month of February 2012.

4.1.3 Sediment Fate Model

The ASA sediment fate model DREDGEMAP was applied in order to model the transport and fate of sediment loads associated with the construction and dredging phases of the ORM development. The flow field used by DREDGEMAP was derived from both the hydrodynamic and wave model frameworks. The flow-field used for the sediment fates modelling covered a total time period of 12-months, matching the expected construction time frame. The method for selecting a representative 12-month period is described in Section 4.6.

The set-up of DREDGEMAP involves configuring the model to simulate detailed timings, rates and locations of the planned dredging and construction schedule. A detailed explanation of the assumptions underpinning the sediment fates modelling of ORM is presented in Section 10.0.

4.1.4 Ecological Model

The ecological modelling component of this study was designed to assess the potential for algal growth within the proposed ORM during its operational phase. More specifically, the ecological modelling component is designed to assess firstly, whether nutrient input to ORM in combination with the natural flushing regime of ORM, would support sustained or seasonal problematic levels of algal growth. Furthermore, if problematic concentrations of algae were to develop within ORM, how might outflows from the ORM affect the adjacent Marmion Marine Park.

It is important to clarify that the scope of the ecological modelling component of the study does not include modelling of the Marmion Marine Park itself. Instead, the approach taken was to assess the potential for increased algal growth relative to background levels that are typical for the Perth metropolitan coastline. To address this specific question, a customised set of water quality substances and processes was configured in Delft3D-WAQ and nutrient inputs to the model were limited to those expected under typical operational conditions.

The typical operational conditions represented in the ecological model included nutrient input from groundwater but didn't include nutrients sourced from rainfall runoff. This approach is based on the drainage design criteria for the ORM, which was communicated by MP Rogers & Associates. Under the designed criteria, runoff from rainfall would not typically discharge directly into ORM unless the rainfall event was large (i.e. 1 in 1 year event). For the case of a large rainfall event, it was assumed that any associated runoff would be transient, implying that the natural flushing of the ORM would counteract the potential for nutrient accumulation and subsequent algal growth. Therefore, this type of atypical event can be considered to fall within the broader scope of the flushing assessment presented in Section 7.0.

4.2 Sources of Input Data

The set-up of hydrodynamic and wave models, in particular their boundary forcing inputs, depended on a combination of different data sources. In the following section we give an overview of the key sources of data that were used in the modelling framework either as model inputs or for purposes of calibration and validation. For clarity, the description of data that follows divides the various data sources into two categories; data derived from actual measurements and data derived from calibrated regional/global scale hindcast models that were produced externally to this study.

4.2.1 Measured Data

The calibration and validation of the model framework is supported by a variety of field measurements, including field data obtained as part of the previous ORM modelling study (APASA 2011) and more recent data made available through the Water Corporation, Department of Transport (DoT) and Bureau of Meteorology (BoM). Details of the measurement locations and deployment periods for the various instruments and data sources are presented in Table 4.1.

Table 4.1 Summary of field measurements and other measured data used for calibration and validation of the model framework

Instrument	Data Type	Location	Depth/ Height	Record Length	Sampling Interval	Sampling Burst Length	Data Source
AWAC-North*	water current vertical profiles	115°41.8466'E 31°44.6826'S	13.4 m	18/1/13 to 19/3/13	10 minutes	1 minute	Water Corporation
AWAC-West*	water current vertical profiles	115°42.2534'E 31°45.7653'S	12.6 m	18/1/13 to 19/3/13	10 minutes	1 minute	Water Corporation
AWAC-ORBH	water current vertical profiles/ surface wave parameters	115°43.5246'E 31°45.7290'S	8.7 m	21/6/11 to 10/8/11	10 mins/ 1 hour	1 mins/ 17 mins	APASA 2011
Rottnest Wave Buoy	surface wave parameters	115°24.47'E 32°05.65'S	48 m	2012 to 2013	30 mins	30 mins	DoT
Cottesloe Wave Buoy	surface wave parameters	115°41.20'E 31°58.66'S	17 m	2012 to 2013	1 hour	unspecified	DoT
Rhodamine Dye Release/Sampling	dye concentrations	Within ORBH (Figure 4.4)	N/A	24/6/11 to 29/6/11	~24 hours	N/A	APASA 2011
Ocean Reef Wind Observation St.	wind speed/direction	115°43.8'E 31°45.6'S	10 m	1993 to 2013	1 hour	10 minutes	BoM
Swanbourne Wind Observation St.	wind speed/direction	115°45.6'E 31°57.6'S	40.1 m^	1993 to 2013	1 hour	10 minutes	BoM
Rottnest Wind Observation St.	wind speed/direction	115°30.0'E 32°00.6'S	43.1 m^	1993 to 2013	1 hour	10 minutes	BoM

**Surface wave data from AWAC-North and AWAC-West was unavailable*

^Wind speeds were scaled to 10 m

Surface wave parameters and vertical profiles of water current velocity were measured by Nortek AWAC instruments. The AWACs are capable of measuring directional surface waves and water levels using acoustic surface tracking, while simultaneously measuring current profiles at approximately 1 m intervals. However, in this case wave data was only available from one of the three AWAC instruments (AWAC-ORBH). The locations of the AWAC instruments in relation to ORBH are indicated in Figure 4.1. Further information about the AWAC-ORBH deployment is available in APASA (2011). Similarly, information about the AWAC-North and AWAC-West deployments is presented in Gardline (2013).

The flushing characteristics of the existing ORBH were quantified by a dye tracer study carried out over several days in June 2011. Rhodamine dye was released at 6 stations within ORBH at approximately 9:00 AM 24 June 2011 using a small vessel towing a spreader diffuser bar. The Rhodamine dye solution was pumped through this diffuser as the vessel motored slowly around the Marina. The diffuser bar was weighted and by varying the speed of the vessel, the bar was able to be moved up and down through the water column to improve the vertical evenness of the seeding. Approximately 4.5 hours after seeding of the ORBH, the concentration of Rhodamine was measured at 6 stations within ORBH (the locations of the stations, R1 to R6, are indicated subsequently in Figure 4.4). The measurements were repeated every 12 hours initially and then every 24 hours until the Rhodamine was dispersed. For each measurement, the relative concentration of Rhodamine dye was calculated by dividing the measured concentration by the initial measured concentration at each station. The measurements from the dye tracer study were used to validate the performance of the hydrodynamic model with respect to simulating the flushing characteristics of the existing ORBH, in particular, to confirm the appropriateness of the eddy and dispersion coefficients used in the model.

Long term wind measurements were obtained from the BoM for three fixed observation stations located at Rottnest, Swanbourne and Ocean Reef. The measured data from Rottnest and Ocean Reef were used as the wind forcing input to the hydrodynamic model. This approach maintained consistency with the previous model framework developed in APASA (2011).

The measured wind data from the three fixed monitoring stations were trialled in wave model calibration runs, but were ultimately rejected in favour of spatially-variable wind data from a BoM hindcast model because the fixed stations did not provide suitable representation of spatial variability over the study domain. Spatial variability of wind is particularly relevant to the accurate generation and propagation of waves within the domain of the wave model. Comparisons of hindcast and measured wind data are detailed in Section 6.1 and Section 4.4.2.2.

Long term surface wave data from two fixed wave buoys, near Rottnest and Cottesloe respectively, were sourced from the DoT and used for calibration/validation of the wave model (the locations of these fixed wave buoys are provided in Section 4.4 (Figure 4.6).

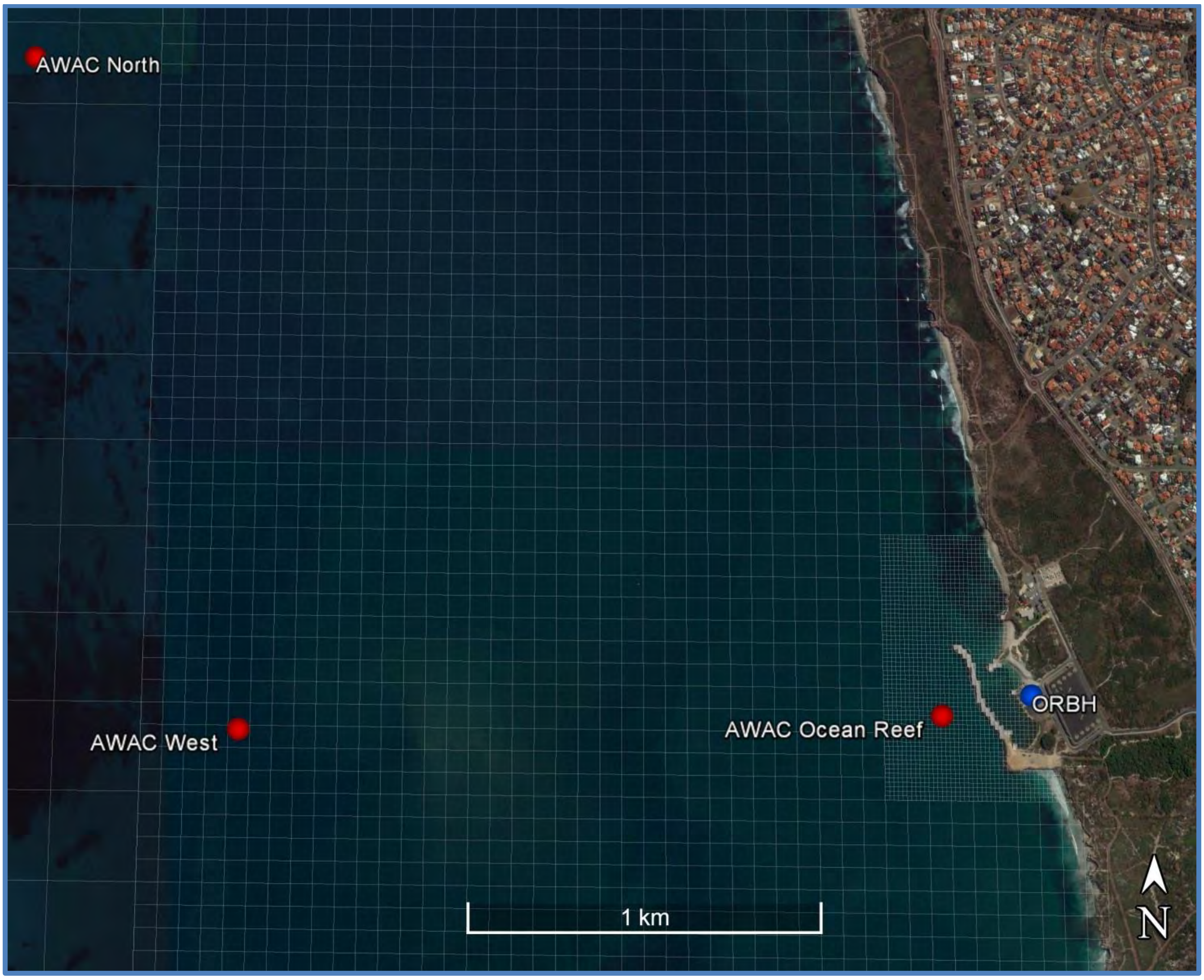

Figure 4.1: The deployment locations of the AWAC instruments used for the calibration and validation of the model framework. The AWAC Ocean Reef also measured surface wave data.

4.2.2 Hindcast Modelled Data

Some input data that is required for the modelling framework was either unavailable or impractical to obtain from measurement. For these data, the results from several well established hindcast models (which are managed by various third parties) were used to provide best available estimates of the boundary conditions.

4.2.2.1 Water Level

Time-varying and spatially-varying information about sea level fluctuations and water density are required to define open ocean boundary conditions for the hydrodynamic model. Similarly, the wave model requires time varying water level information in order to consider the effect of varying depth on the wave processes including frictional loss, refraction and wave-breaking.

Tidal forcing data, in the form of tidal amplitudes and phases for the eight largest tidal constituents for the study region (designated as K2, S2, M2, N2, K1, P1, O1 and Q1) were extracted from the Topex Poseidon TPXO 7.2 global tidal database, which is produced and quality controlled by the US National Atmospheric and Space Agency from decades of satellite altimeter measurements (Egbert and Erofeeva 2002). The

TPXO 7.2 tidal constituents were used to generate spatially-variable time-series of tidal sea levels across the open boundaries of the model.

The tidal sea level data were augmented with non-tidal sea level elevation data from the HYCOM (Hybrid Ocean Coordinate Model) hindcast database (Chassignet *et al.* 2009). HYCOM is a data assimilative general ocean circulation model that generates output at ~10 km resolution, which allowed for the representation of low-frequency sea level oscillations at the edges of the model domain. These oscillations were unrepresented in the previous ORM modelling study (APASA 2011). Subsequent hydrodynamic studies of the Perth coastal region by RPS APASA have indicated that their addition improves model skill. The HYCOM hindcast data was also used to provide water density profile information for the various depth layers at the open ocean boundaries.

For the wave model, hourly tidal predictions for Fremantle were used to generate a spatially-uniform but time-varying water level surface over the model domain. The simplifying assumption of a spatially uniform water level over the area of the model grid was considered appropriate for the purpose of the wave model.

4.2.2.2 Spatially-Variable Wind

Calibration testing for the wave model indicated that the use of spatially-variable wind from a wind hindcast model improved model skill compared to the use of measured winds from a limited number of fixed stations on land.

A spatially-variable wind dataset for the region was available from the BoM in the form of the ACCESS weather model (Australian Community Climate and Earth-System Simulator). The ACCESS model has been developed and tested by research staff from the Centre for Australian Weather and Climate Research (CAWCR) and is based on the UK Meteorological Office's Unified Model/Variational Assimilation system.

The ACCESS wind dataset is available from March 2011 to the present, over a region bound by the latitudes. 55°00'S to 4°44'N and the longitudes 95°00'E to 169°41'E, at a spatial resolution of 0.11° (approximately 12 km). The data set is available at a temporal resolution of 1 hour.

The assessment that was conducted to determine the most appropriate wind field for the wave model is presented in Section 6.1.

4.2.2.3 Waves

Open ocean wave boundary conditions for the wave model were defined by using deep-water wave parameters obtained from the WAVEWATCH III (WW3) global wave model, which is produced by the National Center for Environmental Prediction (NCEP/NOAA). Hindcast wave data was available on a 3-hour time step over a global ocean grid ranging from 77°S to 77°N with a grid resolution of 0.5°.

The WW3 hindcast wave parameters for significant wave height, peak period and peak direction (H_s, T_p and θ_{peak}) were extracted for a single data point on the western boundary of the model (-32°, 115.5°). The point was selected to be the best representative of incident wave conditions at the model boundary based on comparison of model results with measured data from the Rottnest Island wave buoy.

The directional (or frequency) spread of the wave energy at the boundary is not provided by the NOAA global wave model. The directional spreading parameter is a key parameter determining the spread of spectral energy over the direction axis (the directional standard deviation). A directional spread of 20° standard deviation was applied based on calibration to the measured data sets. This value of directional spread is also reasonable based on experience from previous numerical studies.

4.2.2.4 Groundwater

The discharge of terrestrial-sourced groundwater along the Perth coastal margin has the potential to influence the flushing time of semi-enclosed harbours. This mechanism was proposed by Schwartz and Imberger (1988) as a means to explain flushing rates observed in the Hillarys boat harbour, which is nearby to ORBH. Furthermore, the previous ORM modelling study (APASA 2011) confirmed that this mechanism contributed to a reduced flushing time for the existing ORBH.

The influence of groundwater on the flushing time of a given contaminant depends on whether the contaminant is present in the groundwater. Assuming it is not, the effect of the groundwater will be to reduce the flushing time, all other matters being equal. However, the reverse applies if the contaminant is present in the groundwater (e.g. nutrients). The results of this study will address both of these cases.

To validate the performance of the hydrodynamic model framework with regard to flushing dynamics of the existing ORBH, the flushing study that was conducted in 2011 (APASA 2011) was adapted and revised. For consistency of comparison with the previous study, the ORBH flushing validation component of this study (Section 5.2.2) was conducted using the same groundwater discharge characteristics that were originally used in APASA (2011). These groundwater characteristics were derived from Perth Regional Aquifer Modelling System (PRAMS), incorporating well readings and nutrient samples that were available at that time (Rockwater 2011). Table 4.2 presents a summary of this data.

Table 4.2: Original 2011 groundwater flow and nutrient loads used for ORBH flushing validation (Rockwater 2011).

Location	Season	Total Discharge (m^3/day)	Total Nitrogen (kg/day)	Total Phosphorus (kg/day)
Existing ORBH	End of Summer	1,233	4.0	0.1
	End of Winter	2,267	7.3	0.2
Planned ORM*	End of Summer	4,923	16.5	0.4
	End of Winter	8,273	27.8	0.7

** Data not used for this study but provided for comparative purposes.*

For the water quality modelling components of this study, which mainly involved simulation of the proposed ORM layout rather than the existing ORBH layout, the groundwater characteristics used for the modelling were updated in two respects. Firstly, the discharge characteristics were updated based on more contemporary well readings and nutrient sampling (Rockwater 2015) and these revised groundwater characteristics are presented in Table 4.3. Secondly, the updated groundwater information was extended to a section of the coastline several kilometres north and south of ORM. This was done by extrapolating the groundwater characteristics determined for the ORM site on a pro-rata basis (based on shoreline length). Groundwater discharge cells were added to all coastline adjacent model cells up to ~5 km north and ~4 km south of ORM (corresponding with grid2 and grid3 in the hydrodynamic model setup, Figure 4.2). This approach ensured that the results of the flushing and ecological modelling components of this study were not biased by inconsistent treatment of coastal groundwater inflows at locations inside and outside of ORM.

The substantial increase in groundwater flow to the proposed ORM relative to the existing ORBH shown in Table 4.3 is basically a result of the larger area of ORM rather than any predicted change to groundwater flows.

Table 4.3: Updated 2015 groundwater flow and nutrient loads used for ORM flushing validation and ORM ecological modelling (Rockwater 2015).

Location	Season	Total Discharge (m^3/day)	Total Nitrogen (kg/day)	Total Phosphorus (kg/day)
Existing ORBH*	End of Summer	2,149	26.5	0.2
	End of Winter	3,346	41.2	0.3
Proposed ORM	End of Summer	5,022	64.5	0.4
	End of Winter	8,396	107.9	0.7

** Data not used for this study but provided for comparative purposes.*

Rockwater (2011, 2015) advised that groundwater inflow is expected to discharge through the seabed and into ORM within 20 to 30 m of the shoreline. Therefore, groundwater discharge points in the model were allocated to all cells approximately within 30 m of the shoreline, or to the first coastal adjacent cell in the case of model grid cells larger than 30 m. The salinity of the groundwater discharge was assumed to be 590 mg/L and groundwater temperature was assumed to be constant at 23 degrees over all seasons based on well observations (Rockwater, 2011, 2015).

All modelling of ORM for this study used seasonally appropriate groundwater flow rates based on Table 4.3. The 'end of summer' rates were applied constantly for simulations periods between December to May and the 'end of winter' rates were applied from June to November.

In addition to simulations based on current observed groundwater inputs, additional simulations were completed by Rockwater (2015) to consider potential co-impacts of climate change on groundwater inflows. According to Rockwater (2015), the major change in groundwater inflow is expected to occur from reduced rainfall rather than sea level rise. Reduced rainfall is expected to result in reduced groundwater inflow to ORM. A groundwater modelling climate change scenario that assumed a 20% reduction in groundwater recharge rates resulted in a forecast reduction in groundwater discharge to ORM of 8% for end of summer (4,600 m^3/day) and 6% for end of winter (7,900 m^3/day) relative to the base cases presented in Table 4.3.

4.3 Hydrodynamic Model Configuration

A nested grid configuration was developed to model the existing ORBH. The two innermost nests of the ORBH grid were subsequently modified to accommodate modelling of the larger proposed ORM, including updating the model bathymetry so that nearshore areas were dredged to the design depth of -3.5 m AHD.

4.3.1 Grid and Bathymetry

The boundaries and bathymetry of the outer grid and nested sub-grids are indicated in Figure 4.2 and Figure 4.3. The cell dimensions of the various nested grids are detailed in Table 4.4.

Bathymetry for the model domains was sourced primarily from the Department of Transport (DoT) LiDAR topography set (~5 m resolution). The data is available approximately from the shoreline to the 30 m depth contour along the coast from Two Rocks to Cape Naturalist. The high-resolution dataset allowed for adequate representation of coastal reefs at 250 m scale, as indicated by the middle panel in Figure 4.2. Digitised spot depths and depth contours from the C-MAP database were used for areas not covered by the LiDAR data (which were relatively small areas for depths less than ~20 m).

Table 4.4: Summary details for the grid configuration used in the ORBH hydrodynamic model.

Grid Name	Grid Cell Dimensions [m]	North-South Extent [km]	East-West Extent [km]	Number of Grid Cells
grid0	1000 x 1000	141	72	8664*
grid1	250 x 250	46.25	15.5	7351
grid3	62.5 x 62.5	12.06	3.18	6291
grid4	12.5 x 12.5	0.76	0.51	1934

** For computational efficiency grid0 was divided into outer and inner sections, with 5649 and 3015 cells respectively.*

For the modelling of ORM, the innermost nested grid of the ORBH configuration (grid3, Figure 4.3) was enlarged to accommodate the larger structure of ORM and grid2 was cropped by the same amount to accommodate, but the respective grid resolutions were maintained. The modified grid3 used for the ORM modelling is presented in Figure 4.4. The grid depths in the near shore regions within ORM reflect the post construction depth after planned dredging. The entrance to the ORM is resolved by at least three grid cells in the horizontal to improve calculations of flow through this narrow structure. Therefore, the minimum entrance width in the model is 37.5 m. This width is slightly narrower that the ~38.5 m minimum width of the actual design entrance, implying that the model configuration is slightly conservative with respect to flushing.

For the modelling of the breakwater construction period, which is expected to be 5 months, the hydrodynamic model grid was modified month by month to reflect the progressive construction of the breakwaters (these grids are presented later in Section 10.0). The monthly rate of breakwater construction was advised by MP Rogers. Construction of the southern and northern breakwaters was assumed to progress simultaneously and the rate of construction was approximately pro-rata of the total lengths during each month. The progressively modified ORM grids were used in sequence to generate the current fields for the first 5 months of the ORM construction period (Nov 12 to Mar 13). For the latter 7 months of the construction period (Apr 13 to Nov 13), when all of the dredging work is scheduled, the model grid used the final layout of the ORM.

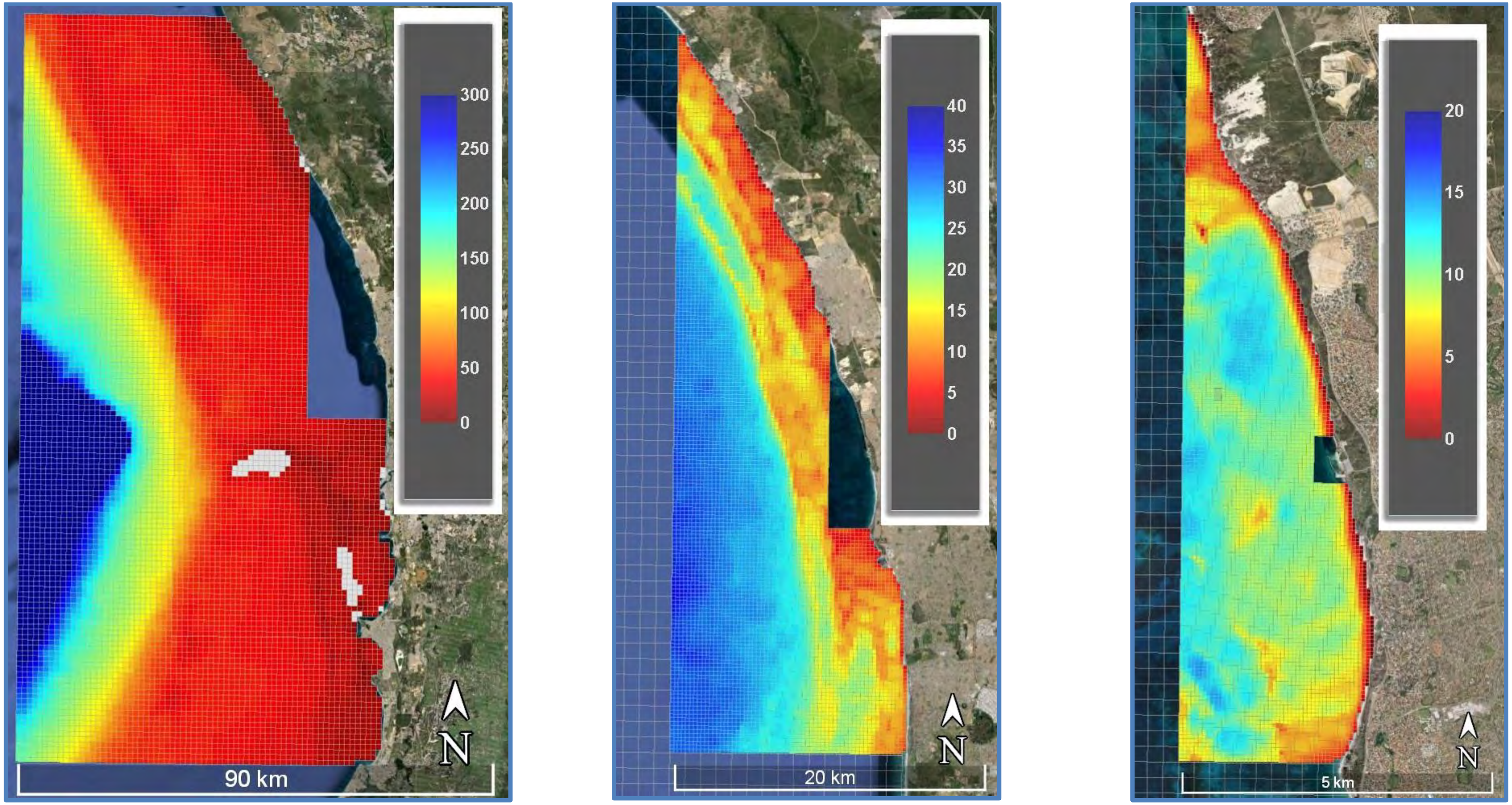

Figure 4.2: The boundaries of the grid0, grid1 and grid2 domains used in the nested hydrodynamic model are indicated by the panels left to right. The internal grid cut-outs in each panel progressively indicate the next neighbouring sub-grid region. The model bathymetry used for each grid is represented by the colour scale in each inset, and defined is relative to MSL. Cells shaded white are designated are model dry cells.

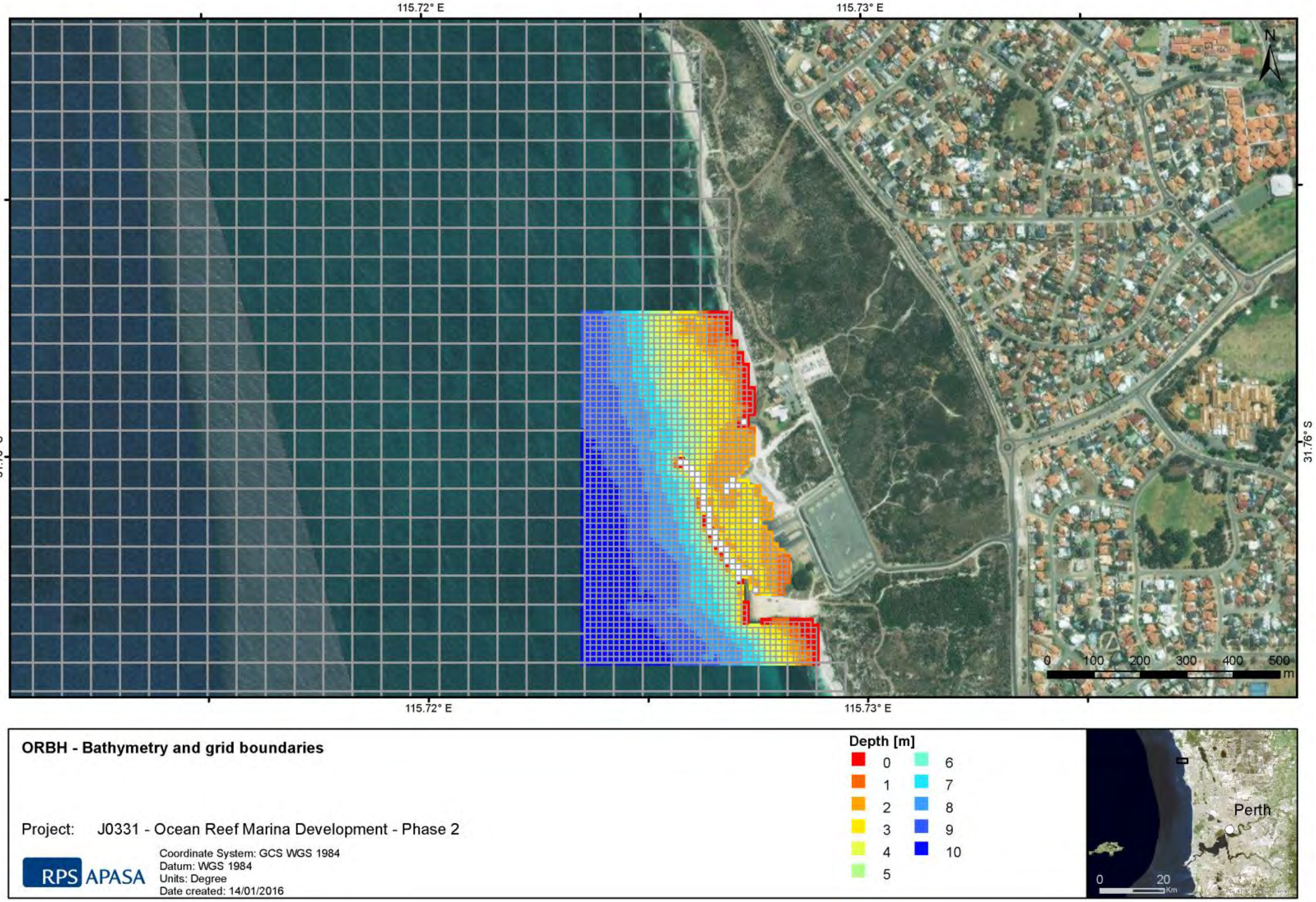

Figure 4.3: The boundaries of grid3 used in the nested hydrodynamic model of ORBH. The model representation of ORBH is indicated by the white shaded cells (model dry cells) and aerial imagery. The coloured shading indicates the model bathymetry, which is with respect to MSL.

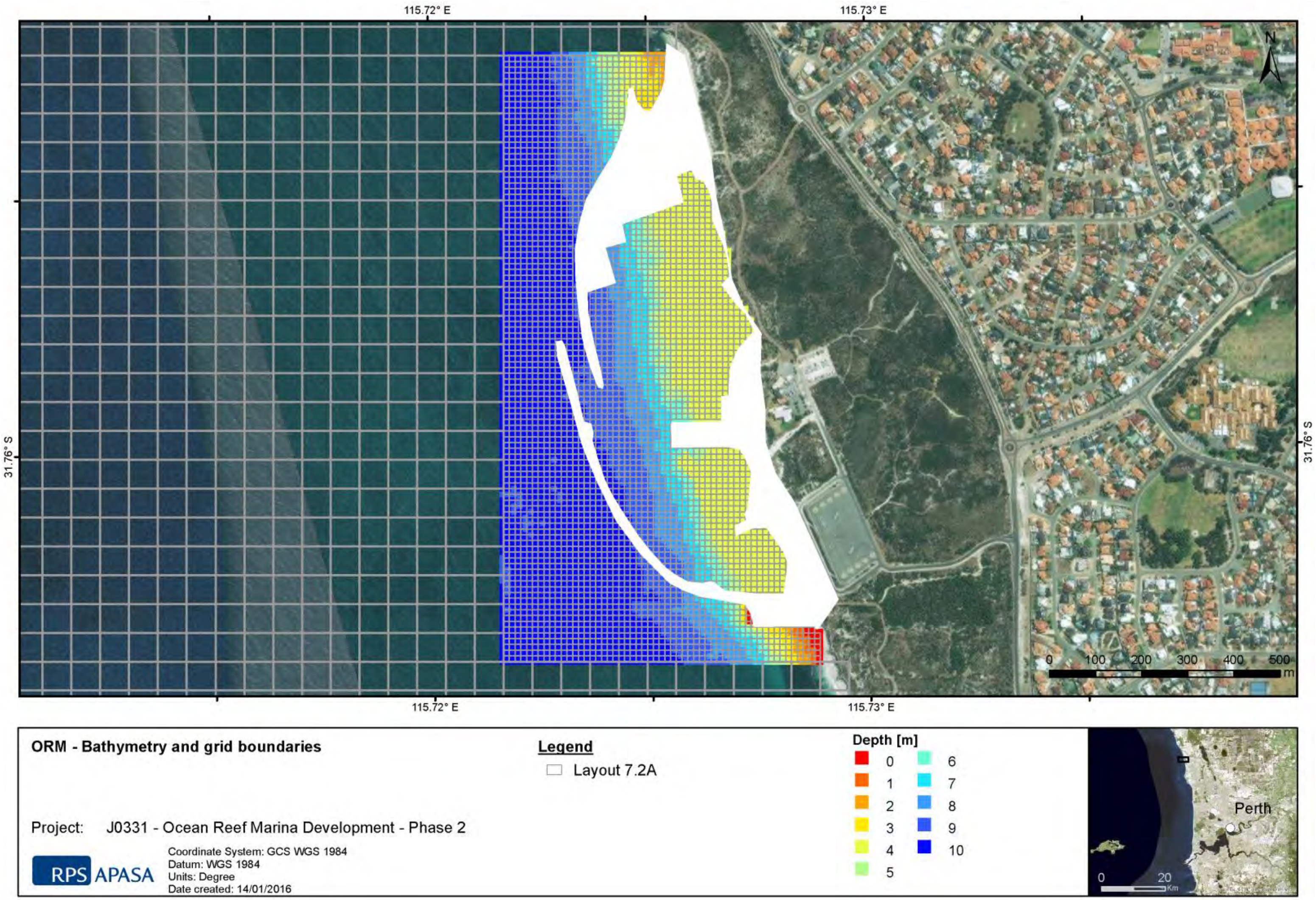

Figure 4.4: The boundaries and bathymetry of the innermost grid of the hydrodynamic model for ORM. The models dry cells are overlayed by white shaded cells, aerial imagery and a draft concept plan layout. The coloured shading indicates the model bathymetry with respect to AHD, and includes dredging of nearshore areas within the marina to a design depth of 3.5 m.

4.3.2 Boundary Forcing

4.3.2.1 Sea level

Sea level information from the Topex Poseidon TPXO 7.2 tidal data set was augmented with data from the HYCOM hindcast (tide removed) database (Chassignet *et al.* 2009). This allowed for the representation of tide and low-frequency sea level oscillations into the model domain. Spatial variation along the boundary was achieved by distance weighted interpolation between the available data points.

4.3.2.2 Wind

Wind forcing was applied to the hydrodynamic model using hourly observations of measured winds at Ocean Reef and Rottnest Island. The Rottnest wind data was applied uniformly over the outermost grid domain (grid0). The Ocean Reef wind was applied to all of the finer sub-grids (grid1, grid2 and grid3). This approach can cause some discontinuity in the modelled wind field at the boundary between grid0 and grid1, which in turn can lead to artefacts in the modelled currents near this boundary. However, any such artefacts would not influence results because of the distance between this boundary and the areas of interest (>10 km).

4.3.2.3 Temperature and salinity

The open boundaries of the model were forced with the spatially-variable temperature and salinity profiles from the HYCOM hindcast database (Chassignet *et al.* 2009). The temperature and salinity HYCOM data was time matched to each simulation period. Linear interpolation was used to match the HYCOM data to the model grid and time step.

4.3.2.4 Groundwater discharge

Seasonally variable groundwater discharge rates were introduced to the bottom layer of the model grids with flow rates as described in Section 4.2.2.4. The distribution of the groundwater discharge cells for the ORBH grid configuration is indicated in Figure 4.5. The discharge cells for the ORM grid configuration were distributed in a similar manner, within approximately 30 m of the shoreline.

4.3.2.5 Tracer release

For the ORBH flushing component of the model validation, a conservative tracer was added to the hydrodynamic model to simulate the release of Rhodamine dye into ORBH that occurred during the 2011 field study (APASA 2011). At the time corresponding to the Rhodamine dye release, and subsequent to a two-day model spin-up period, the simulated tracer was released instantaneously into all of the grid cells within ORBH. The subsequent concentration of tracer was tracked at six stations within ORBH (Figure 4.5), mimicking the 2011 field study.

For the flushing studies of the ORM and nearshore abalone habitats, the tracer initialisation and calculation methodology was similar. Conservative tracer was released instantaneously following a two-day model spin up period.

4.3.2.6 Atmospheric heating

Atmospheric heat transfer was not activated in the hydrodynamic model for the purposes of calibration and validation of the ORBH hydrodynamic model framework. However, for the ORM model framework heat flux, cloud cover and atmospheric pressure data were sourced from the CFSR model (Suranjana *et al* 2010).

Although the model results are typically not very sensitive to atmospheric heating, this module was activated because of the potential for diurnal differential heating and cooling to affect marina flushing. The model data was chosen as an input for this purpose as the measured data record for heat flux variables is patchy, and the spatial variability in pressure fields that was available from the model data would provide a higher level of accuracy than spatially-constant fields. The data used for the heat flux calculation in Delft3D includes relative humidity, air temperature, and cloudiness (as a fraction of sky cover).

Solar radiation was calculated within Delft3D-FLOW using a formula that is based on the position and rotation of the earth relative to the sun, and thus is latitude and time based. The incoming solar radiation was modified by taking into account the modelled cloud coverage data.

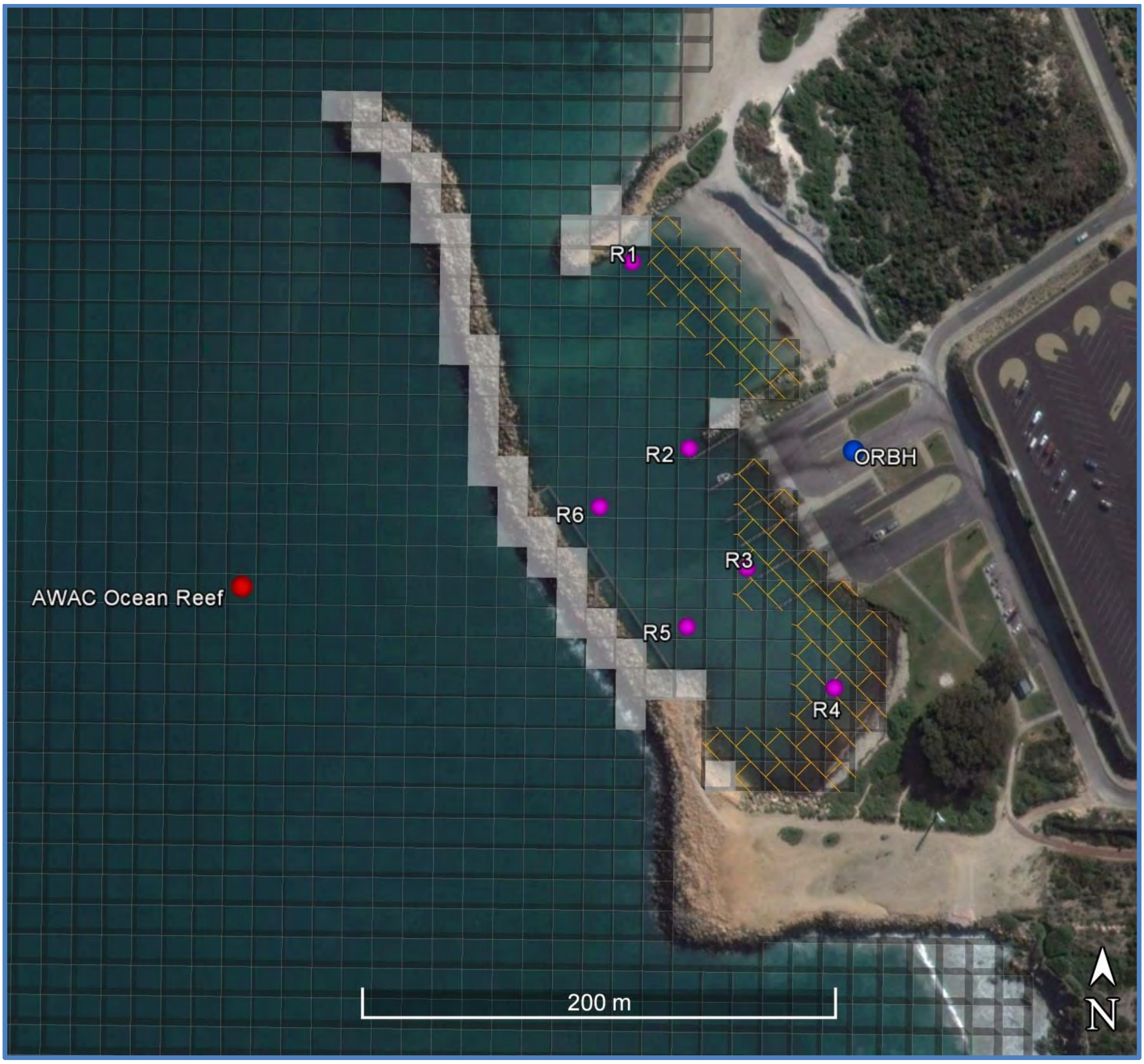

Figure 4.5: A zoomed view of the innermost model grid mesh (grid3) for the ORBH layout. Purple dots indicate the six locations (R1 to R6) where Rhodamine dye was released and measured as part of the 2011 field study. The purple dots also mark the six grid cells in which the concentration of a simulated tracer was tracked. The orange hatching marks indicate the grid cells that were used for groundwater discharge. The location of AWAC-ORBH instrument is provided for reference.

4.3.3 Model Parameters

A number of choices regarding physics and numerical schemes can be invoked within Delft3D-FLOW. A summary of the most significant choices in the numerical scheme is presented below.

4.3.3.1 Bottom friction

A quadratic friction law was applied to simulate the shear-stress at the seabed, using a Manning coefficient as the parameter to quantify the frictional effects of the seabed. A uniform Manning roughness coefficient of 0.02 was selected as representative of the seabed in the region. This value was selected based on previous experience and the value is commonly used for coastal studies. A bottom roughness 'sponge layer' was employed on the open boundary, with a buffer zone of higher-bottom roughness applied to smooth out transient instabilities.

4.3.3.2 Vertical turbulence parameterization

For the sigma-coordinate vertical system, 5 equally proportioned layers were specified. This is adequate to reproduce baroclinic flows within the coastal waters of the region, while maintaining computational efficiency over the domain. The κ-ε turbulence closure scheme was selected for the vertical viscosity and diffusivity, with background values set to zero.

4.3.3.3 Horizontal eddy diffusivity and viscosity

Sub-grid scale turbulence in the horizontal plane was parameterised by the horizontal eddy viscosity and diffusivity parameters, which were considered a calibration parameter. The parameters can be specified as constant values or can be set as a dynamic quantity using a sub-grid-scale model known as Horizontal Large Eddy Simulation (HLES).

There is no definitive way of establishing the values of eddy viscosity and diffusivity to use for a given model simulation. The general principle is that the values used for horizontal diffusivity and viscosity should decrease with decreasing grid size. In the case of viscosity, the value should be no greater than what is required to establish model stability. Appropriate diffusivity values can be established from field experiments with tracer dyes, and estimates can be found in the literature.

The Delft3D manual (Deltares, 2013) suggests that for detailed models where much of the details of the flow are resolved by the grid (grid sizes typically tens of metres or less), the values for the eddy viscosity and the eddy diffusivity are typically in the range of 1-10 m^2/s. For large (tidal) areas with a coarse grid, grid sizes of hundreds of metres or more, the coefficients typically range from 10-100 m^2/s. Based on Okubo (1971), and with guidance from the measured values in literature, the minimum values set for the background diffusivity ranged between 0.1 m^2/s for the finest grid (grid3), up to 1 m^2/s for the coarsest grid (grid 0).

For all grids except the finest scale grid, the HLES scheme was applied to add diffusivity to these background values based on the eddy-generating shear in the flow fields. However, for the finest scale grid that represents ORBH and is most critical to the flushing study, only the background diffusivity values were applied. This choice represents a conservative approach with regard to predicted flushing in ORBH and achieves consistency with the previous model of ORBH flushing, which was successfully validated (APASA 2011).

Selection of appropriate horizontal eddy viscosity values for hydrodynamic models is difficult because there are few guidelines available. Compared to diffusivity, field data measurements of viscosity are more uncommon and more difficult to characterise. A general rule of thumb is that the eddy viscosity should be roughly an order of magnitude greater than the diffusion. Experience and experimentation (calibration) often determine their selection. Choosing a value that is low enough to achieve stability does not apply well to Delft3D-FLOW, as the model is so stable it will run with unrealistic values of eddy viscosity, which can create very strong currents. The final background values for horizontal eddy viscosity selected after extensive calibration testing were 1, 30, 150 and 200 m^2/s for the finest to coarsest grids, respectively. The 200 m^2/s value of eddy viscosity is slightly higher than the typical range (Deltares, 2013) because the grid cells widths for grid0 are relatively large (1 km), however the selected value is still well within the models upper limit of 1000 m^2/s.

4.4 Wave Model Configuration

4.4.1 Grid and Bathymetry

The computational grid for the SWAN model was set-up using an unstructured mesh which was subdivided by triangular cells of varying size. The use of an unstructured mesh allows a more efficient representation of complex bathymetry, due to the ability to use finer mesh cells in the areas of interest and larger mesh cells for the broader region. The model domain spanned approximately 75 km in the east-west direction (Longitude 115° to 115.78°E) and approximately 220 km in the north-south direction (Latitude 31° to 33°S), including all of Perth coastal waters from Lancelin to Preston Beach (Figure 4.6). The same bathymetric dataset that was developed for the hydrodynamic modelling was also applied to the wave model grid.

The wave model grid and bathymetry is shown in Figure 4.7, with depths given in metres relative to AHD. The final unstructured mesh contained 7,455 triangles with 3,912 vertices. The mesh resolution was adjusted to maximise computational efficiency. Generally, the mesh was set with higher resolution in areas where the bathymetry changes rapidly. The computational mesh resolution becomes progressively finer moving from offshore to nearshore with the highest resolution being in the region in the immediate vicinity of the ORBH. In the vicinity of ORBH, the minimum triangle edge length in the mesh was 100 to 150 m. In the offshore region the maximum triangle edge length was approximately 7 km.

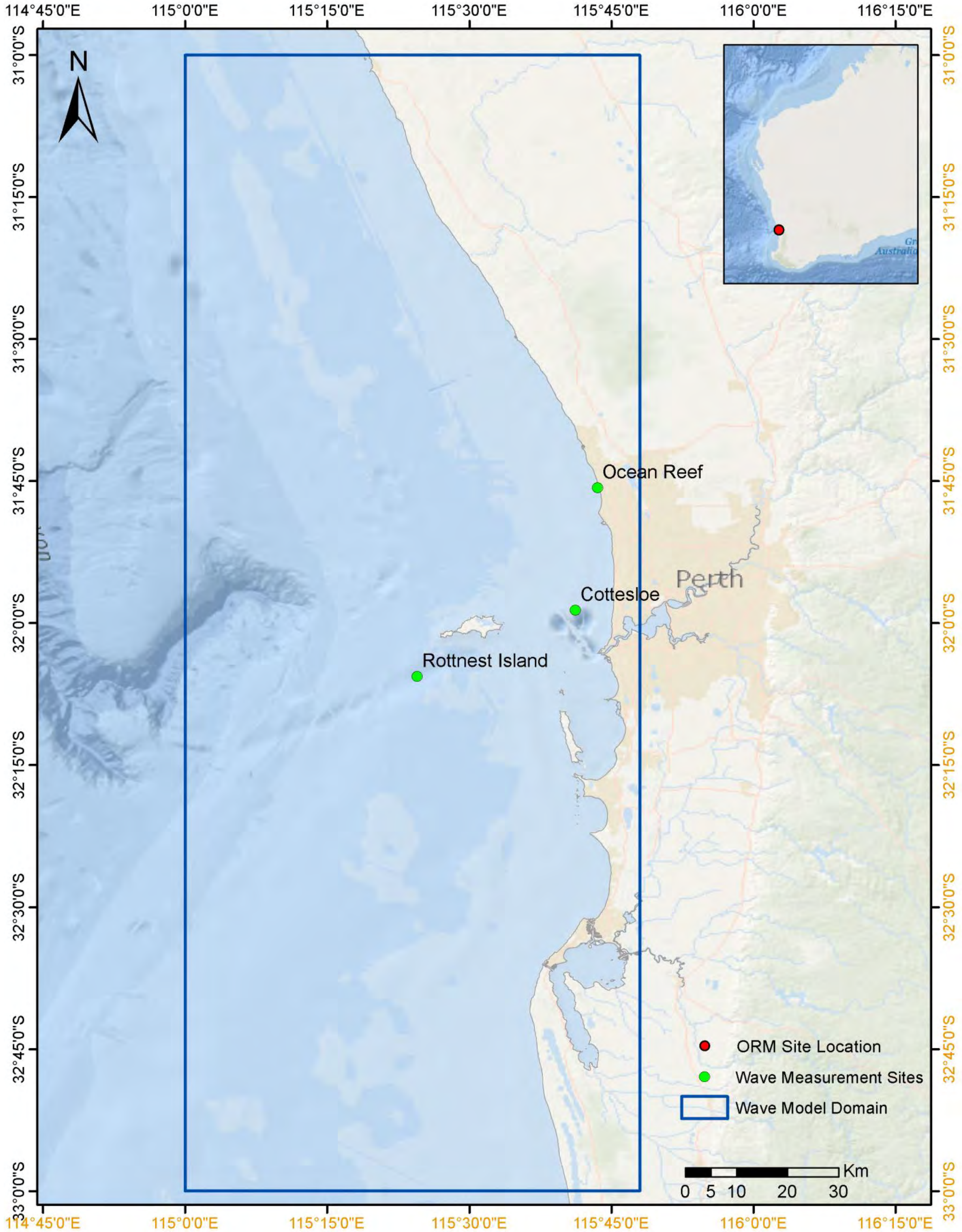

Figure 4.6: The outer boundary of the SWAN spectral wave model domain and the location of wave measurement sites used for calibration and validation.

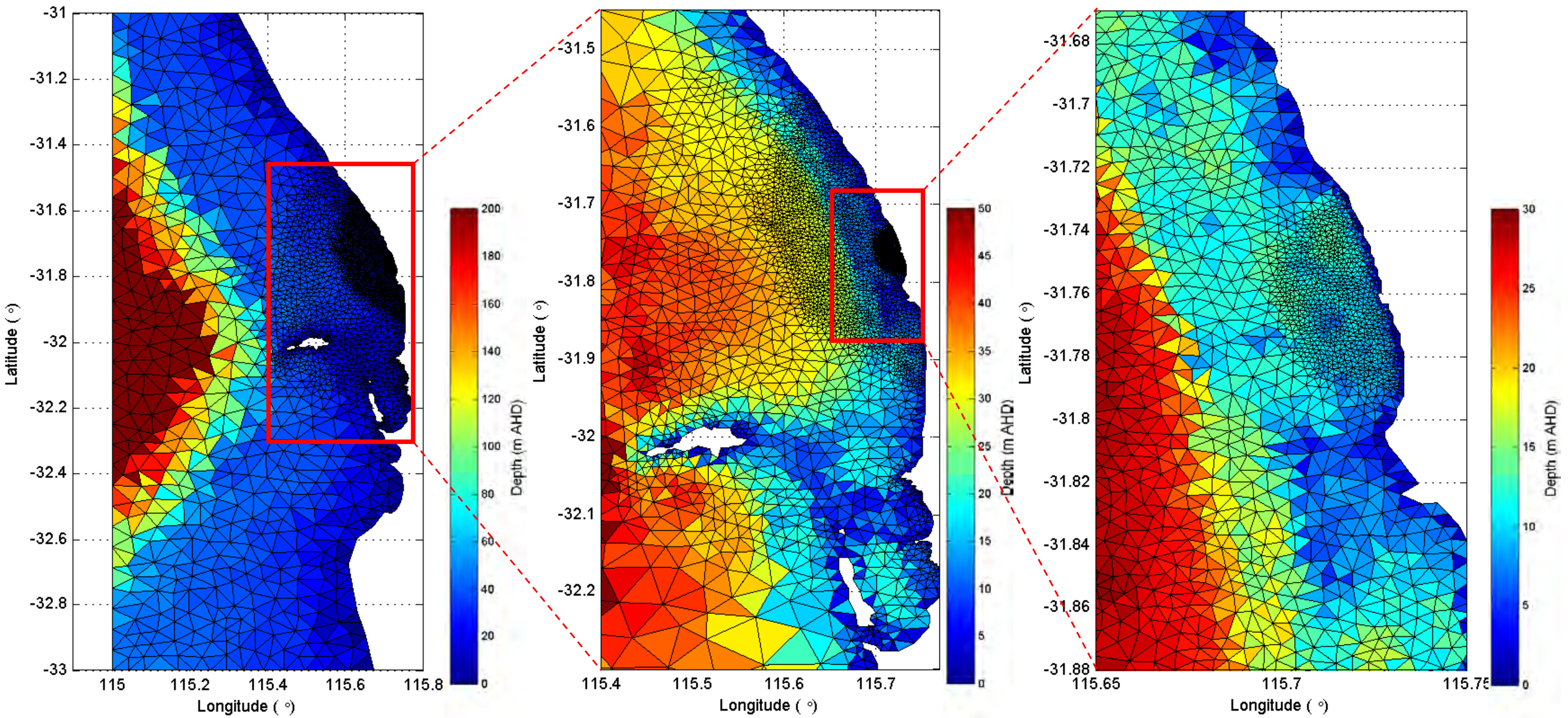

Figure 4.7: SWAN wave model unstructured computational mesh with depth indicated by the inset colour bars. The left panel shows the mesh over the entire model domain, with the middle and right panels showing zoomed in views of the area highlighted by the red box in the panel to the left of it. Note each figure has a different bathymetry scale.

4.4.2 Boundary Forcing

4.4.2.1 Waves

The wave model domain was defined with northern, western and southern open boundaries. The land boundary on the east of the grid was assumed to absorb all incoming wave energy. A parametric spectral input (offshore boundary condition) was generated from WW3 data using a JONSWAP spectrum with the value of the peak enhancement factor set to 3.3; a value that is widely adopted in application of the SWAN model worldwide. The wave parameters that govern the spectral shape of the JONSWAP spectrum are significant wave height (H_s), peak wave period (T_p), peak wave direction (θ_{peak}) and the directional spreading of waves (i.e. how 'focused' the swell conditions are).

Seasonal wave roses at the WW3 site that was used along the open boundaries of the model are presented in Figure 4.8 for the 1-year period from March 2011 to March 2012. The wave roses reveal that the predicted offshore wave climate in the region is dominated by west-southwest to south-westerly swell waves during all seasons with the H_s magnitudes being largest during winter/early spring and smallest during summer/autumn. The WW3 model predicts the wave heights at the boundaries of the domain are typically in the range 0 to 7 m.

4.4.2.2 Wind

The wind data used to drive the wave model was selected after trialing different types of wind data, i.e. measured data at fixed stations and modelled hindcast wind data. Ultimately the hindcast wind data was selected for the wave model while the measured data was used for the hydrodynamic model. The use of hindcast wind data for the wave modelling and measured wind data for the hydrodynamic modelling is inconsistent in some respects. However, this approach represents the best compromise under the constraints of imperfect wind data and the different emphases of the hydrodynamic and wave models.

A well resolved spatial wind field is critical for forecasting wave distributions within the domain, especially the propagation of waves from within other parts of the model domain. In addition, the wave model was calibrated/validated against wave buoys that were dispersed widely throughout the model domain (i.e. ORBH, Rottnest and Cottesloe). Under these constraints, it was found that the superior spatial resolution of the hindcast data was more important than the (presumed) local accuracy of the wind monitoring stations to achieve good model skill at all locations.

For the wind field constructed from measured data, long term hourly wind records were available at Rottnest Island, Swanbourne and Ocean Reef from the Bureau of Meteorology (BoM). An interpolated wind field derived from these data was initially trialed in the wave model but the results indicated that the spatial variability of the wind forcing was inadequately represented by the three stations.

For the wind field constructed from hindcast model data, a spatial wind dataset for the region was available from the ACCESS weather model (see Section 4.2.2.2 for details), which covered the calibration and validation periods. It was found that application of the ACCESS spatial wind dataset improved wave model accuracy compared with the measured wind data. Therefore the spatial dataset was used for the wave model. A comparative analysis of the hindcast and measured wind data is presented in Section 6.1.

For the hydrodynamic model, the locations of the ADCPs used for calibration/validation were all close to ORBH and local wind effects would tend to dominate local circulation at these locations. Consequently, the use of measured wind data from the Ocean Reef Observation Station led to the good agreement between modelled and measured currents at these locations. Similar findings were demonstrated in a previous study (APASA 2011).

4.4.2.3 Water Level

Water levels were applied to the wave model to incorporate the effects of time-varying depth on the wave processes of frictional loss, refraction and wave breaking. For the purpose of the wave model, the water level was based on a time-series of half hourly tidal predictions for Fremantle and was assumed to be uniform over the domain.

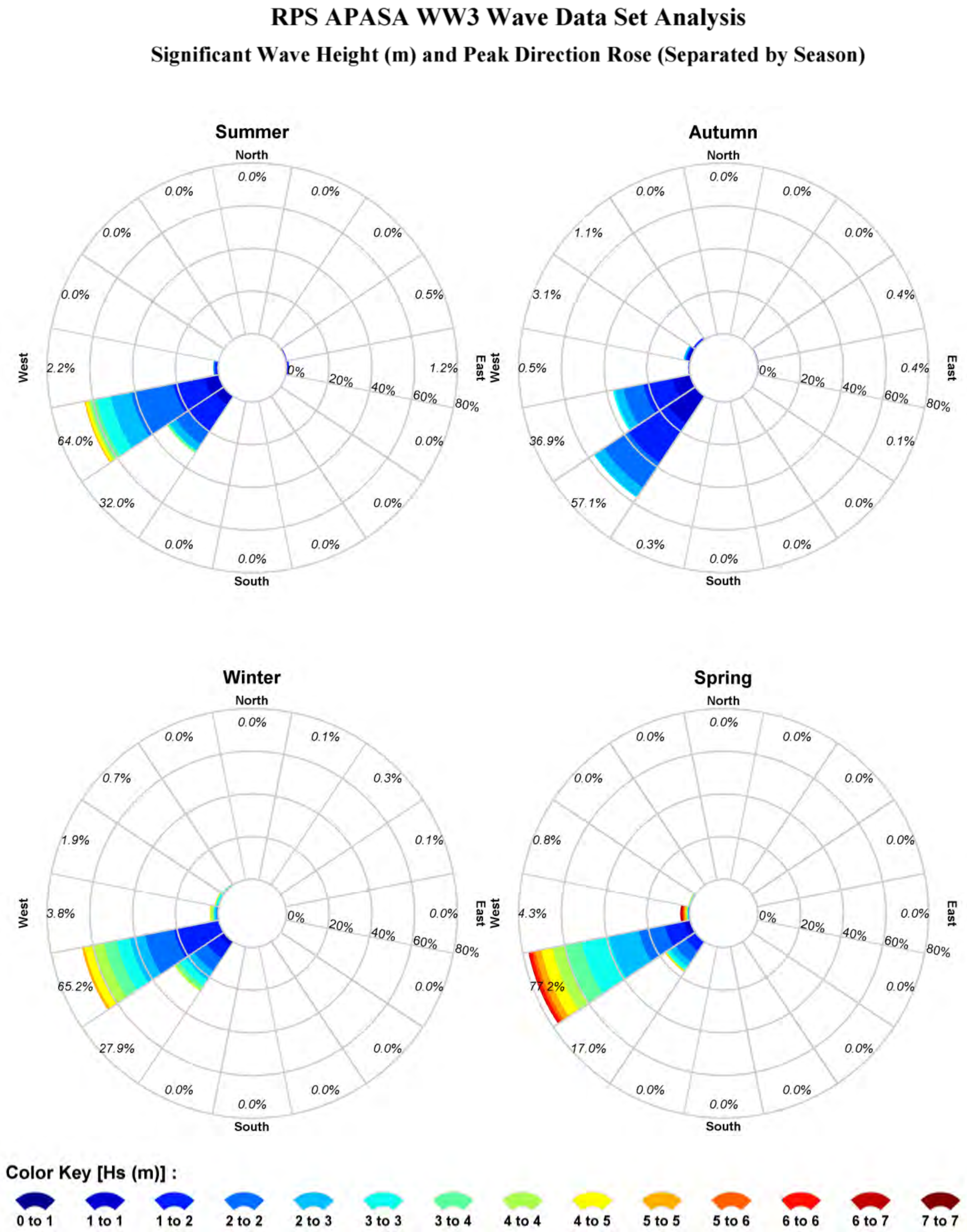

Figure 4.8: Seasonal wave roses of WW3 boundary point for the period March 2011 to February 2012 (12 months covering both the calibration and validation simulation periods). Seasons defined: SUM (Dec-Feb), AUT (Mar-May), WIN (Jul-Aug) and SPR (Sep-Nov).

4.4.3 Model Parameters

The physical processes applied to the final, calibrated, wave model included white-capping, depth-induced wave breaking, bottom-friction and triad and quadruplet wave-wave interactions. The process of white-capping in the SWAN model is represented by the pulse-based model of Hasselmann (1974), reformulated in terms of wave number as to be applicable in finite water depth (Komen *et al.*1984). The default SWAN parameterisation of depth-induced wave breaking was used with a 0.73 constant breaking factor (Eldeberky and J.A. Battjes 1996).

Bottom friction was activated using the Madsen model (Madsen *et al.* 1988). This formulation is similar to that of Hasselmann *et al.* (1968), but in this case the bottom friction factor is a function of the bottom roughness length scale and the wave conditions. The bottom roughness length scale was set to 0.2 m. For modelling the triad wave-wave interaction SWAN uses the Lumped Triad Approximation (Eldeberky 1996) in each spectral direction. Quadruplet wave-wave interaction was also included.

Non-stationary SWAN simulations were performed with a time step of 30 minutes for all simulated periods. The model was run with the Janssen (1989, 1991) model of wave growth, which specifies exponential growth.

The wave climate of Perth coastal waters is composed of two distinct seasonal regimes; the winter storm period and a calmer summer period. These two periods experience quite different wave conditions, therefore during the calibration and validation process, the set of model parameters was carefully selected to ensure that the wave conditions during both of these seasonal regimes were well represented in the model period.

The results of the calibration (winter period) are presented in Section 6.2 and of the validation (summer period) are presented in Section 6.3.

4.5 Components of Water Quality Modelling

Details of the methodologies that were applied for the various components of water quality modelling, i.e. the flushing assessment, abalone habitat assessment, sediment fates, ecological modelling and climate change assessment are presented subsequently as a part of each of those sections.

4.6 Selection of Simulation Time Periods

The hydrodynamic model was run for a range of different past periods (i.e. subjected to recent historical weather and metocean forcing) to satisfy the varying requirements of model calibration, model validation and the water quality assessments considered for this study.

The periods selected for model calibration and validation were determined by the availability of appropriate field measurements. The field measurements and time periods used for validation/calibration of the hydrodynamic model framework were the same as those described in the previous ORM study (APASA 2011), and details of these periods are presented in the Section 5.0 and Section 6.0.

The simulation periods applied to the various water quality assessments were selected following an analysis of wind conditions from two measurement stations, Ocean Reef and Rottnest. Wind forcing was used as a general indicator of weather because it is the most important driver of local circulation in the hydrodynamic model. The wind analysis computed statistics for each season of each year from 2011 to 2015 and compared the results to bulk seasonal statistics based on a 10-year period from October 2005 to

September 2015. The main criteria for the comparison were the mean wind speeds supplemented by analysis of various wind speed percentiles. The outcomes of this analysis are summarised in Table 4.5.

Table 4.5: Selection of recent representative seasons based on analysis of historical measured wind speed (corrected to 10 m) at Rottnest and Ocean Reef stations

Season	Best Representative Year	Best Representative Mean Wind Speed – Ocean Reef (m/s)	10-Year Mean Wind Speed – Ocean Reef (m/s)	Best Representative Mean Wind Speed – Rottnest (m/s)	10-Year Mean Wind Speed – Rottnest (m/s)
Summer (Dec – Feb)	2012/2013	6.7	6.7	6.7	6.9
Autumn (Mar – May)	2012	5.6	5.6	5.6	5.8
Winter (Jun – Aug)	2013	6.0	5.8	5.7	5.8
Spring (Oct – Nov)	2014	6.6	6.5	6.3	6.3

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For the construction and dredging simulations a continuous period of 13 months was used. The 13 months from the beginning of November 2012 to November 2013 were selected as the best overall representative 13-month period for this purpose. November was selected as the start month based on a forecast of the construction schedule communicated by MP Rogers. The hydrodynamic simulations for the dredging and construction period were discretised into 13 one-month blocks.

For the ecological (Delft3D-WAQ) simulations the period of analysis was from 01 December 2012 to 30 November 2013. These 12-months were discretised into four 3-month blocks according to conventional seasonal periods (i.e. Dec-Feb, Mar-May, Jun-Aug and Sep-Nov).

For the flushing, abalone habitat and climate change assessments, the approach used considered multiple simulation periods but of shorter duration. Simulations were carried out spanning spring and neap tide periods in different seasons. Representative periods were chosen based on the information detailed in Table 4.5.

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Table 4.6: Summary of simulation periods selected for use in flushing studies, abalone habitat assessment and climate change scenarios.

Season	Hot Start Date*	Hot Start Time (HH:MM)	Simulation Period (days)	Tide Cycle at Hot Start	Used in Flushing Analysis	Used in Abalone Habitat Analysis	Used in Climate Change Scenarios
Summer	9 Jan 13	00:00	15	Spring	Yes	Yes	No
Summer	12 Feb 13	00:00	15	Neap	Yes	Yes	No
Autumn	8 Apr 12	00:00	15	Spring	Yes	Yes	No
Autumn	21 Mar 12	00:00	15	Neap	Yes	Yes	Yes
Winter	19 Jul 13	00:00	15	Spring	Yes	Yes	Yes
Winter	9 Aug 13	00:00	15	Neap	Yes	Yes	No
Spring	24 Oct 14	00:00	15	Spring	Yes	Yes	No
Spring	1 Nov 14	00:00	15	Neap	Yes	Yes	No

* Simulation “hot start” date followed a two-day prior model spin-up period

4.7 Model Skill Measures

4.7.1 Statistics

The model results were calibrated and validated through both quantitative and visual comparison of measured and modelled data. The Index of Agreement (IOA) (Willmott 1981) and the Mean Absolute Error (MAE) (Willmott 1982, Willmott and Matsuura 2005) were used together with other traditional error estimates, such as the correlation coefficient and the root mean square error (RMSE). The latter two measures in particular should be interpreted with caution as they can be unforgiving of relatively inconsequential mismatches in modelled and measured data (e.g., Willmott and Matsuura, 2005, Willmott 1982); however, they have the advantage of being relatively intuitive and give context to the slightly more sophisticated IOA and MAE measures.

The Index of Agreement (IOA) is determined by:

$$\mathrm{IOA} = 1 - \frac{\sum |X_{\mathrm{model}} - X_{\mathrm{obs}}|^2}{\sum \left(|X_{\mathrm{model}} - \overline{X_{\mathrm{obs}}}| + |X_{\mathrm{obs}} - \overline{X_{\mathrm{obs}}}| \right)^2}$$

In this equation, X represents the variable being compared and $\overline{X}$ the time mean of that variable.

A perfect agreement can be said to exist between the model and field observations if the index gives a measure of one, and complete disagreement will produce an index measure of zero. While it is difficult to find definitive guidelines for what values of the IOA might represent a good agreement, Willmott *et al.* (1985) suggests that values meaningfully larger than 0.5 represent good model performance.

The MAE is simply the average of the absolute values of the difference between the observed and modeled value. Therefore, a lower MAE implies better model performance. MAE is a more natural measure of average error (Willmott and Matsuura 2005) and more readily understood.

One important point to note regarding both the IOA and MAE, and in fact most measures of model performance, is that slight phase differences between two compared series can result in a seemingly poor statistical comparison. It is therefore always important to consider both the statistics and the visual representation of the comparison (Willmott *et al.* 1985). Another potential issue is that directional fluctuations near 0-360° can bias the skill measures of direction. Therefore, the directional skill based on the average of x-y vector components of a unit directional vector has been calculated whenever northward direction is common in the dataset.

4.7.2 Time Series

In addition to bulk statistical measures, model performance for calibration and validation periods was assessed visually with the aid of scatterplots and q-q plots. The scatterplots show the correlation between the x and y components of the measured and modelled current/wave data. The q-q plots show the quantile values of measured current speed against equivalent quantiles for the modelled current speeds.

The model performance was also evaluated against time series plots of water level, current speed and current direction data. This approach is valuable because statistical measures of model skill can heavily penalise errors in phase (i.e. time lags) even when the dynamics of flow are broadly reproduced.

4.7.3 Flushing Calculations

Model calculations for flushing rates were tested by comparison to results of a Rhodamine dye flushing experiment that was carried out within ORBH (Section 4.2.1). Flushing rates were calculated for individual stations within the ORBH.

To facilitate direct comparison of measured and model data, results of both were normalised to represent a proportion of the initial concentration at the station. This approach resulted in a time series of relative (dimensionless) concentrations for each station, expressed as percentages of the initial concentrations. At each station, measurements were taken near to the surface and near to the sea-bed, except at some stations were the depth was deemed insufficient.

The dye results were compared from the time of first measurement until concentrations return to background levels. The time of first measurement was approximately 6 hours after the tracer was released. The initial 6-hour period between release and measurement allowed time for the point releases to diffuse.

5.0 Hydrodynamic Model Results

5.1 Summer Period Calibration

The hydrodynamic model was calibrated against water level and currents measured at two of the AWAC stations (AWAC-West and AWAC-North) over the period 1 February 2013 to 15 March 2013. Model skill statistics were computed for three depths representative of each site; near-surface, mid-depth and near-seabed (see Table 4.1 for the depths of instrument deployment).

In general, the statistical assessments of model skill for current speed and direction were similar at both the AWAC-North and AWAC-West locations (Table 5.1). Model skill was consistently higher near to the sea-bed than it is near to the surface.

The RMSE values, albeit small, are more significant when compared with the actual current speed magnitudes because the actual speeds were very low. Also, slight phase (timing) differences are likely affect the RMSE form of comparison and this means time series plots can give a more meaningful indication of model performance. Some component of the statistical discrepancy between measured and modelled currents is related to necessary spatial and temporal averaging of turbulent fluctuations in the modelled data. This point will be further expanded in Section 5.1.2.

Table 5.1: Summary of model calibration performance statistics with respect to measured currents in the summer calibration period.

Site	Model Period	Depth	Speed RMSE (m/s)	Speed IOA	Speed MAE (m/s)	Direction IOA^	Direction MAE^
AWAC-North	1/2/2013 to 15/3/2013	Near-Surface	0.048	0.73	0.037	0.71	0.036
		Mid-Depth	0.044	0.72	0.034	0.72	0.032
		Near-Seabed	0.036	0.75	0.028	0.70	0.029
AWAC-West	1/2/2013 to 15/3/2013	Near-Surface	0.076	0.62	0.061	0.67	0.051
		Mid-Depth	0.041	0.75	0.032	0.65	0.031
		Near-Seabed	0.036	0.75	0.030	0.67	0.029

^ IOA and MAE direction statistics were calculated from averages of IOA and MAE values that were determined separately for x and y directional components.

** Relatively lower values of RMSE and MAE indicate higher model skill; IOA values closer to 1 also indicate higher model skill.*

5.1.1 Water level

A comparison of water level changes over the calibration period is presented in Figure 5.1. Both measured and modelled data were adjusted to a common datum (mean of zero) for this comparison because the AWAC water level measurements can't be corrected to the AHD datum. The measured and modelled water level show good visual agreement, particularly as modelled data only relies on water level inputs that are themselves modelled rather than measured.

There is a small discrepancy in the mean water level in the last 2 to 3 days of comparison (12 March onward). This difference may be explained by a discrepancy between the actual sea level anomaly due to weather during that time and the sea level anomaly predicted by the HYCOM hindcast model. This could be related to a short duration high wind speed event around 12 March that can be seen in the lower panels of Figure 5.1.

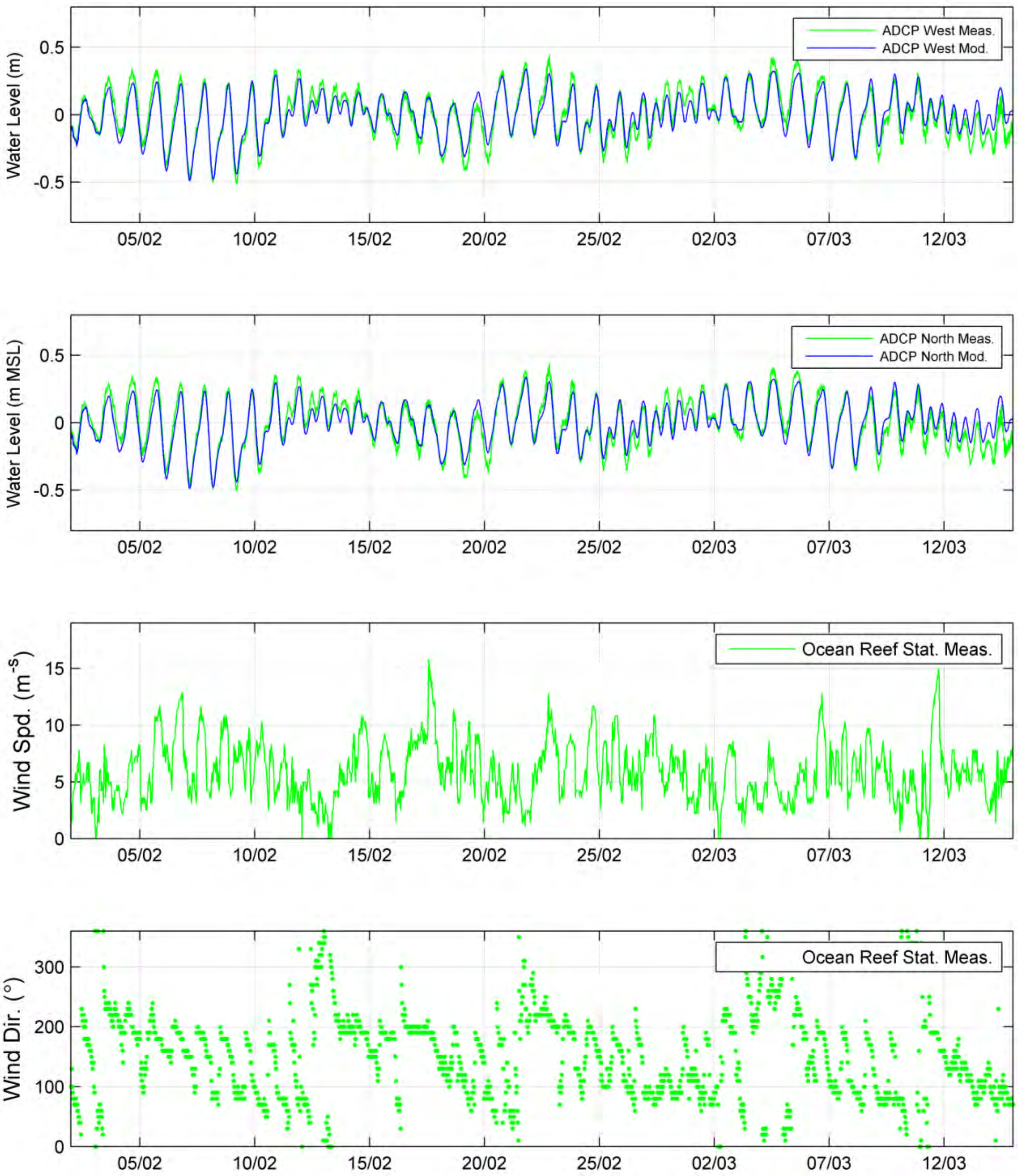

Figure 5.1: Time-series of measured (green) and modelled (blue) change in water level (relative) at ADCP-West (first panel) and ADCP-North (second panel) locations for the year 2013. The measured wind speed and direction data from Ocean Reef station is also indicated in the third and fourth panels to assist interpretation of model results for this period.

5.1.2 AWAC-North currents

Time series of current speed and direction near the water surface at the AWAC-North location are presented in Figure 5.2. In the upper panel, which shows current speeds, a 1-hour filtered version of the measured current speed is shown in addition to the unfiltered measured and modelled data. The 1-hour filter matches the time resolution of the wind input to the model. The lower panels of Figure 5.2 show the U and V components of velocity (positive U indicates current direction towards the east, positive V indicates current direction towards the north).

The modelled currents are smoother (i.e. less noisy) than the unfiltered measured currents because the modelled data is constrained to only represent averages in space and time. More specifically, for any particular location, the modelled currents necessarily represent the average of the current over the spatial scale of the model grid (e.g. 62.5 m), whereas the measured currents are true ‘point’ measurements. Similarly, but in a temporal sense, the wind input data for the model is hourly, therefore the modelled currents will likely have fewer wind induced fluctuations than the measured currents.

Such relatively rapid and small scale processes tend to average out, as indicated by the better match between the modelled current data and the 1-hour filtered version of the measured current speed. The inability to model sub-grid scale current fluctuations does not affect the ability to model larger scale flows of longer period, such as tidal flows and larger scale wind driven currents, both of which are of primary importance to the fate and transport processes considered in this study.

In addition to these sub-grid and sub-time scale effects, there is also a small but notable difference in the vertical averaging depths used for the modelled and measured data. The vertical bin depth used for AWAC measurements was 2 m; however, the model layer depth at these AWAC locations was around 2.5 m (varying with water level). Given that highest current speeds are usually observed nearest to the surface, the modelled current speeds near the surface would be slightly supressed because of their 25% larger averaging depth.

Despite the abovementioned caveats concerning modelled and measured data comparison, the time series comparison shows good general agreement between measured and modelled data. The measured data clearly displays more variance around its trend than the modelled data. A relatively better match is achieved to the 1-hour filtered series.

In terms of lower frequency current speed fluctuations (~2-3 hours), the modelled data slightly overestimates some fluctuations and underestimates some others, but without a clear overall bias. Almost all of the significant fluctuations that occurred on 2-3 hour time scales in the measured data were represented in the modelled data.

The time series of current speed comparisons indicate that there was a ‘spike’ in current speed around 18 February (Figure 5.2) that was somewhat overestimated by the model. This contrasts with a similar spike around 12 March that was captured reasonably well. Comparing these two events, it can be observed that the modelled current speeds responded similarly to similar spikes in wind speed from similar directions (as might be expected), however, the measured current data responded inconsistently during these similar spikes in wind speed. It is difficult to understand the reason for this discrepancy, some sub-grid scale event or some form of measurement error could be considered a possibility (particularly as data from the AWAC-West station that is presented subsequently does not show the same degree of discrepancy for these two ‘spikes’). However, this short duration discrepancy is not representative of the generally good agreement between modelled and measured data. In particular, the timings of the major shifts in current direction were well matched, indicating an appropriate response to changing wind and tide.

The scatterplot shown in Figure 5.3 characterises general trends in model performance. The scatterplot shows a reasonably good overlap between measured and modelled data, with the exception of a small cluster of measured current samples directed toward the south east, which were not matched in the modelled currents. The south-east cluster of measured samples derives from a flow event that occurred just after 20 February (Figure 5.2). The measured wind data for this period (Figure 5.1) doesn't indicate any significant north-westerly wind forcing that would be expected to drive this current in the model, however, inspection of the HYCOM hindcast current data for the same period indicated that there was a switch towards southwards currents during this period (an atypical occurrence for this period). This suggests that the weather component of the open boundary forcing information provided by the HYCOM model might have been inaccurate over this period due to an extreme event or non-existent.

The q-q plot (Figure 5.4) indicates that there was a very good agreement between measured and modelled current speeds from zero up to around the 80th percentile. At current speeds above the 80th percentile, the model current speeds showed a tendency to be higher than the measured current speeds.

For the near-seabed currents at the AWAC-North location, the equivalent time series plot, scatterplot and q-q plot currents (Figure 5.5, Figure 5.6 and Figure 5.7) indicate similar trends and features to the near-surface. In general, the visual comparisons indicate a better match between measured and modelled data at lower depths than at the surface, consistent with the results of the summary statistics (Table 5.1).

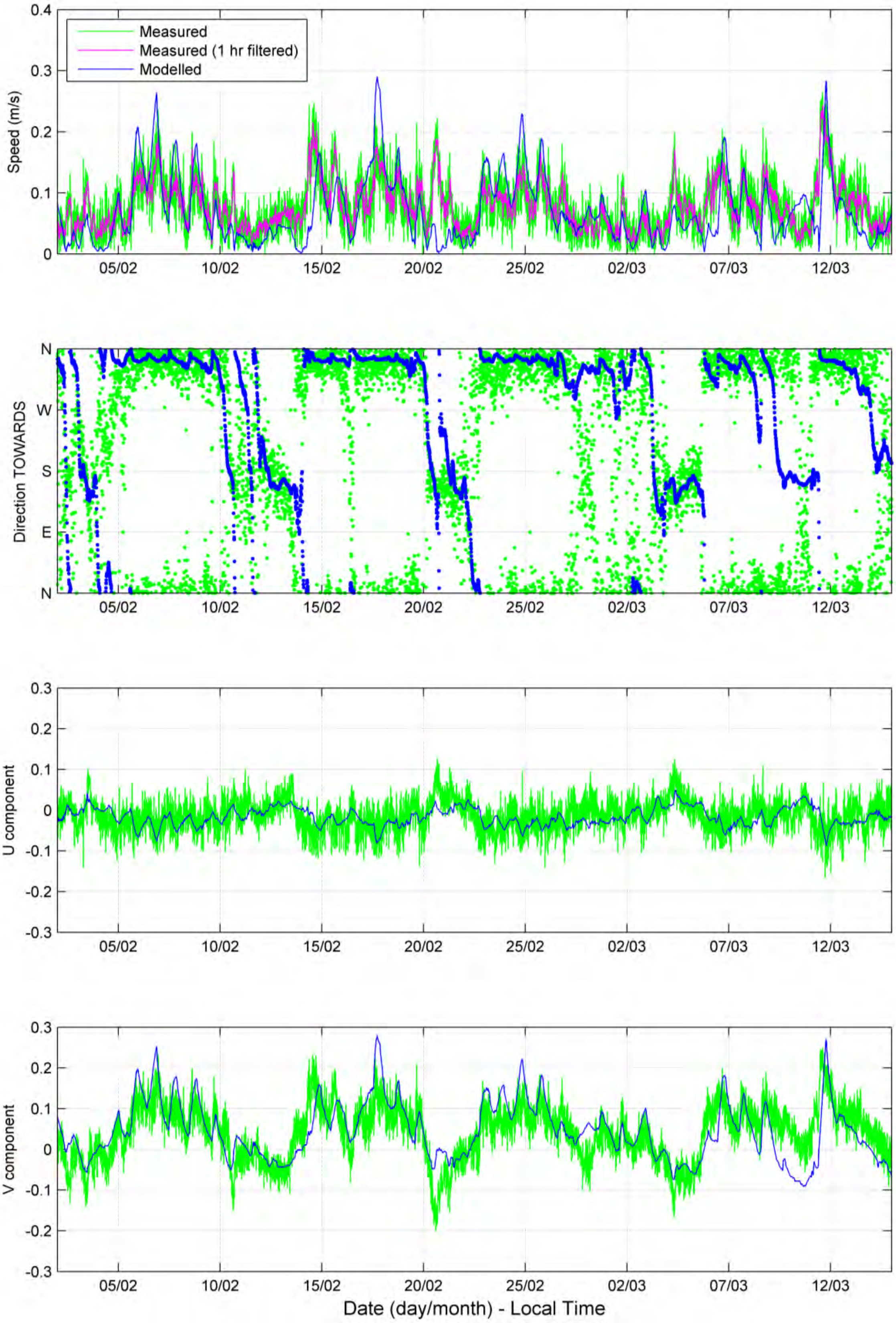

Figure 5.2: Time-series overlay of measured (green) and modelled (blue) near-surface currents at the ADCP-North location for the year 2013. The purple line in the top panel shows the measured data with a 1-hour filter (6 point moving average).

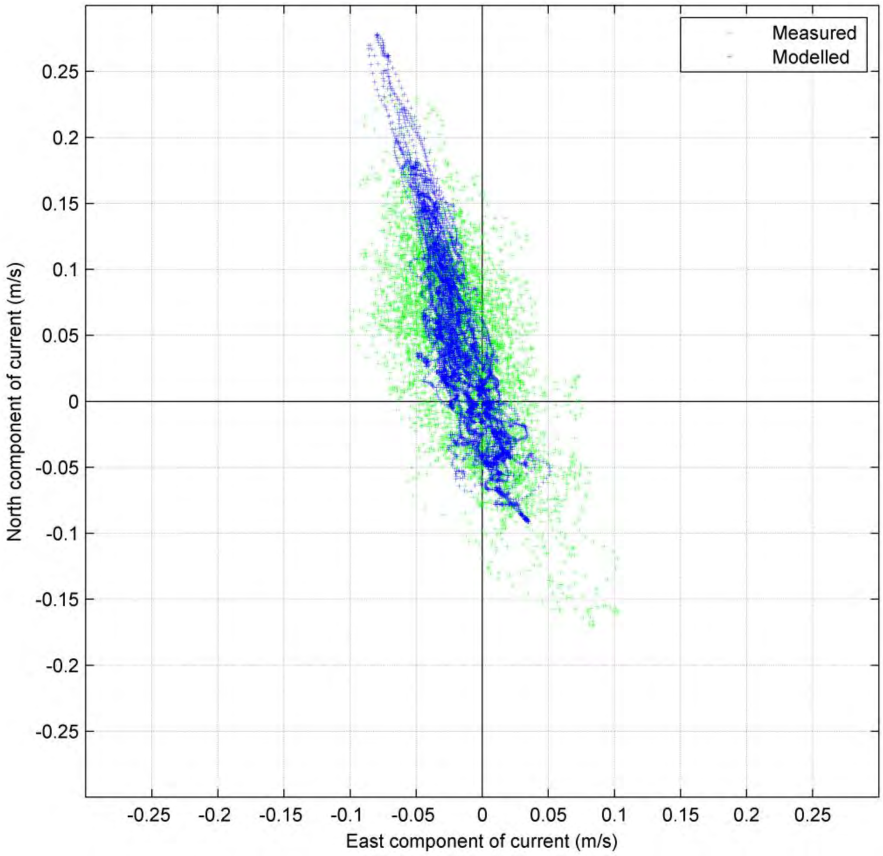

Figure 5.3: Scatterplot of measured (green dots) and modelled (blue dots) near-surface current vectors at the ADCP-North location over the period 1 Feb 2013 to 15 Mar 2013.

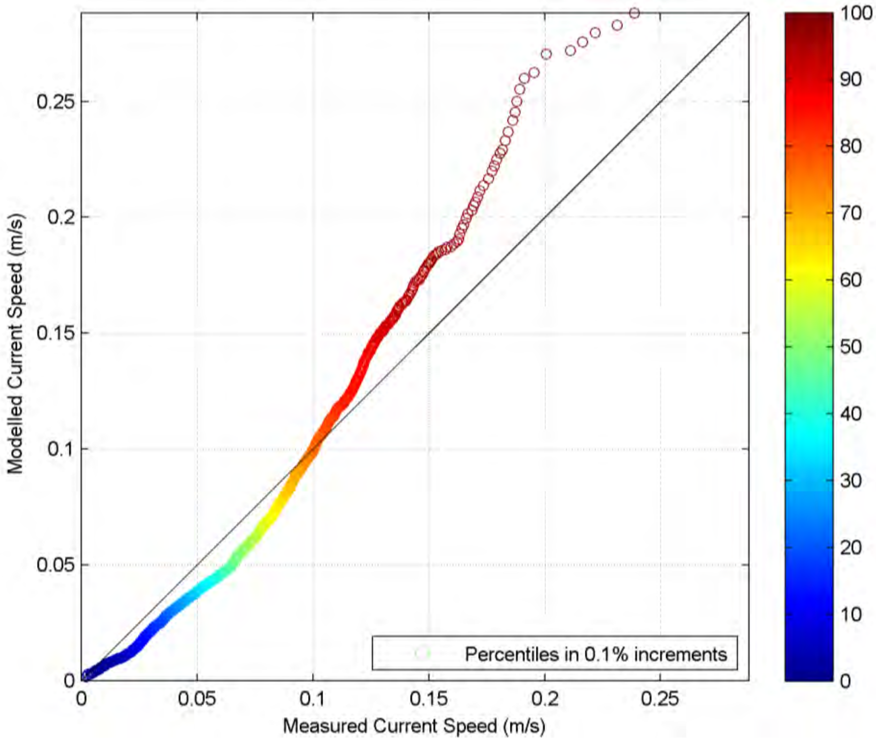

Figure 5.4: Q-Q plot of measured and modelled near-surface current speeds at the ADCP-North location over the period 1 Feb 2013 to 15 Mar 2013.

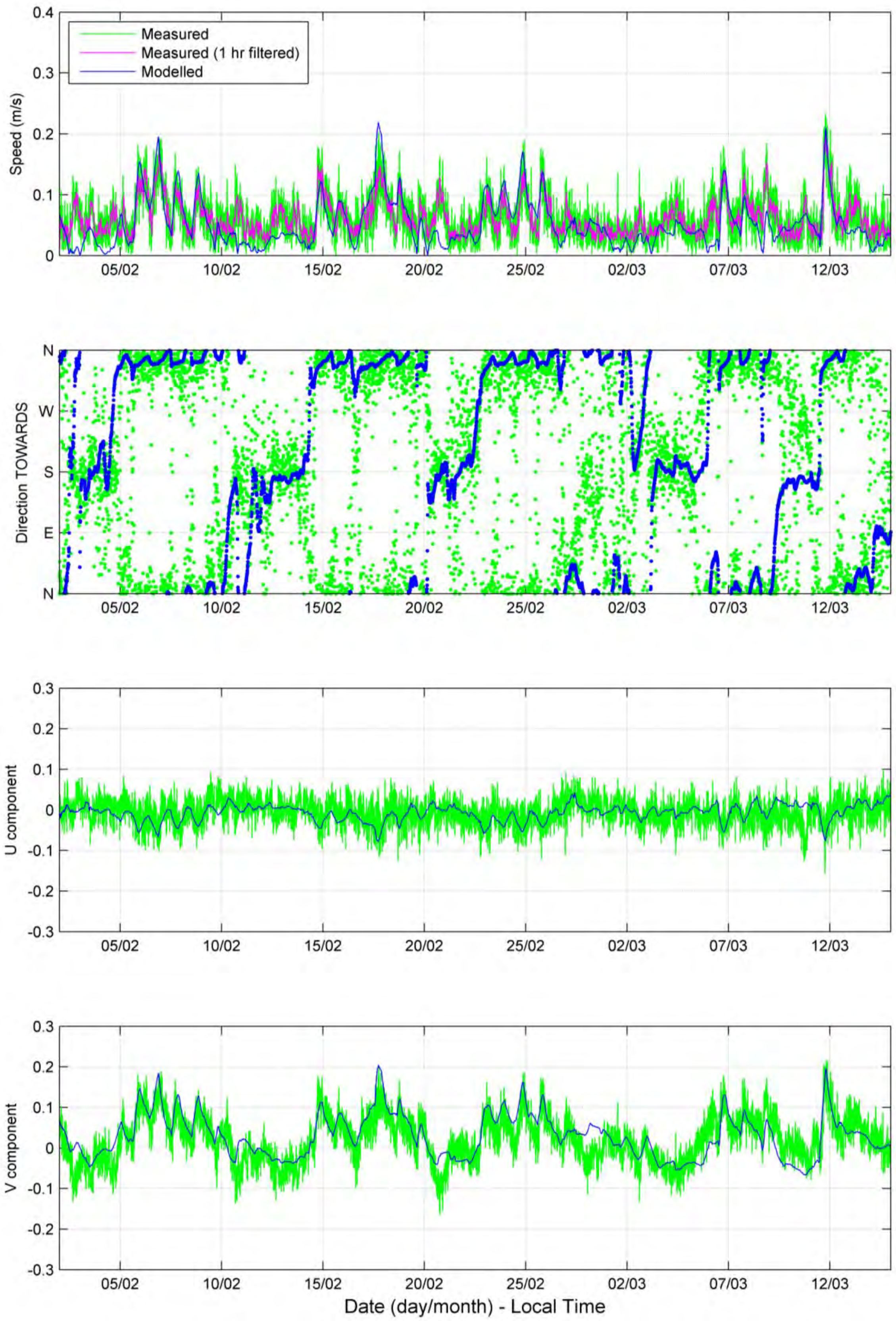

Figure 5.5: Time-series overlay of measured (green) and modelled (blue) near-seabed currents at the ADCP-North location for the year 2013. The purple line in the top panel shows the measured data with a 1-hour filter (6 point moving average).

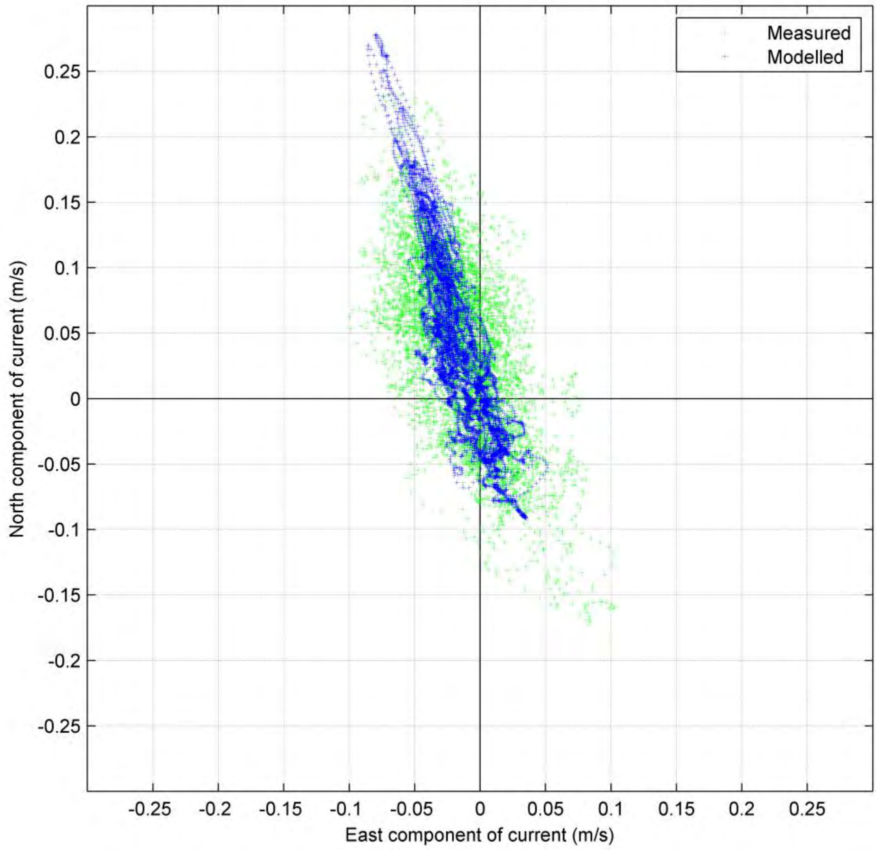

Figure 5.6: Scatterplot of measured (green dots) and modelled (blue dots) near-seabed current vectors at the ADCP-North location over the period 1 Feb 2013 to 15 Mar 2013.

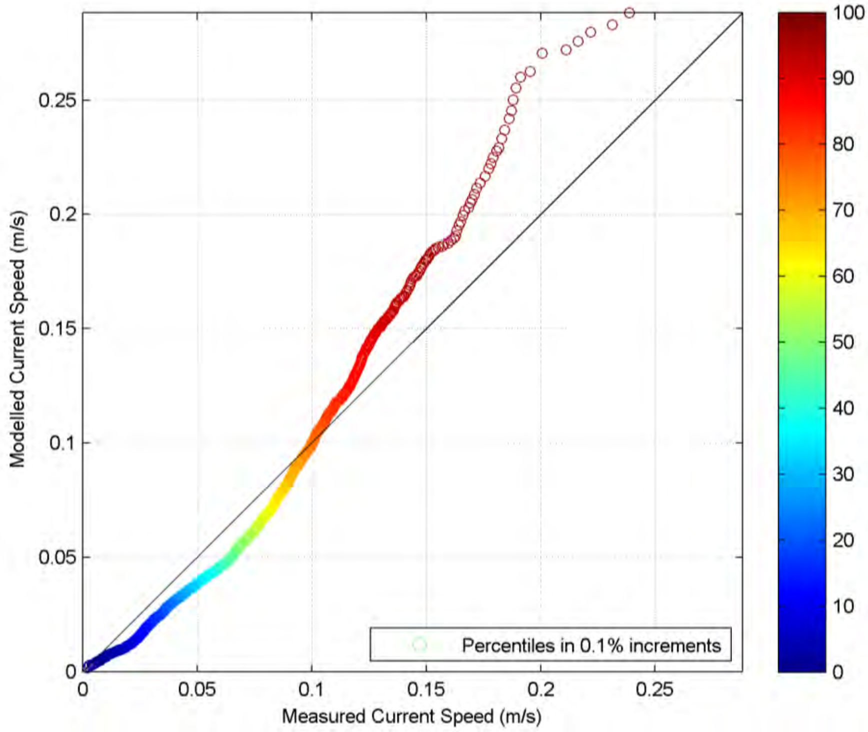

Figure 5.7: Q-Q plot of measured and modelled near-seabed current speeds at the ADCP-North location over the period 1 Feb 2013 to 15 Mar 2013.

5.1.3 AWAC-West currents

The time series plots for the near-surface layer at the AWAC-West location (Figure 5.8) generally indicate an overall agreement between measured and modelled data that is qualitatively similar to that described for the AWAC-North location. However, there were some differences with regard to the east-west component of near-surface currents.

The west-east (U) component of measured current (Figure 5.8), showed significant speeds directed towards the west on regular occasion that were not replicated in the modelled data. These westward currents events appear to show some correlation with measured easterly winds during this period (Figure 5.1). However, it is noted that similar westward near-surface currents were not observed at AWAC-North at the same time.

A possible explanation for this inconsistency is that slightly different configurations and deployment depths between instruments may result in different characterisations of the near-surface layer when there is strong vertical shear in the flow. The AWAC-West measurements in the surface layer are possibly more biased toward the very near-surface than the AWAC-North measurements. This would imply that the near-surface AWAC-West instrument may have captured flow features near the water surface that were sub-grid scale with respect to the upper layer of the hydrodynamic model.

Another possible explanation is that the west-east component of the measured AWAC-West current data was simply faulty near the surface. As the current speeds are high but not unrealistic, this conclusion would be difficult to support in the absence of any other information; however, because the nearby AWAC-North measurements did not show similar speeds during the same period this gives some weight to this possibility. It is also possible that the difference is due a slight directional bias in the model at the AWAC-West location.

The near-surface AWAC-West scatterplot (Figure 5.9) shows good general agreement between modelled and measured data except for the relative absence of westward directed currents in the modelled data, which was previously mentioned. Similarly, the q-q plot (Figure 5.10) indicates that the more common modelled current speeds (i.e. mid percentile) generally under predict the measured data by around 25%. This discrepancy is directly attributable to the disagreement between the modelled and measured west-east (U) component of current discussed previously, and which may be due to measurement error (Figure 5.8).

The near-seabed model results at the AWAC-West location show very good agreement with the measured data (Figure 5.11, Figure 5.12 and Figure 5.13). The apparently improved comparison relative to the near-surface measurements could be because the currents nearer to the bottom had a less rapid response to the wind, particularly short duration wind events.

The tabulated model statistics for the AWAC-West location (Table 5.1) indicate that that the model performance in the mid-depth region was similar to that near-seabed. This indicates that the overall model skill is good when averaged over the water column.

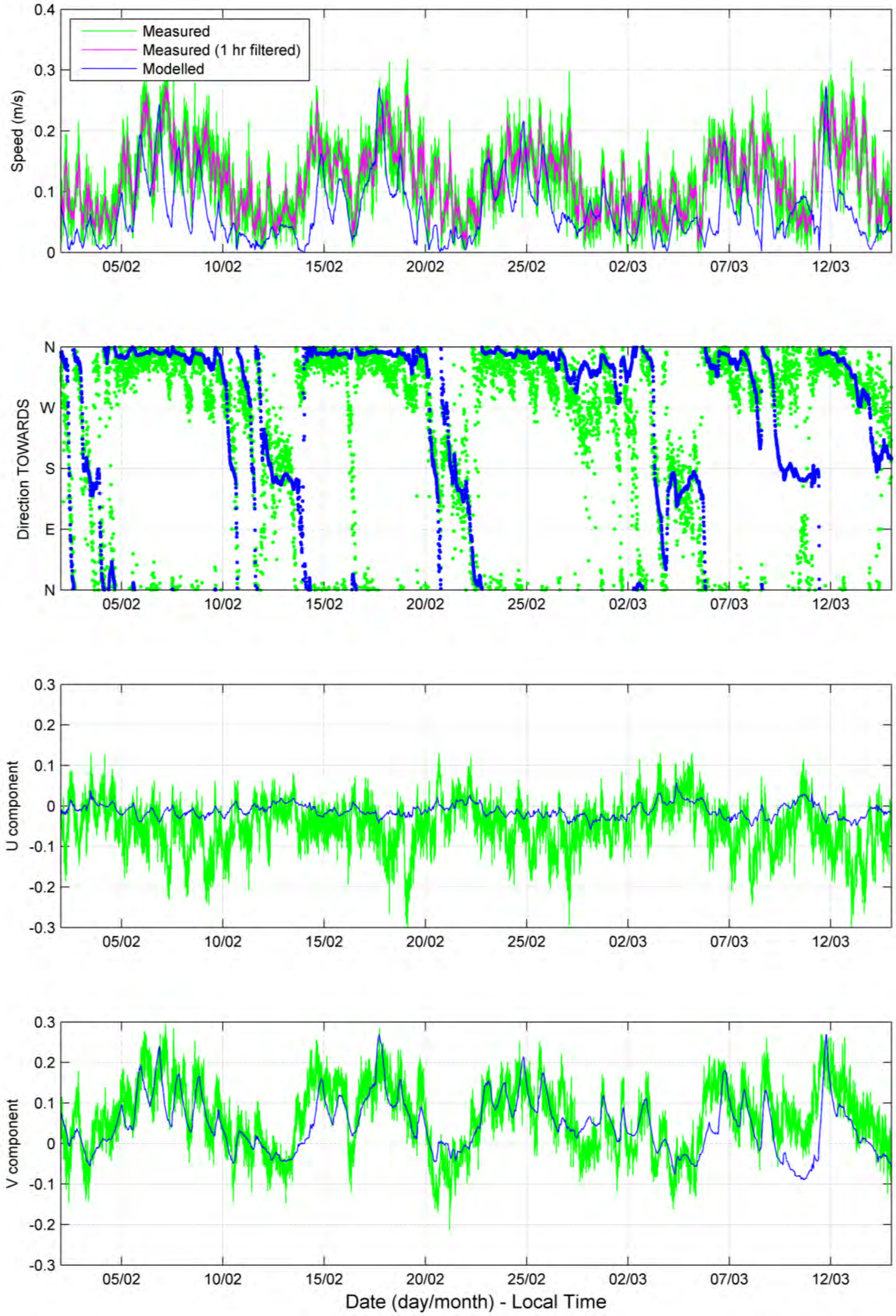

Figure 5.8: Time-series overlay of measured (green dots) and modelled (blue dots) near-surface currents at the ADCP-West location for the year 2013. The purple line in the top panel shows the measured data with a 1-hour filter (6 point moving average).

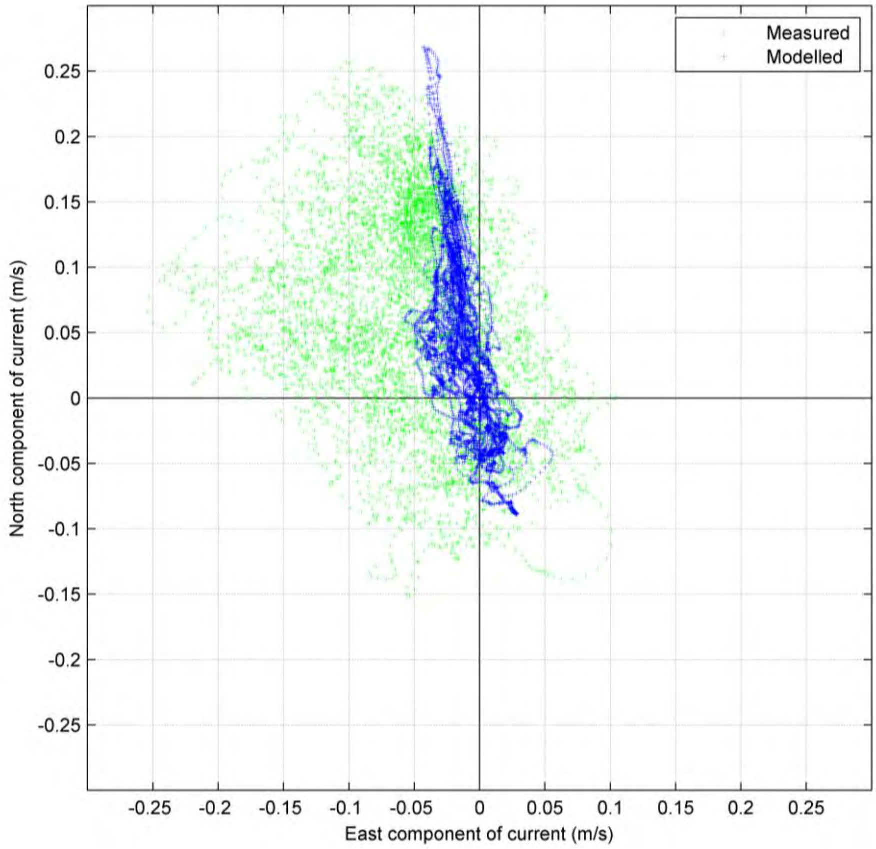

Figure 5.9: Scatterplot of measured (green dots) and modelled (blue dots) near-surface current vectors at the ADCP-West location over the period 1 Feb 2013 to 15 Mar 2013.

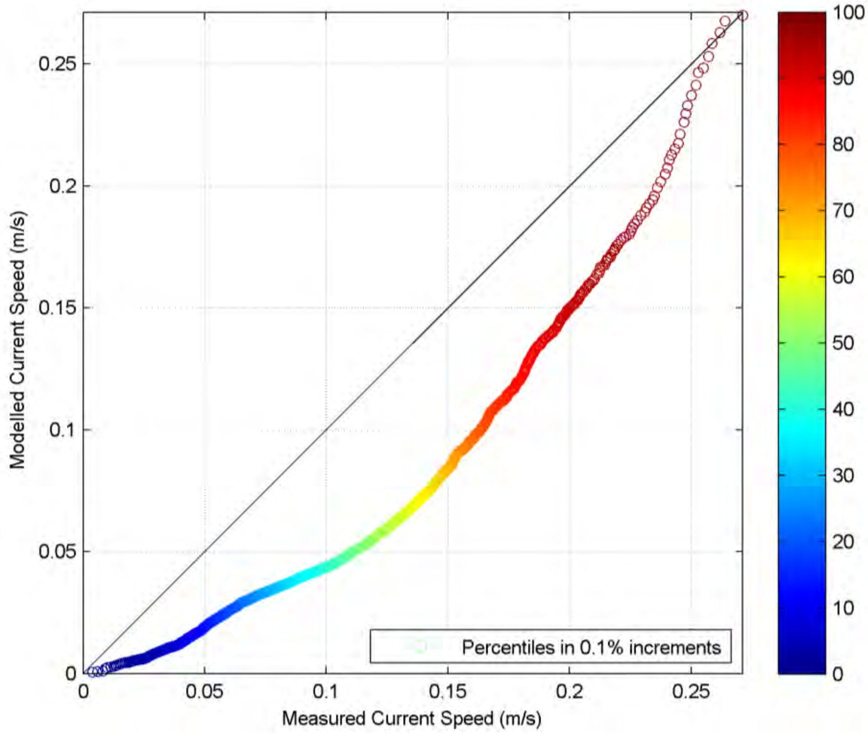

Figure 5.10: Q-Q plot of measured and modelled near-surface current speeds at the ADCP-West location over the period 1 Feb 2013 to 15 Mar 2013.

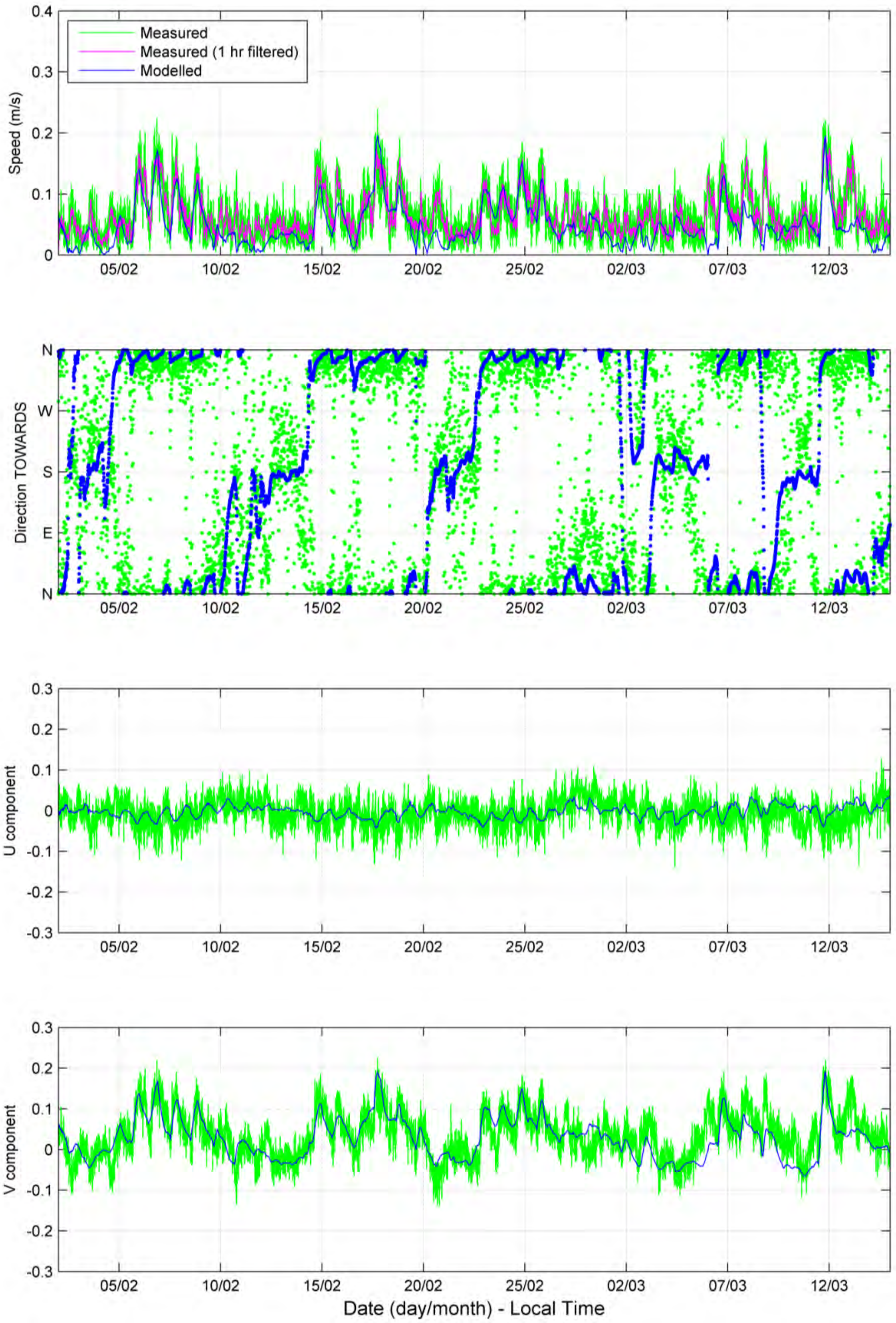

Figure 5.11: Time-series overlay of measured (green dots) and modelled (blue dots) near-seabed currents at the ADCP-West location for the year 2013. The purple line in the top panel shows the measured data with a 1-hour filter (6 point moving average).

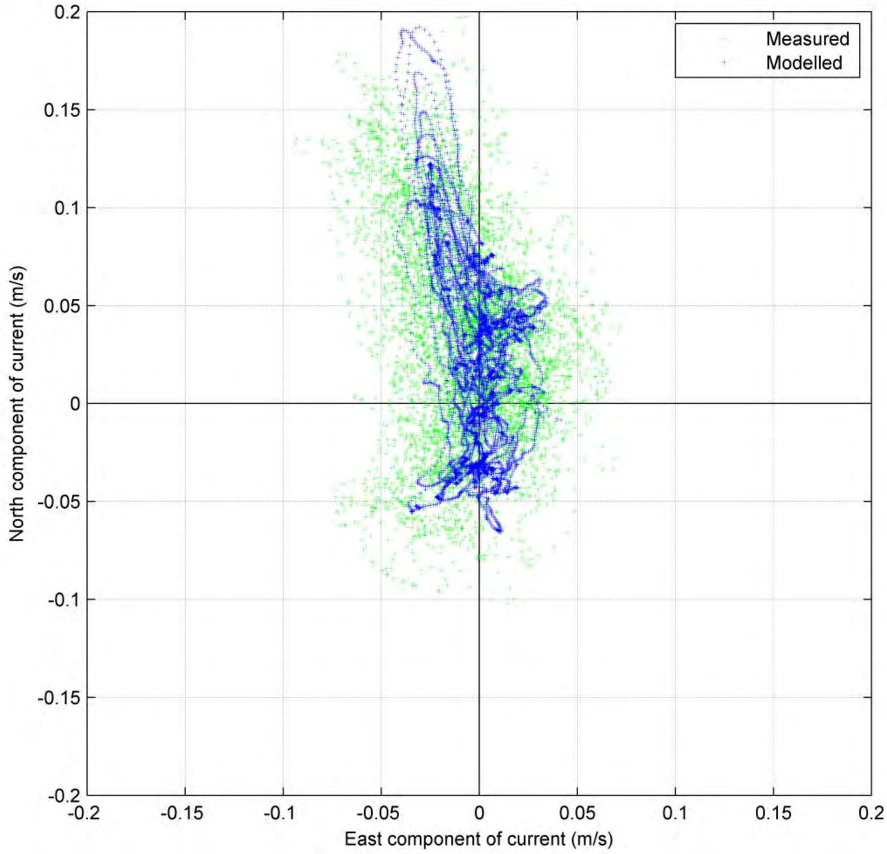

Figure 5.12: Scatterplot of measured (green dots) and modelled (blue dots) near-seabed current vectors at the ADCP-West location over the period 1 Feb 2013 to 15 Mar 2013.

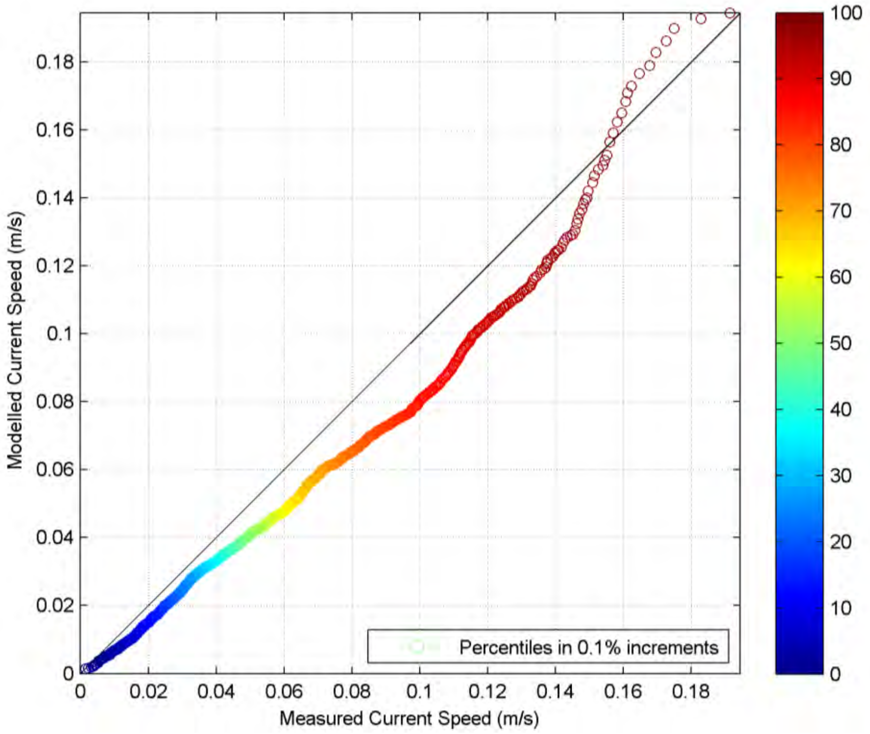

Figure 5.13: Q-Q plot of measured and modelled near-seabed current speeds at the ADCP-West location over the period 1 Feb 2013 to 15 Mar 2013.

5.2 Winter Period Validation

The calibrated hydrodynamic model was validated against currents measured at the AWAC-ORBH station over the winter period from 2 Jul 2011 to 11 Aug 2011. Model skill statistics were computed at the near-surface, mid-water and near-seabed (for absolute depths at the deployment site see Table 4.1).

The statistical assessments of model skill for current speed and direction (Table 5.2) generally indicate that the model performance during the validation period approximately equals or possibly exceeds the calibration period performance (Table 5.1). Relatively good model skill is achieved over all of the representative depths.

Table 5.2: Summary of model validation performance statistics with respect to measured currents in the winter validation period.

Site	Model Period	Depth	Speed RMSE (m/s)	Speed IOA	Speed MAE (m/s)	Direction IOA^	Direction MAE^
AWAC-ORBH	2/7/2011 to 11/8/2011	Near-Surface	0.037	0.80	0.029	0.72	0.026
		Mid-Water	0.035	0.79	0.027	0.76	0.023
		Near-Seabed	0.028	0.79	0.022	0.77	0.020

^ IOA and MAE direction statistics were calculated from averages of IOA and MAE values that were determined separately for x and y directional components.

** Relatively lower values of RMSE and MAE indicate higher model skill; IOA values closer to 1 also indicate higher model skill.*

5.2.1 AWAC-ORBH Currents

The time series plots of near-surface (Figure 5.14) and near-seabed currents (Figure 5.17) at AWAC-ORBH indicate similar flow features and consistent model performance at both depths. The ability of the modelled currents to replicate the main features in the current speed time series is evident; with the exception of some intermediate magnitude spikes in current speed that were either not reproduced or were under-estimated.

The comparison of measured and modelled current direction is relatively weak during the first several days of the validation period, but this performance can be somewhat discounted when it is considered that the speeds were very low at that time and the measured direction data itself was extremely variable (Figure 5.17).

Unlike the summer calibration period results, there is relatively little distinction to be made between the model performance near-seabed and near-surface. This may be explained by the relatively shallow deployment depth of AWAC-ORBH, which was around 8.5 m (Table 4.1).

The scatterplots and q-q plots for both depth layers confirm the generally good agreement between modelled and measured results (Figure 5.15, Figure 5.16, Figure 5.18 and Figure 5.19). There is a small break in linear correlation trend of the scatterplot in the measured data that is not replicated by the modelled data (i.e. in the bottom right corner of Figure 5.15). This implies that there is a difference between the measured current directions (southward) and the modelled current direction (south-south-eastward) when the current speeds were relatively high and southward directed. This corresponds with a period in the time series record between 26 July and 5 August (Figure 5.14). During this period there was a winter storm event as evidenced by the relatively high southward current speeds. The small but consistent offset between the direction of measured and modelled currents can be observed in the time series data for this period. The directional discrepancy during this storm period may have been due to the uniform spatial wind data used in the model not being well suited to this particular storm period. Alternatively, higher wave activity during the storm period may have caused second order effects (e.g. Stokes drift or ‘wave pumping’ of shallow reefs) that are not represented in the model. During storm conditions these second order effects may explain the small directional discrepancy in the results, however, as storm events are limited in their duration and relatively infrequent any negative effects on the modelled predictions would be similarly temporary.

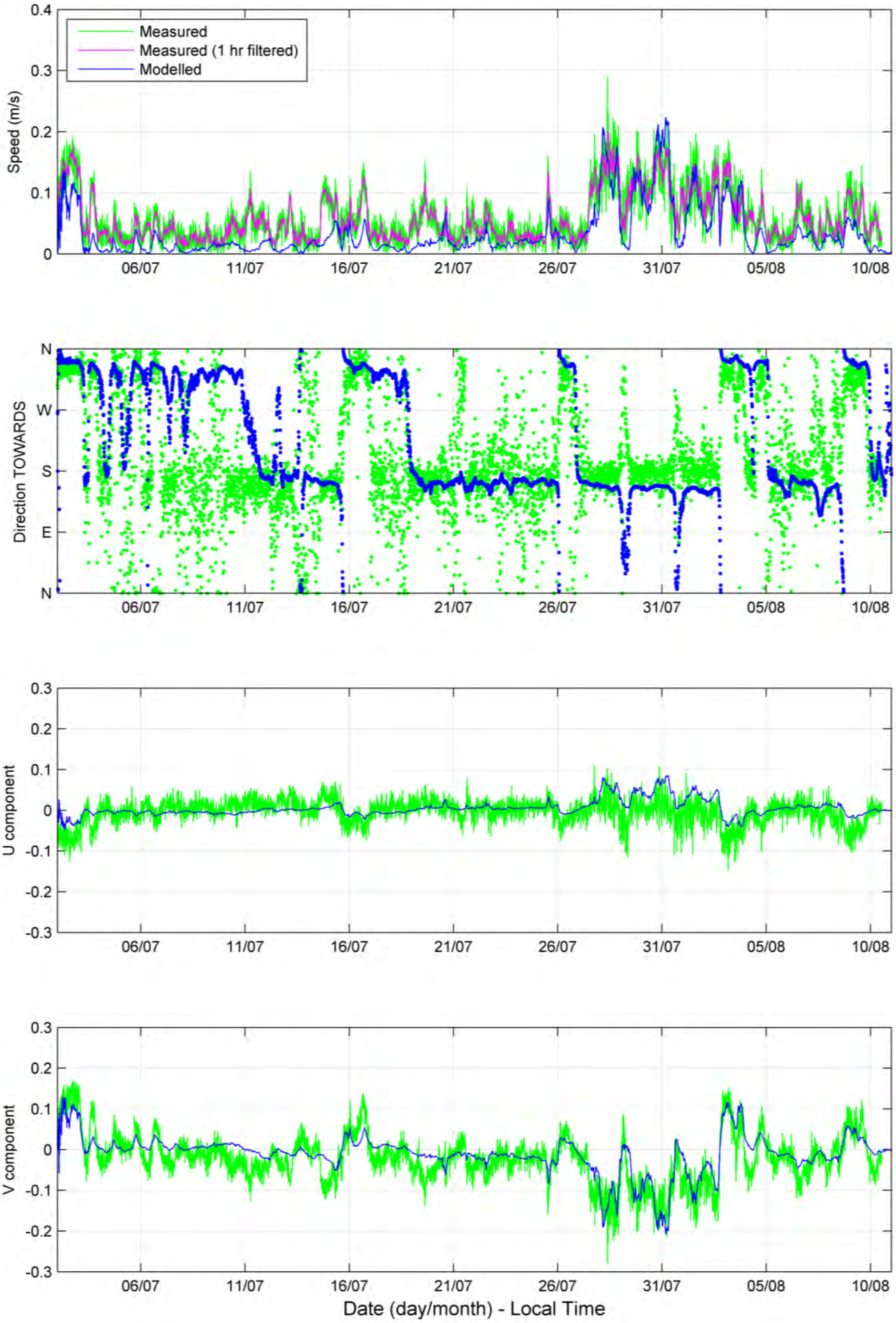

Figure 5.14: Time-series overlay of measured (green dots) and modelled (blue dots) near-surface currents at the ADCP-ORBH location for the year 2011. The purple line in the top panel shows the measured data with a 1-hour filter (6 point moving average).

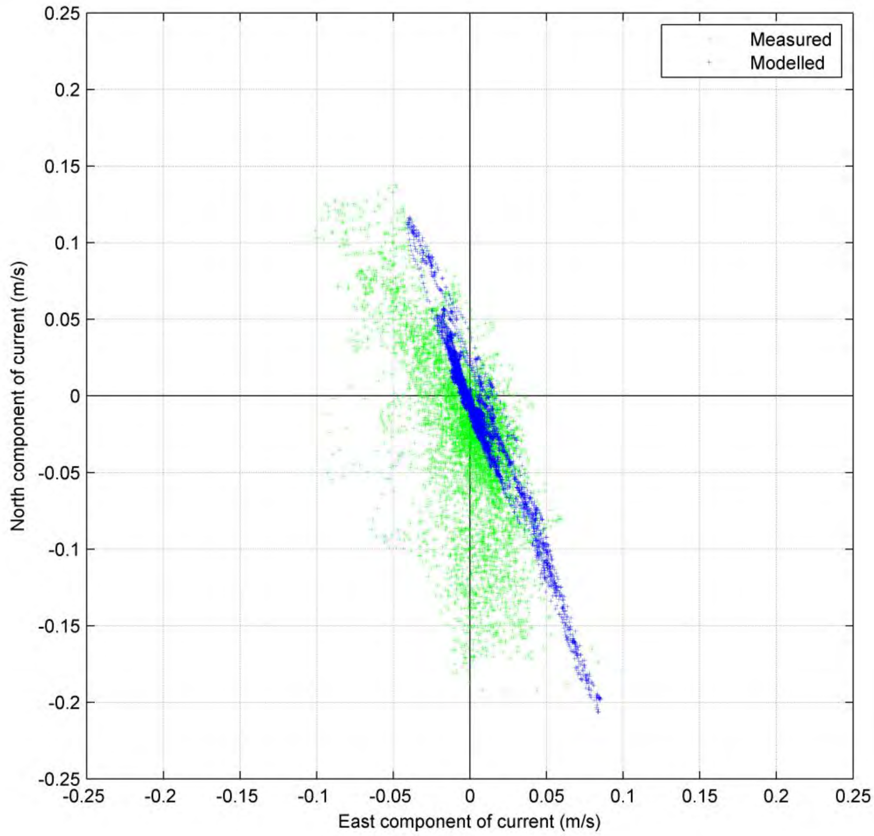

Figure 5.15: Scatterplot of measured (green dots) and modelled (blue dots) near-surface current vectors at the ADCP-ORBH location over the period 2 Jul 2011 to 11 Aug 2011.

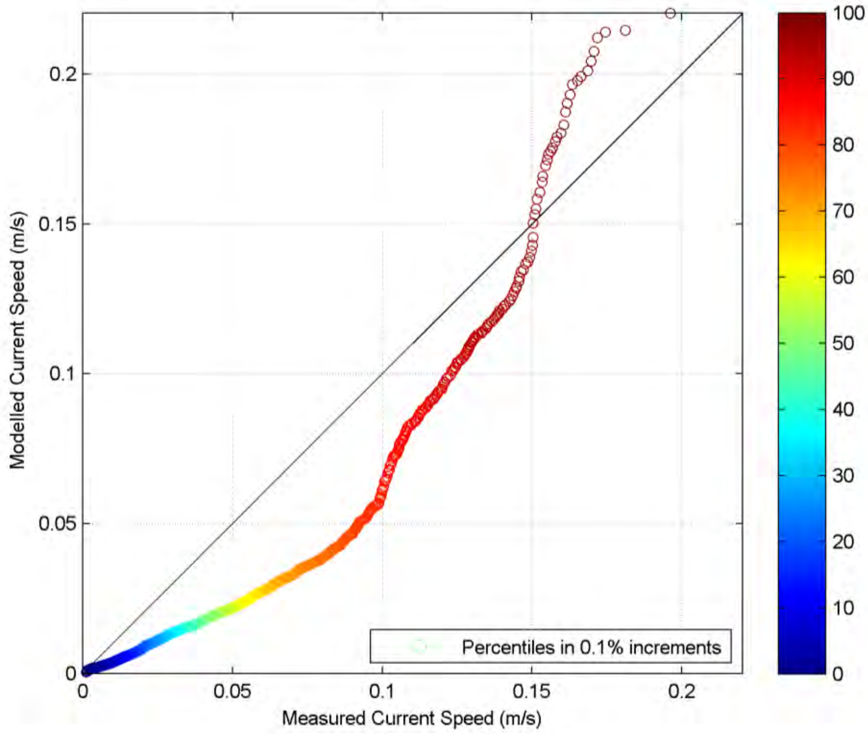

Figure 5.16: Q-Q plot of measured and modelled near-surface current speeds at the ADCP-ORBH location over the period 2 Jul 2011 to 11 Aug 2011.

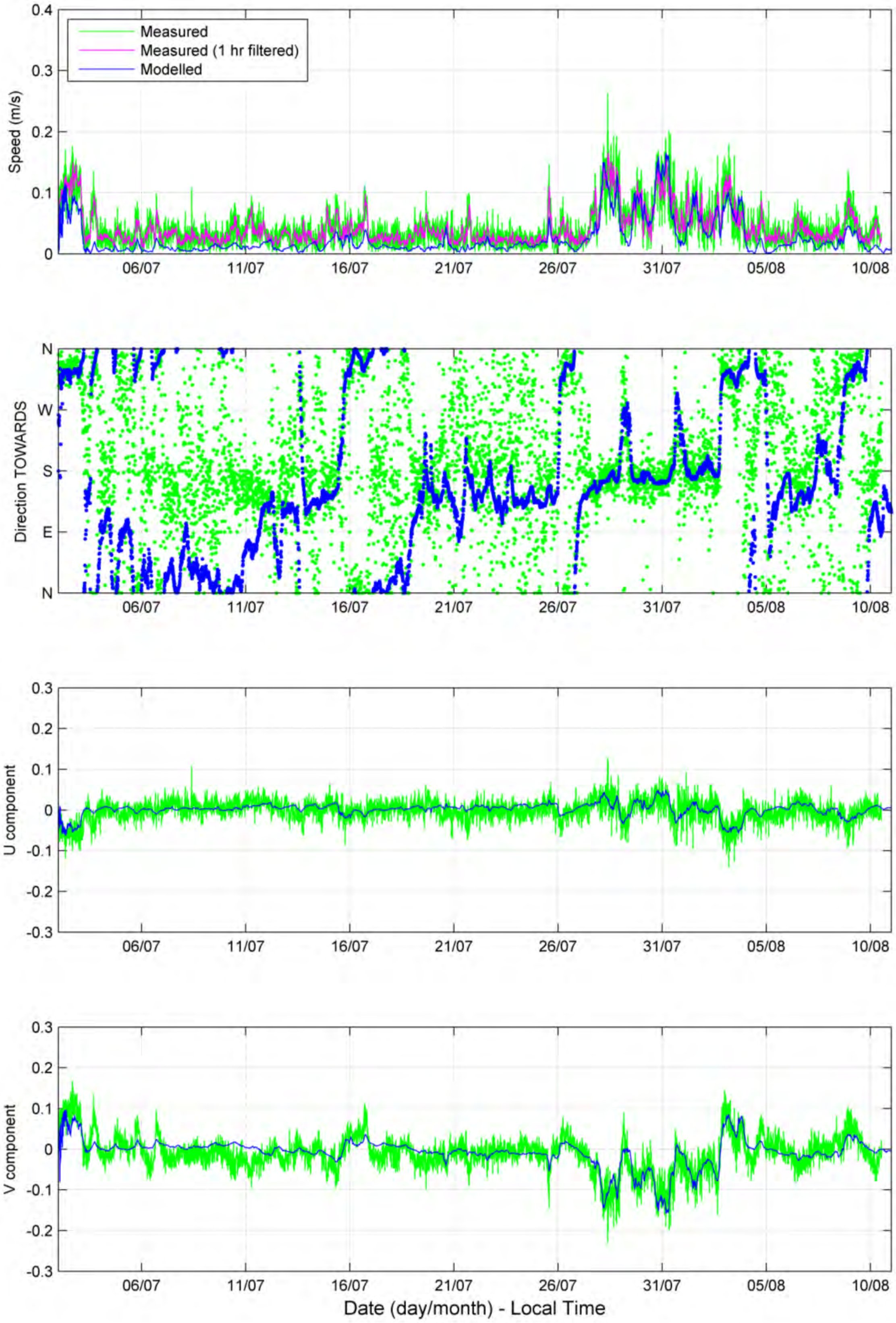

Figure 5.17: Time-series overlay of measured (green dots) and modelled (blue dots) near-seabed currents at the ADCP-ORBH location for the year 2011. The purple line in the top panel shows the measured data with a 1-hour filter (6 point moving average).

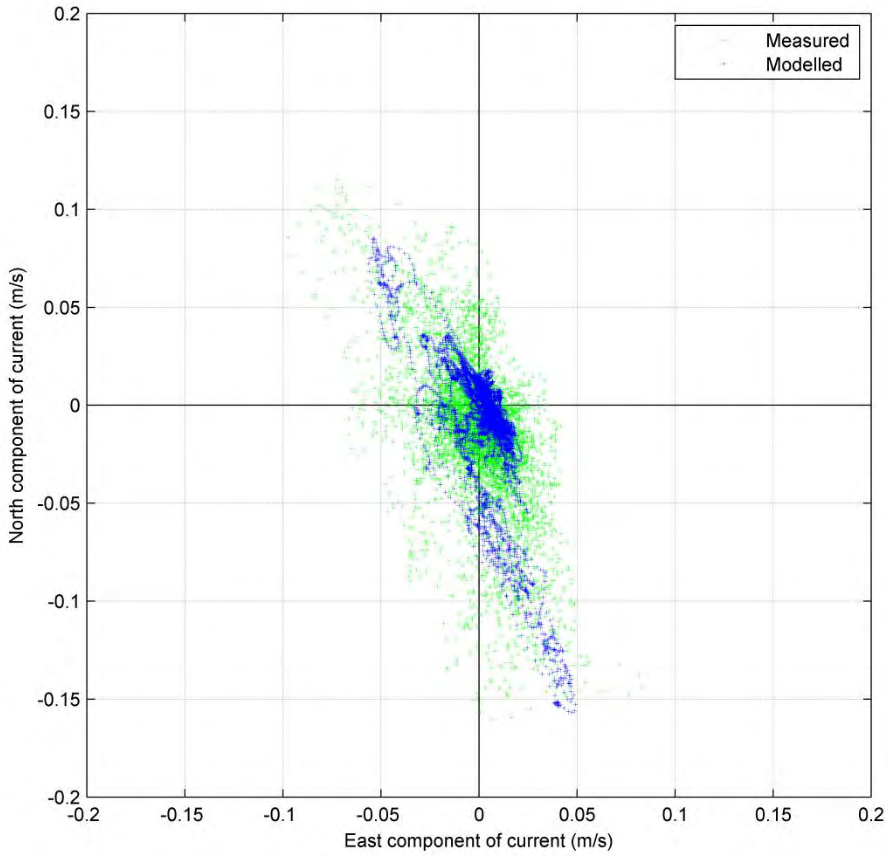

Figure 5.18: Scatterplot of measured (green dots) and modelled (blue dots) near-seabed current vectors at the ADCP-ORBH location over the period 2 Jul 2011 to 11 Aug 2011.

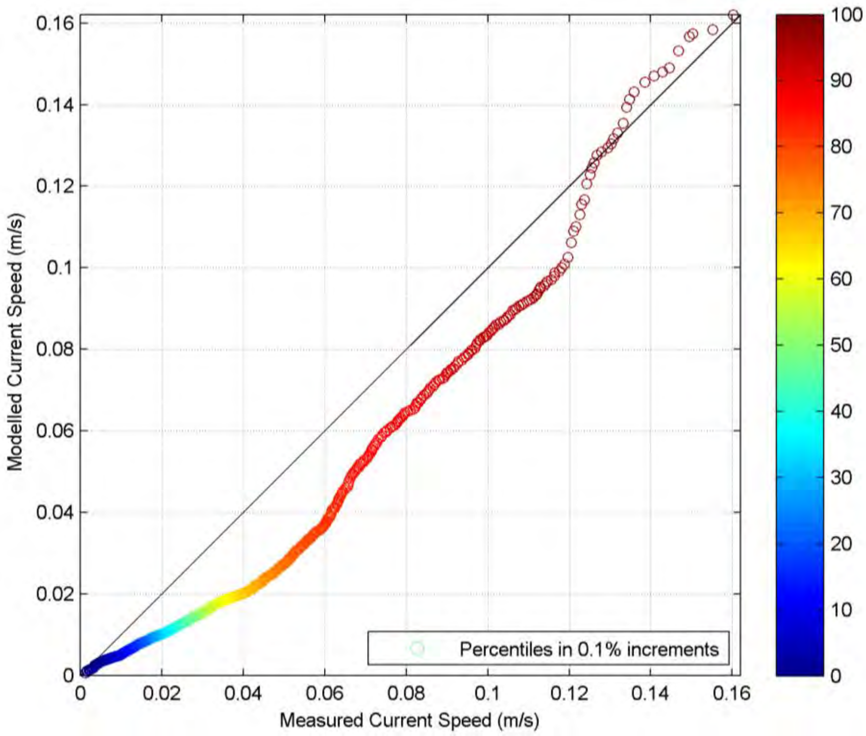

Figure 5.19: Q-Q plot of measured and modelled near-seabed current speeds at the ADCP-ORBH location over the period 2 Jul 2011 to 11 Aug 2011.

5.2.2 ORBH Flushing

Based on data from the 2011 dye flushing experiment, the flushing characteristics of ORBH were characterised by plotting the time series decay of tracer concentrations as measured (and modelled) at 6 stations within ORBH (Figure 4.5). The comparison between the measured and modelled estimates of ORBH flushing is presented for all individual stations (and available depths) in Figure 5.20. The modelled scenario is based on seasonally appropriate values for groundwater flow determined from prior groundwater modelling (Rockwater 2011), tide data and measured wind data corresponding to the simulation period.

The measured and modelled results show excellent overall agreement. The overall degree of spatial variability in the first 24 hours was broadly replicated. In particular, in both the modelled and measured results, the stations R2-bottom and R1-surface appear as the stations with the fastest and slowest flushing times respectively (Figure 5.20). The relatively long flushing time at R1 is despite the fact that this is the closest station to the ORBH entrance (Figure 4.5). This result does not imply that R1 is a particular stagnation point, but rather it occurs due to an anticlockwise circulation pattern within ORBH at the time of the tracer release. Under this circulation pattern, a proportion of the tracer that was originally released in the southern part of ORBH (i.e. furthest from the entrance) was swept past R1 before exiting ORBH. If the flushing tests were performed using a different methodology, such as releasing an independent dye patch at each location instead of filling-up the marina with the same dye, then the relative flushing times of the stations would have been different.

To improve the clarity of Figure 5.20, two stations (R1-bottom and R4-bottom) were excluded from the plot. Because these stations were both shallow (~1.5 - 2 m deep) there was no discrepancy between surface and seabed results for these stations (i.e. they remained vertically mixed).

The overall station average time series of tracer decay for measured and modelled data is presented in the Figure 5.21. The averages were computed based on the data from all stations and all sampled depths. It is clear that there is excellent agreement between measured and modelled data, with both data sets suggesting an e-folding time (i.e. ~37%) of approximately 12 hours.

The lower panels of Figure 5.21 indicate the tidal and wind conditions during the period of the flushing experiment. As noted in APASA (2011), the dye experiment occurred during the period of a winter storm with relatively strong wind from the north, which might be expected to have enhanced the flushing rate compared to more benign wind conditions.

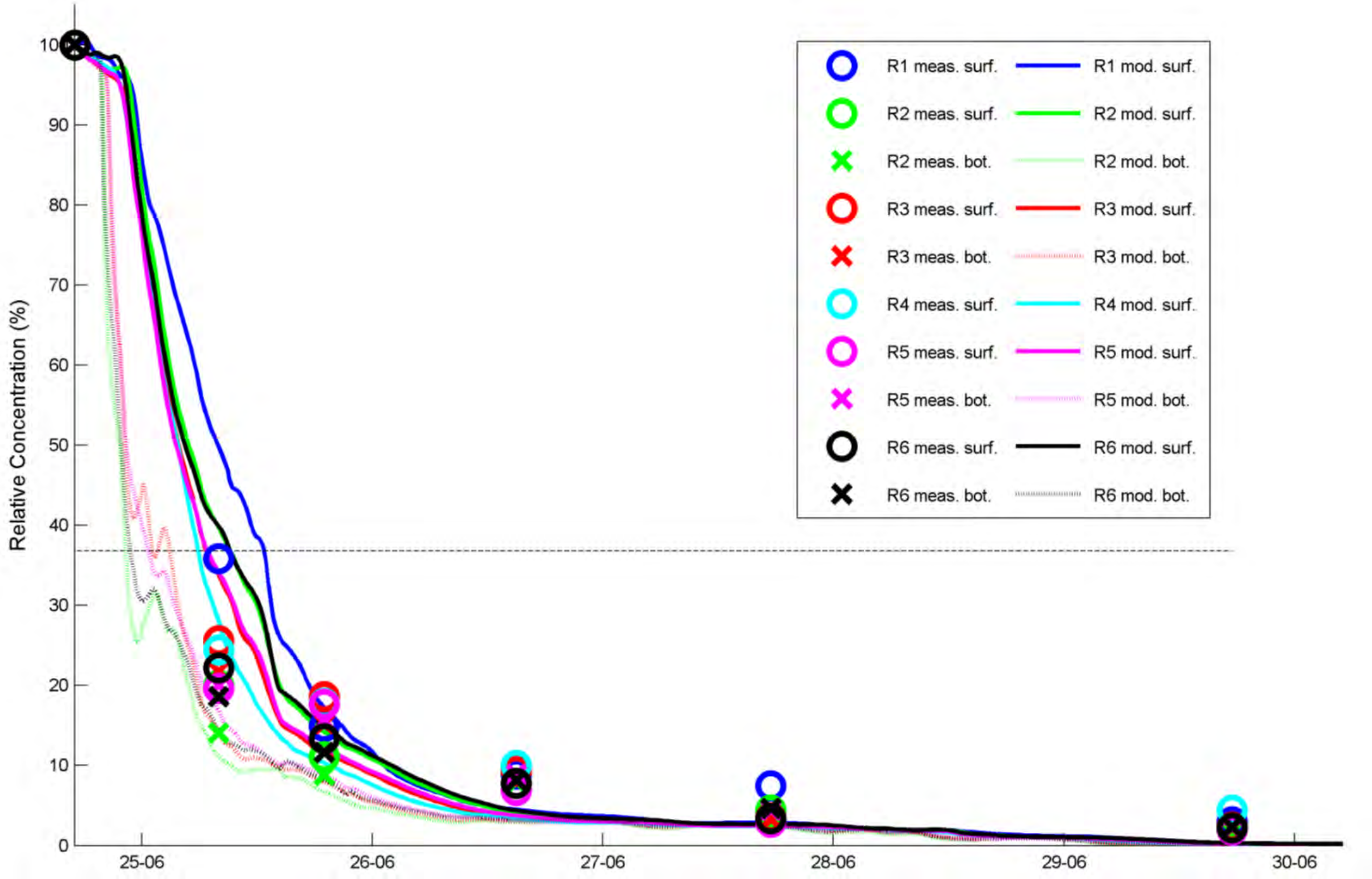

Figure 5.20: Time series of relative concentrations Rhodamine dye calculated from field measurements carried out in July 2011 compared to modelled output. The marker colours represent the stations R1 to R6 (see Figure 4.5). Circles distinguish measurements made near the surface and crosses indicate near-seabed measurements. The similarly coloured lines indicate the relative concentration of a simulated tracer at the equivalent locations within the model grid. The e-folding level is indicated by a dashed line.

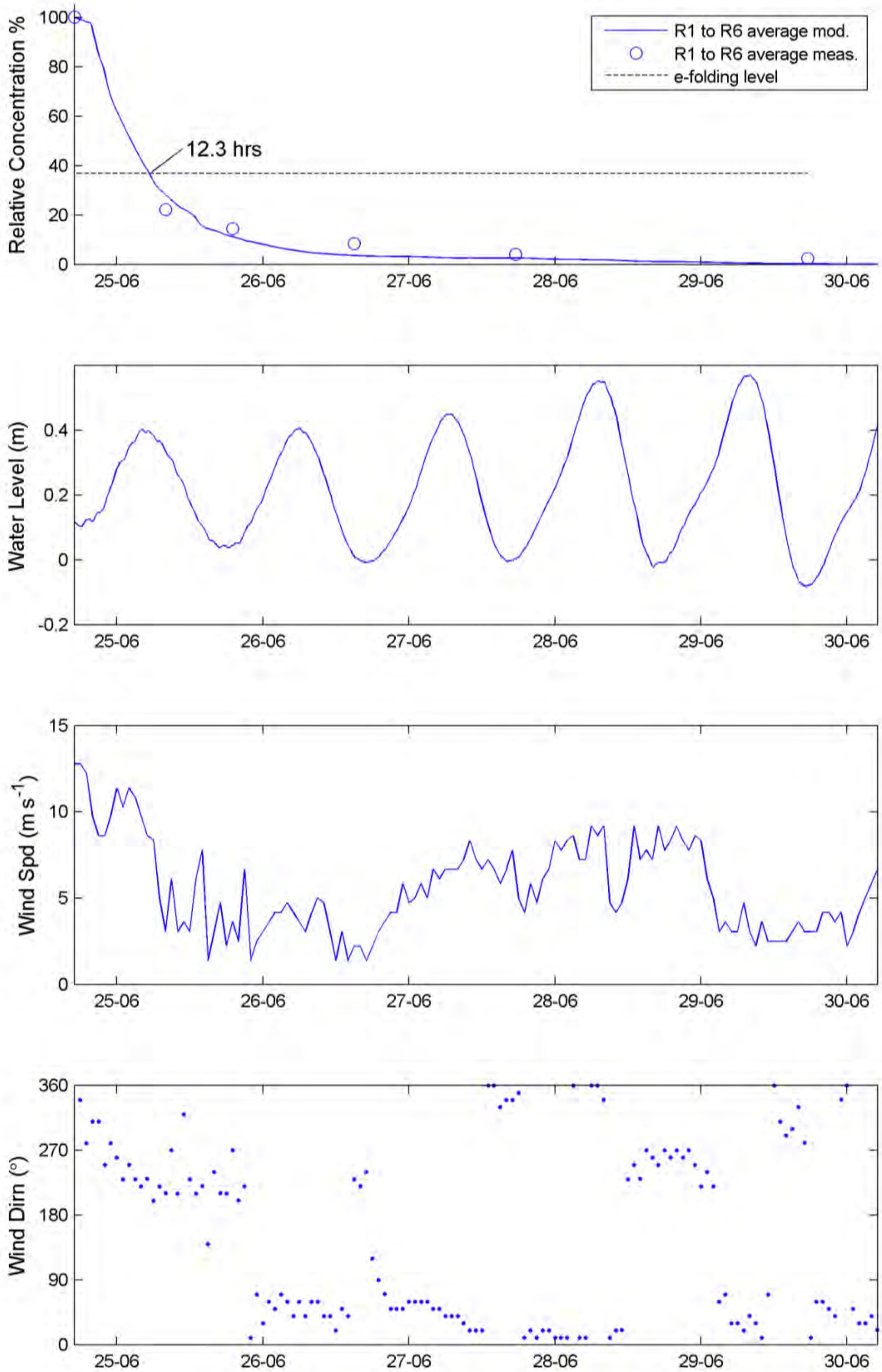

Figure 5.21: The first panel indicates spatially averaged relative Rhodamine dye concentrations determined from measurements (circles) and simulated relative tracer concentrations averaged across the equivalent locations in the model grid. Other panels indicate water level fluctuations, wind speed and wind direction, respectively, for the same 2011 period.

6.0 Wave Model Results

6.1 Evaluation of Wind Input Data

Preliminary calibration runs were conducted with spatially constant wind fields based on measured Rottnest wind data. The results of these simulations indicated that significant wave height (H_s) values were over predicted at the nearshore sites. This over prediction can probably be attributed to the inappropriate use of offshore measured winds over nearshore areas, which typically experience weaker winds. Therefore, it was necessary to investigate the sensitivity of the wave model to spatially-variable winds.

The development of an appropriate spatial wind data set from measured data sets was hampered by the limited spatial resolution of the measurement sites, in particular, the lack of suitable data to define the offshore extent of the sea breeze. Test runs with a spatial wind field derived from interpolated measured data were found to under predict H_s, particularly at the nearshore sites.

Accordingly, the use of spatial winds from a hindcast model was evaluated. The BoM ACCESS weather model is available at a resolution of 0.11° (~12 km) for the relevant period. The accuracy of spatial wind hindcasts from global models can be limited in the nearshore zone due to their relatively course spatial and temporal resolution. However, given that the spatial and temporal resolution (hourly) of the ACCESS model is relatively fine, nearshore effects should be adequately represented.

The accuracy of the ACCESS model data is indicated in Figure 6.1 and Figure 6.2 by comparing the data against measured wind speed and direction at the Rottnest Island and Swanbourne stations. The plots show that wind speed and direction are well represented in the ACCESS data set during both the winter and the summer sample periods, and at both the offshore and nearshore comparison locations. Of particular interest is the nearshore comparison over the summer period (Figure 6.2, bottom panel), where the model is shown to capture the changes in direction and magnitude over the daily sea breeze cycle.

Calibration simulations using the ACCESS wind dataset were found to improve overall model skill in both seasons, particularly at the nearshore locations. Therefore, the ACCESS wind dataset set was selected as the wind input for the wave model.

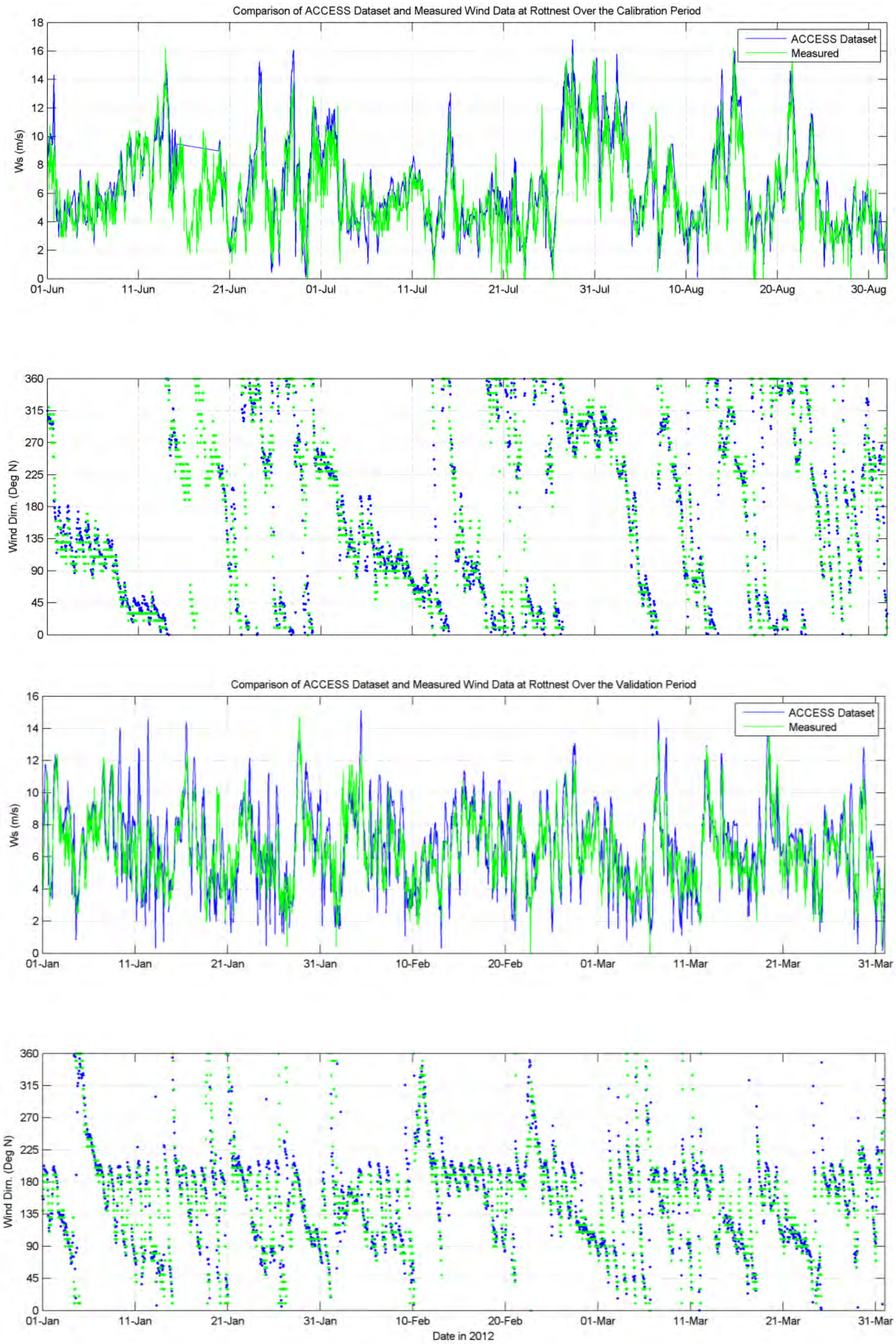

Figure 6.1: Time-series of measured wind speed and direction plotted against ACCESS data from the nearest grid cell to the Rottnest Island wind station, June 2011 to August 2011 (top) and January to March 2012 (bottom).

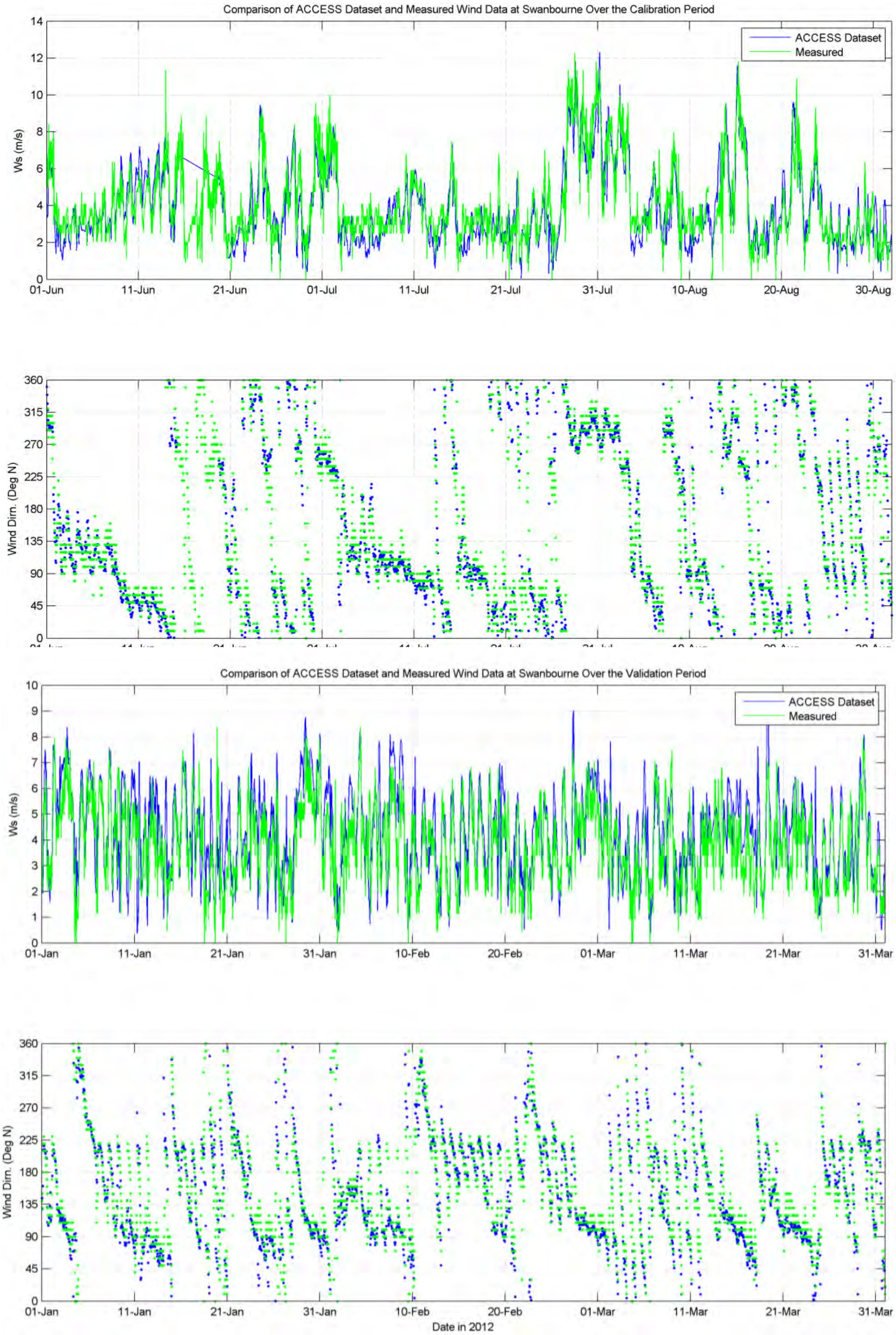

Figure 6.2: Time-series of measured wind speed and direction plotted against ACCESS data from the nearest grid cell to the Swanbourne wind station, June 2011 to August 2011 (top) and January to March 2012 (bottom).

6.2 Winter Period Calibration

The wave model was calibrated over a winter period from 1 July to 31 August 2011, based on data measured near Rottnest and ORBH during this period.

Time-series, scatterplots and wave roses present the comparison of modelled and measured wave parameters for Rottnest (Figure 6.3, Figure 6.4 and Figure 6.5) and AWAC-ORBH (Figure 6.6, Figure 6.7 and Figure 6.8).

The statistical comparisons for the Rottnest and AWAC-ORBH wave buoy locations are presented in Table 6.1. From the statistics and from visual comparison of the figures, it is evident that the model reproduced the wave climate well at both the offshore and nearshore locations. Good statistical agreement was achieved at both wave measurement sites, particularly for H_s (IOA of 0.96 - 0.97).

The model reproduced the principal features of the measured H_s time series, including the magnitude and timing of large wave events and the range of wave heights measured at both the offshore and nearshore locations. Given the excellent match with measured H_s at the offshore and nearshore locations, it is evident that the transformation of wave energy from offshore to the nearshore coastal zone has been well represented in the model. Achieving a good match for H_s and wave transformation over the model domain is particularly important for the subsequent calculation of resuspension potential within the sediment fates model.

The model was able to accurately capture the range and variation in peak wave period (T_p) in the measured time-series at both the offshore and nearshore wave measurement locations. The model predicts T_p in a range between 10 and 16 s (swell dominant), the majority of the time in agreement with measurements. Intermittent periods of sea dominant conditions (T_p < 8 s) were also captured successfully by the model. Visually it is evident that the modelled T_p is smoother than the measured T_p. This is because the model is not resolving the relatively fast switching that can occur in T_p in bi-modal seas, which is due to the marginal nature of the switching behaviour compared to the numerical resolution of the model. However, the overall pattern and variation is well represented. The statistical measures reinforce the good match observed in the visual comparisons of T_p with the IOA being between 0.69 - 0.77 and MAE being less than 1.6 s over both the wave measurement locations.

The wave model was comparatively less skilful with regard to simulating wave direction than it was for wave height. For the purposes of this study errors in wave direction are less important than errors in wave height. This is because the primary role of the wave model data is to predict sea bed shear velocities for sediment transport, and these velocities depend on wave height rather than wave direction.

The peak direction (θ_{peak}) is generally within the range of the measured data and follows the overall pattern seen in the measured time-series. The modelled θ_{peak} is smoother than the measured wave data with less scatter, particularly at the nearshore location. This can be attributed to the directional resolution of the model and the use of parameterised wave spectra on the boundary. The IOA for θ_{peak} show an acceptable agreement at the measurement locations, but with less skill than for H_s and $T_{p.}$ The lower IOA values for θ_{peak} are due to slight shifts in the overall θ_{peak} at the sites. The RMSE values were relatively high, which could be indicative of a persistent directional bias in the modelled direction. The visual representation of the time-series together with the scatter plots and wave roses show generally a good match between the modelled and measured θ_{peak}.

The wave direction over the calibration period is relatively focused at both of the measurement locations, coming dominantly from the west to west-southwesterly direction (83-91% of the time). The comparison wave roses at both the measurement sites show that the model generally captures the dominant wave directions with some slight shifting evident at the nearshore site (Figure 6.7). Specifically, the peak wave direction was slightly more northward in the measured data. The slight shift in the overall θ_{peak} at the nearshore site is likely due to some smoothing of the bathymetry as a result of the resolution of the model grid.

At the Rottnest measurement location there were some isolated periods where the modelled θ_{peak} deviated from the measured data, to a more northerly direction (e.g. 8-13 Jun, 10-13 Jul, 8-9 Aug). These deviations occur during times of lower wave energy (H_s < 2 m) when the wind direction is coming from the north-west to north-east. In particular, around 11 June (Figure 6.3), during a period when waves were very small, there is a large disagreement between the modelled and measured wave direction. In the small swell conditions, the wave model incorrectly predicted that the peak waves would be due to easterly wind waves rather than background ocean swell, which was incorrect. This error is not significant because the wave heights are very small but it does lead to some anomalous data points that are evident in the third panel of Figure 6.4.

It is known that ocean waves tend to be less focussed in low wave energy conditions, and this makes it more difficult to adequately characterise a 2-dimensional wave spectra with a summary statistic such as θ_{peak}. This may explain some the observed discrepancy between measured and modelled θ_{peak}. However, these isolated periods represent a relatively small proportion of the calibration period and they are not evident at the nearshore location, which is more critical to the planned construction and dredging operations. Furthermore, with regard to the use of the wave model to predict suspension of sediment, θ_{peak}.is a less critical parameter than H_s and T_p.

Table 6.1: The statistical comparison between measured and modelled wave parameters at the Rottnest and AWAC Ocean Reef wave measurement stations.

Site	Period	Wave Parameter	IOA	RMSE	MAE
Rottnest Wave Buoy	1/7/2011 to 31/8/2011	H_s (m)	0.96	0.44	0.34
		T_P (s)	0.77	1.90	1.32
		θ_{peak} (°)	0.48	29.0	17.0
AWAC-ORBH	1/7/2011 to 31/8/2011	H_s (m)	0.97	0.16	0.13
		T_P (s)	0.69	2.03	1.59
		θ_{peak} (°)	0.47	19.4	16.8

** Relatively lower values of RMSE and MAE indicate higher model skill; IOA values closer to 1 also indicate higher model skill.*

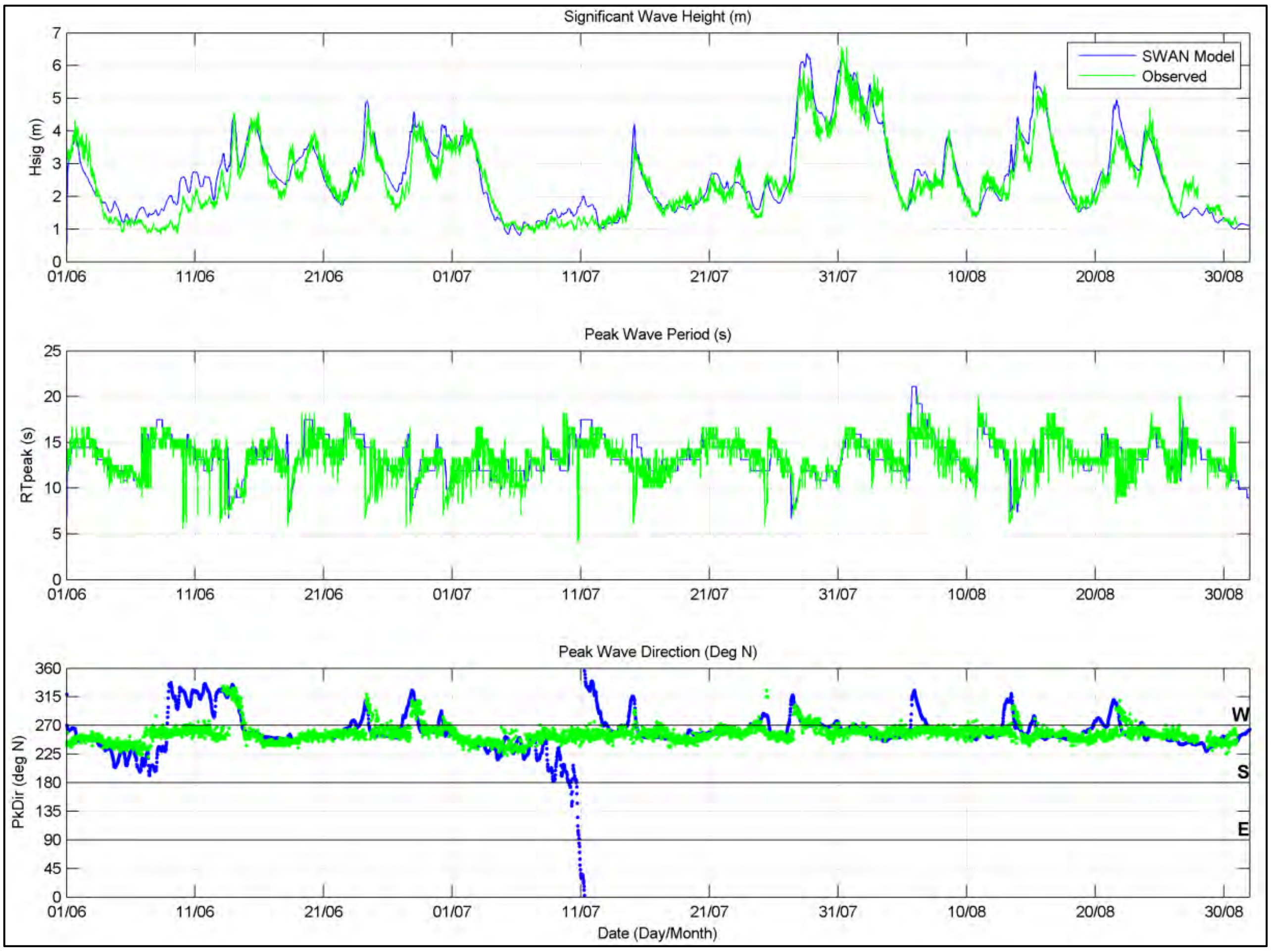

Figure 6.3: A comparison of modelled and measured H_s, T_p and θ_{peak} for the period 1st June to 31st August 2011, at the Rottnest wave station.

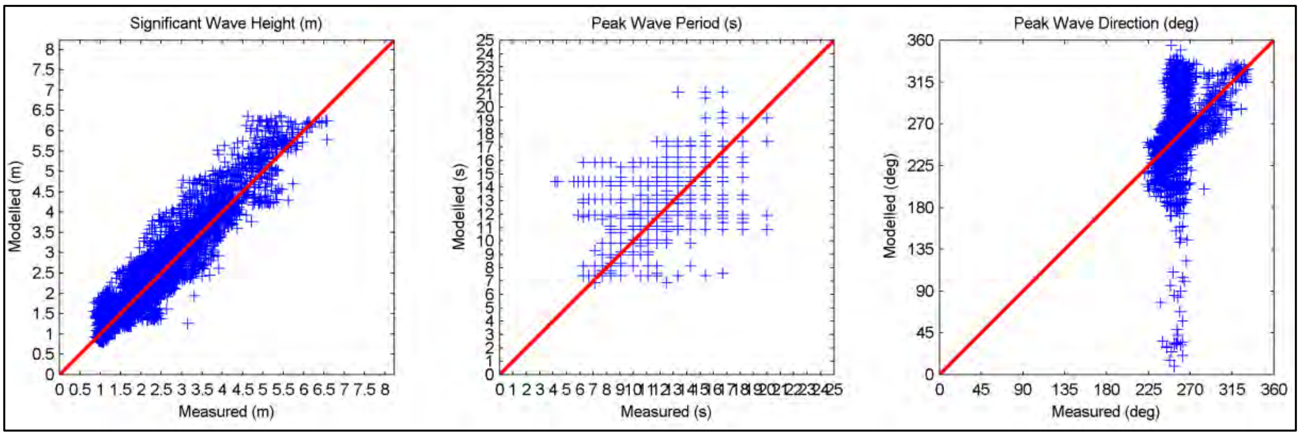

Figure 6.4: Scatter comparison of modelled and measured H_s, T_p and θ_{peak} over the period 1st June to 31st August 2011, at the Rottnest wave buoy.

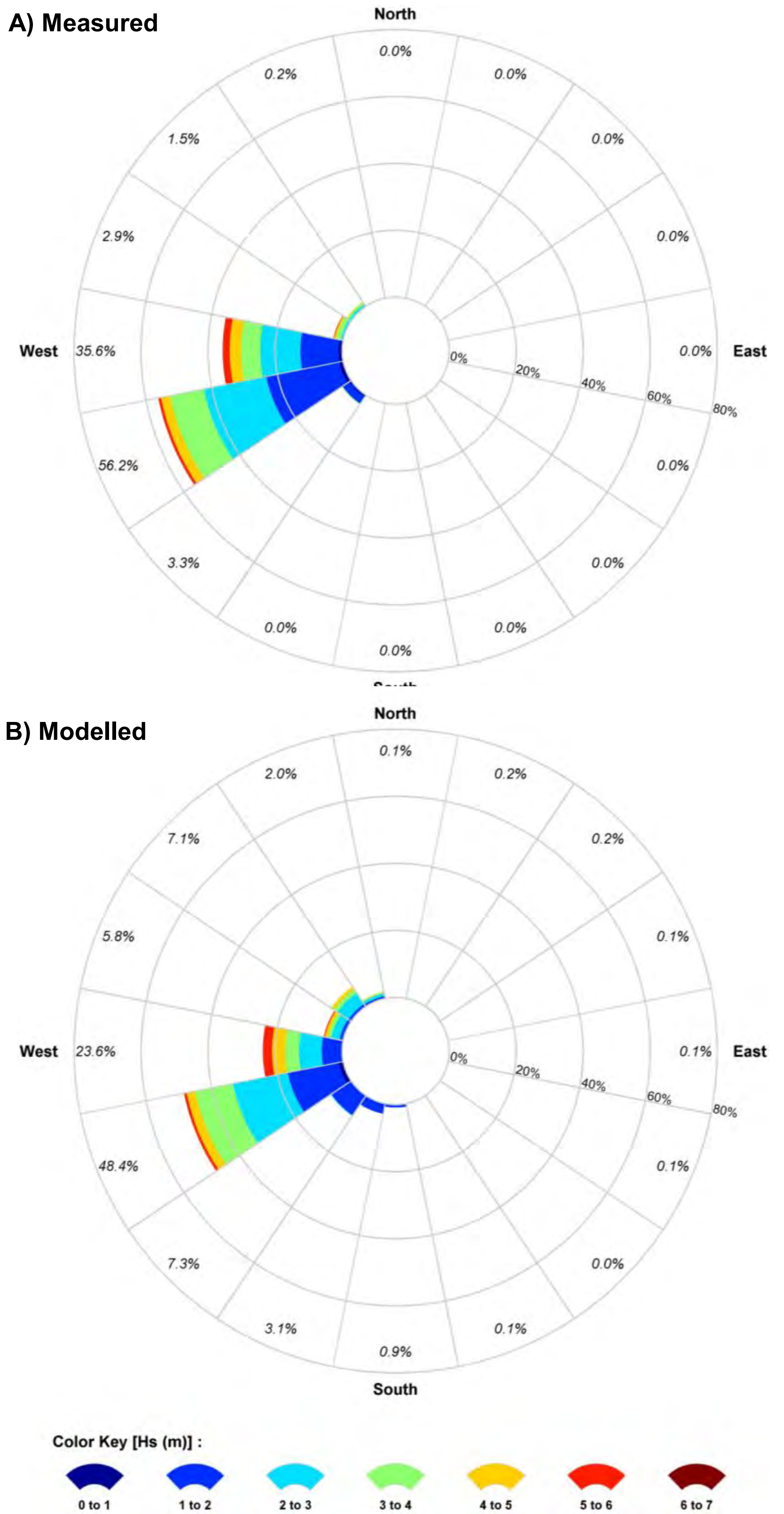

Figure 6.5: Significant Wave Height and Peak Direction Roses for measured data (A - top) and modelled data (B - bottom) for the period 1st June to 31st August 2011, at the Rottnest wave buoy.

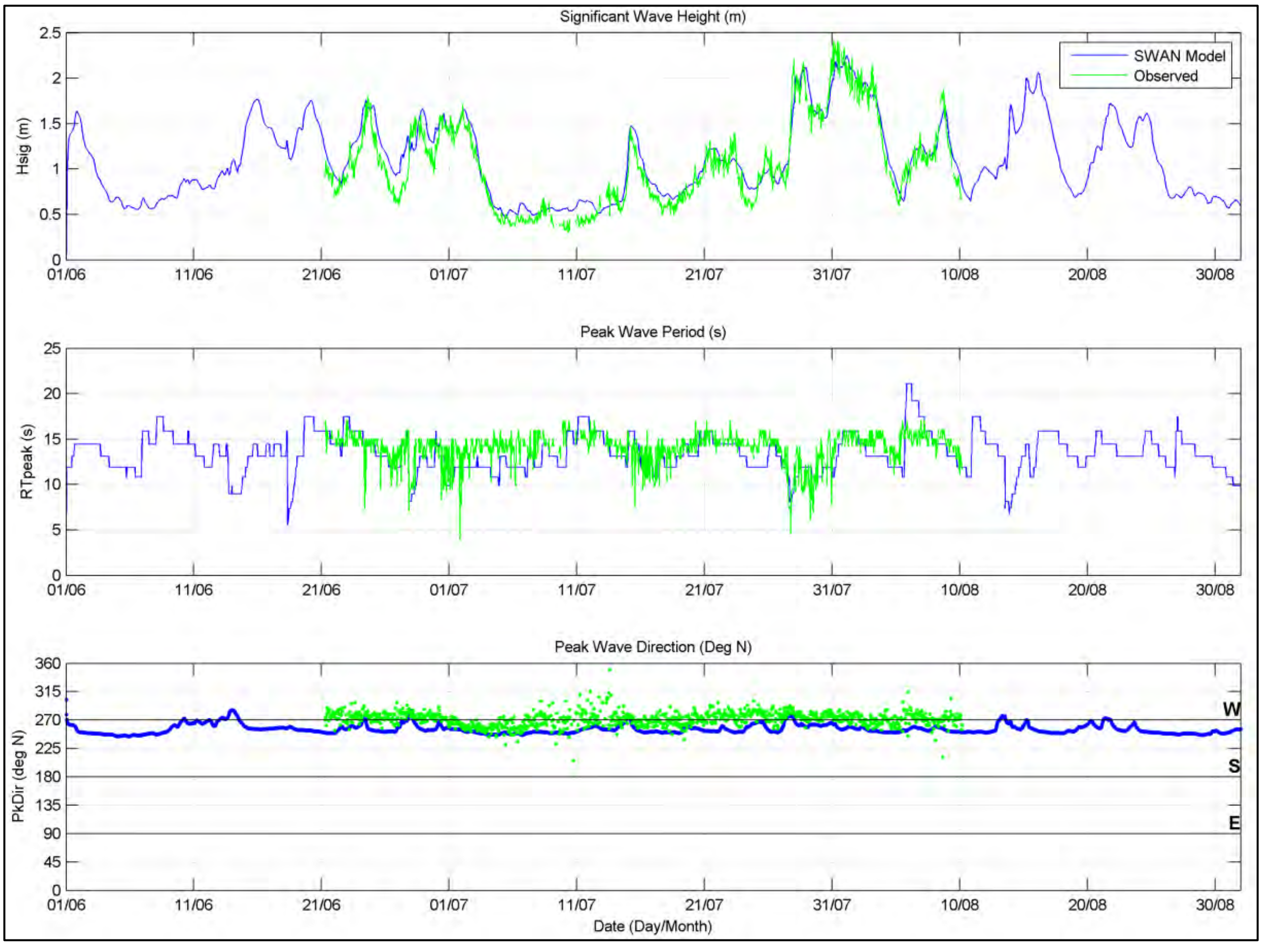

Figure 6.6: A comparison of modelled and measured H_s, T_p and θ_{peak} for the period 1st June to 31st August 2011, at the AWAC Ocean Reef wave station.

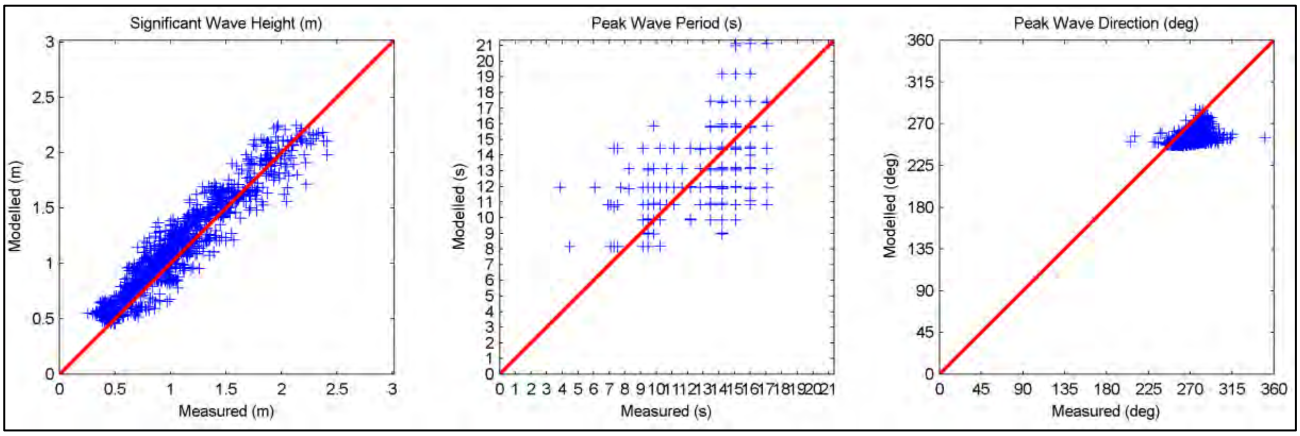

Figure 6.7: Scatter comparison of modelled and measured H_s, T_p and θ_{peak} over the period 1st June to 31st August 2011, at the AWAC Ocean Reef wave station.

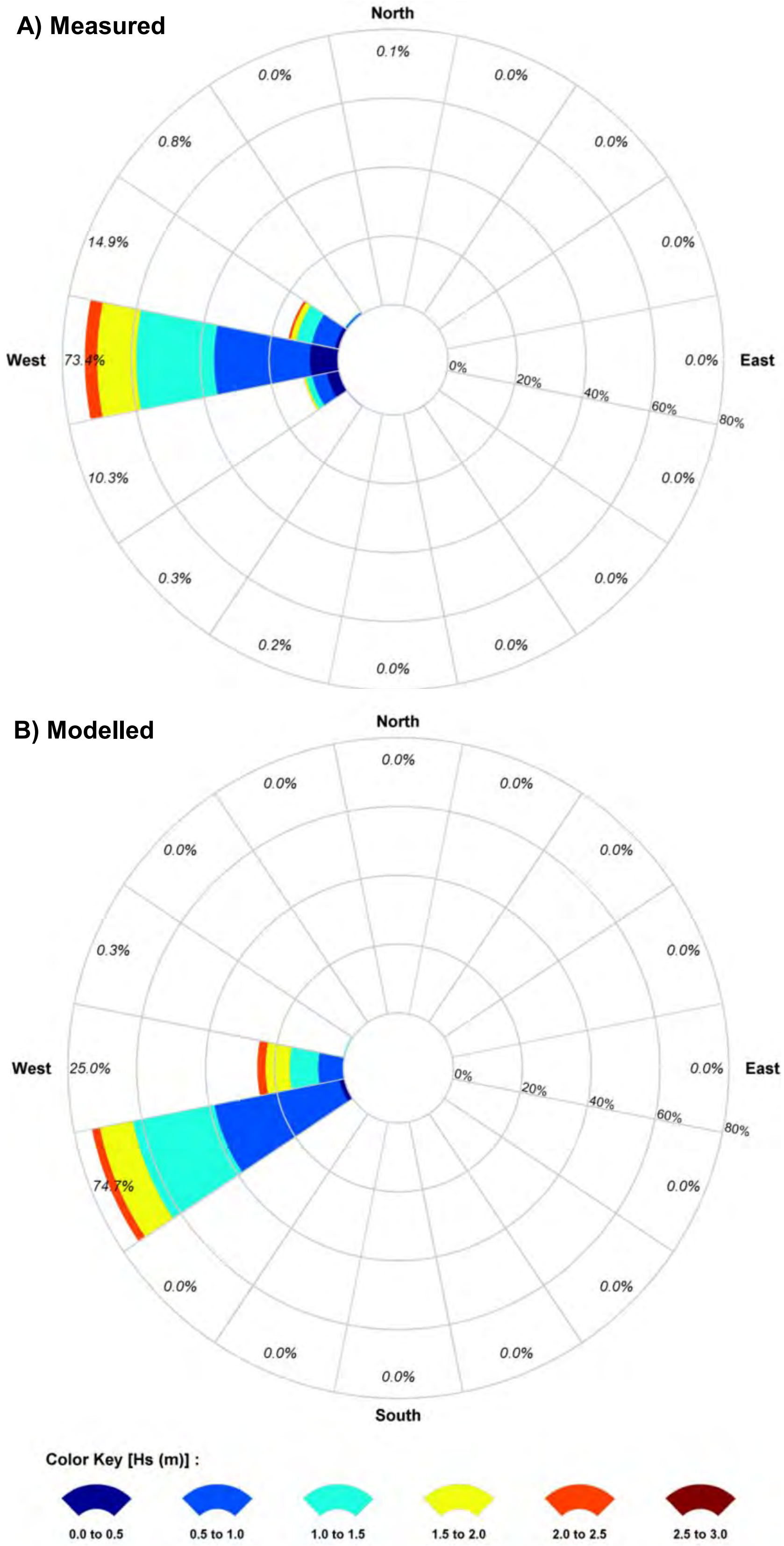

Figure 6.8: Significant Wave Height and Peak Direction Roses for measured data (A - top) and modelled data (B - bottom) for the period 1st June to 31st August 2011, at the AWAC Ocean Reef wave station.

6.3 Summer Period Validation

To ensure that the parameters determined from the winter period calibration process were able to capture typical summer conditions, a validation of the model was performed based on Rottnest and Cottesloe wave buoy data from the month of February in 2012.

Time-series, scatter plots and wave roses for modelled and measured wave parameters at Rottnest (Figure 6.9, Figure 6.10 and Figure 6.11) and Cottesloe (Figure 6.12, Figure 6.13 and Figure 6.14) are presented. The statistical analysis at the Rottnest and Cottesloe wave buoys is presented in Table 6.2. The plots and statistics show that the model is capturing the summer sea breeze dynamics well, with a good match between the measured and modelled wave parameters at both the offshore and nearshore measurement locations.

As was found for the calibration period, the match between measured and modelled H_s was excellent, with the IOA being above 0.9 at both the offshore and nearshore measurement locations. The model reproduced the magnitude and timing of wave events well at both the offshore and nearshore locations. Overall the modelled H_s values were slightly over predicted; however, the MAE was relatively low, being only 0.23 m at Rottnest and 0.10 m at Cottesloe.

The model accurately captured the range and variation in T_p that can be seen in the measured time-series, at both the offshore and nearshore wave measurement locations. The model captured the changes in T_p, between the typical summer morning offshore breeze and the afternoon sea breeze conditions; however, the modelled data had a slightly higher proportion of swell conditions. Given that the higher proportion of swell conditions will lead to slightly conservative estimates of resuspension, the modelled T_p is considered acceptable for use with the sediment fates model.

Similar to the calibration period results, the θ_{peak} was generally within the range of the measured data and followed the overall pattern seen in the measured time-series. The IOA for θ_{peak} shows a strong agreement, being greater than 0.74 at both the measurement locations. The model captured the changes in θ_{peak} between the morning offshore breeze and the afternoon sea breeze conditions.

At the Rottnest measurement location there were some isolated periods when the modelled θ_{peak} deviated from the measured data. As was noted in the Section 6.2, many of these deviations occur during times of lower wave energy ($H_s < 2$ m). This is significant because when the wave energy is low, the comparison of measured and modelled data can be susceptible to problems where waves of similar height arrive from different directions (i.e. bimodal seas). In this case, the modelled peak wave direction can appear very different to the measured data because of small errors in wave height can affect which wave direction is considered dominant.

Table 6.2: The statistical comparison between measured and modelled wave parameters at the Rottnest and Cottesloe wave measurement stations.

Site	Period	Wave Parameter	IOA	RMSE	MAE
Rottnest Wave Buoy	31/1/2012 to 1/3/2012	H_s (m)	0.92	0.29	0.23
		T_P (s)	0.65	2.82	1.86
		θ_{peak} (°)	0.74	32.8	24.3
Cottesloe Wave Buoy	31/1/2012 to 1/3/2012	H_s (m)	0.91	0.12	0.10
		T_P (s)	0.58	4.22	2.90
		θ_{peak} (°)	0.79	36.8	24.9

** Relatively lower values of RMSE and MAE indicate higher model skill; IOA values closer to 1 also indicate higher model skill.*

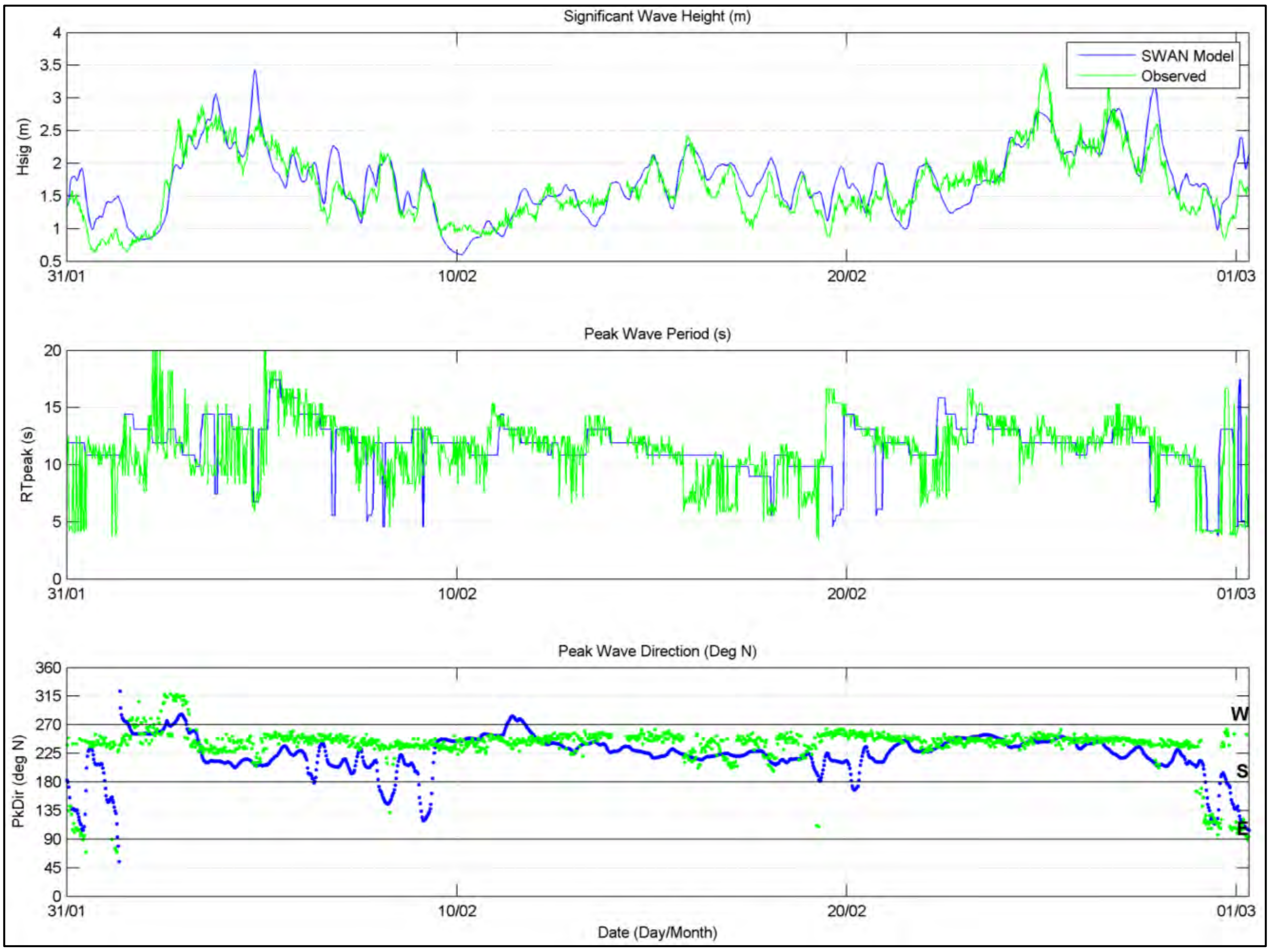

Figure 6.9: A comparison of modelled and measured H_s, T_P and θ_{peak} for the period 31st January to 1st March 2012, at the Rottnest wave station.

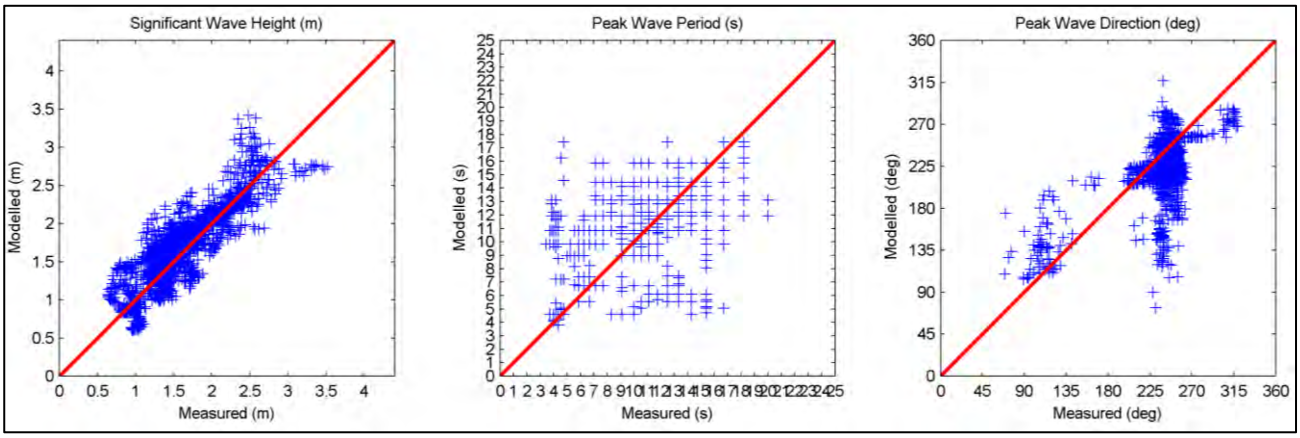

Figure 6.10: Scatter comparison of modelled and measured H_s, T_p and θ_{peak} over the period 31st January to 1st March 2012, at the Rottnest wave buoy.

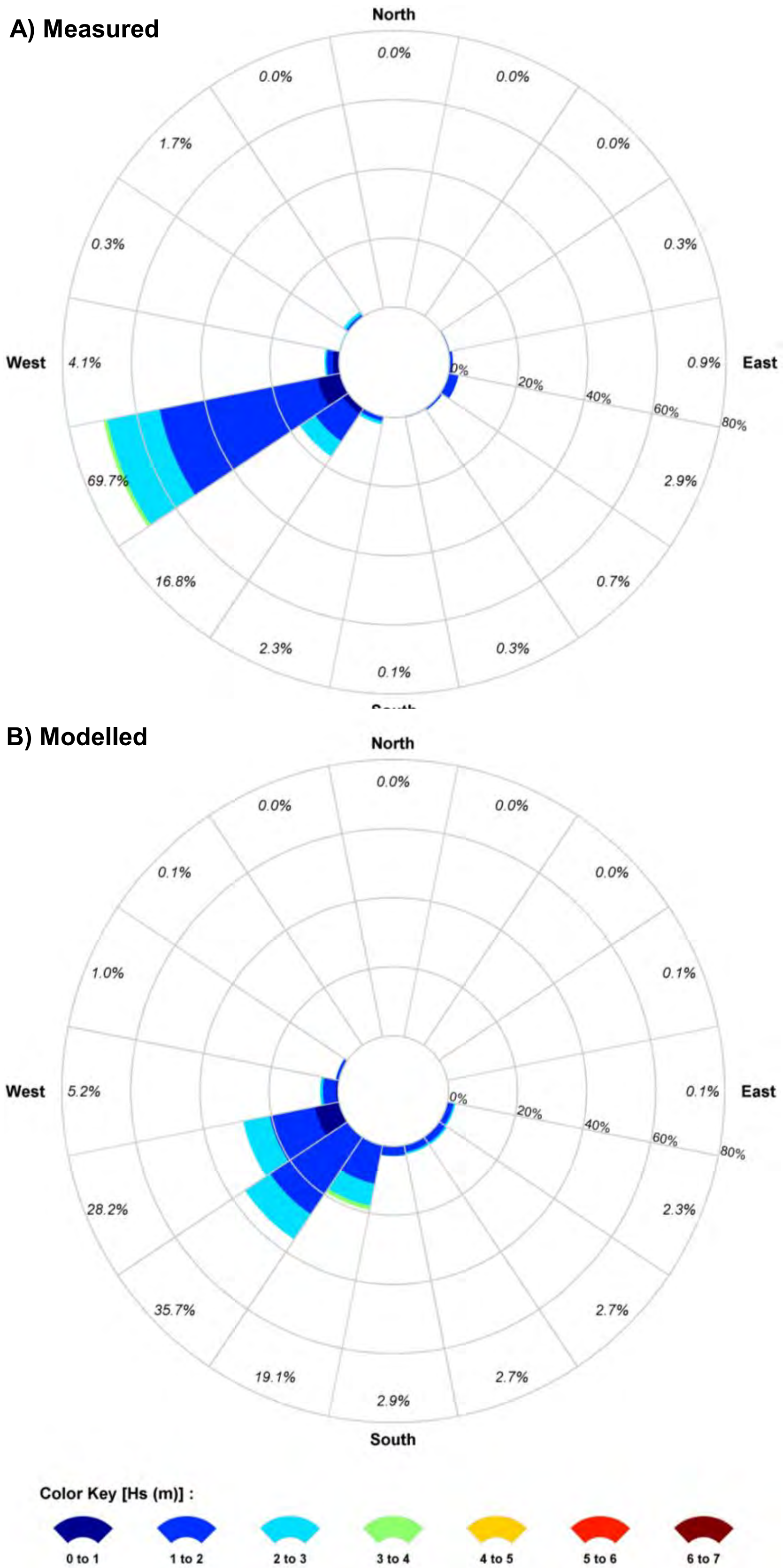

Figure 6.11: Significant Wave Height and Peak Direction Roses for measured data (A - top) and modelled data (B - bottom) for the period 31st January to 1st March 2012, at the Rottnest wave buoy.

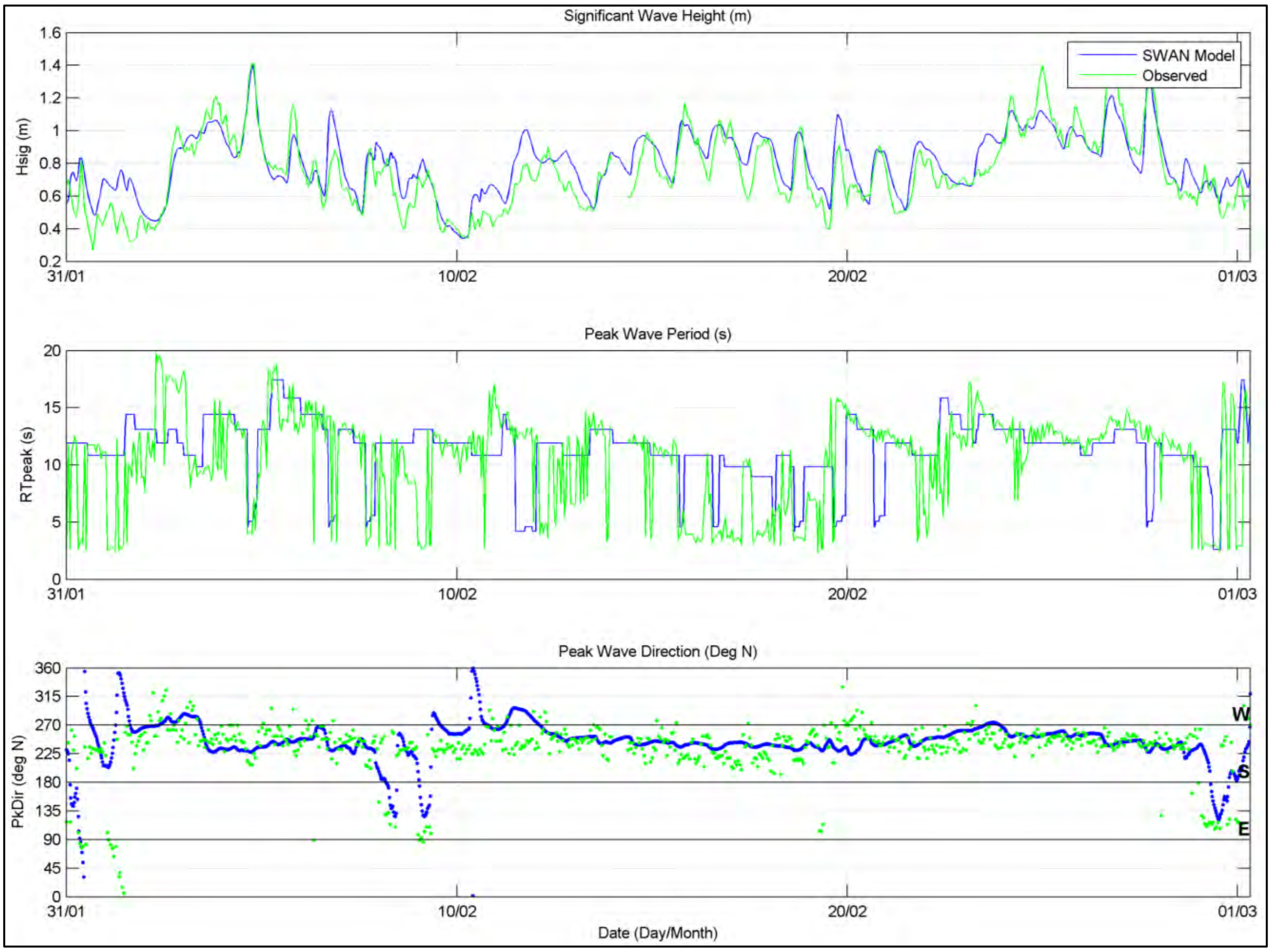

Figure 6.12: A comparison of modelled and measured H_s, T_P and θ_{peak} for the period 31st January to 1st March 2012, at the Cottesloe wave station.

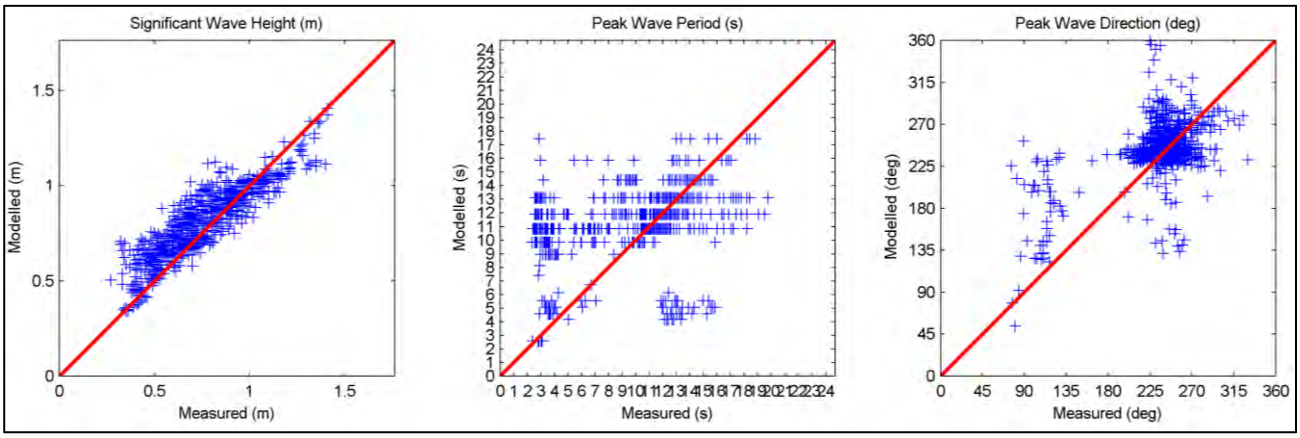

Figure 6.13: Scatter comparison of modelled and measured H_s, T_p and θ_{peak} over the period 31st January to 1st March 2012, at the Cottesloe wave buoy.

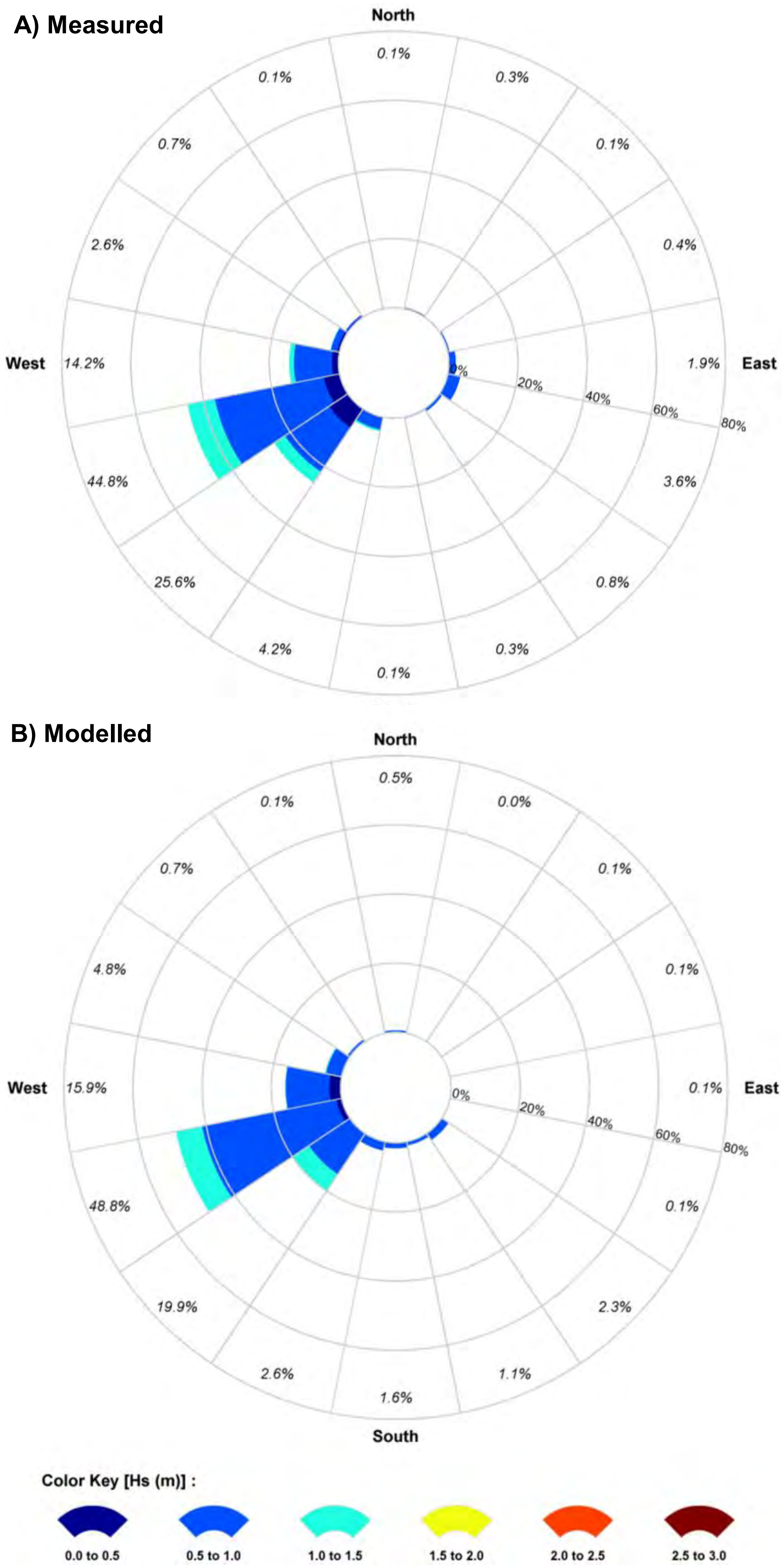

Figure 6.14: Significant Wave Height and Peak Direction Roses for measured data (A - top) and modelled data (B - bottom) for the period 31st January to 1st March 2012, at the Cottesloe wave buoy.

7.0 Flushing Assessment for ORM

Flushing is a measure of the rate of renewal of waters within a defined water body. A water body that is efficiently flushed experiences a turnover in water that results in local water quality very near that of the adjacent source water. Assuming that the source water quality meets environmental and aesthetic standards, efficient flushing generally indicates that the adjacent water body will also meet those standards.

7.1 Flushing Assessment Methodology

The flushing assessment was conducted by assessing eight 15-day periods that were selected to be representative examples covering spring and neap tide conditions in each season. For each simulation period the hydrodynamic model was initialised under 'hot start' conditions that were generated after a two-day prior spin-up period. There were two separate components to the flushing assessment.

The first component considered the flushing characteristics that would be relevant in the (short term) event of a large instantaneous contaminant discharge into the ORM. This form of analysis assumes that the contaminant would have a similar density to seawater (i.e. not be resistant to vertical mixing) and that its growth/decay rate would be negligible. To perform this analysis, a conservative tracer was introduced instantaneously to all model grid cells within the boundary of ORM at the commencement of the hot-start period. The hourly time series concentration of the tracer was then monitored in the surface and bottom layers of the model at the 10 virtual monitoring stations indicated in Figure 7.1. For these simulations groundwater discharge was active inside and outside of ORM, but the concentration of tracer in the groundwater discharge was zero. In addition to the monitoring stations within the ORM, some locations directly outside the entrance were also considered. These external stations are indicated in Figure 7.2.

The second component of the flushing study considered the potential for accumulation of nutrients within ORM, which are assumed to be sourced only from ongoing groundwater discharge into ORM. The form of analysis adopted assumed that the nutrients behave as unreactive conservative tracers. While this is unrealistic, it is a conservative approach that allows upper bound potential effects to be assessed. For this component of the flushing study, two additional conservative tracers were configured in the hydrodynamic model (i.e. not Delft3D-WAQ) to represent dissolved inorganic nitrogen and phosphorus. The initial concentration of both 'nutrient tracers' was set to zero throughout the grid domain at the beginning of the model spin-up period. The nitrogen and phosphorus concentrations in the inflowing groundwater were constant and the groundwater discharge rates were seasonally appropriate (Rockwater, 2015). The median and 80th percentile nitrogen and phosphorus concentrations were determined for the surface layer at each station based on hourly time series.

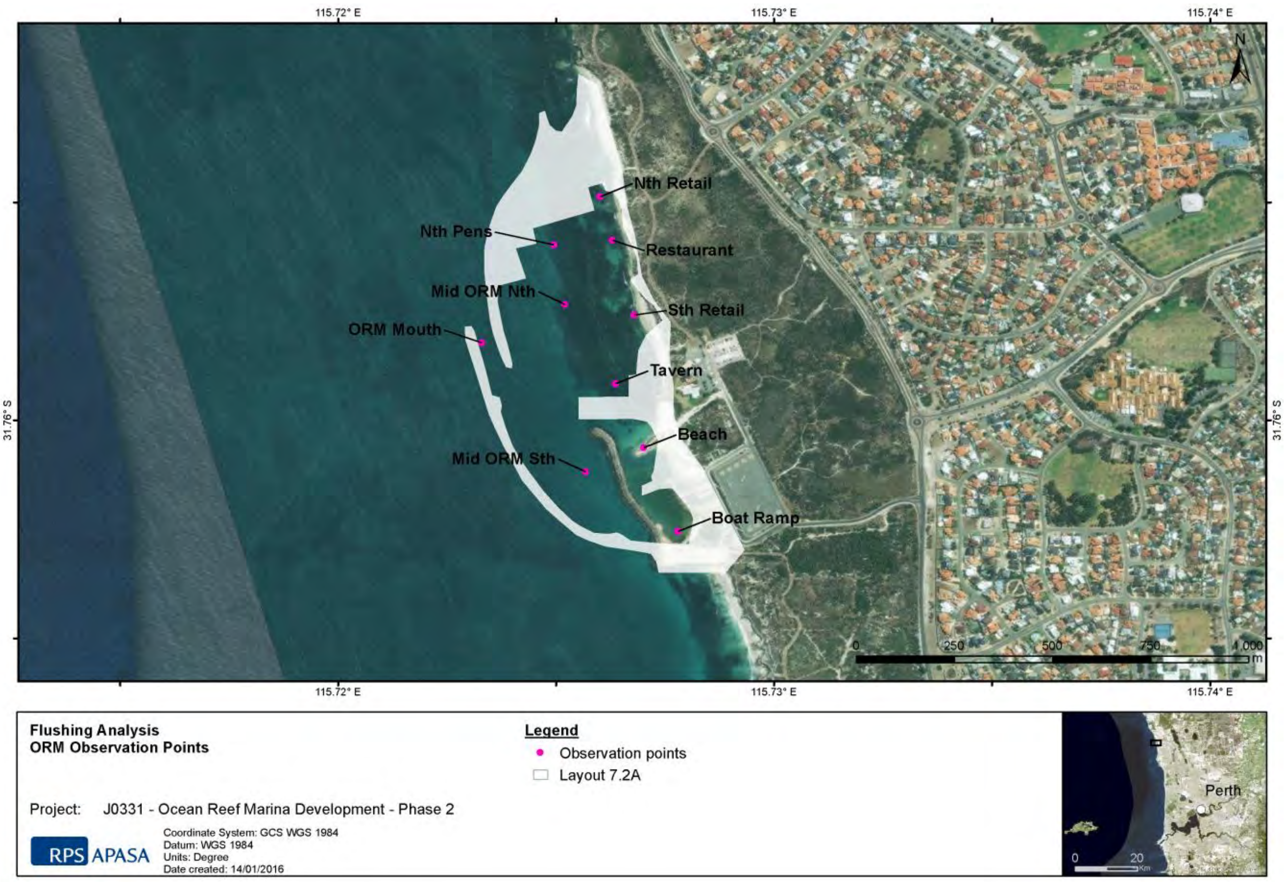

Figure 7.1: Stations used to monitor the flushing characteristics within ORM.

Figure 7.2: Stations used to monitor the flushing characteristics at some locations external to ORM.

7.2 Flushing Assessment Results

To give some general context to the results of the flushing assessment, one scenario was selected to provide an example of how the tracer concentration can evolve in space and time after it is released. Spatial maps showing tracer concentrations at selected time instances for a scenario that commenced 21 Mar 12 are presented in Figure 7.4. This example shows that the tracer disperses northward after discharging from the ORM, which was the same pattern observed in most other scenarios.

The maximum time taken for the tracer to dilute below the e-folding level (~37%) is tabulated for each location and for each scenario in Table 7.1. The maximum e-folding time at any observation point in any of the scenarios was approximately 7 days, which occurred at the Nth Pens station for a simulation commencing 21 Mar 12. Very similar results were observed at neighbouring observation stations in the northern section of ORM (i.e. Nth Retail and Restaurant). The monitoring stations that were located along the south and mid coastal sections had maximum e-folding times that were slightly lower, around 6 days. The shortest flushing time was only 2.4 days for a simulation commencing 9 August 2013. The range in flushing time results is due to different weather.

The flushing results can be given context by comparison to results from measurements made at Hillary's Marina (Schwartz and Imberger 1988). Based on measurements made in month of April/May 1987, during a period when winds speeds were up to 12 m/s, the flushing time for Hillarys Marina was calculated to be 5 days. This result sits between the minimum and maximum flushing times predicted for ORM, which were based on a wider sample of weather conditions.

In general, there was little difference between the e-folding times for surface and bottom layers at each station, with the exception of the deeper stations located closer to the ORM entrance (i.e. Mid ORM Nth, ORM Mouth and Mid ORM Sth). At these stations, the maximum e-folding times were approximately 24 hours longer in the bottom layer than in the surface layer.

With respect to the variation in e-folding times across the different simulation periods, the maximum e-folding times occurred in the autumn neap tide period (21 Mar 2012), with similarly high values in the winter spring tide period (19 Jul 2013). The shortest flushing times were during the winter neap period (9 Aug 2013). Typically, the shortest flushing times might be expected to occur in conjunction with spring tide, all other matters being equal. But the results demonstrate that wind conditions can dominant tidal effects if wind speeds are high.

In addition to the analysis of flushing and dilution characteristics within the ORM, some monitoring stations outside of ORM were also considered. The reason for considering these stations is understand the impact that a potential contaminant spill within the marina would have on the receiving waters outside of the marina. In this context it is important to emphasize that the approach used assumes no pre-dilution of the contaminant within the ORM itself. In other words, it is assumed that the contaminant spill is large enough to fill the volume of the ORM. This is not intended to be realistic, but the dilution results in this form can be multiplied by a pre-dilution level that is appropriately matched to a spill of arbitrary volume. The results of this analysis are presented in Table 7.2.

The temporal dynamics of the flushing behaviour at each monitoring station within the marina are illustrated in a set of time series plots that were produced for each scenario (Figure 7.4 to Figure 7.11). The time series plots also show corresponding time series of tidal and wind forcing. In general, these figures show the tracer concentration reducing at a similar steady rate for each station. The main exception is the ORM Mouth station which tends to flush relatively quickly. The type of tidal regime at the commencement of a scenario also had a significant effect on the initial rates of dilution. The low winds and neap tidal cycle experienced around 21 Mar 2012 (Figure 7.7) explain why the e-folding time was a maximum during this period. On some occasions the water level within the marina was affected by wind and pressure, for example during the 9 Jan 13 period (Figure 7.4) a switch to northerly winds and weather around 15 Jan resulted in a temporary increase in water level.

The results for the second component of the flushing assessment, regarding the potential for nitrogen and phosphorus accumulation within ORM, are tabulated in Table 7.3 and Table 7.4. The maximum P50 concentrations from any station and any scenario were 0.48 mg/L and 0.0031 mg/L for nitrogen and phosphorus respectively. It is important to emphasize that this component of the assessment considers nutrients only as passive tracers, which is a conservative assumption. This assumption is relaxed in the ecological modelling component of the study where the impact of these nitrogen levels on algal growth was investigated.

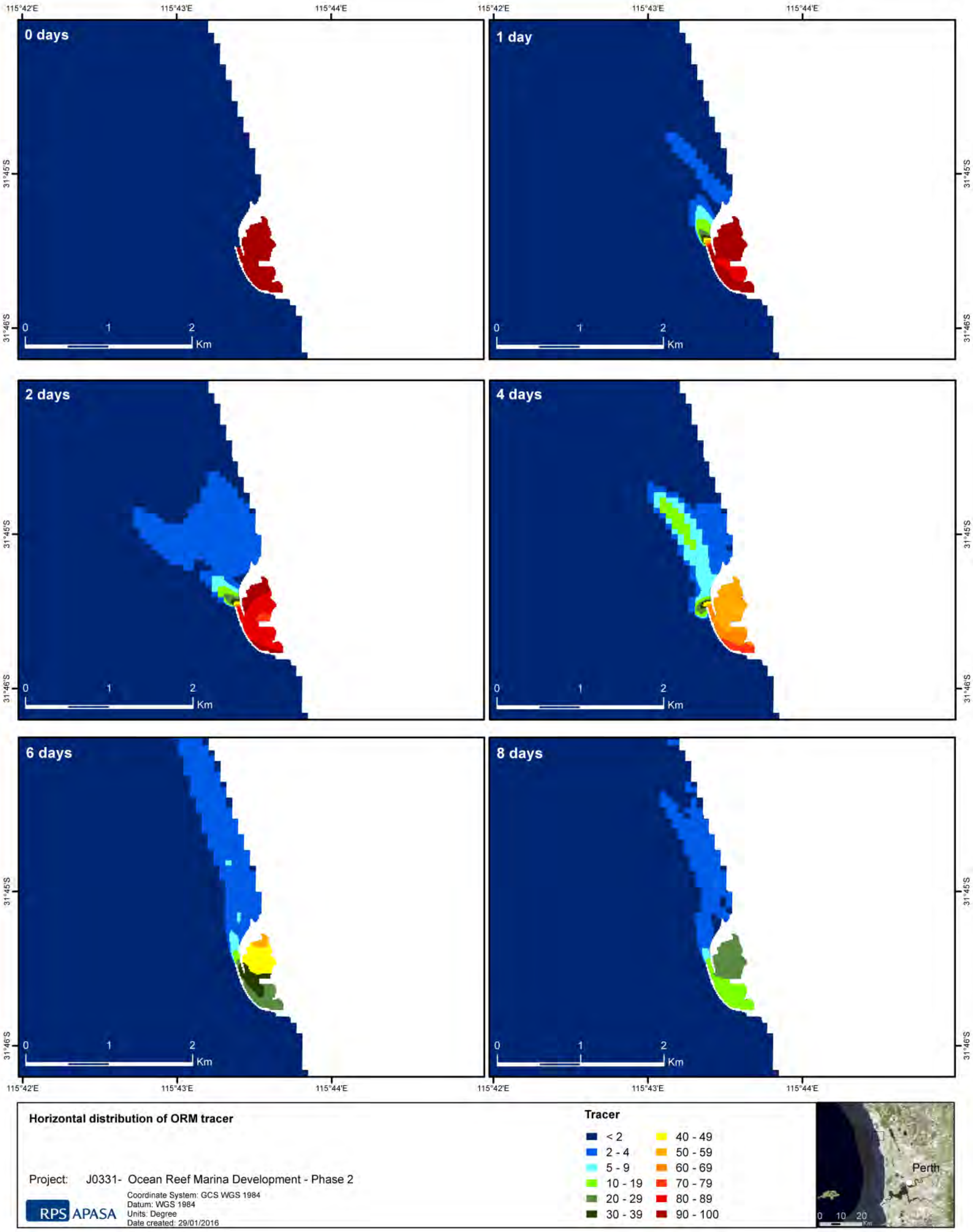

Figure 7.3: Maps showing spatial variations in surface layer tracer concentrations at selected time instances for a 15-day scenario commencing 21 Mar 12. The upper left panel shows the initial tracer release area.

Table 7.1: Summary of e-folding times for a conservative tracer released instantaneously throughout the volume of the proposed ORM

	Season	Summer	Summer	Autumn	Autumn	Winter	Winter	Spring	Spring	Median	Maximum
	Cycle	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap		
	Start Date	9 Jan 13	12 Feb 13	8 Apr 12	21 Mar 12	19 Jul 13	9 Aug 13	24 Oct 14	1 Nov 14		
Nth Retail	Surface	6.0	6.0	6.1	7.2	6.3	1.8	6.3	5.2	6.1	7.2
	Bottom	6.3	6.0	6.2	7.2	6.3	1.8	6.4	5.4	6.2	7.2
Restaurant	Surface	6.0	5.7	6.1	7.1	6.2	1.7	6.2	5.2	6.0	7.1
	Bottom	6.3	5.7	6.2	7.2	6.3	1.6	6.4	5.5	6.2	7.2
Nth Pens	Surface	5.9	5.8	5.8	7.1	5.6	1.7	5.8	4.9	5.8	7.1
	Bottom	6.3	5.8	6.3	7.3	6.4	1.6	6.5	5.5	6.3	7.3
Mid ORM Nth	Surface	4.5	5.7	5.3	5.9	5.6	1.8	5.7	4.8	5.4	5.9
	Bottom	6.3	5.7	6.3	6.7	6.4	1.5	5.5	5.6	6.0	6.7
Sth Retail	Surface	6.0	5.6	5.8	6.4	6.2	1.5	5.5	5.2	5.7	6.4
	Bottom	6.3	5.6	5.8	6.4	6.3	1.4	5.5	5.4	5.7	6.4
ORM Mouth	Surface	0.1	0.2	0.0	0.7	4.7	2.3	0.1	0.0	0.2	4.7
	Bottom	5.6	4.7	5.0	6.5	6.7	0.9	4.6	4.5	4.8	6.7
Tavern	Surface	5.1	4.8	4.3	6.0	5.6	1.5	3.9	4.2	4.6	6.0
	Bottom	6.3	4.8	4.5	6.1	6.0	1.3	4.3	4.4	4.7	6.3
Beach	Surface	5.1	4.7	4.4	5.1	5.7	1.4	3.8	3.8	4.5	5.7
	Bottom	5.3	4.7	4.4	5.2	5.9	1.4	3.8	3.9	4.5	5.9
Mid ORM Sth	Surface	4.3	3.8	2.2	4.2	5.0	2.3	2.3	3.5	3.6	5.0
	Bottom	6.3	4.6	4.8	5.4	6.5	1.2	4.4	5.4	5.1	6.5
Boat Ramp	Surface	5.3	2.8	3.9	4.9	5.8	1.4	2.8	3.7	3.8	5.8
	Bottom	5.3	3.0	4.1	5.0	6.1	1.4	3.0	3.8	3.9	6.1
Median	**All depths**	5.9	5.2	5.1	6.2	6.1	1.5	5.1	4.9		
Maximum	**All depths**	6.3	6.0	6.3	7.3	6.7	2.3	6.5	5.6		

Table 7.2: Predicted minimum dilution of a tracer released within ORM at three representative sampling stations located 100 m from the ORM entrance. For each simulation period indicated the tracer was released throughout the entire volume of ORM at the beginning of each simulation. Tabulated values show the maximum tracer concentration (in terms of percentage of initial tracer release concentration) that was detected in the surface and bottom layers at any time in each simulation. The eight simulation periods each had duration of 15 days.

Station Name	Depth Layer	Season	Summer	Summer	Autumn	Autumn	Winter	Winter	Spring	Spring
		Cycle	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap
		Start Date	9 Jan 13	12 Feb 13	8 Apr 12	21 Mar 12	19 Jul 13	9 Aug 13	24 Oct 14	1 Nov 14
BM070	surface		35	43	44	25	41	32	52	33
	bottom		8	18	6	1	10	7	11	5
BN070	surface		27	6	39	21	31	38	42	28
	bottom		8	36	5	2	11	9	26	8
BS070	surface		33	50	32	13	31	8	50	27
	bottom		7	11	4	1	5	4	9	7

Table 7.3: Median percentile values for surface layer nitrogen concentrations (mg/L) based on a 15-day time series for each simulation period. The concentrations reflect the contribution from seasonally variable input from groundwater sources (based on Rockwater, 2015) under the conservative assumption that the sources behave a passive tracers.

Season	Summer	Summer	Autumn	Autumn	Winter	Winter	Spring	Spring
Cycle	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap
Start Date	9 Jan 13	12 Feb 13	8 Apr 12	21 Mar 12	19 Jul 13	9 Aug 13	24 Oct 14	1 Nov 14
Nth Retail	3.9E-01	4.1E-01	4.2E-01	4.2E-01	4.0E-01	4.8E-01	4.8E-01	4.6E-01
Restaurant	3.4E-01	3.5E-01	4.0E-01	3.9E-01	3.6E-01	4.4E-01	4.2E-01	4.0E-01
Nth Pens	3.0E-01	3.2E-01	3.8E-01	3.3E-01	3.1E-01	3.9E-01	3.7E-01	3.5E-01
Mid ORM Nth	2.7E-01	2.9E-01	3.5E-01	3.1E-01	3.0E-01	3.4E-01	3.3E-01	3.2E-01
Sth Retail	3.2E-01	3.2E-01	3.9E-01	3.7E-01	3.6E-01	3.9E-01	3.9E-01	3.7E-01
ORM Mouth	2.1E-01	2.0E-01	2.8E-01	2.4E-01	2.3E-01	2.5E-01	2.3E-01	2.2E-01
Tavern	2.7E-01	2.7E-01	3.3E-01	3.1E-01	3.5E-01	3.5E-01	3.1E-01	3.0E-01
Beach	2.7E-01	2.6E-01	3.2E-01	3.0E-01	3.4E-01	3.4E-01	2.9E-01	2.9E-01
Mid ORM Sth	2.1E-01	1.9E-01	2.9E-01	2.4E-01	3.0E-01	3.0E-01	2.2E-01	2.1E-01
Boat Ramp	2.5E-01	2.5E-01	3.0E-01	2.9E-01	3.9E-01	4.3E-01	2.6E-01	2.6E-01
P50 Mean	**2.8E-01**	**2.9E-01**	**3.5E-01**	**3.2E-01**	**3.3E-01**	**3.7E-01**	**3.3E-01**	**3.2E-01**
P50 Maximum	**3.9E-01**	**4.1E-01**	**4.2E-01**	**4.2E-01**	**4.0E-01**	**4.8E-01**	**4.8E-01**	**4.6E-01**

Table 7.4: Median percentile values for surface layer phosphorus concentrations (mg/L) based on a 15-day time series for each simulation period. The concentrations reflect the contribution from seasonally variable input from groundwater sources (based on Rockwater, 2015) under the conservative assumption that the sources behave a passive tracers.

Season	Summer	Summer	Autumn	Autumn	Winter	Winter	Spring	Spring
Tide Cycle	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap
Start Date	9 Jan 13	12 Feb 13	8 Apr 12	21 Mar 12	19 Jul 13	9 Aug 13	24 Oct 14	1 Nov 14
Nth Retail	2.4E-03	2.5E-03	2.7E-03	2.6E-03	2.6E-03	3.1E-03	3.0E-03	2.9E-03
Restaurant	2.1E-03	2.2E-03	2.5E-03	2.4E-03	2.3E-03	2.8E-03	2.7E-03	2.5E-03
Nth Pens	1.9E-03	2.0E-03	2.4E-03	2.1E-03	2.0E-03	2.5E-03	2.4E-03	2.2E-03
Mid ORM Nth	1.7E-03	1.8E-03	2.2E-03	2.0E-03	1.9E-03	2.2E-03	2.1E-03	2.0E-03
Sth Retail	2.0E-03	2.0E-03	2.4E-03	2.3E-03	2.3E-03	2.5E-03	2.5E-03	2.3E-03
ORM Mouth	1.3E-03	1.3E-03	1.8E-03	1.5E-03	1.5E-03	1.6E-03	1.4E-03	1.4E-03
Tavern	1.7E-03	1.7E-03	2.1E-03	1.9E-03	2.3E-03	2.3E-03	2.0E-03	1.9E-03
Beach	1.7E-03	1.6E-03	2.0E-03	1.9E-03	2.2E-03	2.2E-03	1.8E-03	1.8E-03
Mid ORM Sth	1.3E-03	1.2E-03	1.8E-03	1.5E-03	1.9E-03	1.9E-03	1.4E-03	1.3E-03
Boat Ramp	1.6E-03	1.6E-03	1.9E-03	1.9E-03	2.5E-03	2.8E-03	1.7E-03	1.6E-03
P50 Mean	**1.8E-03**	**1.8E-03**	**2.2E-03**	**2.0E-03**	**2.2E-03**	**2.4E-03**	**2.1E-03**	**2.0E-03**
P50 Maximum	**2.4E-03**	**2.5E-03**	**2.7E-03**	**2.6E-03**	**2.6E-03**	**3.1E-03**	**3.0E-03**	**2.9E-03**

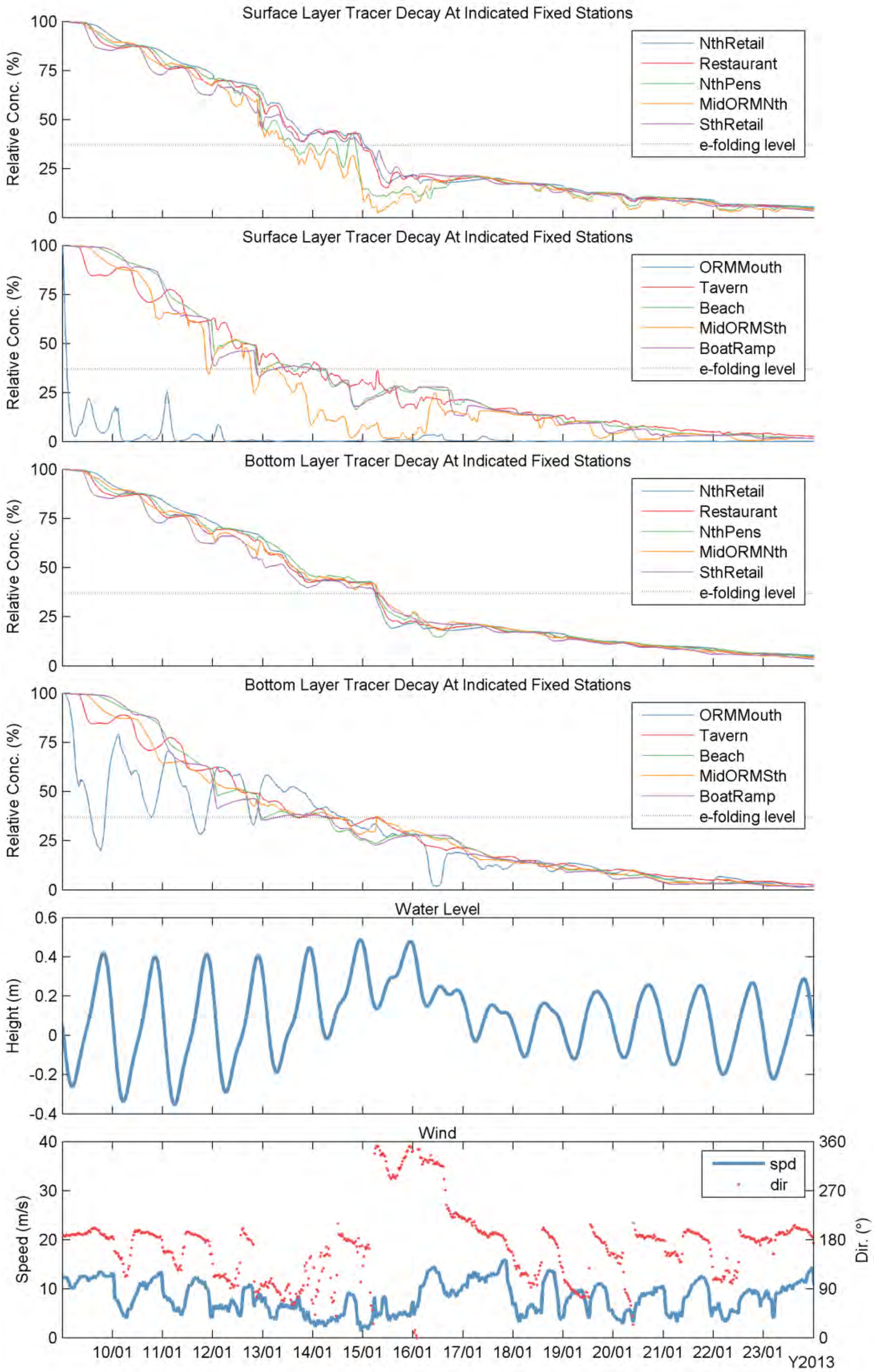

Figure 7.4: Time-series of tracer concentration at ten monitoring stations for a summer season spring tide scenario commencing 9 Jan 2013. Tide and wind forcing for same period are shown in lower panels.

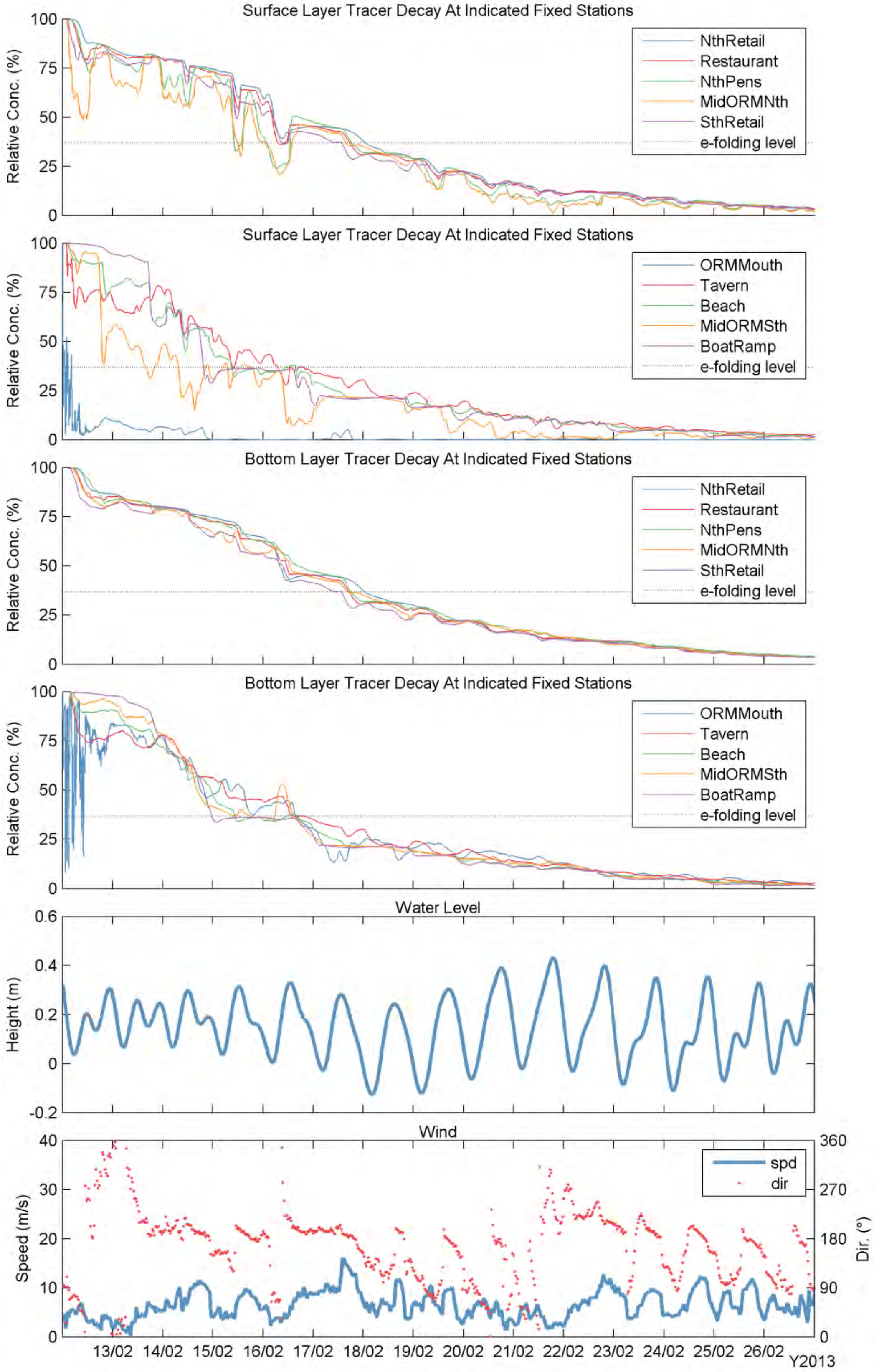

Figure 7.5: Time-series of tracer concentration at monitoring stations for a summer season neap tide scenario commencing 12 Feb 2013. Tide and wind forcing for same period are shown in lower panels.

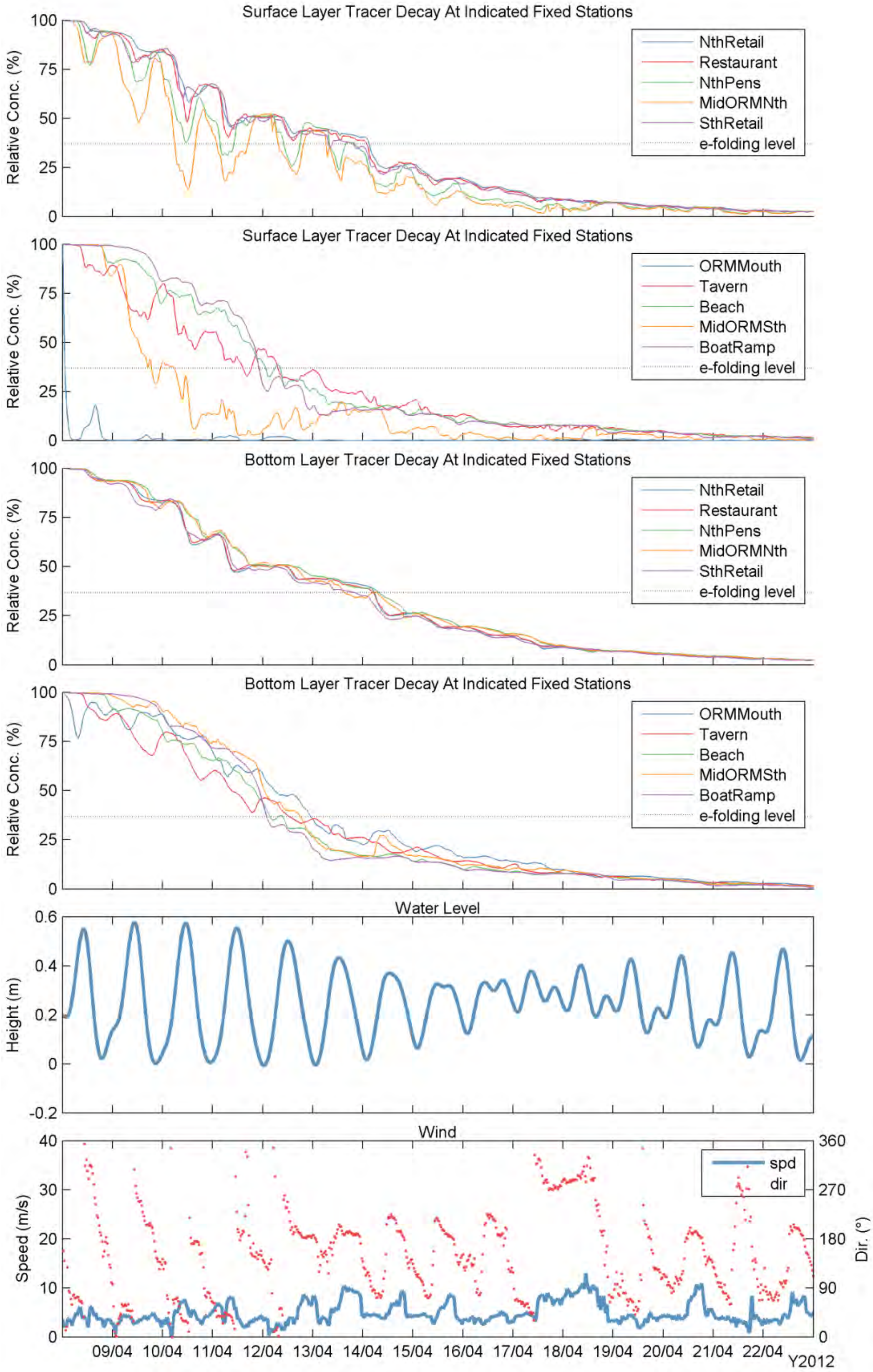

Figure 7.6: Time-series of tracer concentration at monitoring stations for an autumn season spring tide scenario commencing 8 Apr 2012. Tide and wind forcing for same period are shown in lower panels.

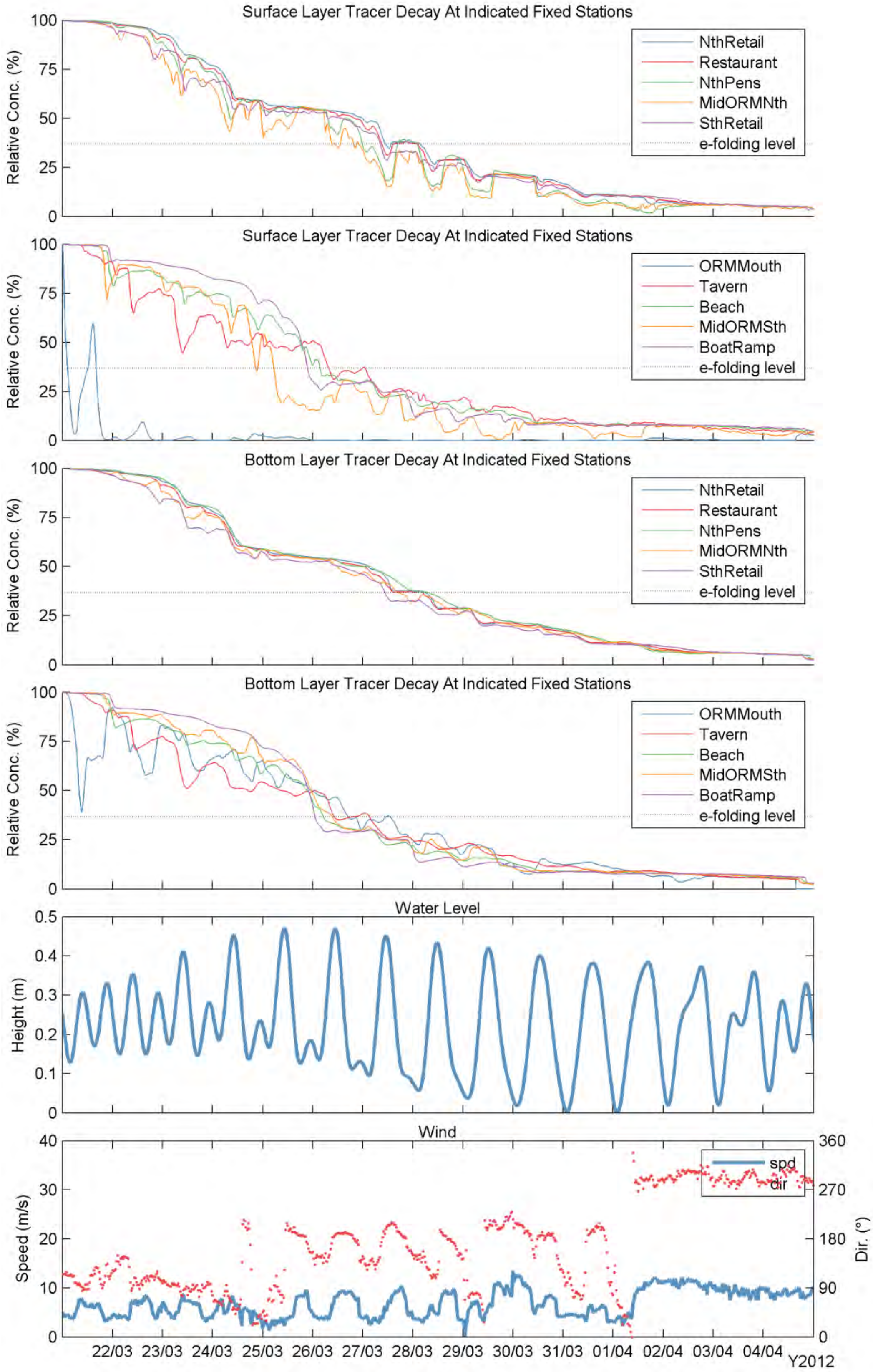

Figure 7.7: Time-series of tracer concentration at monitoring stations for an autumn season neap tide scenario commencing 21 Mar 2012. Tide and wind forcing for same period are shown in lower panels.

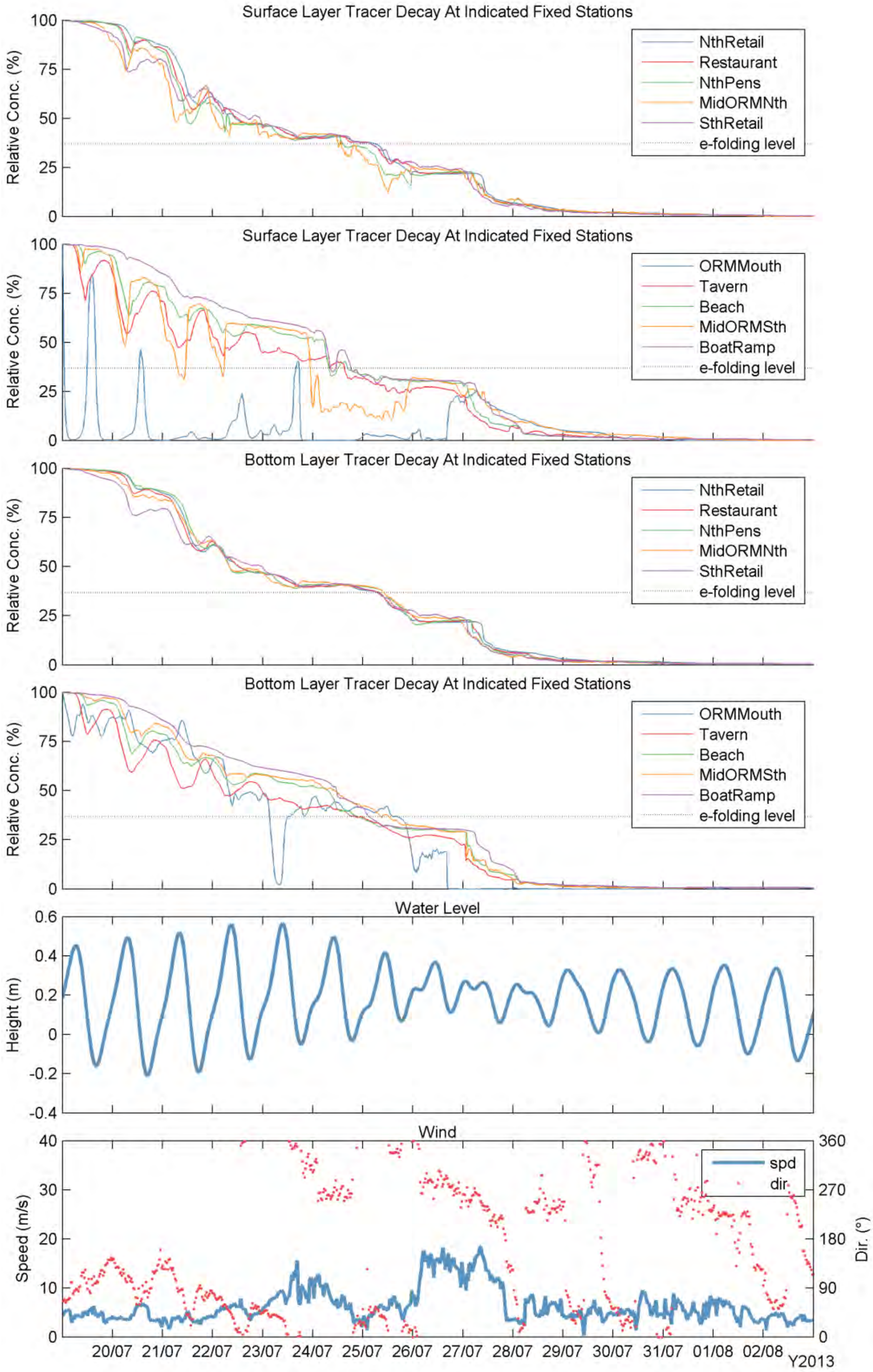

Figure 7.8: Time-series of tracer concentration at monitoring stations for a winter season spring tide scenario commencing 19 Jul 2013. Tide and wind forcing for same period are shown in lower panels.

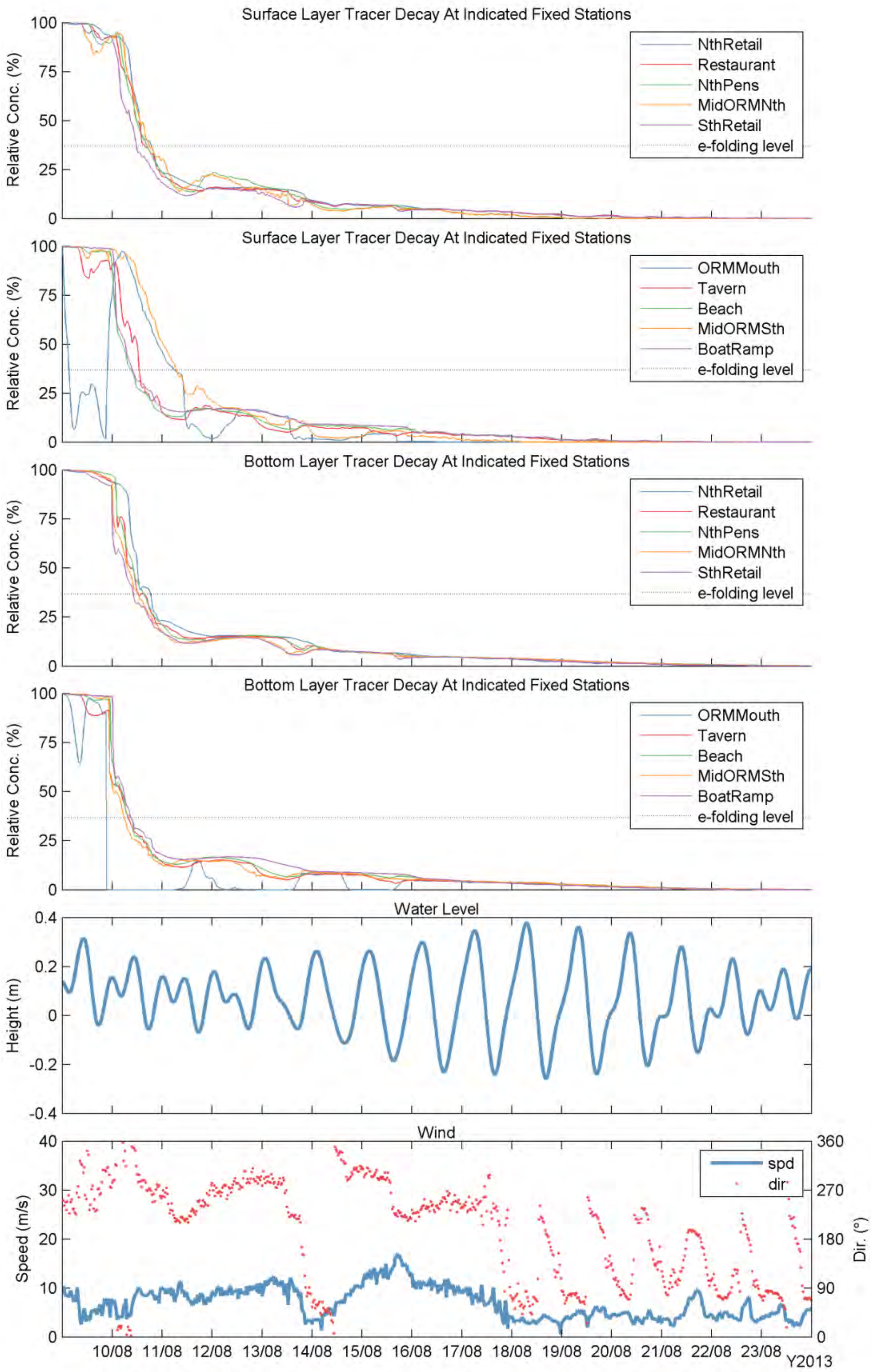

Figure 7.9: Time-series of tracer concentration at monitoring stations for a winter season neap tide scenario commencing 9 Aug 2013. Tide and wind forcing for same period are shown in lower panels.

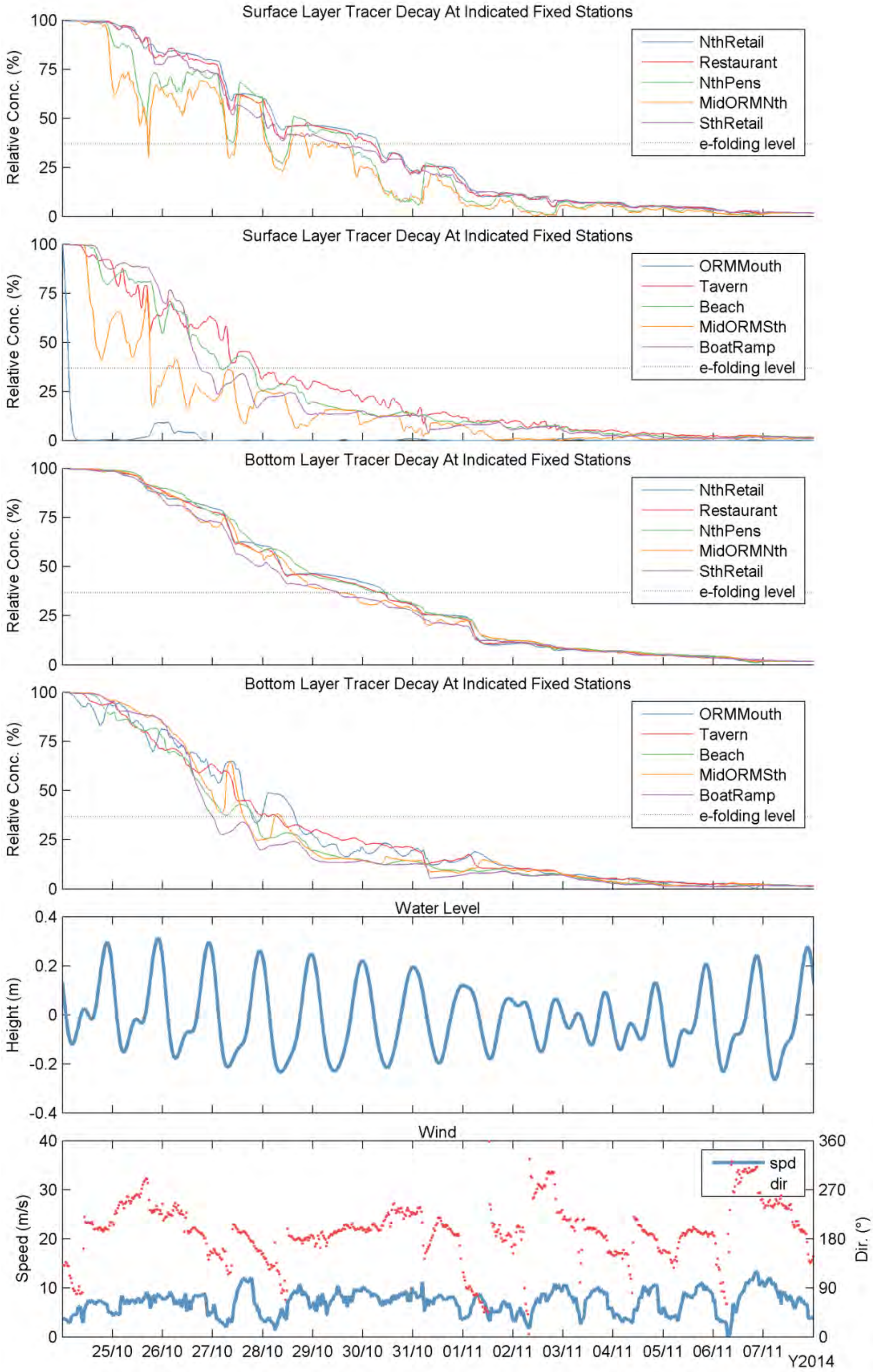

Figure 7.10: Time-series of tracer concentration at monitoring stations for spring season spring tide scenario commencing 24 Oct 2014. Tide and wind forcing for same period are shown in lower panels.

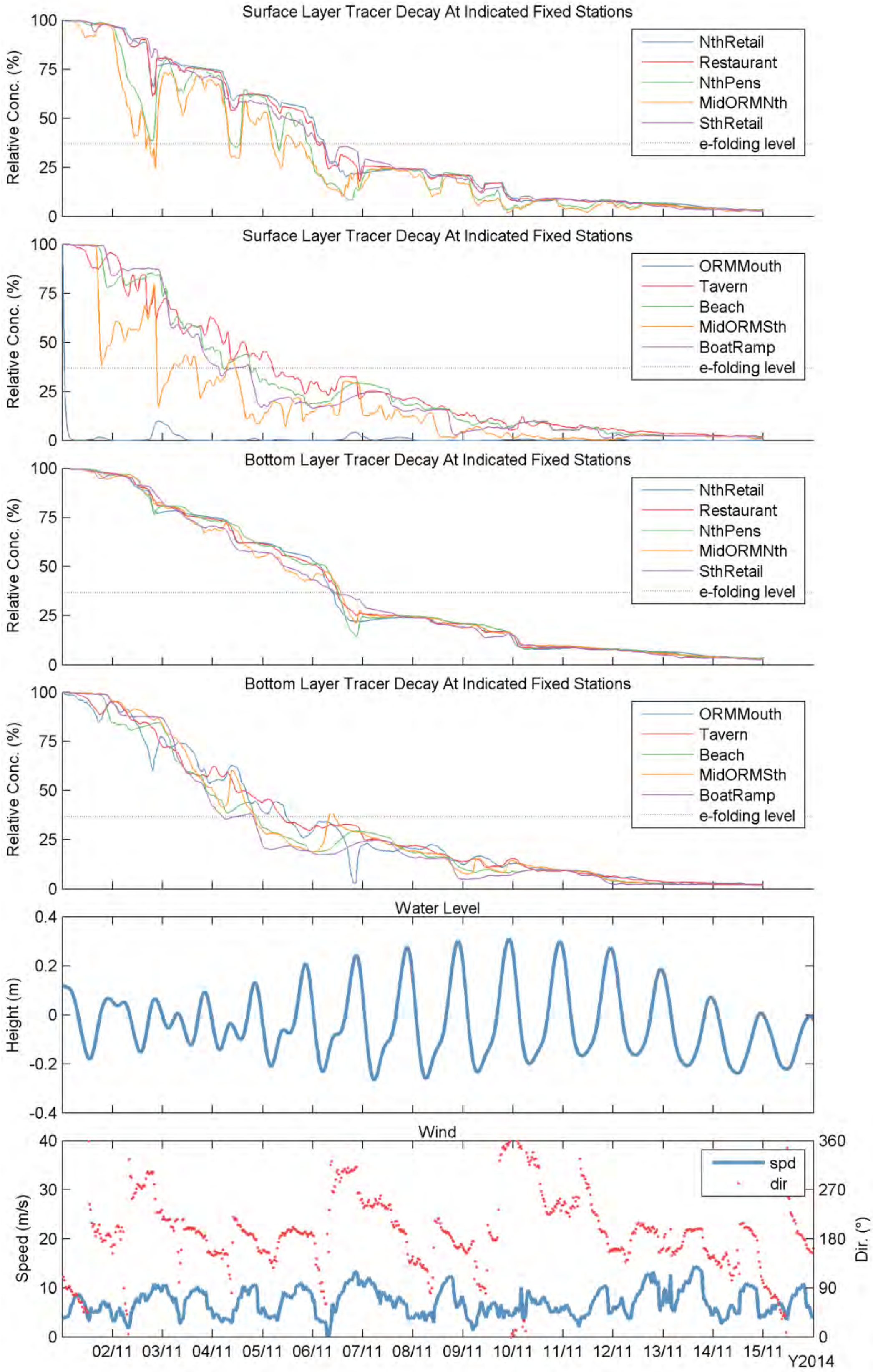

Figure 7.11: Time-series of tracer concentration at monitoring stations for a spring season neap tide scenario commencing 1 Nov 2014. Tide and wind forcing for same period are shown in lower panels.

8.0 Ecological Modelling

The ecological modelling component of this study was designed specifically to assess the potential for algal growth to occur within the proposed ORM at concentrations over and above the normal background concentrations in the neighbouring marine environment.

High levels of algal production within the ORM are undesirable because it would inhibit the recreational use of waters within the ORM and/or lead to odour and aesthetic issues. Furthermore, if high levels of algal production were sustained within ORM, the outflow from the Marina would potentially have an impact on the adjacent waters of the Marmion Marine Park. The ecological modelling presented in this section provides a screening level assessment of these possibilities.

The overall approach that was adopted for the ecological modelling was to focus only on the component of algal growth within the ORM that is expected to occur over and above the background levels that are normal in the marine environment outside of ORM. Therefore, the algae concentration presented in the results of this section are all ‘above background’ unless specified otherwise.

An important strength of the ‘above background’ approach is that the required nutrient flux boundary inputs to the ecological model are limited to those that will contribute to ‘higher than background’ nutrient concentrations within ORM. Therefore, nutrient sources that may by significant but uncertain, such as offshore nutrient flux input, were able to be neglected for the purpose of the analysis. However, consideration needed to be given to the potential mechanisms that might contribute to above background algal growth within ORM.

Relatively high above background concentrations of algae may only develop within ORM if the conditions within the ORM are more suitable for algal growth than the conditions outside of ORM. Theoretically, favourable conditions within ORM could develop due differences in nutrients, light, temperature or water residence time compared to outside neighbouring waters. Of these factors, temperature gradients are expected to be insignificant with respect to algal growth and light levels aren’t expected to be more favourable inside ORM than external to it. However, differences in nutrients and water residence time were considered to be potentially significant in the context of algal growth. Therefore, consideration was given to the different pathways that might lead to relatively high nutrient concentrations within ORM. The potential nutrient pathways that were initially considered were:

- groundwater input
- surface runoff after rainfall
- decomposition of wrack within ORM
- input from the Beenyup Waste Water Treatment Plant (WWTP) ocean outlet

Elevated nutrient input to the ORM from the Beenyup WWTP outlet was considered unlikely. The outlet is approximately 1.5 km offshore from ORM, and therefore, nutrients in the treated waste water plume would normally be expected to be diluted to near background concentrations before potentially reaching the marina entrance. Furthermore, this particular mechanism would not be expected to affect the algal concentration within ORM anymore than it would affect the background concentration outside of ORM.

Decomposition of wrack within the ORM was considered unlikely to significantly affect nutrient concentrations within the ORM. If a significant mass of wrack were to accumulate on shorelines within the ORM it is expected that it would be removed by the ORM management authority, as is the case for the existing ORBH. The arrival of wrack is also expected to be episodic rather than regular, which means any decomposition of wrack within the ORM would also be counteracted by the natural flushing and exchange that occurs on an approximately weekly timescale (i.e. Section 7.0). The potential for oxygen depletion due to wrack decomposition would be similarly limited.

Surface runoff from rainfall is not expected to contribute to the nutrient load within ORM under typical conditions. This assumption takes into account the drainage design criteria for the ORM, which was communicated by MP Rogers & Associates. Under the designed criteria, runoff from rainfall would not typically discharge directly into ORM unless there was a large rainfall event (i.e. 1 in 1 year event).

The influence of nutrient loading from groundwater input is expected to cause nutrient concentrations within ORM to be higher than background levels outside the marina. The potential for nutrient build-up was confirmed previously in the results of the flushing assessment (Section 7.0). Although the groundwater loading into ORM isn't considered particularly different to that along the adjacent coastline, the nutrients tend to accumulate inside the ORM due to the increased fluid residence time within ORM. Because this nutrient accumulation mechanism is persistent rather than episodic, there is a possibility that algae could accumulate via growth within the Marina faster than they are diluted by natural flushing.

In summary, the ecological modelling approach is designed to consider all significant factors that might lead to concentrations with ORM that are persistently higher than background. Nutrient loading to the ORM from groundwater is considered the only systematic and regular mechanism could theoretically lead to concentrations persistently higher than background. The subsequent ecological modelling results are designed to quantify this effect. Other mechanisms that are irregular or unpredictable are considered less significant because the natural flushing of the ORM will counteract shorter term or one-off influences over approximate time scale of one week.

8.1 Method

The ecological model framework provided by Delft3D-WAQ can potentially be configured to an extremely complex degree, representing several algal species, and yet with this configuration would still represent a very much simplified version of a natural aquatic system. Given the tight focus of the current ecological study on the ORM, it is possible to simplify the required parameter set significantly. This approach has the advantage that key results can be manageably related back to a relatively small parameter set (this often isn't a trivial issue given the nonlinear biological processes being modelled). Furthermore, where there is uncertainty in the relatively small parameter set, conservative values may be used to provide an upper bound estimate on questions of management interest, such as the potential for eutrophication.

This assessment used a single generic algal group to represent the characteristics of the local algae assemblage in bulk, which follows a similar modelling approach for Perth coastal waters that was adopted by Machado and Imberger (2012). The representative algal group was designed to grow (or decay) according to available concentrations of inorganic nitrogen and phosphorus. Growth (but not decay) was also constrained by a variable number of daylight hours per day, but solar radiation (i.e. light penetration) was assumed to be replete during daylight hours. Silica availability was not considered limiting.

The maximum potential growth rate of the representative algal group was set a rate of 2 day^{-1}, which is exactly twice the value used by Machado and Imberger (2012). The high growth rate is intended to overestimate the likely potential for growth within ORM, but the rate is still theoretically plausible in ideal conditions for the faster growing species of algae. The high growth rate used in the model is also to compensate for not modelling the dependence of growth rate on water temperature, in effect; the modelling assumes algae always grow at their optimal temperature, which is conservative. This approach is intended to give an upper bound estimate of the potential for algal growth within ORM. The assumption of a high growth rate implies that the estimate of algal production is robust because a large amount of parameter uncertainty is eliminated. The maximum growth rate can only be achieved in the model if nutrient requirements are fully met; otherwise the growth rate is scaled downwards in proportion to the limitation at each time step. The key parameters used to configure the Delft3D-WAQ model are presented in Table 8.1; all parameters except for the growth rate and the carbon to chlorophyll a ratio are standard model parameters.

Table 8.1: Parameters used for Delft3D-WAQ simulation of a representative algal group.

Algal Parameter	Value
Maximum growth rate (day^{-1})	2
Base respiration rate (day^{-1})	0.045
Active respiration rate (day^{-1})	0.15
Nitrogen to carbon ratio (gN/gC)	0.16
Phosphorus to carbon ratio (gP/gC)	0.02
Carbon to chlorophyll a ratio (gC/gChla)	50
Nitrogen half saturation constant (gN/m^3)	0.005
Phosphorus half saturation constant (gP/m^3)	0.001
Initial concentration (µgChla/L)	0.2

Delft3D-WAQ was run continuously for each season of a representative year (i.e. 4 x 3 month scenarios). It is necessary to 'seed' the algal concentration in Delft3D-WAQ with a non-zero initial concertation. At the beginning of each scenario the concentration of algae was initialised at a typical background level for Perth regional waters of 0.2 µgChla/L (Machado and Imberger, 2012). This background concentration is approximately half the concentration that has been measured in the nearshore around the site of the ORM but it is appropriate for use in this context because the model grid area extends to deeper offshore waters (see Figure 4.2). The same initial value could be used for all seasons because the seasonal model results were not sensitive to the initial condition after the first few days of simulation. The initial nutrient concentration was set to zero throughout the entire domain. This approach ensures that the fluctuations in algal concentration within the ORM are not overwhelmed by external inputs. In effect, it ensures the 'signal' of above background growth within the ORM is separated from the 'noise' due to oceanic exchange.

During the simulation nutrient sources were fed into the model coastline (inside and outside ORM) via groundwater discharge points and using seasonally appropriate flow rates and nutrient loadings (Rockwater 2015). The nutrient loading from groundwater inflow to the coastline outside of ORM is not expected to contribute significantly to algal growth within ORM but this approach means that the predicted concentration inside the ORM can be directly compared to the predicted concentration along the coastline adjacent to the ORM, with all influences equal other than the physical structure of the ORM that is the central issue.

Although there is a treated waste water discharge outlet offshore from ORBH that is operated by the Water Corporation, it was assumed that nutrient loading from this source will be the same pre and post development, and that these nutrient loads will rapidly dilute into the ambient background concentrations. For the open boundaries influxes, the modelled algae were set to the same concertation as the initial background value but nutrient concentrations were set to zero. The grid used for Delft3D-WAQ was the same as that used in the hydrodynamic model framework but the model time step was 1-hour.

The time series of (depth averaged) algal concentrations were monitored at 12-hour intervals at several points within the model domain. Time series concentration values within ORM were determined by averaging the results from three virtual monitoring locations in the north, south and mid sections of ORM. Time series concentrations along the nearby coastline outside of ORM were represented by nearshore model output observation stations that were approximately 1.5 km north and south of ORM (the locations of the observation stations are shown in subsequent figures). The time series of algal concentrations inside ORM and along the neighbouring adjacent coastline were compared to isolate the effect of the ORM structure on the growth of algae in the nearshore.

To give context to the predicted ‘above background’ algal concentrations, the results from the modelling were compared to season and location appropriate background concentrations for algae that were determined from field measurements. Background concentration values for each season were advised by BMT Oceanica based on data from a water quality sampling program that was carried out during 2014/2015.

Table 8.2 Summary of seasonal percentile chlorophyll a concentrations determined from results of water sampling program carried out during 2014/15 (BMT Oceanica)

Season	Concentration (µgChla/L)
Summer P95	0.7
Summer P80	0.6
Summer P50	0.5
Autumn P50	0.5
Winter P50	1.8
Spring P50	0.4

The predicted algal concentrations for the summer season results were directly compared to relevant benchmarks for water quality in accordance with the processes identified in Environmental Quality Criteria Reference Document for Cockburn Sound (EPA, 2015). To achieve this comparison the predicted algal concentrations determined from the modelling were added to an appropriate median summer background concentration to give a ‘total’ predicted concentration. The total predicted concentration within the ORM was then compared to the Moderate Ecological Protection Area threshold (MEPA) for algal blooms, which is equal to three times the 80th percentile of the summer season background measurements (EPA, 2015). Similarly, the total predicted concentration at the outer boundary of a 70 m buffer zone around the ORM was compared to the High Ecological Protection Area Threshold (HEPA), which is equal three times the 50th percentile of the summer season background measurements (EPA, 2015).

The predicted algal concentrations were also evaluated against the HEPA and MEPA thresholds for benthic primary producer health. For the benthic primary producer health HEPA threshold, the predicted median chlorophyll concentration at the edge of the ORM 70 m buffer was compared to the 80th percentile of the summer season background concentration. For the benthic primary producer health MEPA threshold the predicted median chlorophyll concentration within ORM was compared to the 95th percentile of the summer season background concentration.

8.2 Ecological Modelling Results

The results from the ecological modelling are presented in Figure 8.1 through to Figure 8.8. For the summer season scenario, the counteracting influences of algal growth and (weather dependent) flushing tend to balance out and lead to relatively stable algal concentrations within the ORM that were between 0.2 to 0.4 µgChla/L above the background (Figure 8.1), which implies a total concentration of 0.7 to 0.9 µgChla/L once the background for the summer season is added (Table 8.2).

Spatial contours of above background algae concentration at selected time instances during the summer season (Figure 8.2) clearly indicate persistently higher concentrations within ORM than outside of it, however an increase in the concentration due to outflow from ORM isn't detectable during these selected time instances (i.e. <0.1 µgChla/L), except for a small plume near the ORM opening.

In the modelled region outside of the ORM, the concentration of algae quickly decayed from its initial value because nutrients were more limiting than within the ORM (Figure 8.1). Although the model output observation stations north and south of ORM were positioned relatively closely to the coastal groundwater discharge sources, the results indicate that the flushing in this exposed coastal region is too rapid to allow any significant algal growth.

For the autumn seasonal scenario the dynamics of algal growth and the predicted above background concentrations were similar, reflecting the fact the nutrient loading from groundwater was the same as in the summer scenario and that the flushing behaviour was broadly similar. The predicted above background concentration for the autumn season was typically around 0.3 µgChla/L (Figure 8.3), which implies a total concentration of 0.8 µgChla/L once the autumn background is added (Table 8.2). The exception was during the last month of the scenario when the above background concentration of algae within the marina decayed quickly. This was due to increased flushing due to strong wind forcing in the modelled scenario around 10 May 2013.

For the winter season scenario the concentration of algae within ORM was higher than for summer and autumn seasons, and more variable. Above background concentrations of algae were typically in the range of 0.2 to 1.0 µgChla/L, which implies a total concentration of 2 to 2.8 µgChla/L once the winter background is added (Table 8.2).

For the spring season scenario the changes in the time series concentration of algae within ORM were broadly similar to the winter scenario. Above background concentrations of algae were typically in the range of 0.2 to 1.1 µgChla/L, which implies a total concentration of 0.6 to 1.5 µgChla/L once the spring background is added (Table 8.2).

The higher variability in above background concentration during winter and spring than in summer and autumn was due to variance in weather that is typically experienced in these seasons combined with the higher nutrient loadings applied to the groundwater discharge. In winter and spring there were calm periods that allowed algal growth but these periods were punctuated by the increased flushing that occurred during storm events. The higher concentrations within the ORM during these seasons led to a larger effect of outflows from ORM on occasion (e.g. 9 Oct 2013, Figure 8.8).

During the winter scenario there were some instances when the concentrations along the coastline outside of ORM were detectable above background levels (e.g. 13 Aug 2013, Figure 8.6). The patchy growth along this coastline occurred around some very shallow model grid cells along the coastal margin that were not as well flushed as other nearby cells. These patches were temporary in nature and can be considered artefacts caused by the gridded discretisation of the coastline.

The above background concentrations of algae in each season were also predicted at some model observation stations external to the marina. The purpose of these model output monitoring stations was to gauge how 'above background' concentrations generated within ORM may affect the Marmion Marine Park. Four external model output monitoring points were considered, one located at the ORM entrance, and three others at locations along a 70 m buffer zone from the entrance. The station locations were indicated previously in Section 7.0, Figure 7.2. The results at these stations are presented for all seasons in Figure 8.11 through to Figure 8.12, respectively. The results indicate that the above background algae concentrations were always less than 0.2 µgChla/L at all stations along the edge of the 70 m buffer in winter and spring, and more typically remained less than 0.1 µgChla/L. Based on these results the typical total concentration at the 70 m buffer would be 1.9 µgChla/L in winter and 0.5 µgChla/L in spring. This indicates that although the concentrations within the marina and at the marina entrance are predicted to be slightly elevated above background, the effect 70 m outside of the marina is predicted to be minimal (i.e. practically undetectable).

8.2.1 Evaluation of Ecological Protection Areas Thresholds

The predicted algal concentrations for the summer season results were directly compared to relevant benchmarks for algal blooms and benthic primary producer health in accordance with the processes identified in Environmental Quality Criteria Reference Document for Cockburn Sound (EPA, 2015).

For the summer season, the total predicted algal concentration within the ORM was determined by adding the predicted above background concentration to the measured median background concentration for summer (i.e. 0.5 µgChla/L).The same method was used to calculate the total predicted concentration at the edge of the 70 m buffer zone. The time series of predicted total concentrations at these locations are both shown in Figure 8.13. The median total predicted concentration within ORM for the summer season was 0.7 µgChla/L. The median total predicted concentration at the edge of the ORM 70 m buffer for the summer season was 0.5 µgChla/L.

The relevant MEPA and HEPA thresholds for algal blooms were calculated from measured data in accordance with the process described in EPA (2015) and are also shown in Figure 8.13. The MEPA threshold for algal blooms was 1.8 µgChla/L, i.e. equal to three times the 80th percentile background concentration (0.6 µgChla/L, Table 8.2). The results indicate that the predicted total concentrations within ORM did not exceed the MEPA threshold. Similarly, the predicted total concentrations at the edge of the 70 m buffer zone did not exceed the HEPA threshold (1.5 µgChla/L) at any time during summer.

The relevant MEPA and HEPA thresholds for benthic primary producer health were also evaluated in accordance with the process described in EPA (2015). The HEPA and MEPA thresholds calculated from measured data are summarized in Table 8.3, along with the model predicted total concentrations inside and outside ORM. The predicted median summer concentration within ORM was equal to 0.7 µgChla/L, which was the same as the MEPA threshold (i.e. 95th percentile of the background). The predicted median summer concentration at the edge of the ORM 70 m buffer was 0.5 µgChla/L, which was less than the 80th percentile of the background concentration that defines the HEPA threshold (0.6 µgChla/L).

Table 8.3 Summary of total predicted chlorophyll a concentrations compared to relevant thresholds for benthic primary producer health

Location	Predicted Summer Concentration (µgChla/L)	HEPA Threshold (µgChla/L)	MEPA Threshold (µgChla/L)
Within ORM	0.7	N/A	0.7
ORM 70 m buffer	0.5	0.6	N/A

N/A: Threshold not applicable to the location

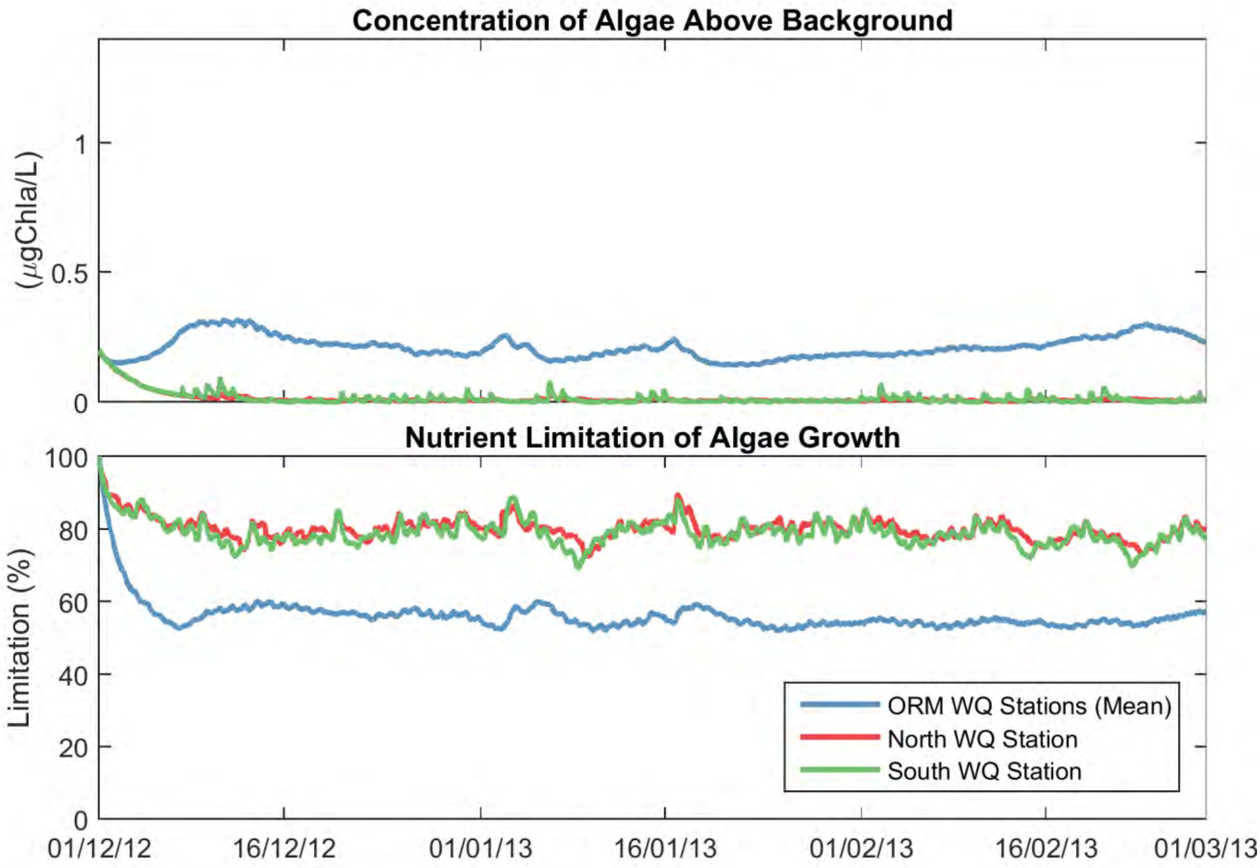

Figure 8.1: Time series of results from model observation stations for the summer season scenario. The locations of the monitoring station are indicated in the next figure (Figure 8.2). The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

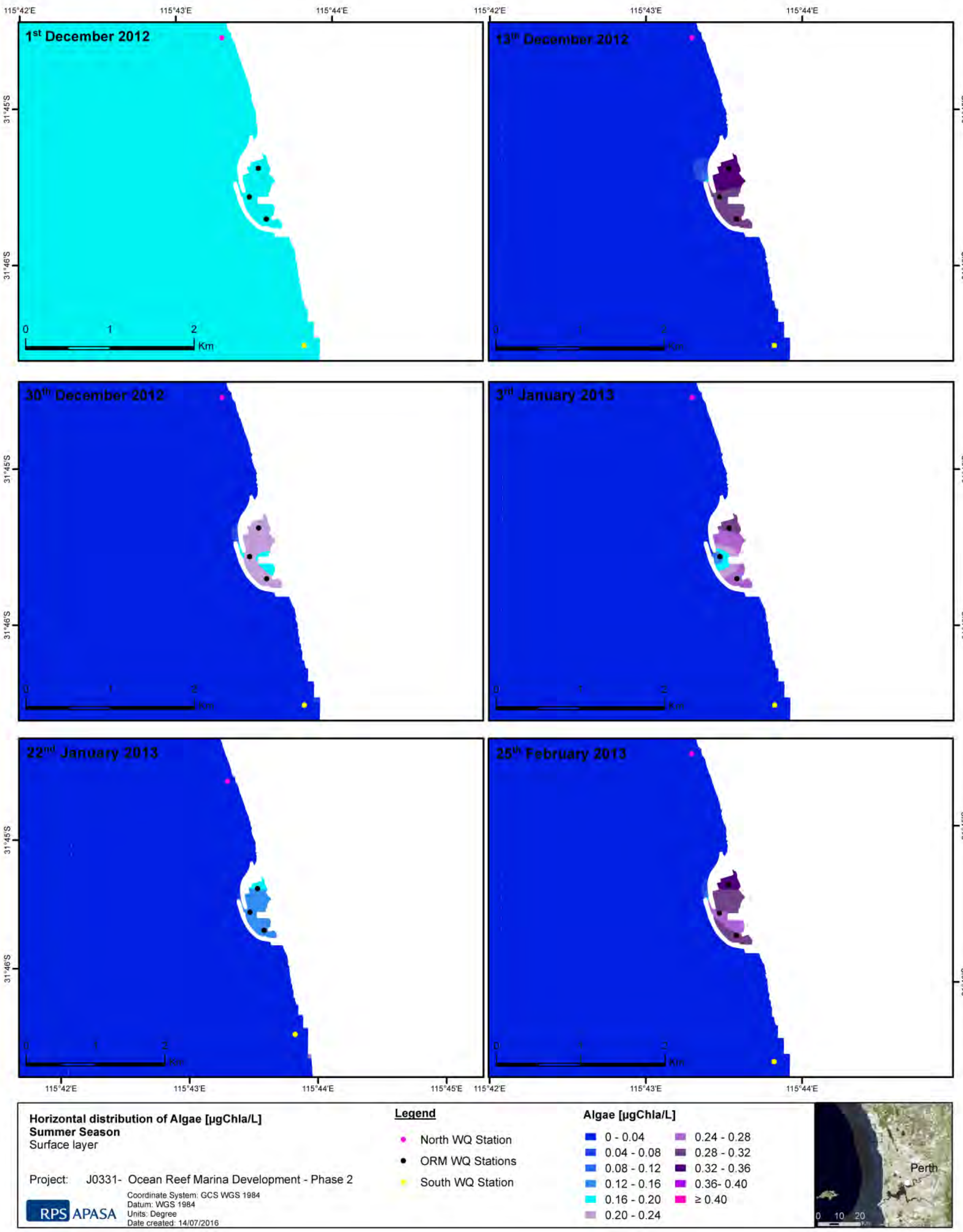

Figure 8.2: Maps showing spatial variations in surface layer algal concentrations (above background) at selected time instances for the summer season scenario. Coloured dots indicate the location of virtual observation stations, as indicated in the legend.

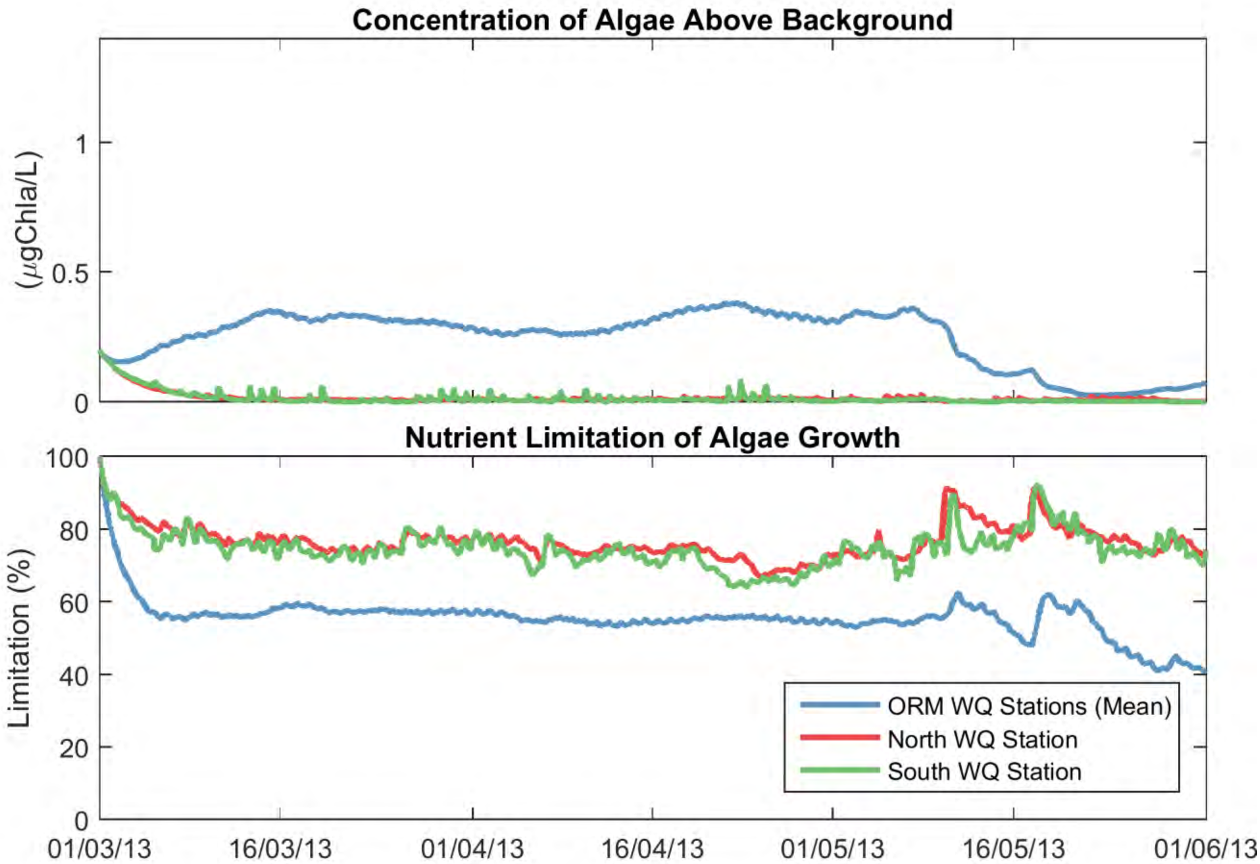

Figure 8.3: Time series of results from model observation stations for the autumn scenario. The locations of the monitoring station are indicated in Figure 8.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

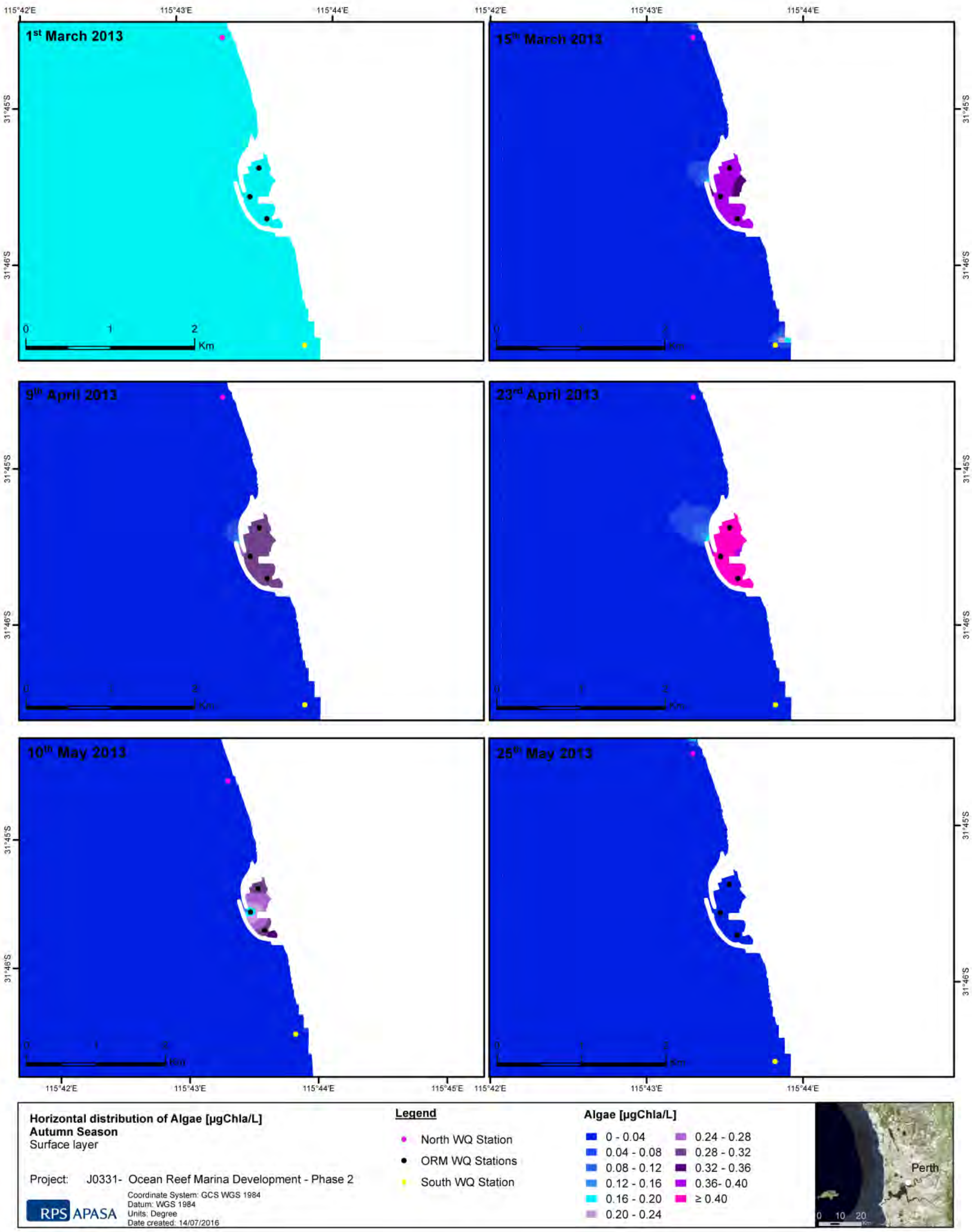

Figure 8.4: Maps showing spatial variations in surface layer algal concentrations (above background) at selected time instances for the autumn season scenario. Coloured dots indicate the location of virtual observation stations, as indicated in the legend.

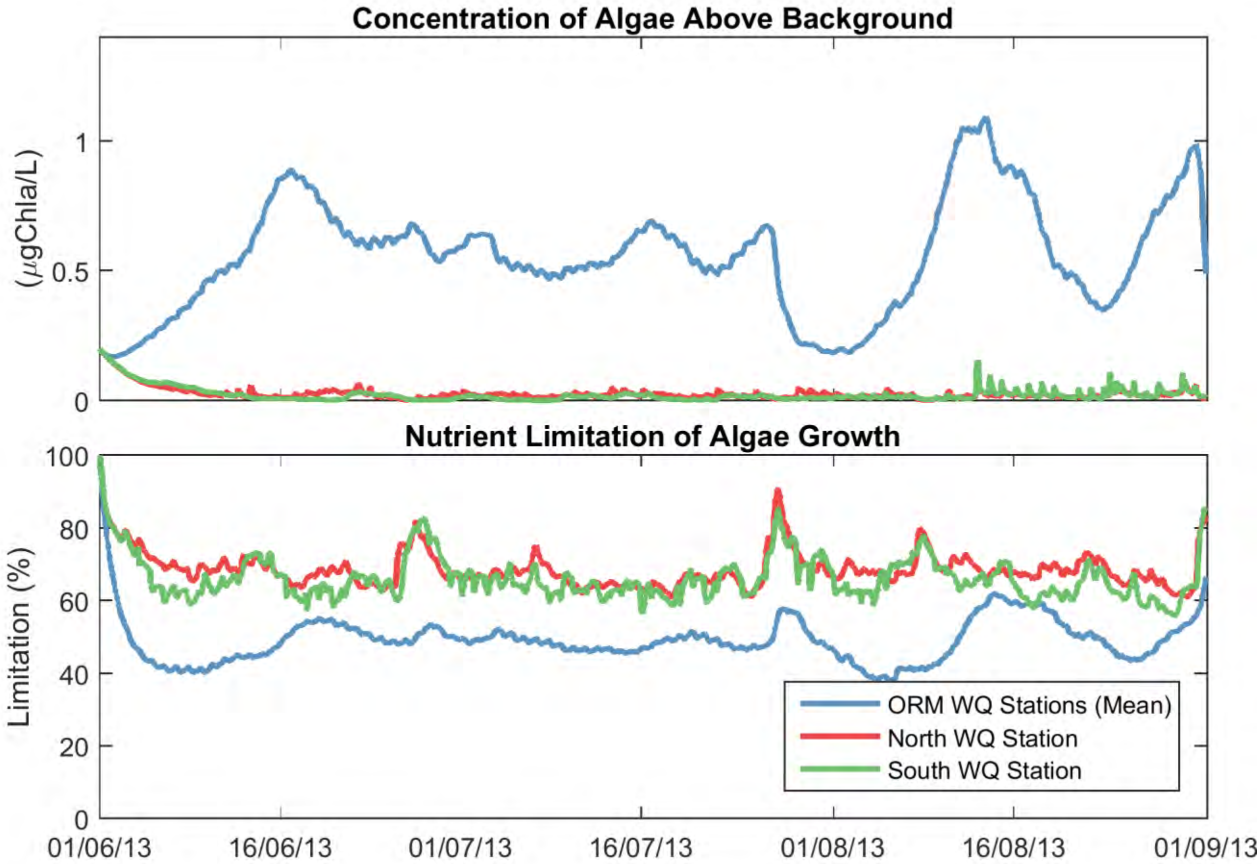

Figure 8.5: Time series of results from model observation stations for the winter season scenario. The locations of the monitoring station are indicated in Figure 8.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

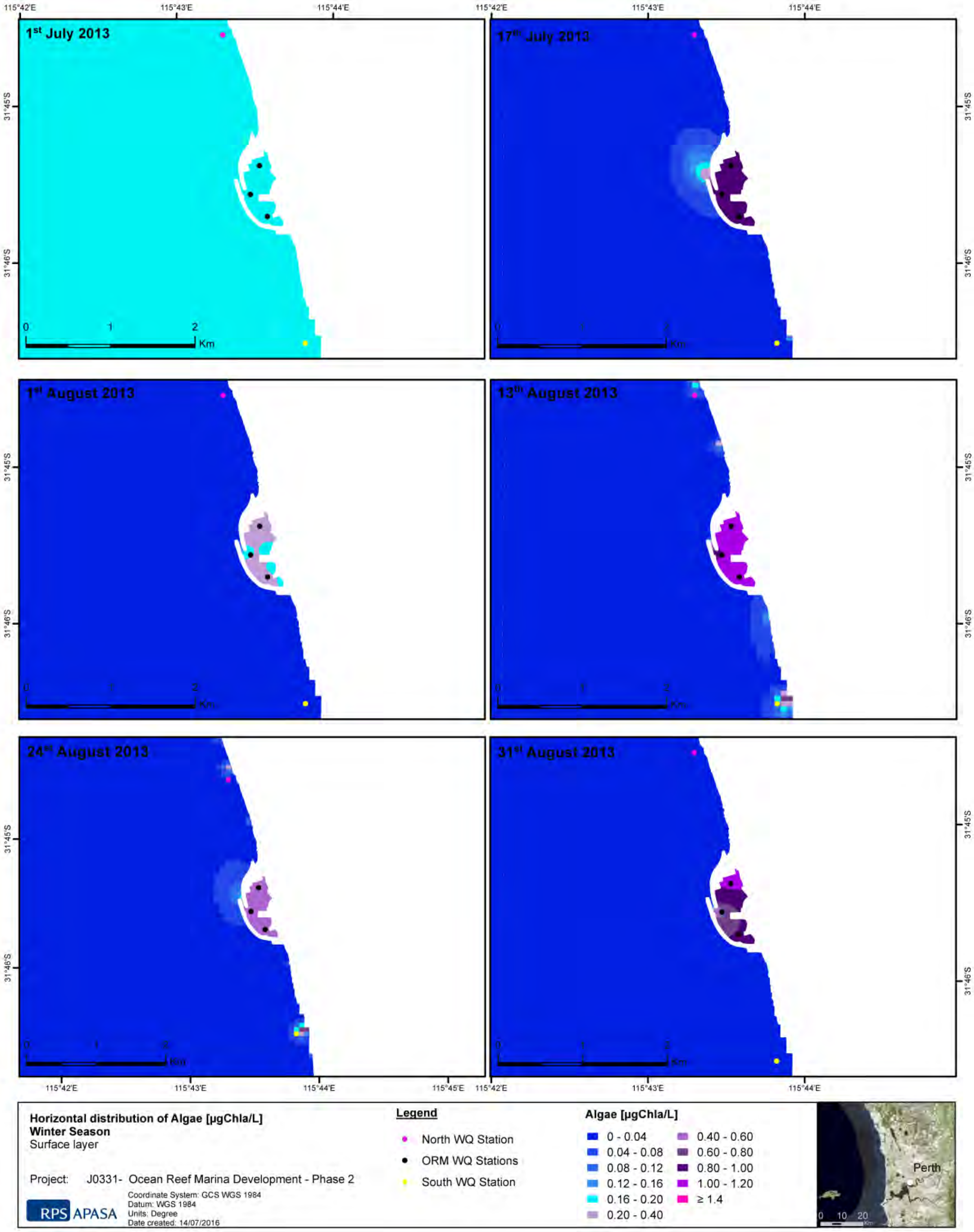

Figure 8.6: Maps showing spatial variations in surface layer algal concentrations (above background) at selected time instances for the winter season scenario. Coloured dots indicate the location of virtual observation stations, as indicated in the legend.

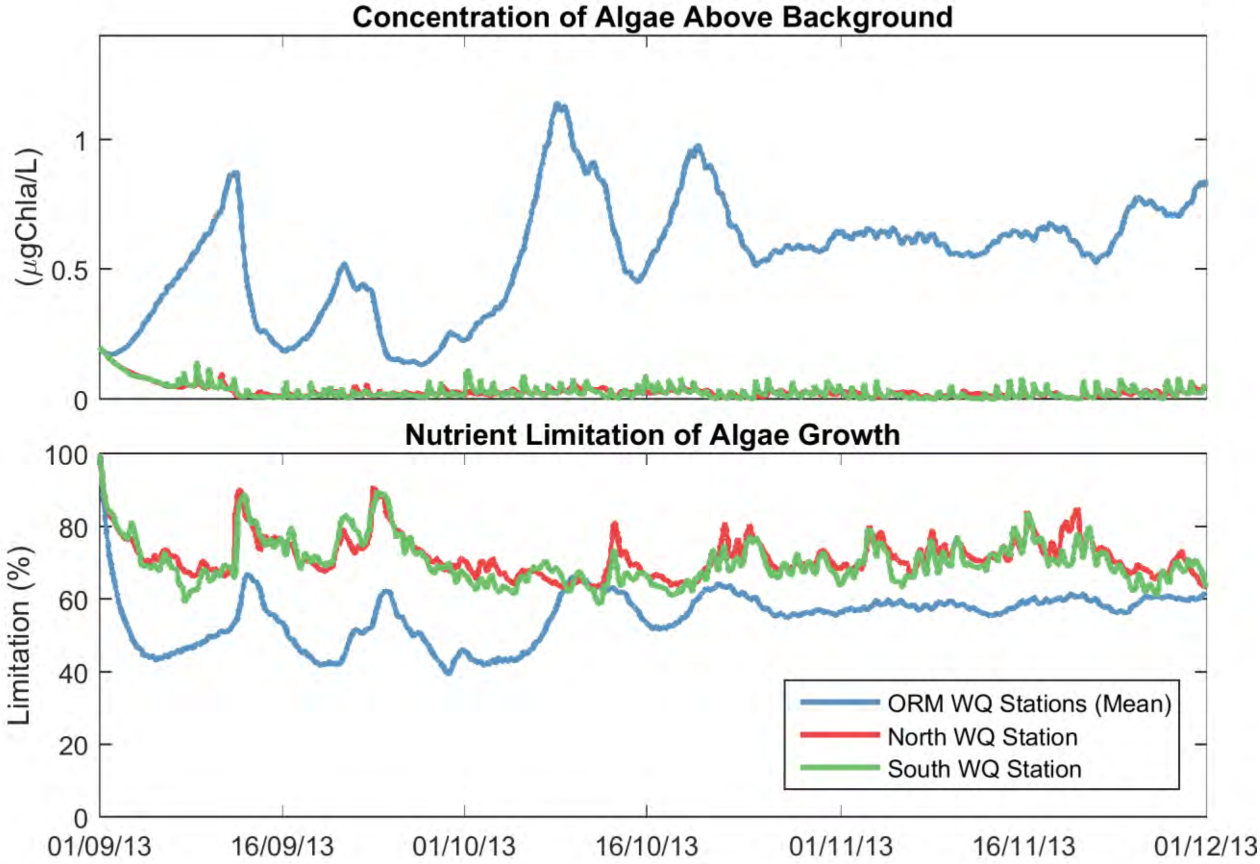

Figure 8.7: Time series of results from model observation stations for the spring season scenario. The locations of the monitoring station are indicated in Figure 8.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

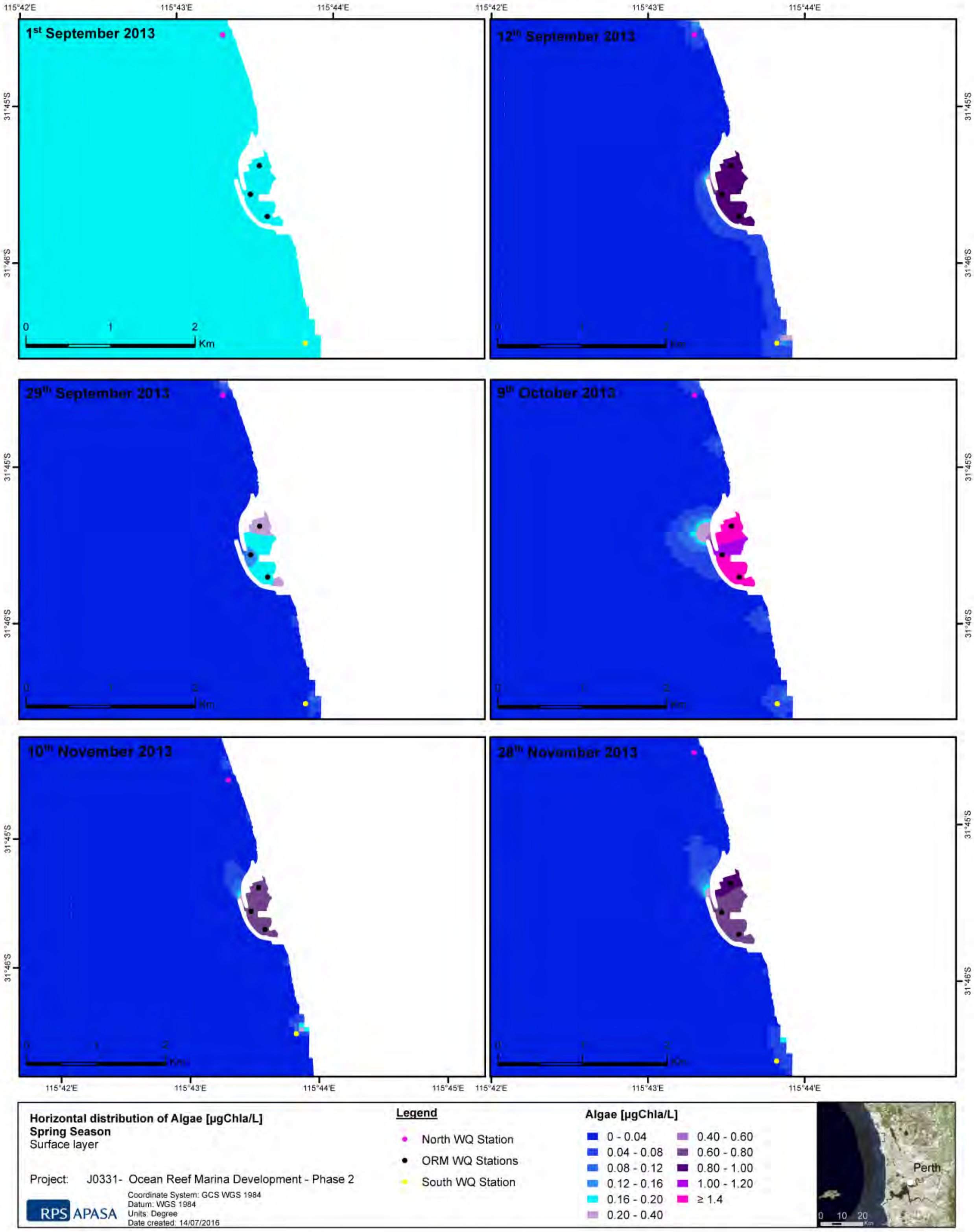

Figure 8.8: Maps showing spatial variations in surface layer algal concentrations (above background) at selected time instances for the spring season scenario. Coloured dots indicate the location of virtual observation stations, as indicated in the legend.

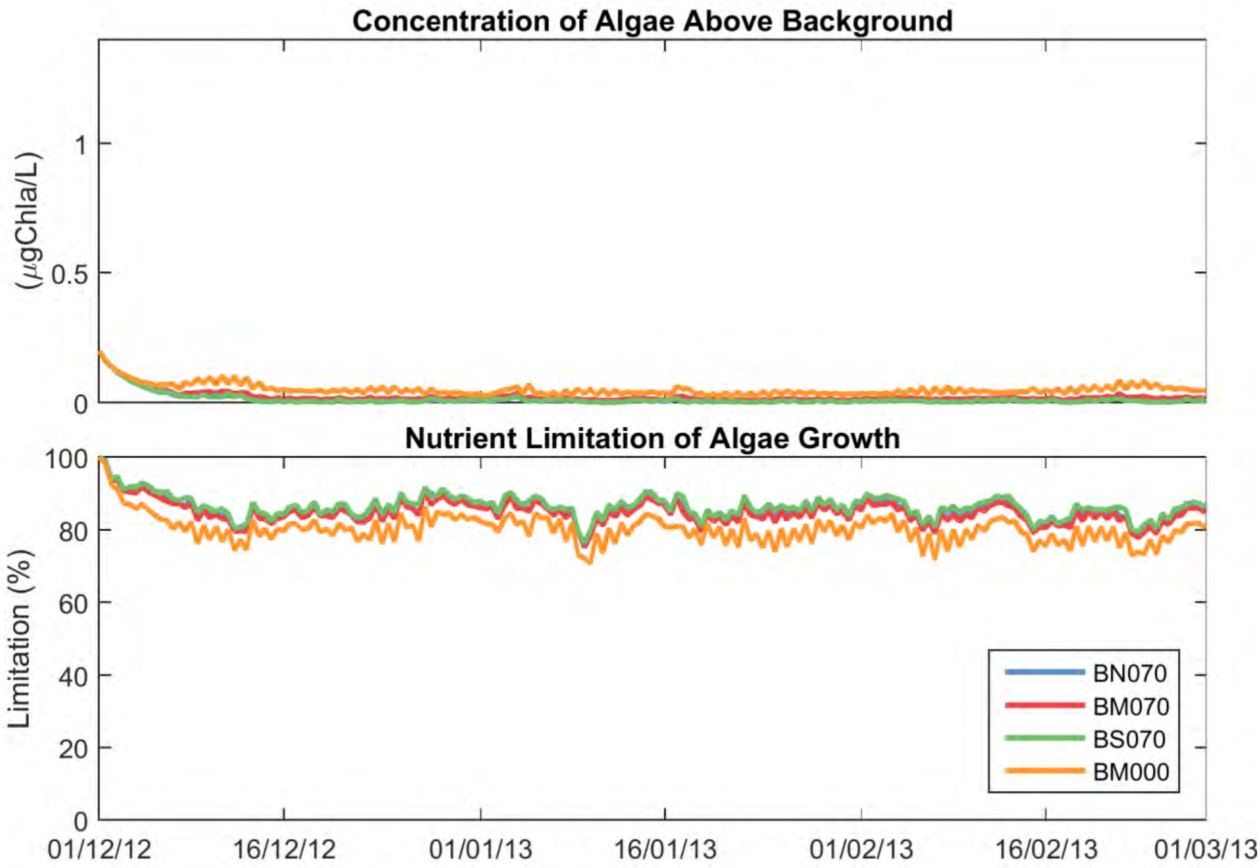

Figure 8.9: Time series of results from model observation stations external to the ORM for the summer season scenario. The locations of the monitoring station are indicated in Figure 7.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

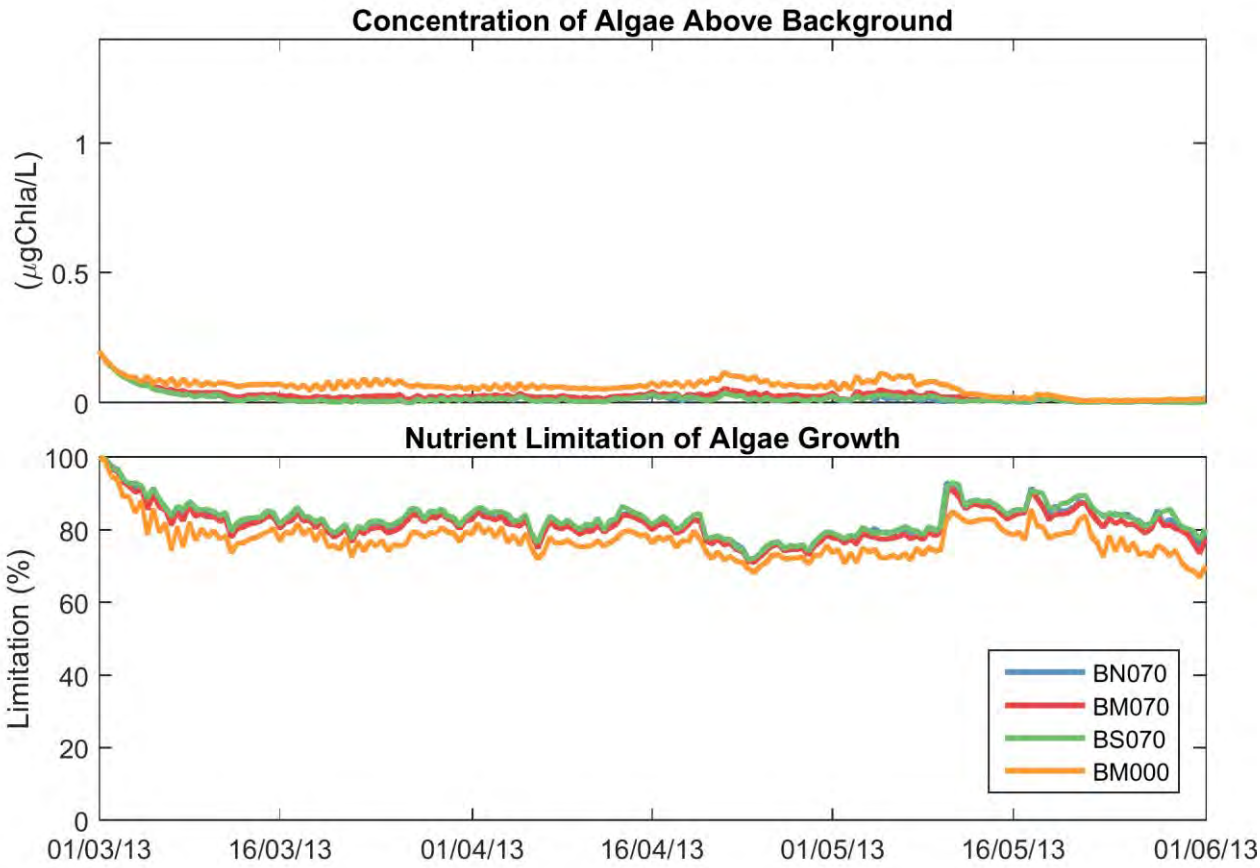

Figure 8.10: Time series of results from model observation stations external to the ORM for the autumn season scenario. The locations of the monitoring station are indicated in Figure 7.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

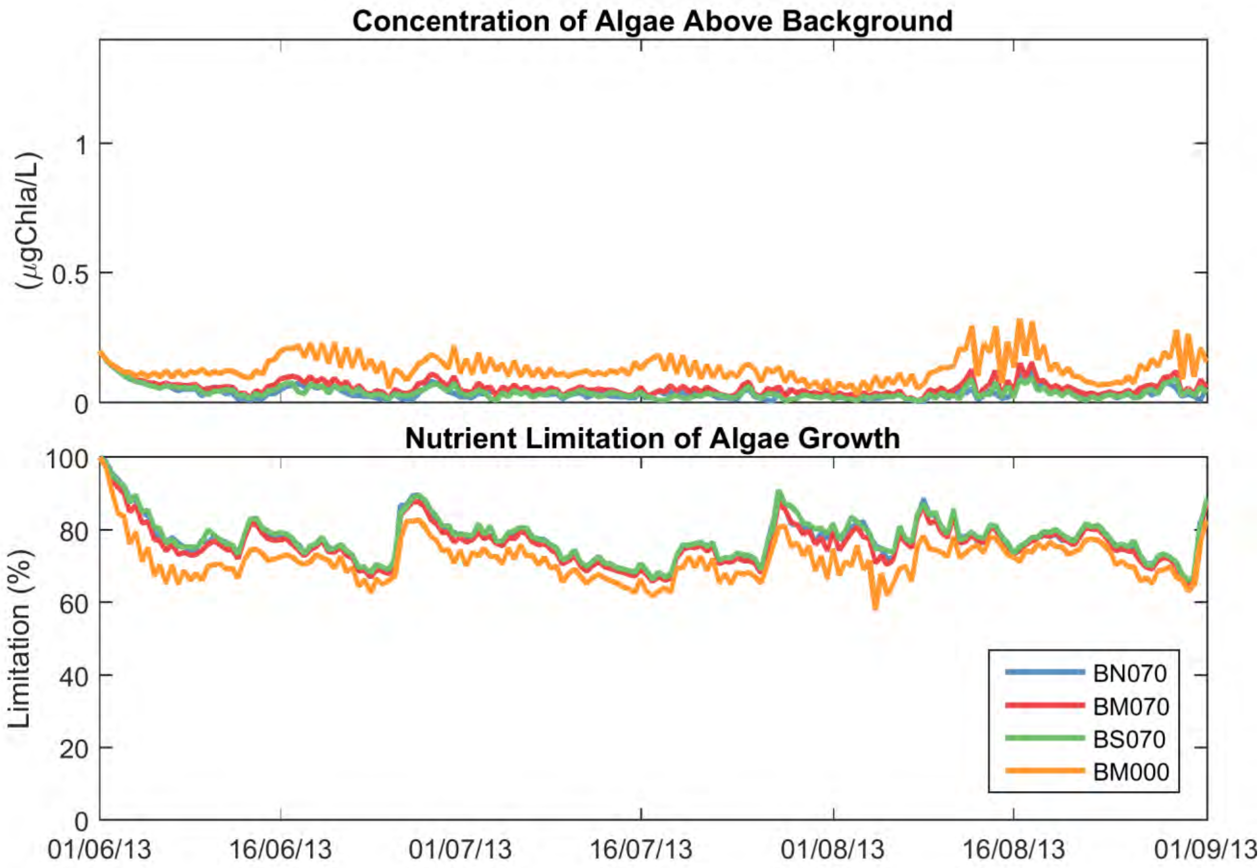

Figure 8.11: Time series of results from model observation stations external to the ORM for the winter season scenario. The locations of the monitoring station are indicated in Figure 7.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

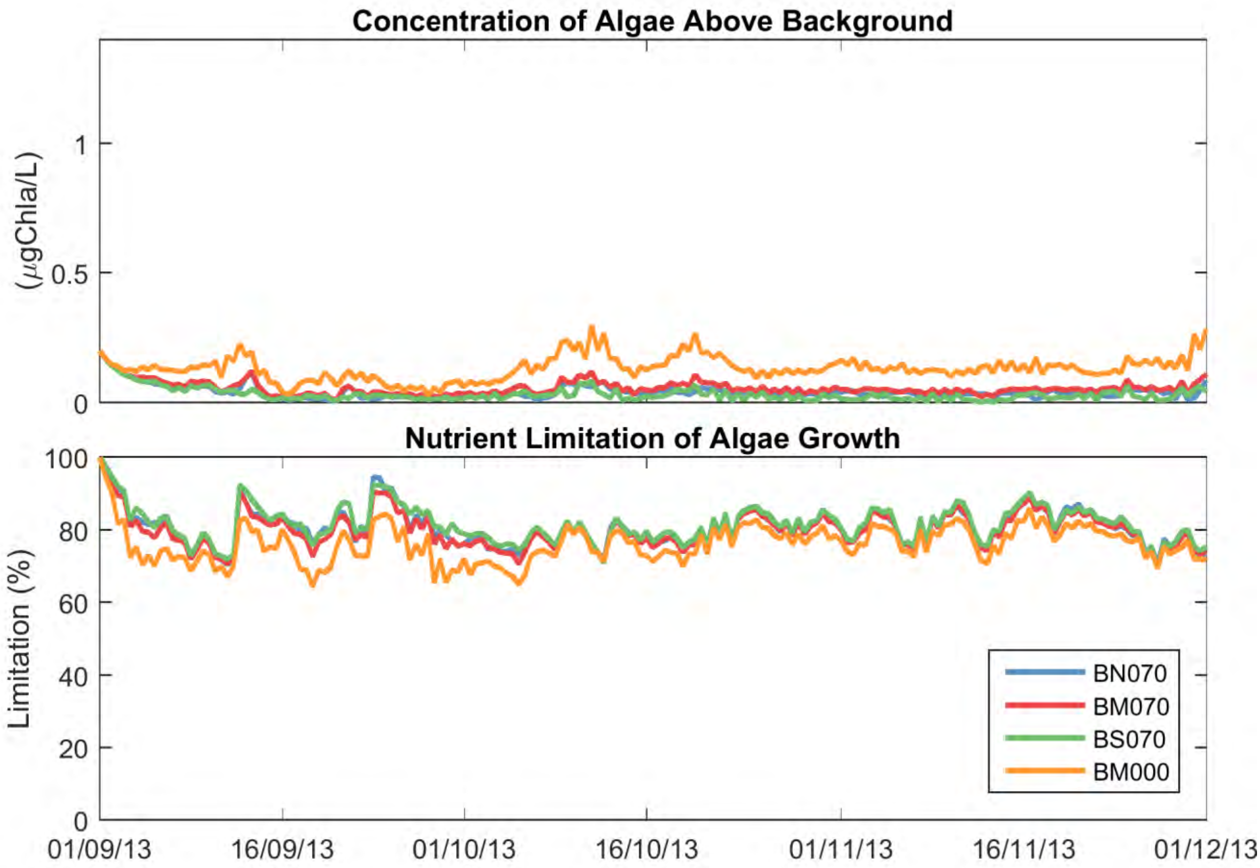

Figure 8.12: Time series of results from model observation stations external to the ORM for the spring season scenario. The locations of the monitoring station are indicated in Figure 7.2. The lower panel indicates the time varying nutrient limitation of algal growth, where 100% is complete inhibition of growth due to insufficient nutrients.

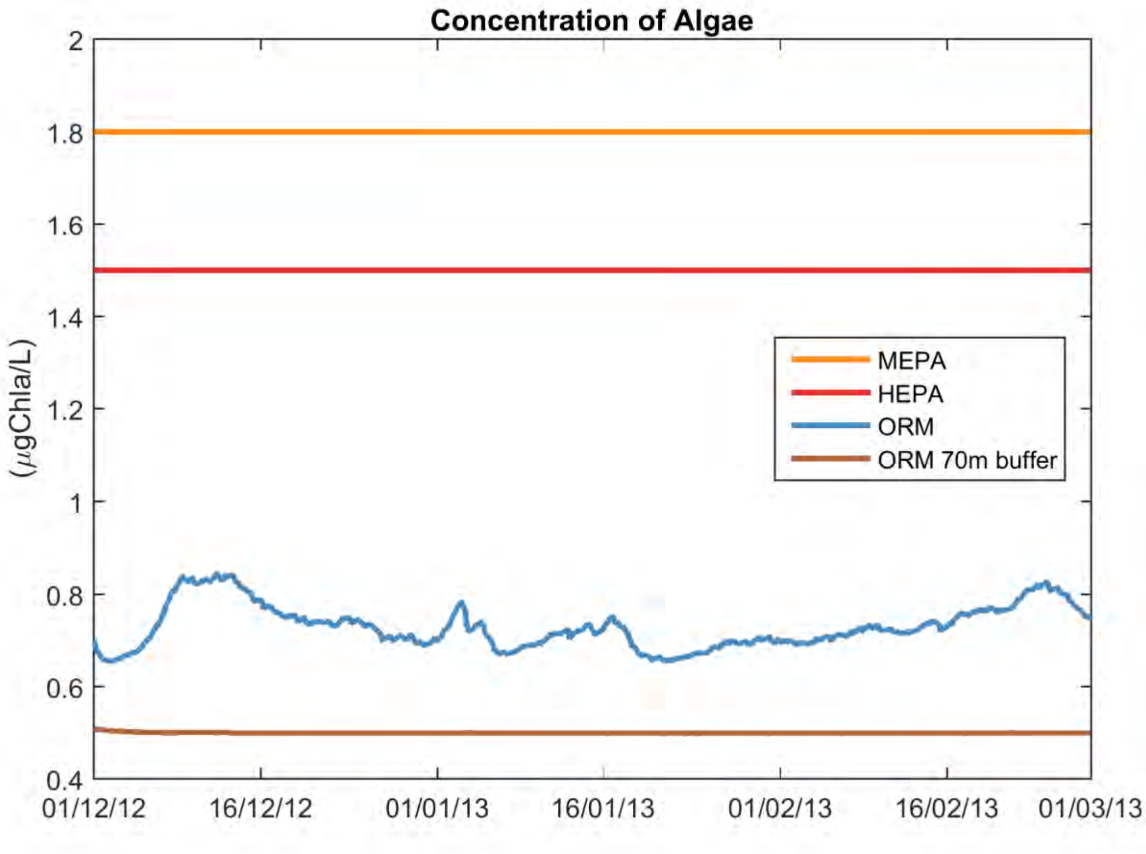

Figure 8.13: Time series of predicted summer season algal concentrations (with background concentration added) compared to High Ecological Protection Area (HEPA) and Moderate Ecological Protection Area (MEPA) thresholds. The "ORM" concentration presented is the maximum of the three monitoring within ORM that are indicated in Figure 8.2. The "ORM 70m buffer" concentration presented is the maximum of the three monitoring stations on the 70m buffer zone outside ORM (i.e. BN070, BM070 and BS070 in Figure 7.2).

9.0 Nearshore Coastal Assessment

The nearshore coastal reef system to the north and south of the proposed ORM is known habitat for Roe's abalone (*Haliotis roei*). This habitat is valued as both a commercial fishery and a recreational fishery. The purpose of this component of the study is to provide quantitative information that will assist others in the broader assessment team to assess potential impacts of the development on abalone habitat.

The habitat in the region of the proposed ORM was recently surveyed by BMT Oceanica (2015). This survey identified the boundary of a reef habitat to the north and south of the existing ORBH, as shown in Figure 9.1. Note that the footprint of the ORM development partially overlaps with some of the habitat shown in Figure 9.1, and that any abalone habitat within the development footprint is assumed lost.

Regarding the proposed ORM, BMT Oceanica (2015) also identified potential influences that might lead to adverse impact on Roe's abalone. These were; increased sedimentation plumes during construction, changes in hydrodynamics, changes in fresh water fluxes, changes in water temperature and/or changes in wrack deposition. However, specific quantitative thresholds for these mechanisms could not be determined (BMT Oceanica, 2015).

Four specific aspects of the ORM development that have the potential to adversely influence abalone habitat will be considered in this chapter:

- Predicted changes in current speed and residual (mean) currents within the abalone habitats
- Predicted dilution of outflows from the proposed ORM in relation to abalone habitat
- Predicted changes in the flushing behaviour of the coastal margin due to the proposed ORM
- Predicted broad changes in surface waves around abalone habitat due to the proposed ORM

The potential adverse impact of sedimentation plumes from the construction and dredging phases on abalone habitat is not considered in this chapter but is considered as part of the sediment fates component of this study (Section 10.0).

The potential for adverse effects due to changes in wrack deposition and/or water temperature were not considered directly in this report. However, general information derived from the results of the habitat assessment, such as predicted flushing times and water currents, may be able to be used by the broader assessment team as a basis to make inferences about their potential impacts.

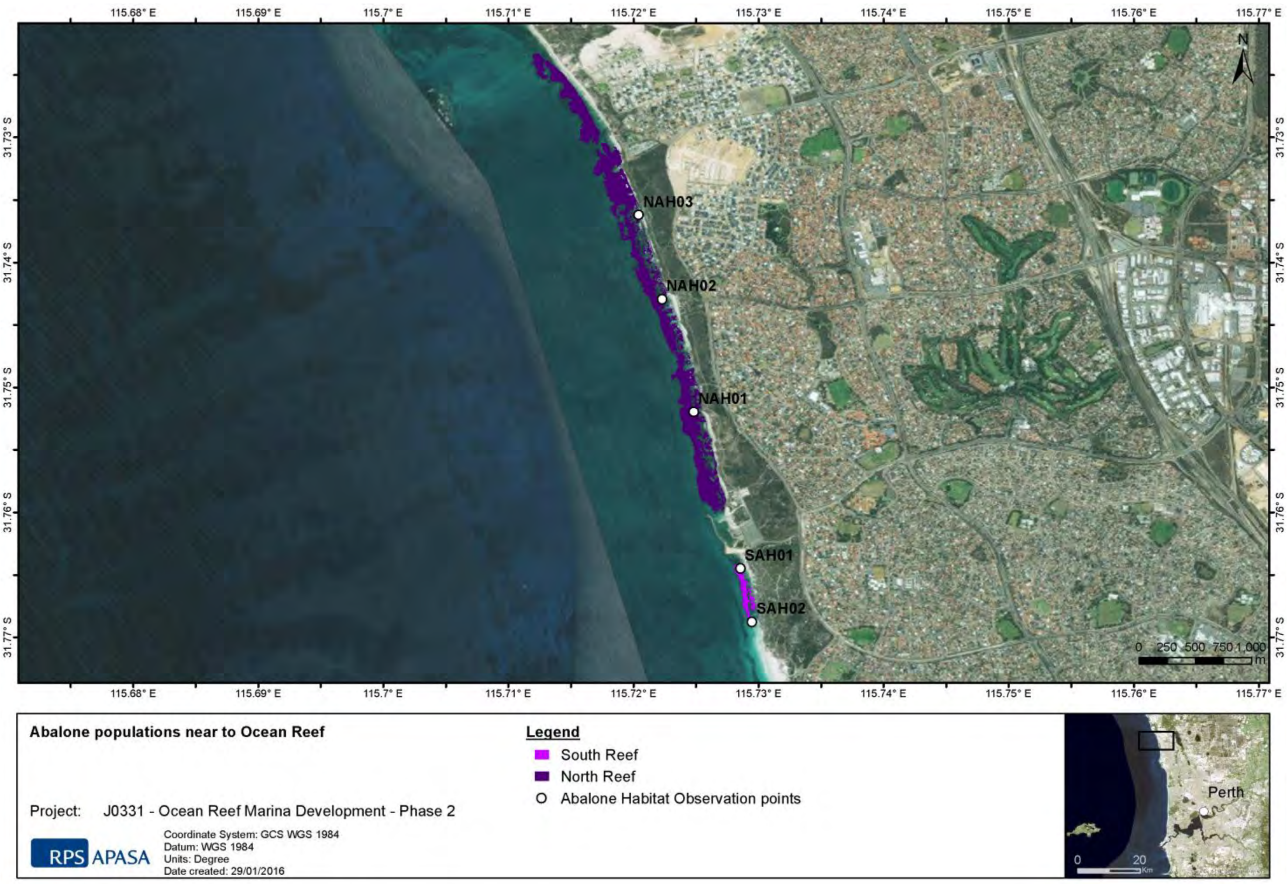

Figure 9.1: Habitat map for Roe's abalone near the existing ORBH (adapted from BMT Oceanica, 2015). The proposed ORM layout is absent from the map for clarity, but for reference, the NAH01 and SAH01 stations are each approximately 100 m from the northern and southern extends of the proposed ORM breakwaters, respectively.

9.1 Methodology of Nearshore Coastal Assessment

9.1.1 Changes in Current Speed and Residual Currents

Predicted changes in hydrodynamics caused by the addition of the proposed ORM to the coastline were investigated with the hydrodynamic model. The model was run with the existing ORBH grid configuration and the results were compared to results from the ORM grid configuration for corresponding time periods. In total, eight different 15-day scenarios periods were analysed in this manner. These scenarios were selected to be representative of typical seasonal conditions and the tidal cycles within each season, as described in Section 4.6. The wind data for these periods is presented in Figure 7.4 through to Figure 7.11. Groundwater discharges were not included with these simulations.

For each scenario, the residual current was calculated for each model grid cell by taking the mean of the time series of current velocities over the 15-day simulation period. Maps of residual current changes were then produced for each scenario by subtracting the residuals for the existing ORBH layout from the residuals calculated for the ORM layout. The residual current difference maps demonstrate seasonally variable changes in general circulation patterns over a relatively broad area, i.e. larger than the immediate area of the abalone habitat. This provides an appropriate context to interpret changes at the smaller scale of the abalone habitat.

To analyse potential changes in hydrodynamics at the abalone habitat scale, time series of current speeds were compared for each of the two marina layouts. This analysis focussed only on the model grid cells in the 62.5 x 62.5 m resolution range that coincided with the abalone habitat areas because these grid cells could be directly compared between both layouts.

For the northern abalone habitat, the model grid cells within the habitat area were identified and then sub-grouped according to their distance from the northern tip of the ORM breakwater. The distance bins were 0 - 500 m, 250 – 500 m, 500 – 1000 m, and then every 500 m out to 2.5 km distance. Hourly time series of current velocity outputs were interrogated for all the grid cells that fell within each distance range. The maximum difference in current speed between the ORBH and ORM was identified for each distance range and for each time step. The absolute current speed at the same grid location as the maximum difference occurred was also identified (for the ORBH layout) to allow a percentage difference to be computed.

An analogous procedure was carried out for the abalone habitat to the south of the existing ORBH.

9.1.2 Influence of Outflows from ORM

In the hypothetical event of waters within the proposed ORM becoming contaminated, due for example to an accidental spill or polluted discharge, then subsequent outflow of contaminant from the ORM could have the potential to affect nearby abalone habitat. To assess this potential, the results of the flushing assessment scenarios that were first presented in Section 7.0 were re-analysed in this context.

As described in Section 7.0, for each of the eight 15-day periods that were considered for the flushing assessment, a conservative tracer was instantaneously released throughout the volume of ORM at the commencement of each scenario. However, in this context the concentration of that tracer was tracked outside of the ORM instead of inside the ORM. Specifically, the concentration of tracer was tracked at three representative point locations within the abalone habitat area north of ORM and at two point locations within the southern habitat (Figure 9.1). Physically, this tracer is intended to be a proxy for a pulse of contaminated water exiting from the ORM.

At each of the monitored point locations, the time taken for the released tracer to arrive to the point location at a concentration that was at least 2% of its initial concentration was noted (the threshold of 2% was used because the concentrations were typically much lower than the 37% e-fold level that was used in Section 7.0). The 2% threshold is intended to give a representative indication of the time lag between release of contaminant within ORM and subsequent arrival of that contaminant at the monitored habitat locations (if at all). Similarly, the time taken for the tracer to subsequently dilute below 2% of its initial release concentration was also noted. When considered together, these ‘start’ and ‘end’ times can be considered indicative of the period taken for a ‘cloud’ of contaminated water (sourced from the ORM) to pass through each point location.

The maximum concentration of tracer that was detected at each station was also noted. This gives an indication of the minimum dilution of contaminant that would be expected at each station.

The potential for adverse effects on abalone habitat due to runoff from rainfall was not explicitly modelled in this study because it was assumed to be negligible. This assumption takes into account the drainage design criteria for the ORM, which was communicated by MP Rogers & Associates. Under the designed criteria, runoff from rainfall would not typically discharge directly into ORM unless there was a large rainfall event (i.e. 1 in 1 year event). Furthermore, in this event, the e-folding calculations presented in Section 7.0 suggest that freshwater runoff entering the ORM from the drainage network would spend some period within the harbour, which would allow an opportunity for mixing with ambient seawater before exiting.

9.1.3 Changes in the Flushing of the Coastal Margin

The development of the northern and southern ORM breakwaters would be expected to influence the flushing characteristics of the coastal margin to some extent, particularly in the regions directly adjacent to these breakwaters. Changes in flushing along the coastal margin have the potential to affect nearby abalone habitat, for example, potentially affecting rates of larval recruitment and wrack deposition.

A tracer release scenario was designed to specifically assess the potential for changes in flushing of the coastal margin. Simulated 'northern' and 'southern' coastal margin tracers were introduced to the ORM model grid. The tracers were released within the abalone habitat directly north and south of ORM, as will be indicated subsequently in Figure 9.21 and Figure 9.22). The two tracers were released over the entire depth at each of their locations. The concentration of the 'northern' tracer was monitored at three point locations within the northern abalone habitat area and the concentration of the 'southern' tracer was monitored at two point locations within the southern habitat (Figure 9.1).

To allow assessment of changes in coastal margin flushing due to the ORM, a base comparison case was established by configuring the model of the existing ORBH layout for the same period and releasing the 'northern' and 'southern' tracers at the same grid cell locations (also indicated subsequently in Figure 9.21 and Figure 9.22).

Similar to the method of tracer analysis that was used in Section 9.1.2, the time taken for the released tracer to arrive each monitoring station was measured as the time for the tracer to arrive at 2% of the initial release concentration (this 'start' time was instantaneous for the stations located within the initial release areas). The time taken for the tracer concertation to fall below 2% of its initial release concentration was also noted at each station, as was the maximum tracer concentration at any time.

For this component of the abalone habitat assessment, a single 15-day period commencing 9 Jan 2013 was chosen for analysis. This period was selected on the basis of the results from the first phase of the alone habitat assessment (Section 9.2.1). These results will show that the differences in current speed between the existing ORBH and proposed ORM layout were relatively high at the commencement of the 9 Jan 2013 simulation period, for both the southern and northern habitats. Therefore, the release of the tracer at the beginning of the 9 Jan 2013 simulation period is intended to coincide with a period when differences in currents are larger than usual.

9.1.4 Changes in Surface Waves

The northern and southern breakwaters that will enclose the proposed ORM have the potential to affect the local wave climate. Significant changes in the local wave climate could influence abalone habitat because it would lead to corresponding changes in shear stress at the seabed and may also affect any nearshore currents that might be generated by breaking waves.

The SWAN wave model was used to give a broad assessment of the potential for changes in wave heights near the abalone habitat due to the proposed ORM. For this broad level assessment, changes in wave height were assessed at three point locations within the northern abalone habitat and two point locations within the southern habitat. These monitoring points characterise locations on the seaward side of abalone habitat in approximately 5 m water depth, representing incident waves to the abalone habitat.

The approximate locations (i.e. within ~100 m) of the monitoring points are shown on Figure 9.1, but their actual locations were determined by the locations of the wave model grid nodes that were nearest to each point (excluding nodes on the shoreline boundary). In addition, the model grid nodes for the ORBH and ORM wave model layouts were located in slightly different positions. This means that comparison of wave heights at each monitoring location is slightly (and variably) affected by the different node locations. The effect of this difference is minor but noticeable in some results (which will be discussed).

The potential for changes in wave heights was considered for two periods that were selected to be representative of summer and winter seasonal wave extremes. A 15-day period commencing 9 Jan 2013 was selected as representative of sea-breeze dominated wave conditions, and a 15-day period commencing 19 July 2013 was selected to cover the period of a winter storm swell. The wind conditions for these periods were presented previously in Section 7.0 (i.e. Figure 7.4 and Figure 7.8, respectively).

For each of the seasonal periods, time series of wave heights were produced to allow comparison between waves generated under the existing ORBH layout and the proposed ORM layout at each of the five monitoring locations. The wave model setup wasn't designed to consider any locations very near to the proposed ORM breakwaters (within 100 m) where wave reflection may occur. A more detailed form of wave analysis wasn't considered necessary because other components of the nearshore coastal assessment presented in this section are sufficient to demonstrate that the 100 m zone will be affected by the development.

9.2 Results of Nearshore Coastal Assessment

9.2.1 Changes in Current Speed and Residual Currents

The residual current maps and time series analysis for each scenario are presented in Figure 9.2 through to Figure 9.17. The dominant pattern of the residual currents is northward, except during the two winter scenarios when it was southward (Figure 9.10 and Figure 9.12). Under the northward current regime, the primary effect of the ORM layout is to increase residual current speeds along the southwestern edge of the ORM and to slightly reduce speeds north of the ORM (note that colour legends used in the residual maps are configured to highlight very small changes). For the two winter scenarios with southward dominated residual currents, the residual speeds are lower and accordingly the net differences were less pronounced.

The time series plots show general trends that are consistent with the mean trends in the residual maps. In particular, the northern reef is more affected in the scenario periods that had northward residual currents. As is expected, the largest differences for the northern area occurred closer to the ORM and these differences diminished with distance. The absolute differences in current speed in the northern area were variable in response to changing winds and tides (note that winds and tides for these same periods were presented in Section 7.2), however, in percentage terms the differences were relatively steady over time.

With regard to potential impacts on the northern habitat, up to 500 m north of the ORM the percentage reduction in current speed was of the order of 40% to 60%. Peak instantaneous absolute differences were of the order of 5 to 10 cm/s within this distance range. Beyond 500 m north of ORM and out to the 1.5 km range the differences were much less discernible, around 20%, with peak instantaneous differences typically less than 5 cm/s. Beyond 1.5 km effects weren't detectable.

The forecast impacts on the southern habitat reef were generally much lower than for the northern reef. The primary reason for this is that the minimum distance between the south reef and ORM is greater than 500 m, which is why the two nearest distance ranges are absent from the southern reef time series plots. The potential impacts to the southern habitat are forecast to be largest in absolute terms during winter type conditions when the residual current field is directed southward. During such periods, the maximum difference in speed can be seen to briefly spike at values around 5 to 10 cm/s for distances less than 1 km from ORM (Figure 9.11), but were more typically less than 1 to 2 cm/s. Absolute differences of less than 1 to 2 cm/s were also typical in the other scenario periods.

Summary statistics for selected distance zones within the northern and southern reefs are presented in Table 9.1. The summary statistics indicate that the changes to currents at the northern reef within 500 m of the marina were typically larger than 20%. Further than 500 m from the marina the changes were typically less than 20% for both the north and the south reefs. A more detailed breakdown of the predicted changes is provided in the form of cumulative frequency histograms in Figure 9.18 to Figure 9.20; The histograms indicate the probability that the current differences will be less than or equal to the indicated values for the northern 0-500 m zone, northern 500-1500 m zone and southern 500-1500 m zone respectively. The histograms all indicate that the most change in absolute current speed will be less than or equal to 0.02 cm/s.

9.2.2 Influence of Outflows from ORM

In this section, the results of the flushing assessment from Section 7.0 are re-analysed to assess the potential for 'tracer contaminated' outflows from ORM to reach abalone habitat. The spatial contours of tracer concentration that were previously presented to give context to the results of Section 7.0 (i.e. Figure 7.3) also give a useful example context to the tabulated results presented in this section. The effects of the 'tracer contaminated' outflows from ORM on abalone habitat for each simulation period are summarised in Table 9.2. The differences observed between simulation periods are largely attributable to different wind, and hence different current conditions, during each period.

The shortest time taken for the tracer to reach a monitoring station at 2% of its initial release concentration was 6 hours. This occurred at the nearest northern station NAH01 during the scenario that commenced 12 Feb 13. The shortest time taken for the tracer to reach either monitoring station within the southern habitat was 84 hours, for a simulation commencing 19 Jul 13. For most other scenario periods, the tracer never reached the southern monitoring stations at the 2% threshold.

The longest time between initial release and the detection of tracer above the 2% threshold at any station was 216 hours at the NAH01 station, for a simulation commencing 21 Mar 12. This result suggests that potential direct impacts to abalone habitat (if any) are likely to occur within approximately 9 days after a 'contamination event' (based on the assumed 2% threshold).

The maximum concentration of tracer that was detected at any station in any scenario period was 15.1% of the initial release concentration, which occurred at the NAH01 station for a simulation commencing 24 Oct 14. This suggests that contaminants released from ORM are likely to have undergone at least an approximately 6-fold dilution before reaching the NAH01 station.

9.2.3 Changes in the Flushing of the Coastal Margin

The coastal margin flushing analysis compared the flushing behaviour of tracers released at nearshore locations north and south of the proposed ORM, under both the ORBH and ORM model layouts. The 15-day simulation period commencing 9 Jan 13 was selected for this analysis based on the results of Section 9.2.1, which indicated that current differences between the ORBH and ORM layouts were relatively large for both the northern and southern abalone habitat at the commencement of this period.

The initial release locations of the 'northern' and 'southern' tracers are indicated in the upper panels of Figure 9.21 and Figure 9.22, respectively. The middle and lower panels of the same figures show time snap shots of the concentration field 12 hours and 24 hours after the commencement of the tracer releases. For the southern habitat Figure 9.22 shows some tracer remaining near the shore after 24 hours but this is an artefact of the model grid resolution. The affected cells are shallow and not well connected at low tide.

The key results of the coastal margin flushing analysis are summarized in Table 9.3. The time to arrival of the tracer at 2% of its initial concentration was instantaneous at stations NAH01 and SAH01 because these stations were located within the initial release area for the northern and southern tracers, respectively. The time taken for the northern tracer concentration to fall below 2% of its initial release value at NAH01 was 1 hour for the ORBH layout and 7.5 hours for the ORM layout. This difference is due to the reduction in current speed north of ORM that was identified previously in Section 9.2.1

The results for the ORM and ORBH layouts both indicate that the northern tracer had undergone an approximately 2-fold dilution (i.e. 50% of initial concentration) by the time it reached the second northern monitoring station NAH02. However, the time taken for the tracer to dilute below 2% at the NAH02 station was longer for the ORM layout (38.5 hours) than for the ORBH layout (21.3 hours).

With respect to the southern habitat, the difference in flushing times was comparatively small, 11.3 hours with the ORBH layout compared to 13.0 hours for the ORM layout at the station SAH01.

The southern tracer did not arrive at the SAH02 station at concentrations above the 2% threshold. This was due to the predominantly northward flushing regime during this period, as indicated by the time series snap shots presented in Figure 9.21 and Figure 9.22.

9.2.4 Changes in Surface Waves

Comparison of wave heights at each of the five coastal monitoring stations indicated that there was very little difference in the wave heights between the ORBH and ORM layouts, regardless of the season (Figure 9.23 and Figure 9.24). In particular, the monitoring station NAH01, which is the station nearest to the northern ORM breakwater (i.e. ~100 m north of the breakwater), showed near identical wave heights under both layouts. This is notable because the effect of the ORM structure on waves should decrease further with distance away from the breakwaters.

The monitoring stations further north of NAH01, NAH02 and NAH03, showed apparently larger (but still small), differences between waves for the ORM and ORBH layouts. The explanation for the slightly larger differences in wave heights at distances further away from the ORM is that this is an artefact of the of the slight differences in grids used for the existing ORBH and proposed ORM. As noted earlier in the methodological description, the locations of the wave model grid nodes were slightly different for the ORM and ORBH layouts. This implies that locations being compared at each station have a slight offset, which is variable from station to station. The small differences in wave heights shown for NAH02 and NAH03 reflect this offset rather than any physical phenomenon.

The differences in wave height for the southern monitoring stations, SAH01 and SAH02, were also very small, and always less than a few centimetres.

Potential changes in wave direction data are unlikely to have any significant influence on the abalone habitats. However, for completeness it is noted that the modelled results indicated that wave direction data was practically the same under both layouts.

Overall, the results from these monitoring stations indicate that the effect of ORM on the local wave climate will be minimal, at least at distances that are 100 m or further from the Marina.

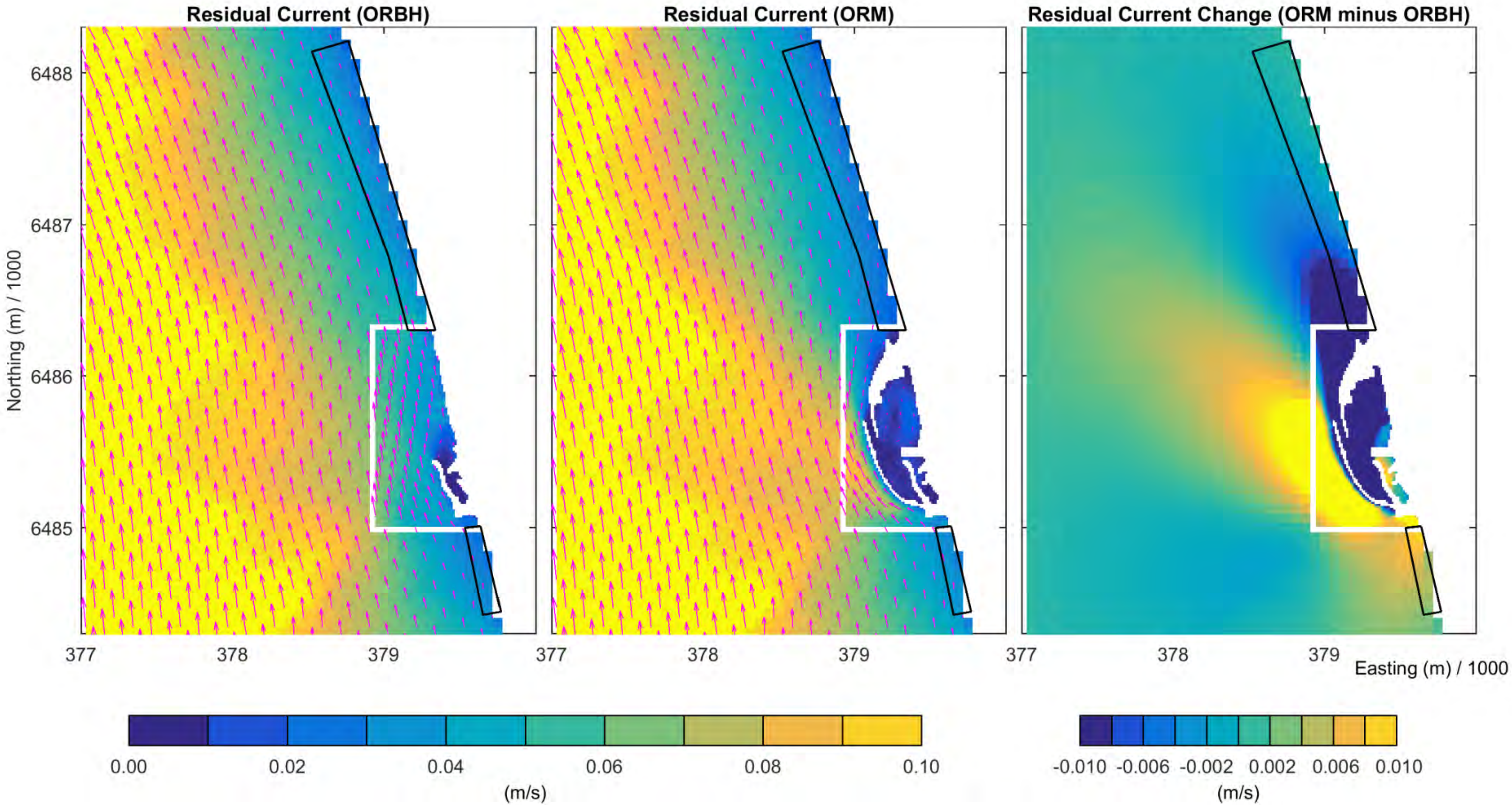

Figure 9.2: Maps of residual currents from a 15-day scenario commencing on 9 Jan 2013. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

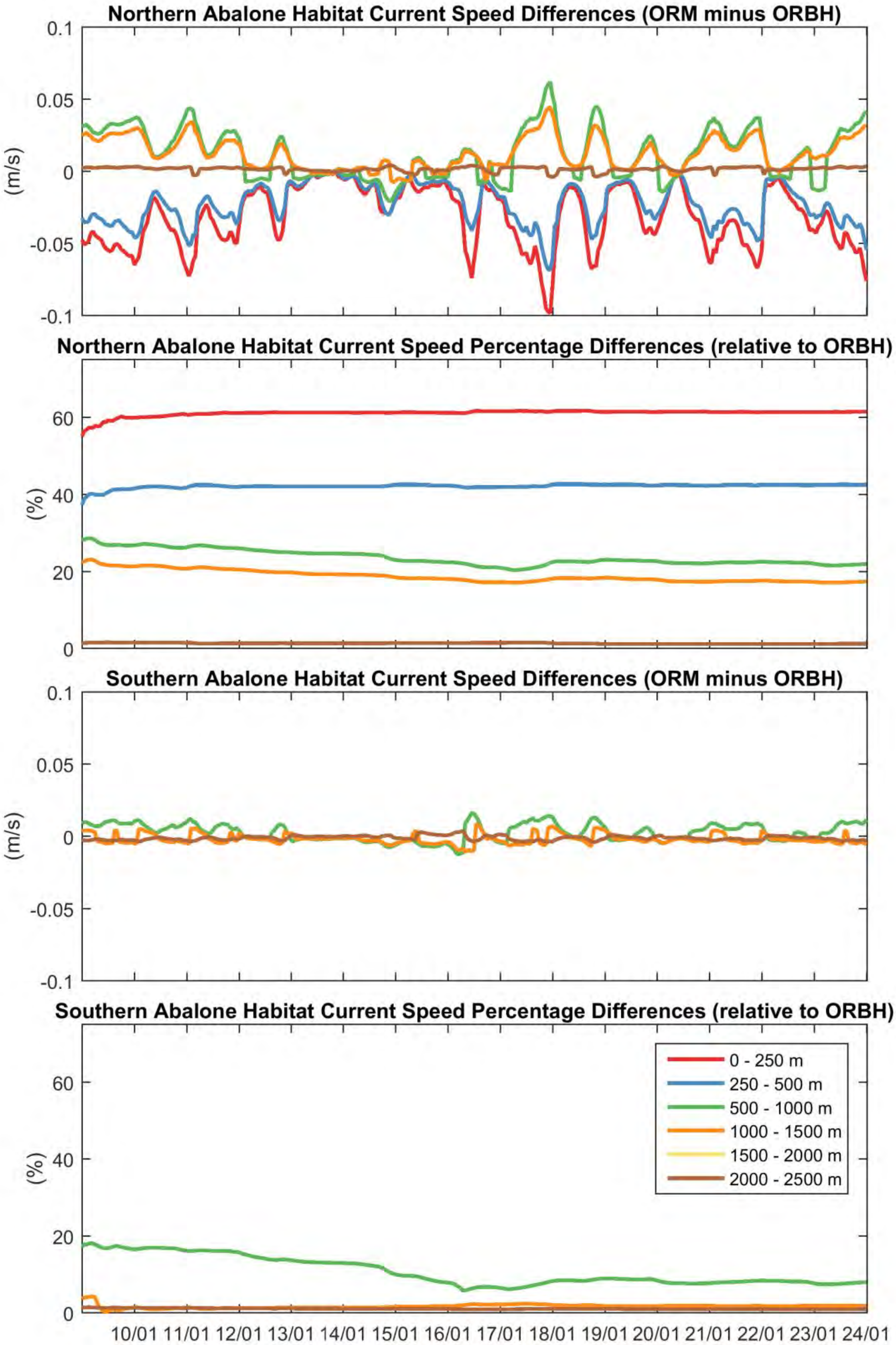

Figure 9.3: Time series of current speed differences within abalone habitat areas for a scenario commencing on 9 Jan 2013. The legend indicates the distance of the points from the ORM and is common to all plots.

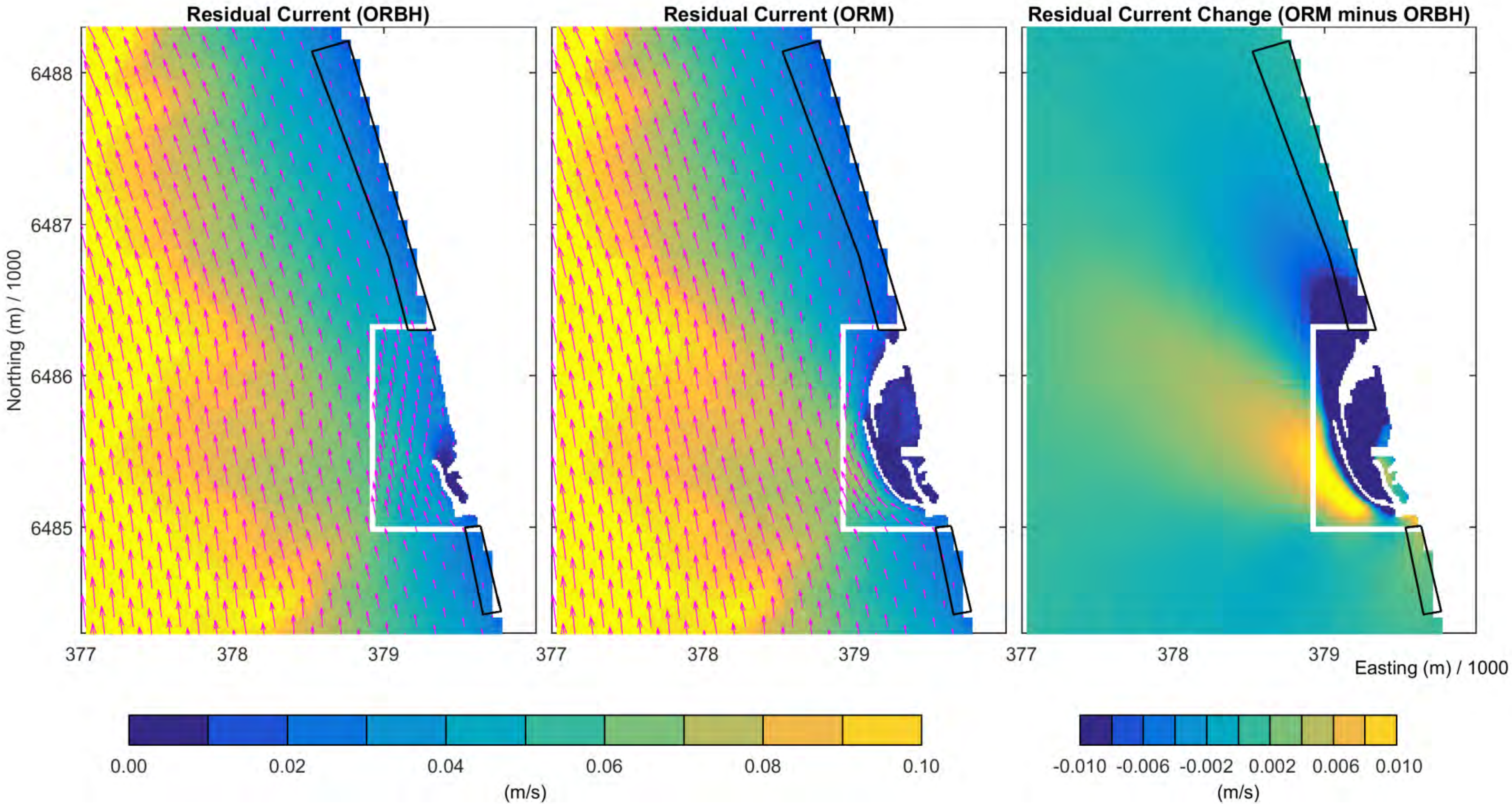

Figure 9.4: Maps of residual currents from a 15-day scenario commencing on 12 Feb 2013. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

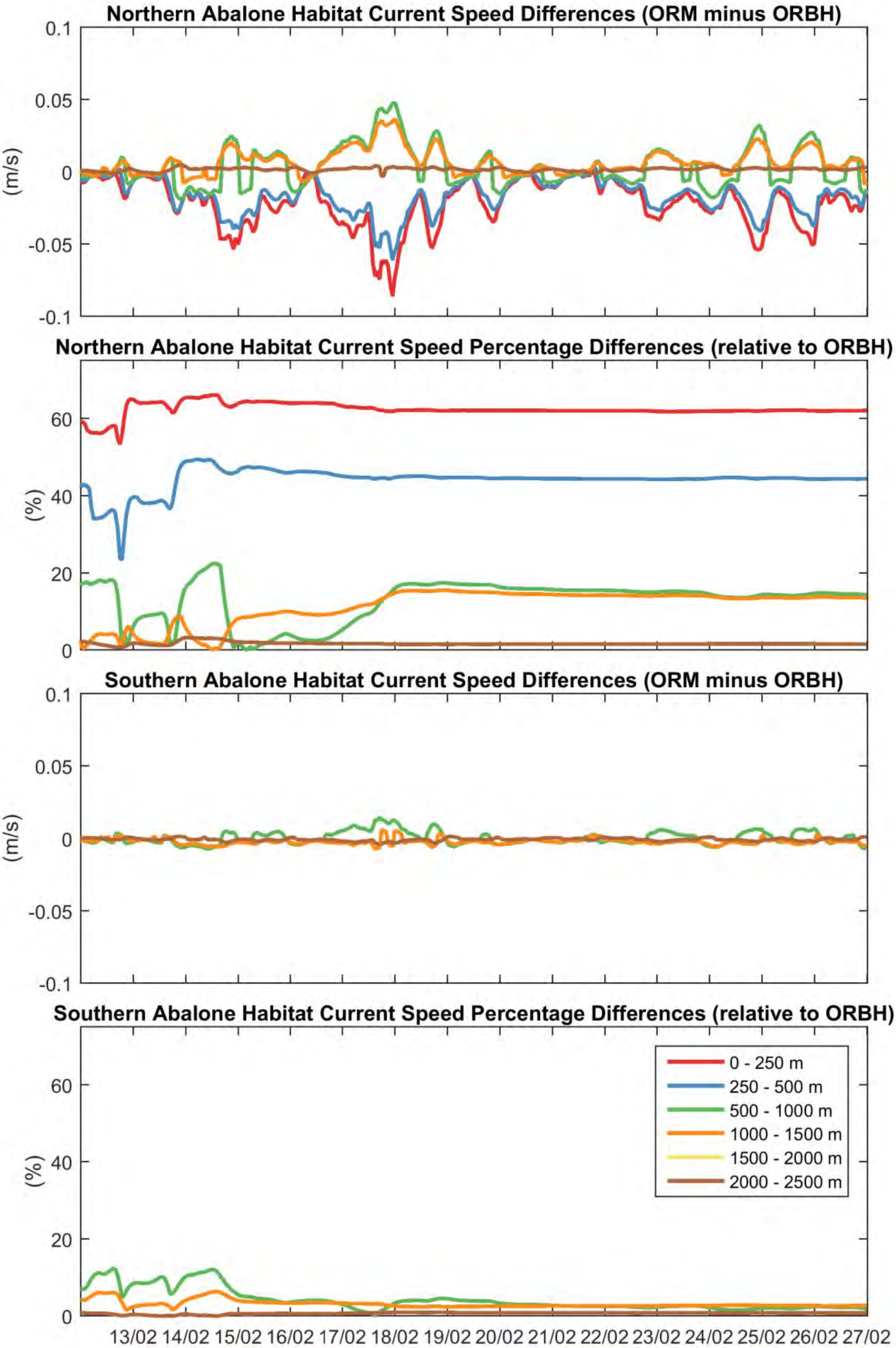

Figure 9.5: Time series of current speed differences within abalone habitat areas for a scenario commencing on 12 Feb 2013. The legend indicates the distance of the points from the ORM and is common to all plots.

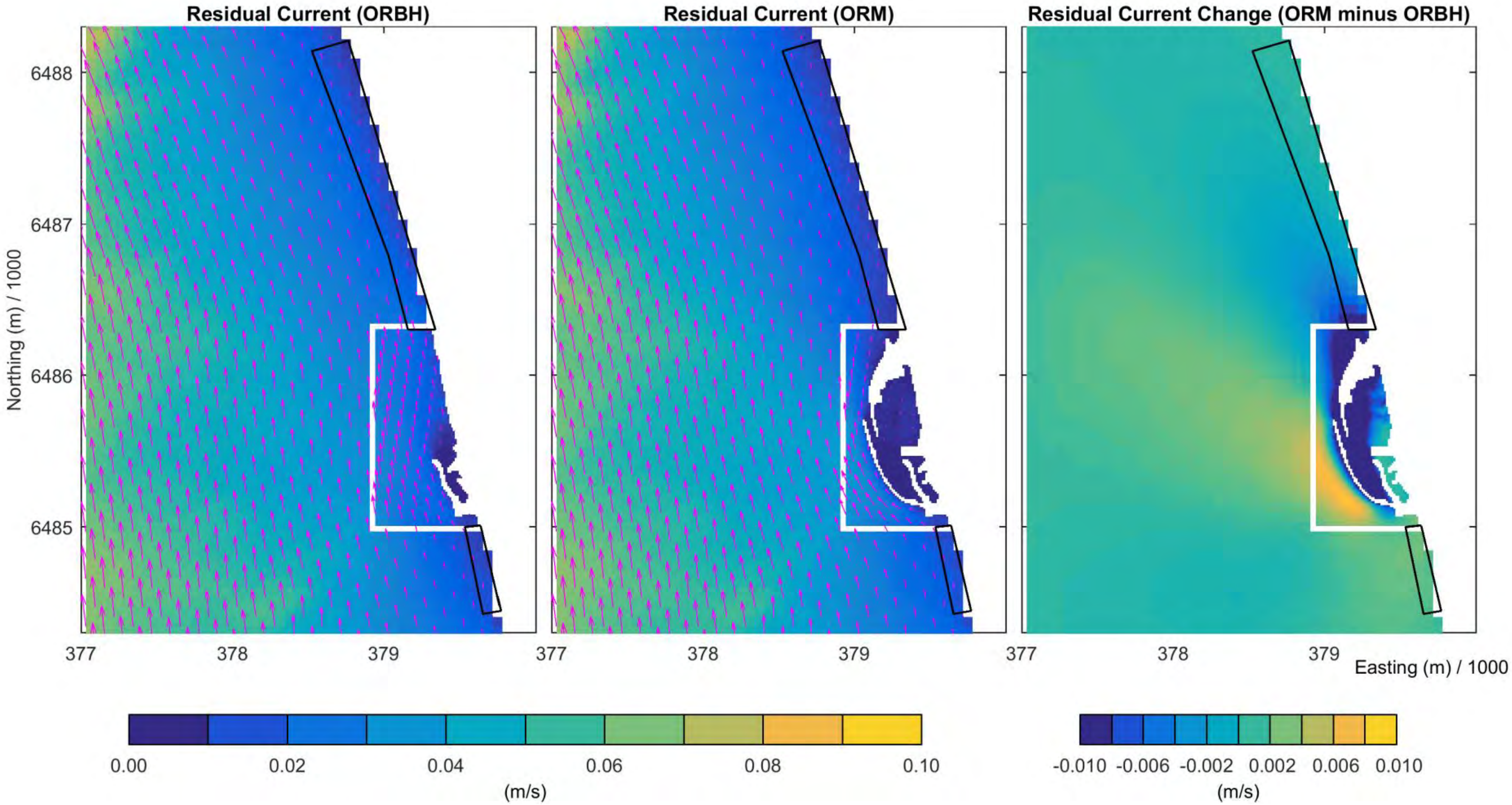

Figure 9.6: Maps of residual currents from a 15-day scenario commencing on 8 Apr 2012. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

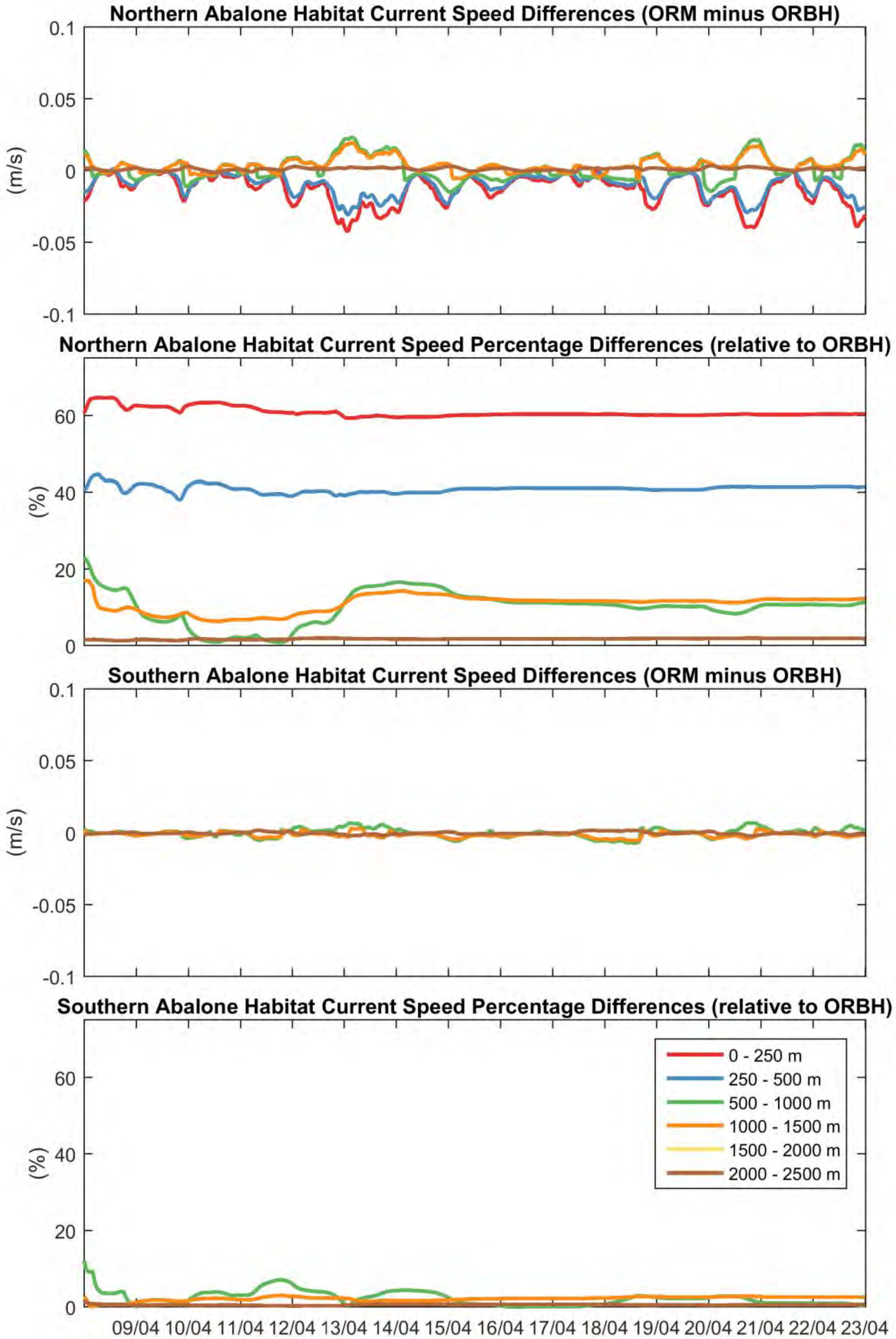

Figure 9.7: Time series of current speed differences within abalone habitat areas for a scenario commencing on 8 Apr 2012. The legend indicates the distance of the points from the ORM and is common to all plots.

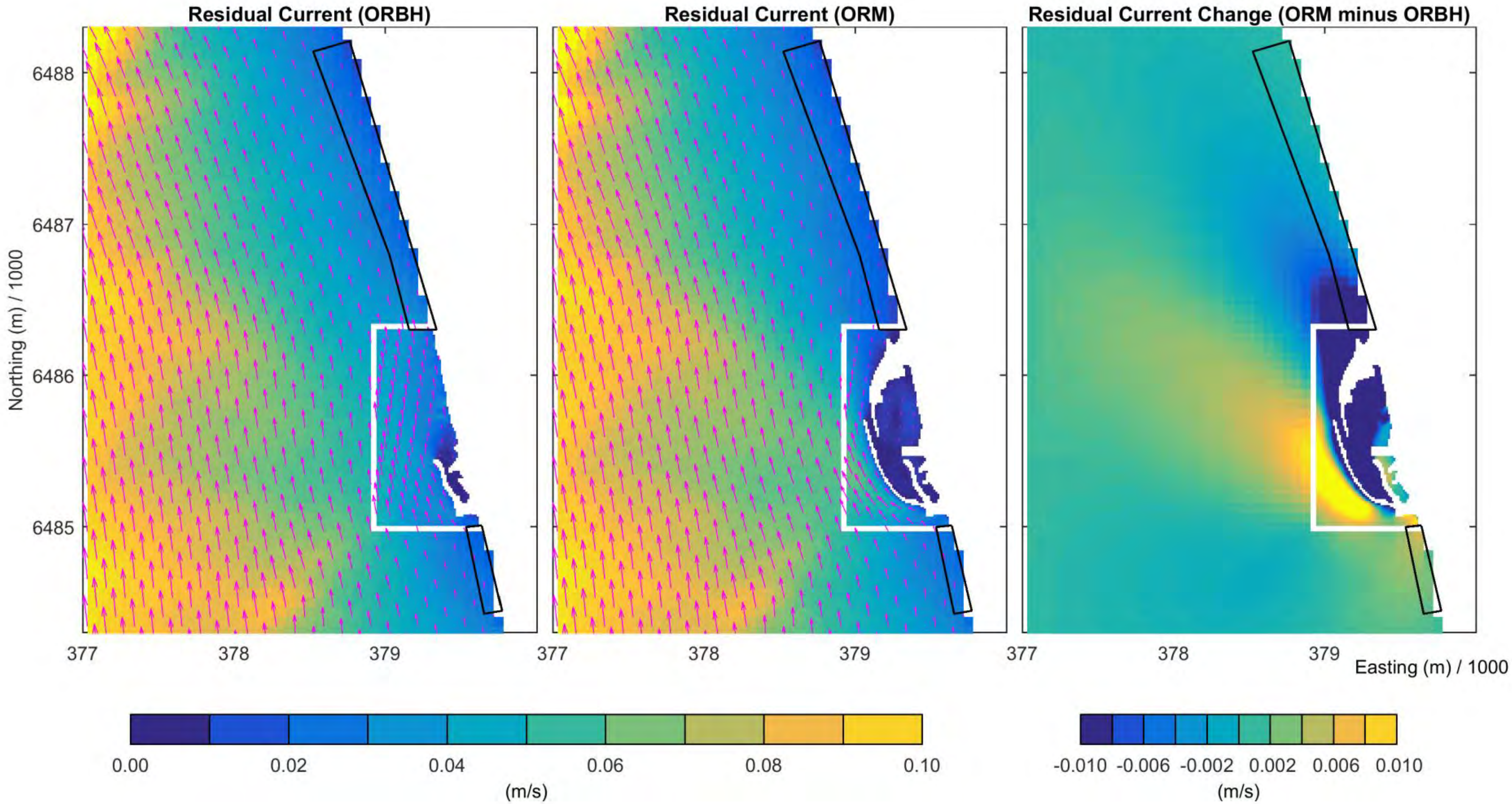

Figure 9.8: Maps of residual currents from a 15-day scenario commencing on 21 Mar 2012. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

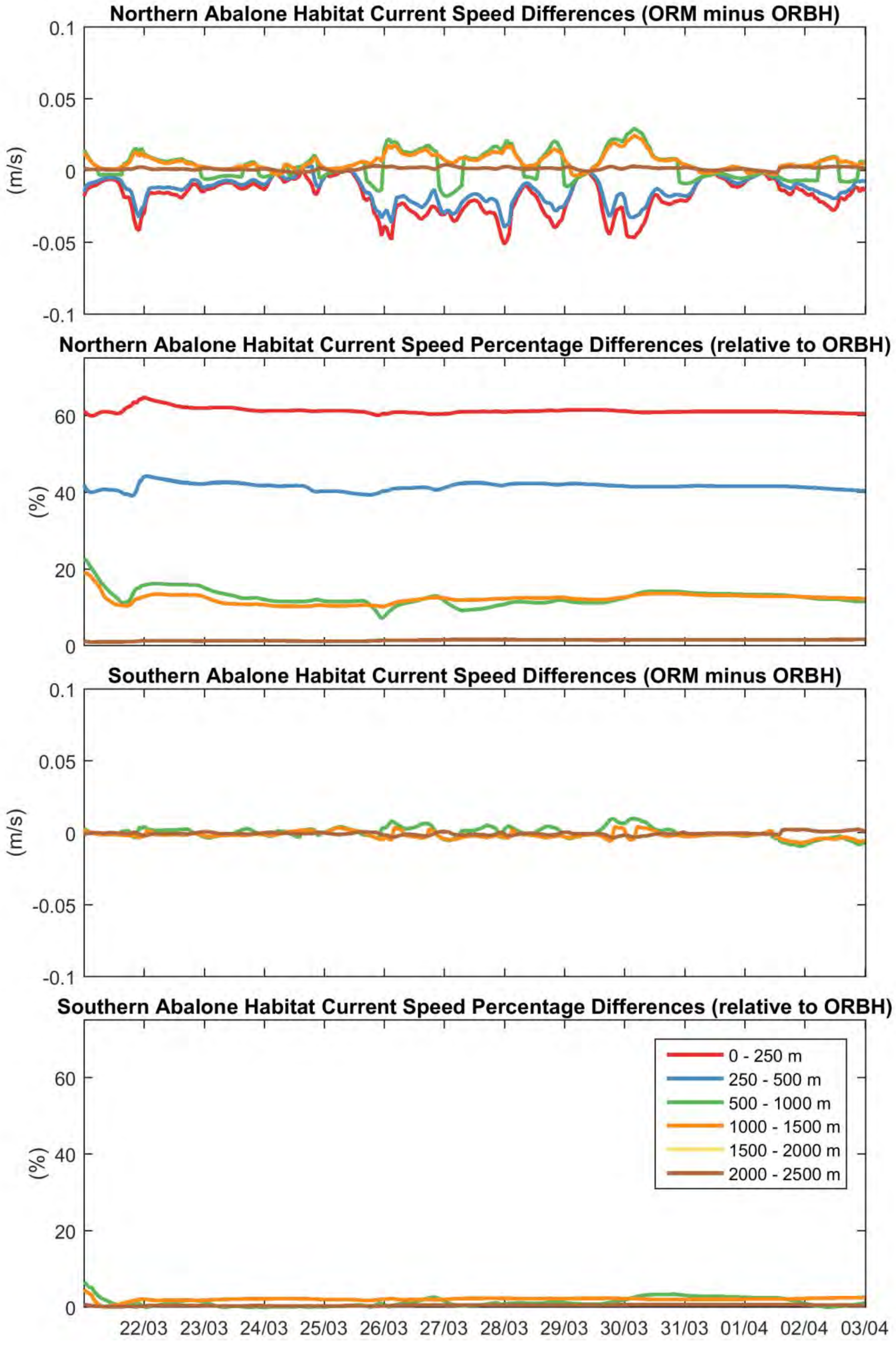

Figure 9.9: Time series of current speed differences within abalone habitat areas for a scenario commencing on 21 Mar 2012. The legend indicates the distance of the points from the ORM and is common to all plots.

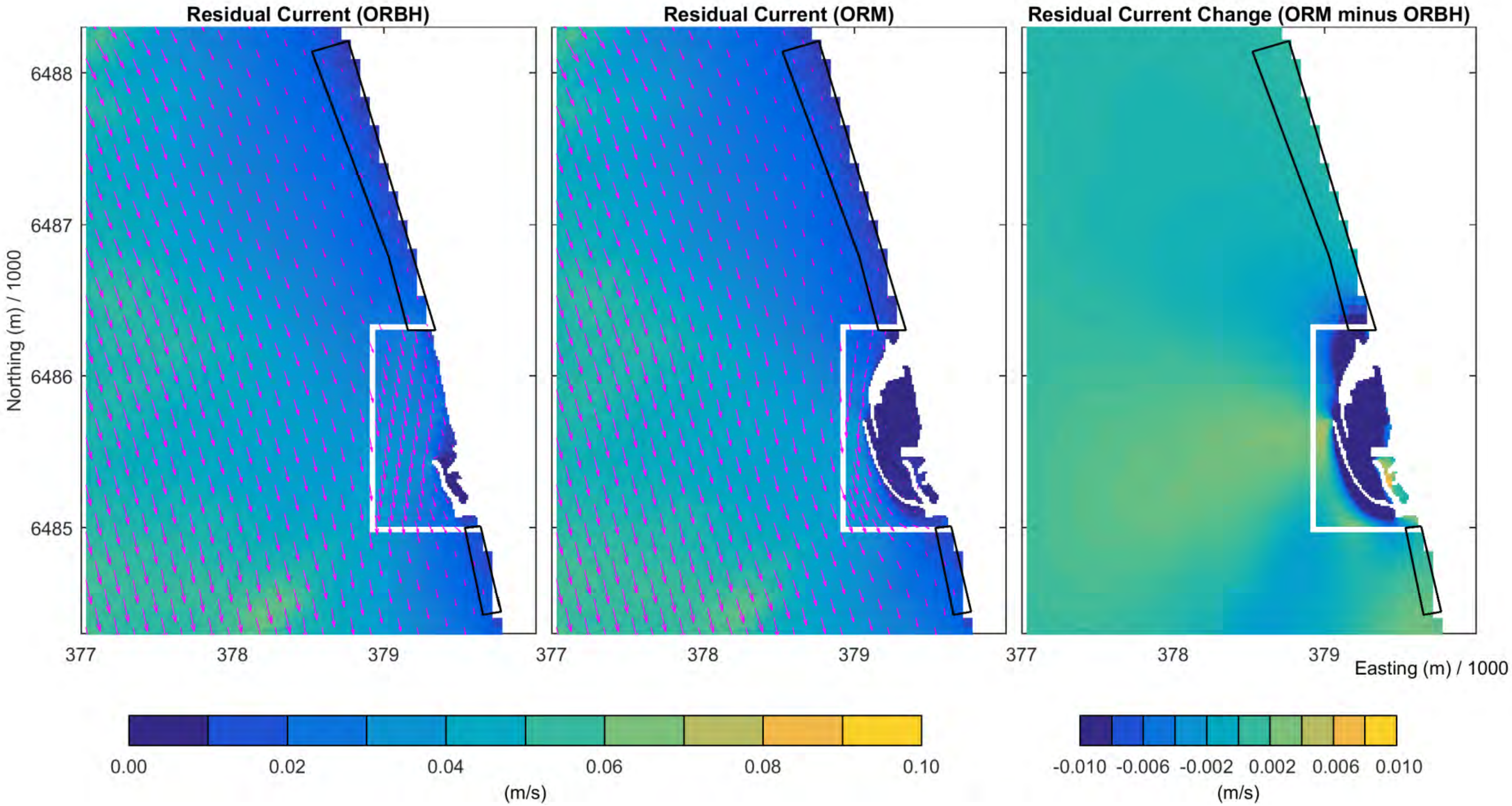

Figure 9.10: Maps of residual currents from a 15-day scenario commencing on 19 Jul 2013. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

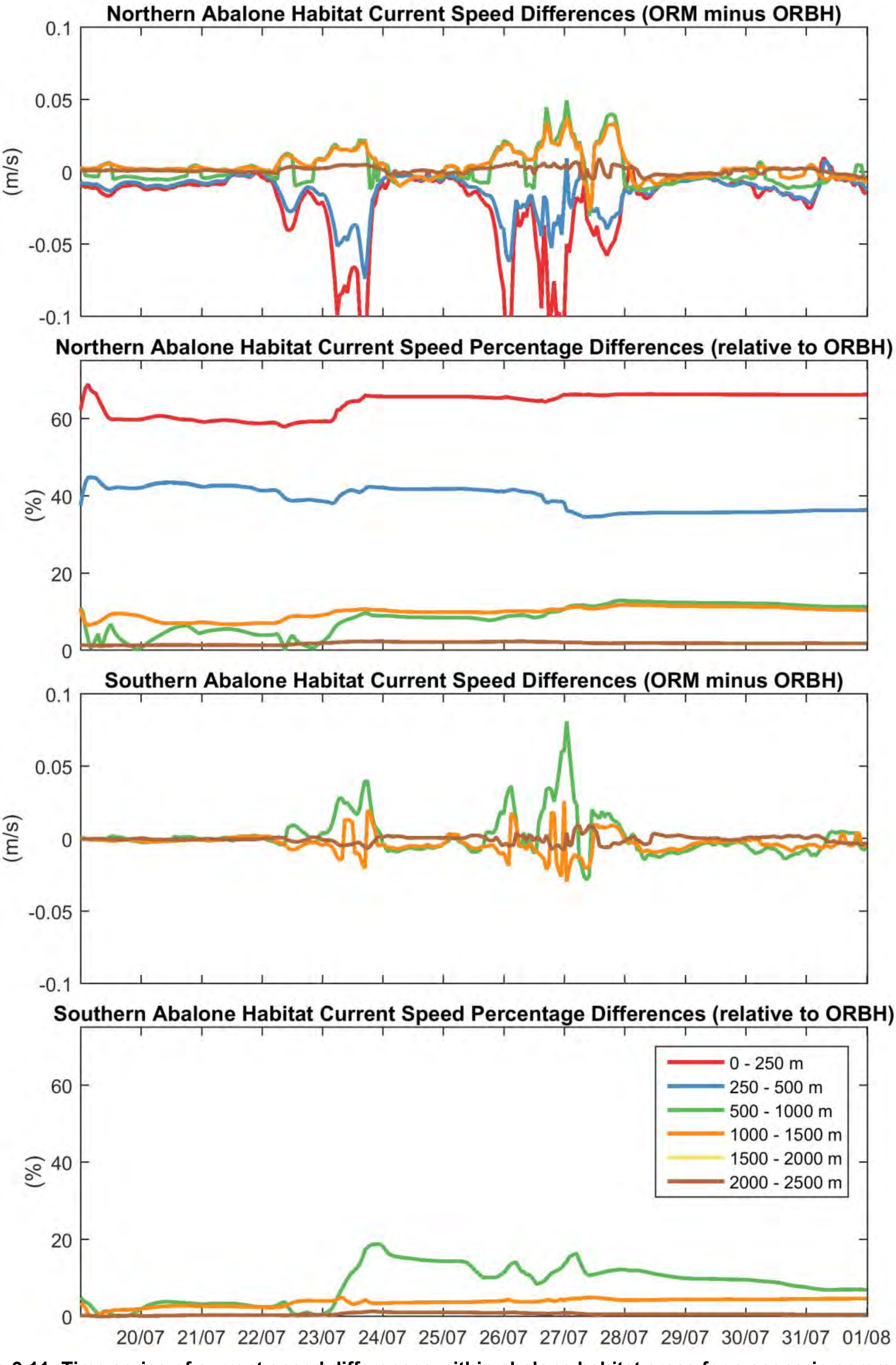

Figure 9.11: Time series of current speed differences within abalone habitat areas for a scenario commencing on 19 Jul 2013. The legend indicates the distance of the points from the ORM and is common to all plots.

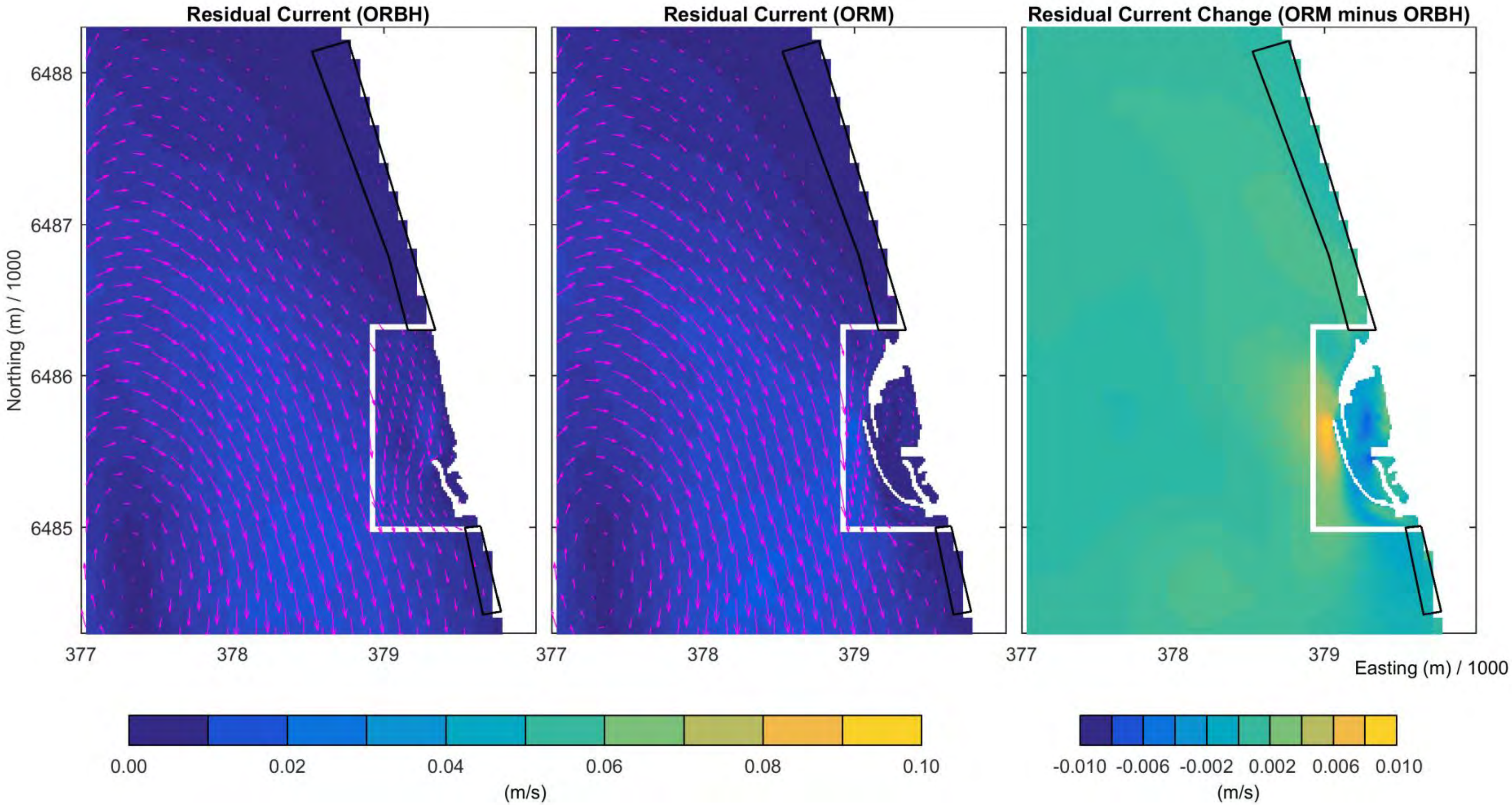

Figure 9.12: Maps of residual currents from a 15-day scenario commencing on 9 Aug 2013. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

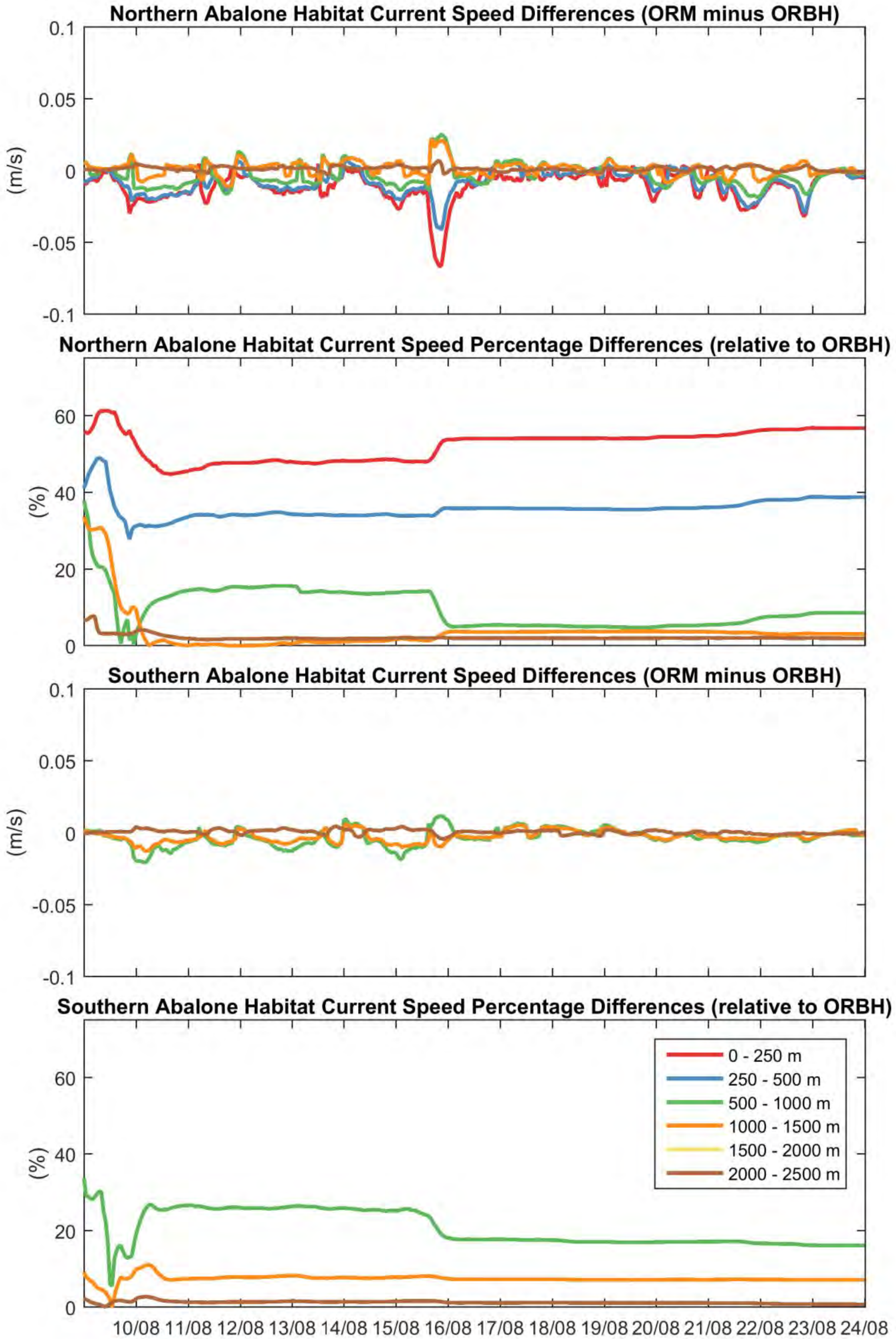

Figure 9.13: Time series of current speed differences within abalone habitat areas for a scenario commencing on 9 Aug 2013. The legend indicates the distance of the points from the ORM and is common to all plots.

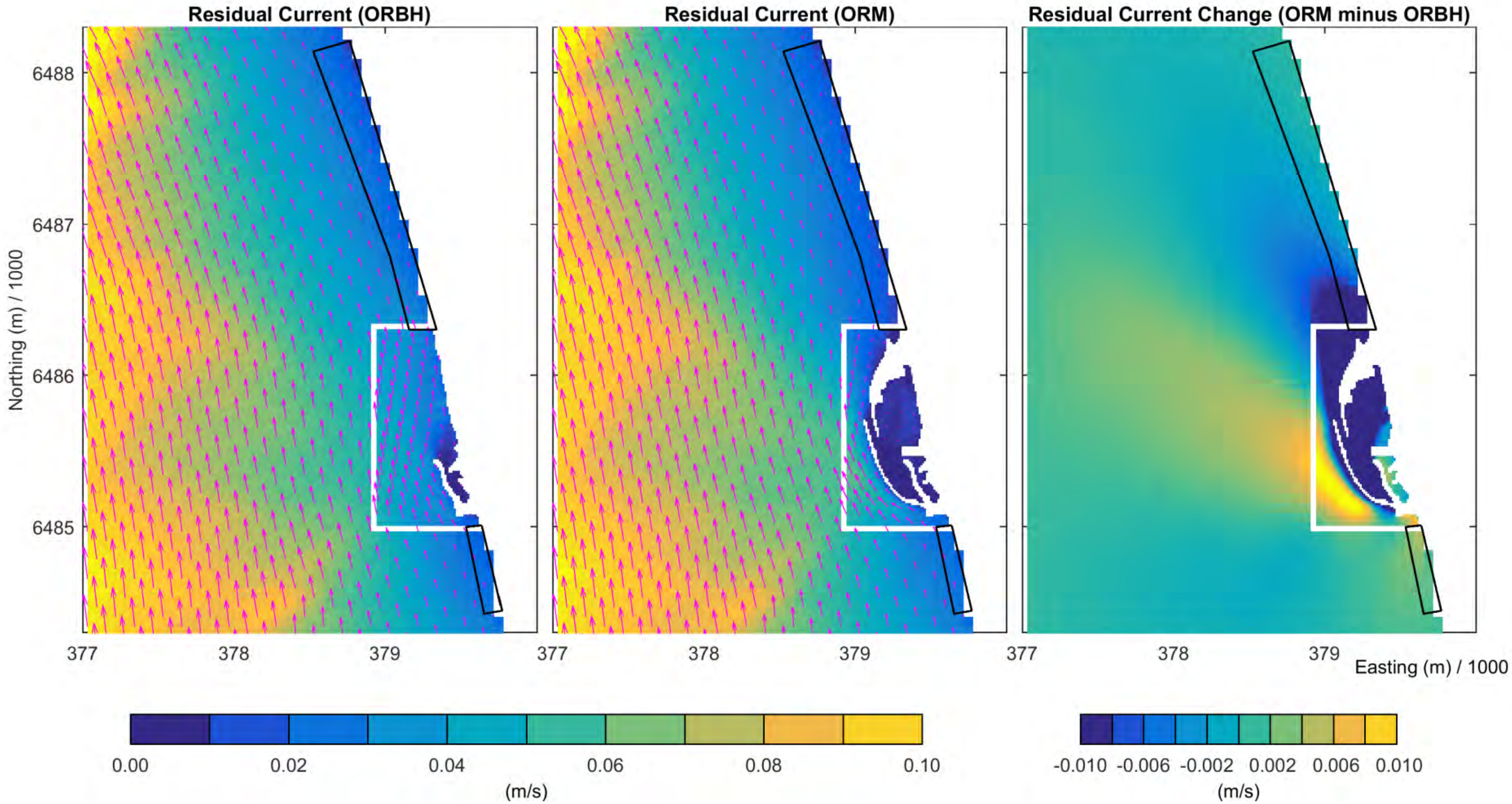

Figure 9.14: Maps of residual currents from a 15-day scenario commencing on 24 Oct 2014. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

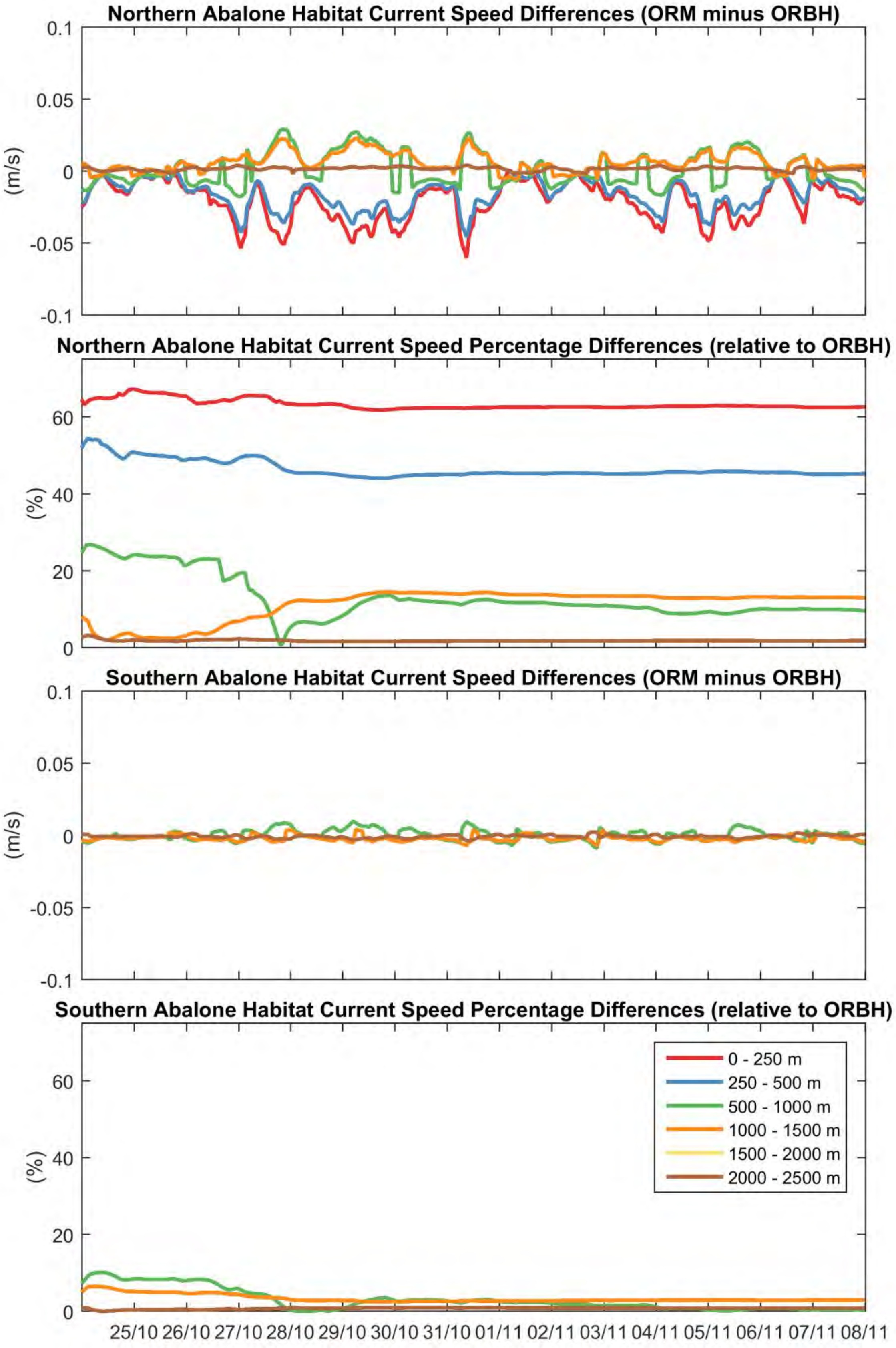

Figure 9.15: Time series of current speed differences within abalone habitat areas for a scenario commencing on 24 Oct 2014. The legend indicates the distance of the points from the ORM and is common to all plots.

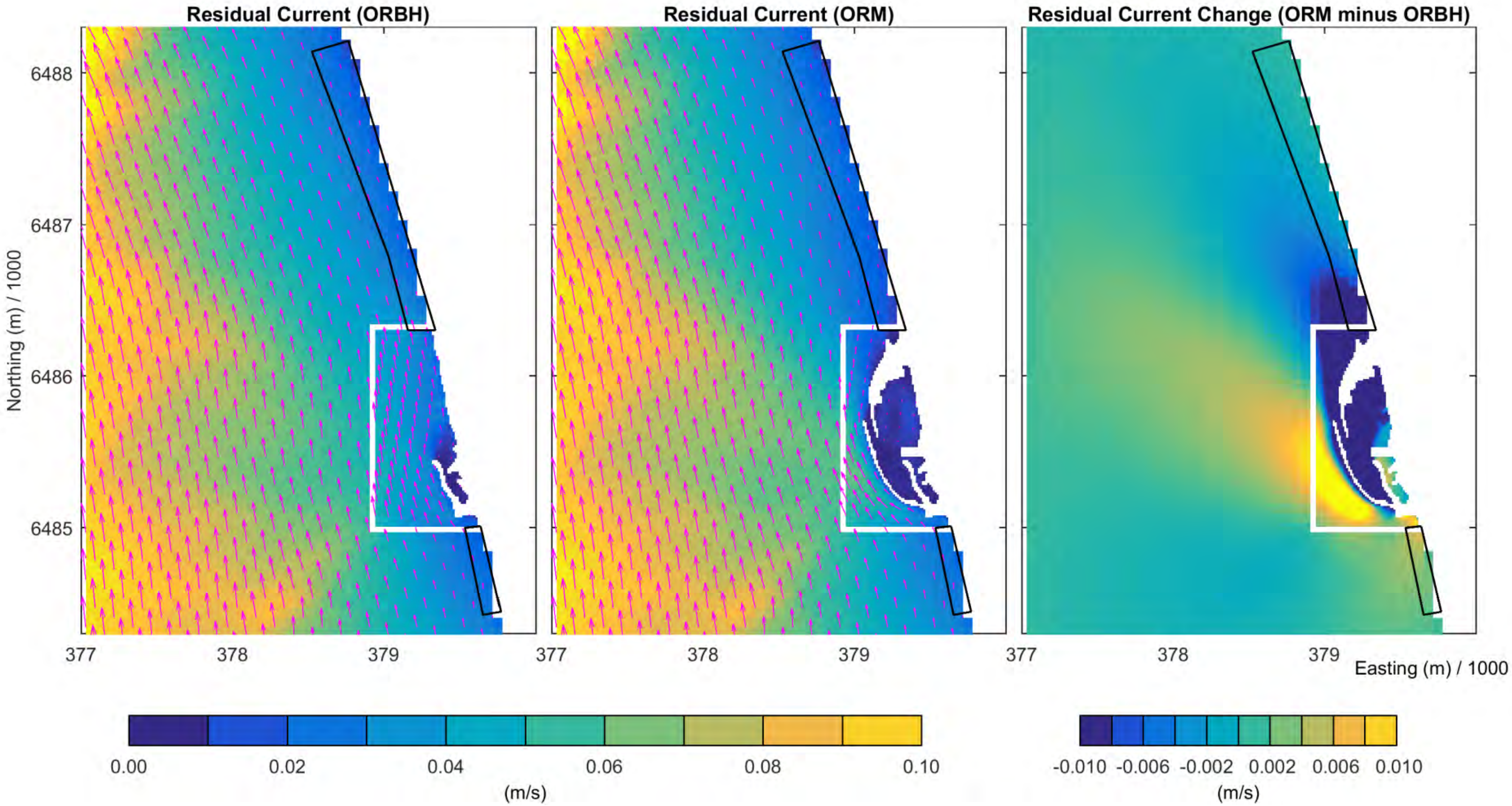

Figure 9.16: Maps of residual currents from a 15-day scenario commencing on 1 Nov 2014. Black boxes indicate the grid cells coinciding with the abalone habits north and south of ORM. Note the different scales on the two colour legends.

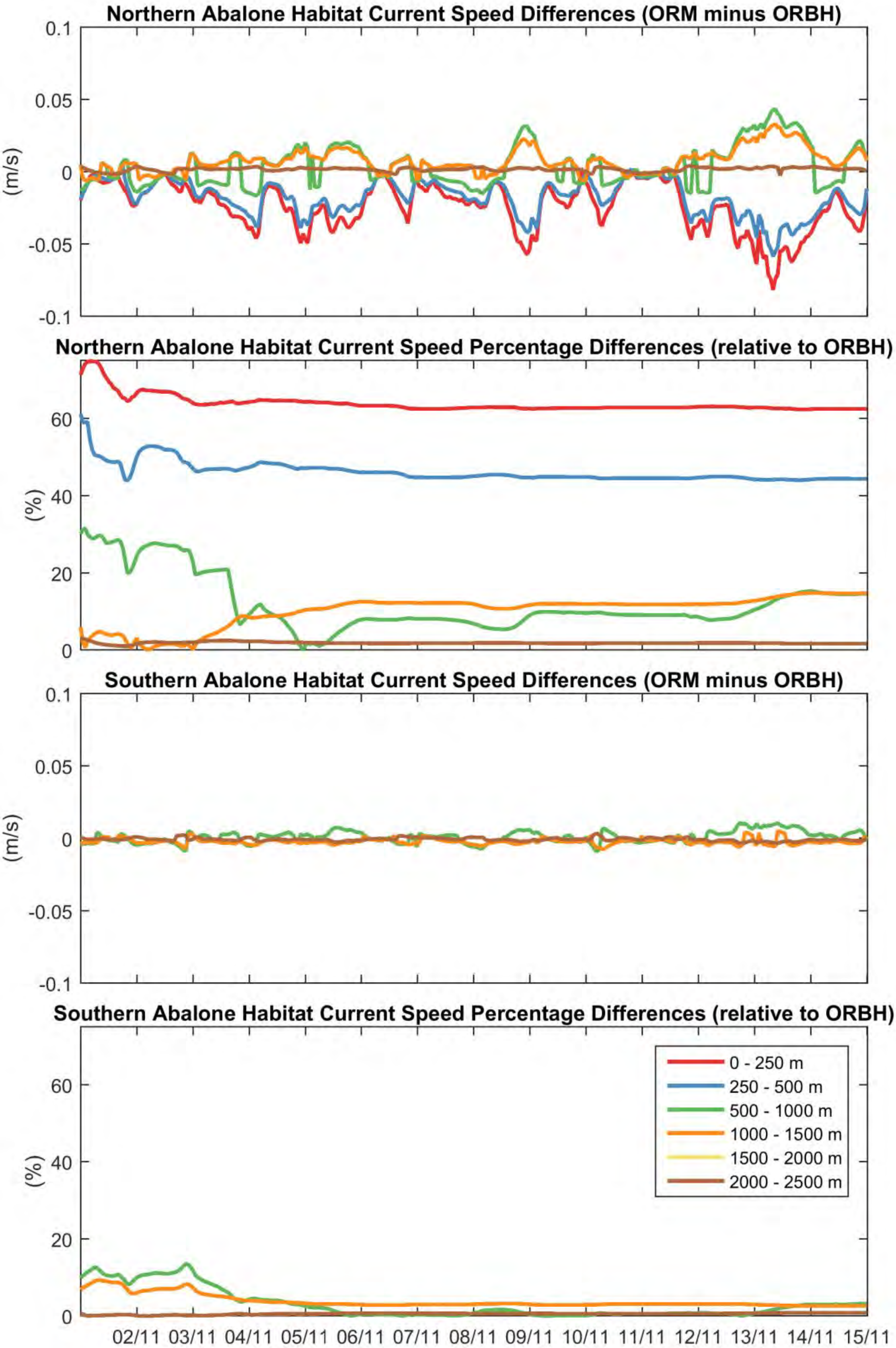

Figure 9.17: Time series of current speed differences within abalone habitat areas for a scenario commencing on 1 Nov 2014. The legend indicates the distance of the points from the ORM and is common to all plots

Table 9.1: Predicted average current speed changes in selected abalone habitat zones for eight simulation periods. Averages are computed from a 15-day hourly time series and based on all grid cells within each zone. The percentage changes are based on absolute value changes (i.e. positive or negative).

Zone	Current Speed Changes	Season	Summer	Summer	Autumn	Autumn	Winter	Winter	Spring	Spring
		Cycle	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap
		Start Date	9 Jan 13	12 Feb 13	8 Apr 12	21 Mar 12	19 Jul 13	9 Aug 13	24 Oct 14	1 Nov 14
North Reef 0 to 500 m	<20%		1	2	4	4	3	5	2	0
	20-40%		50	37	48	48	39	43	29	36
	>40%		48	61	48	48	58	52	69	64
North Reef 500 to 1500 m	<20%		98	97	96	98	89	76	94	91
	20-40%		2	2	2	2	7	12	4	7
	>40%		0	1	1	0	4	12	2	2
South Reef* 500 to 1500 m	<20%		98	95	94	95	70	73	95	93
	20-40%		2	3	5	3	17	12	4	5
	>40%		0	2	1	3	13	14	1	2

** 0-500m zone does not exist for south reef*

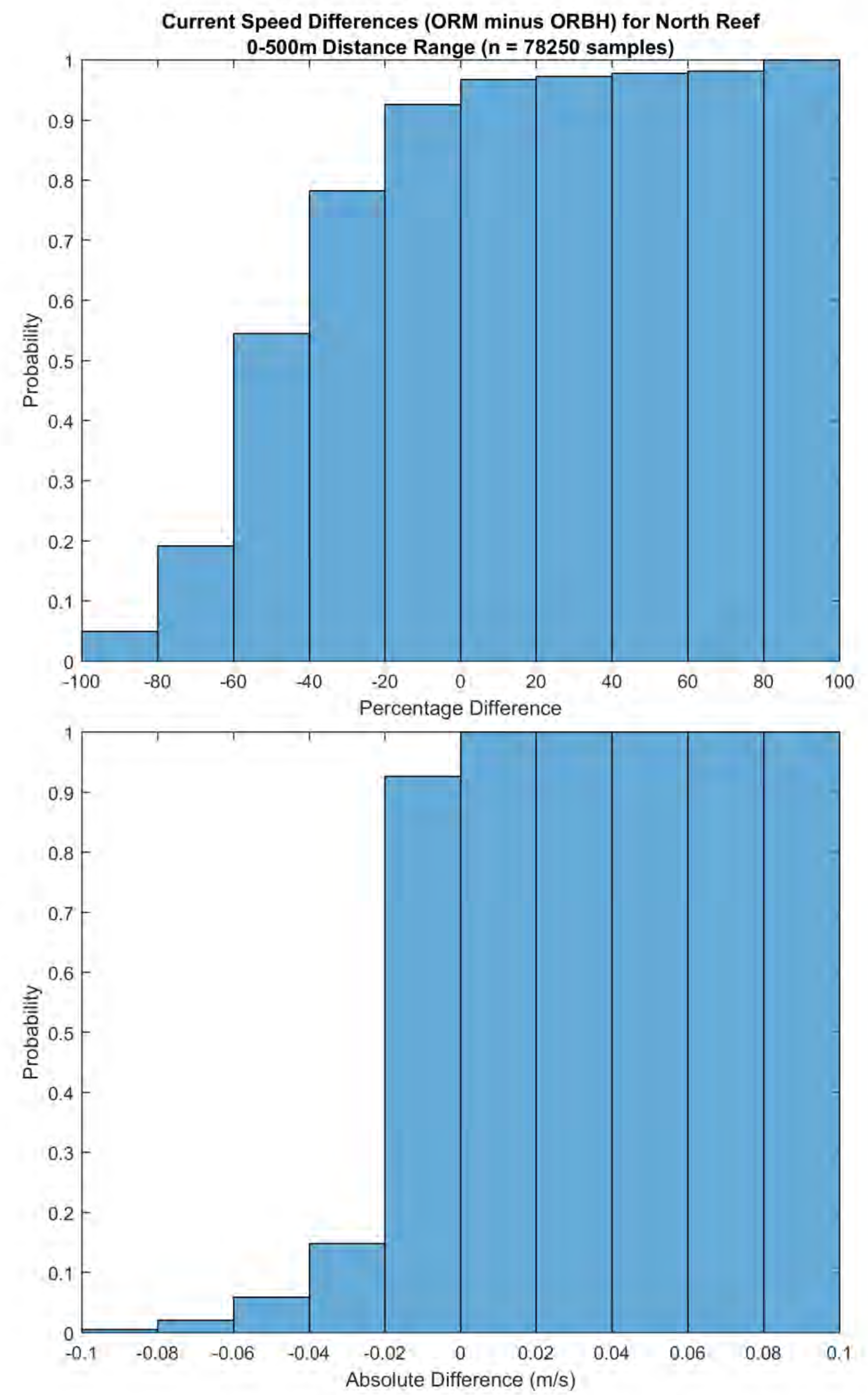

Figure 9.18: Cumulative frequency histogram for predicted current speed changes in selected abalone habitat zones for combined data from eight simulation periods shown in Table 9.1. Averages are computed from a 15-day hourly time series and based on all grid cells within the 0-500 m zone of the northern habitat reef. The graphs show the probability that the changes in currents will be less than or equal to the values indicated on the horizontal axis.

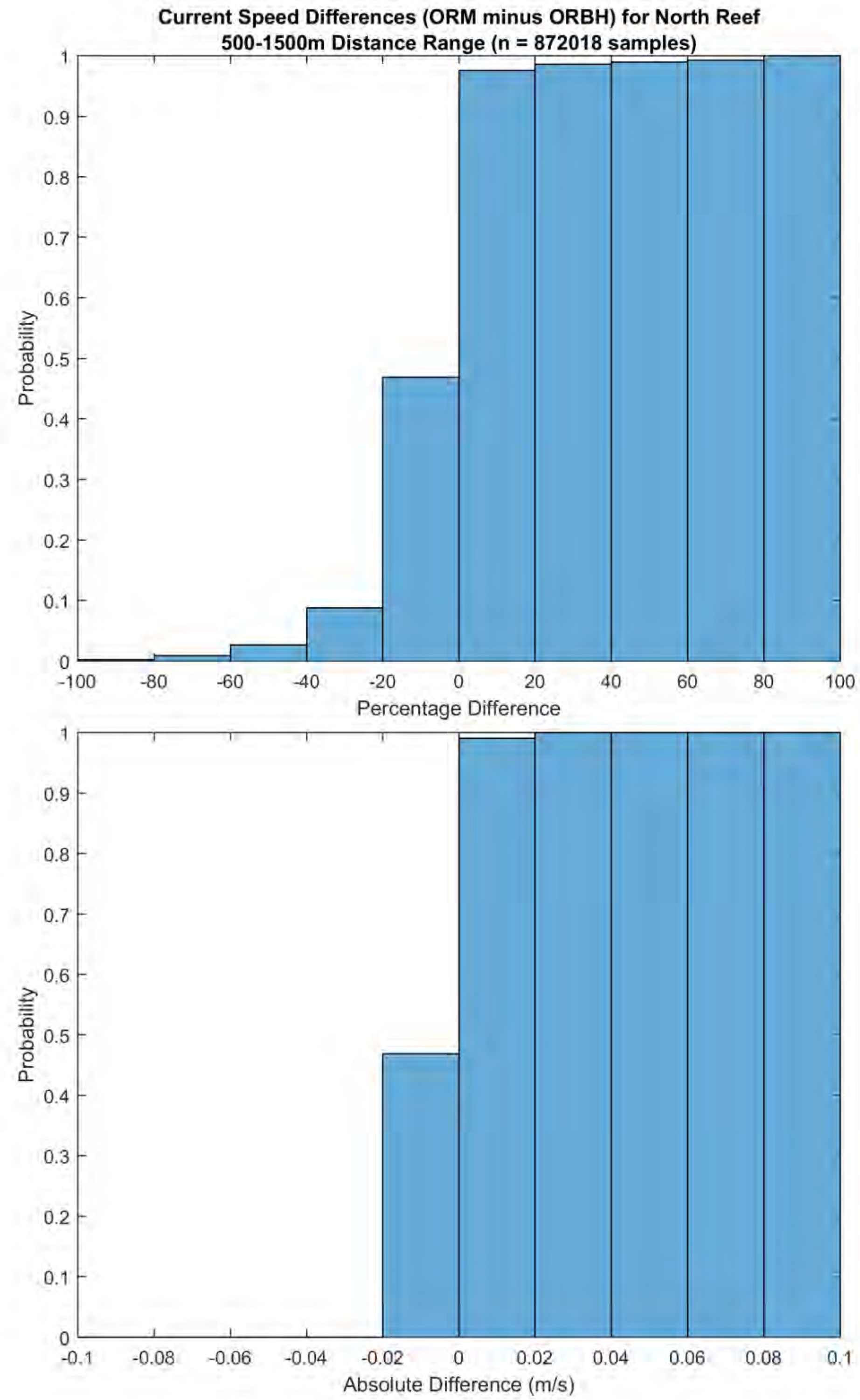

Figure 9.19: Cumulative frequency histogram for predicted current speed changes in selected abalone habitat zones for combined data from eight simulation periods shown in Table 9.1. Averages are computed from a 15-day hourly time series and based on all grid cells within the 500-1500 m zone of the northern habitat reef. The graphs show the probability that the changes in currents will be less than or equal to the values indicated on the horizontal axis.

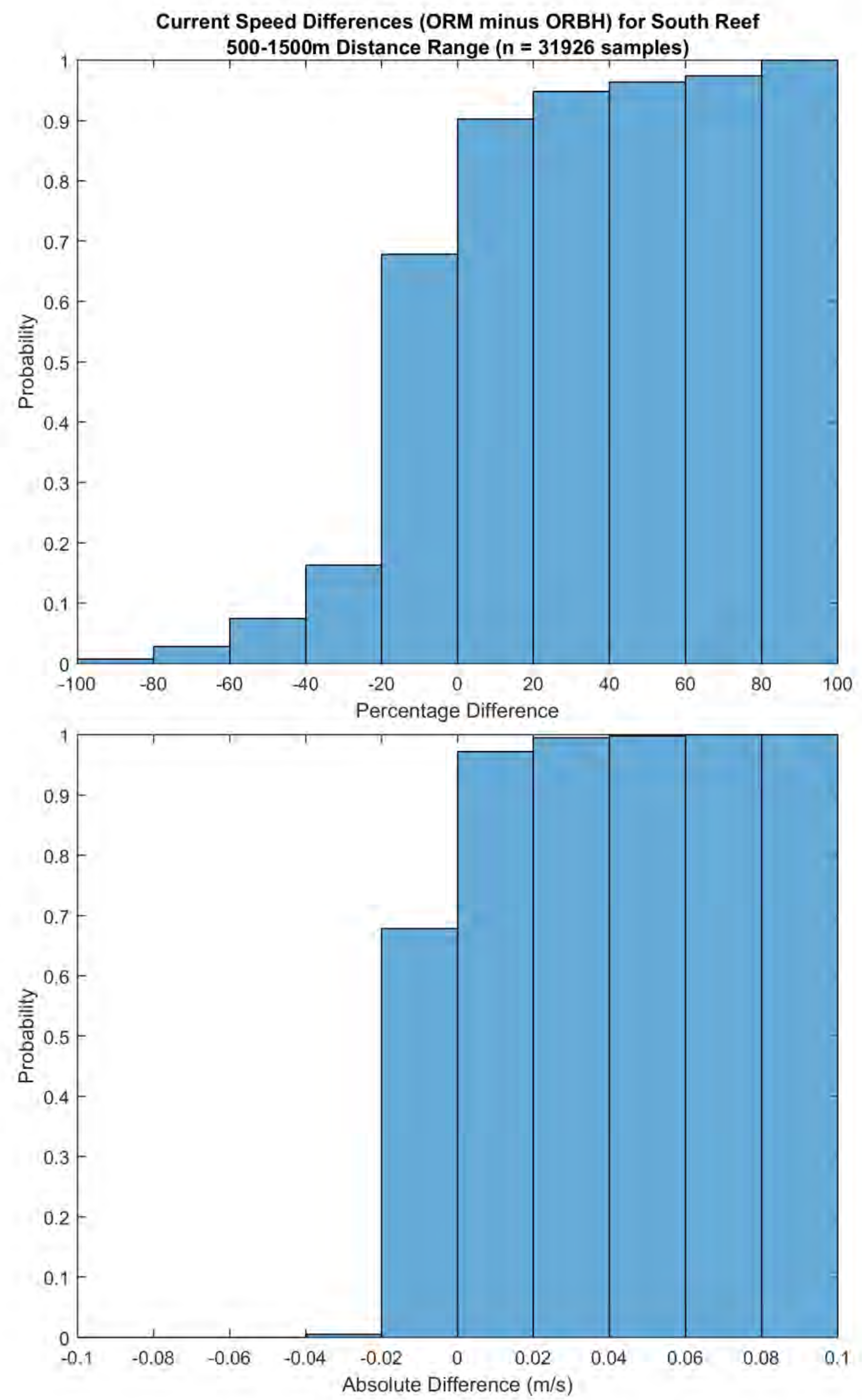

Figure 9.20: Cumulative frequency histogram for predicted current speed changes in selected abalone habitat zones for combined data from eight simulation periods shown in Table 9.1. Averages are computed from a 15-day hourly time series and based on all grid cells within the 0-500 m zone of the southern habitat reef. The graphs show the probability that the changes in currents will be less than or equal to the values indicated on the horizontal axis.

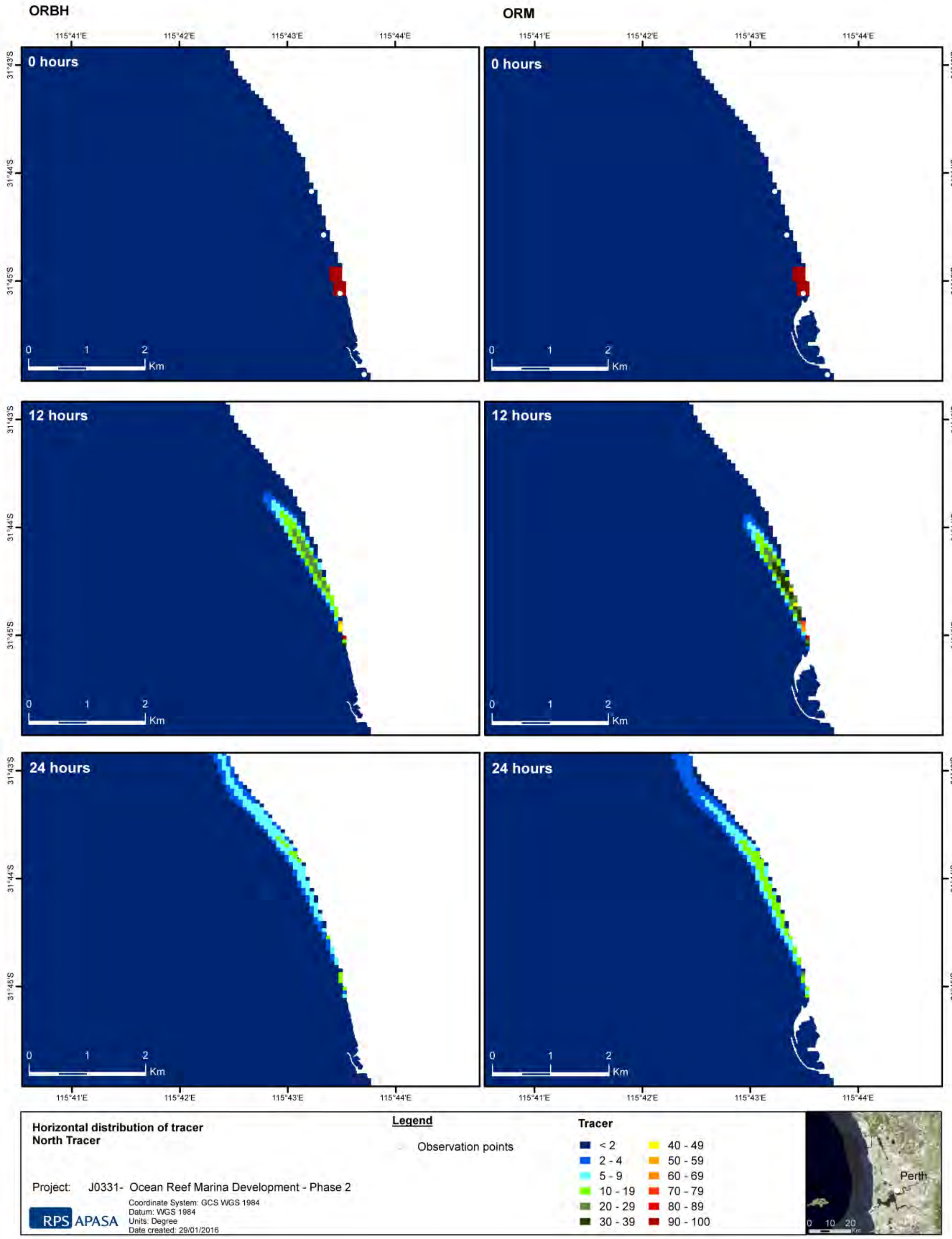

Figure 9.21: Maps showing spatial variations in surface layer tracer concentrations at selected time instances for a 15-day scenario commencing 9 Jan 13. The upper left panels shows the initial northern tracer release area.

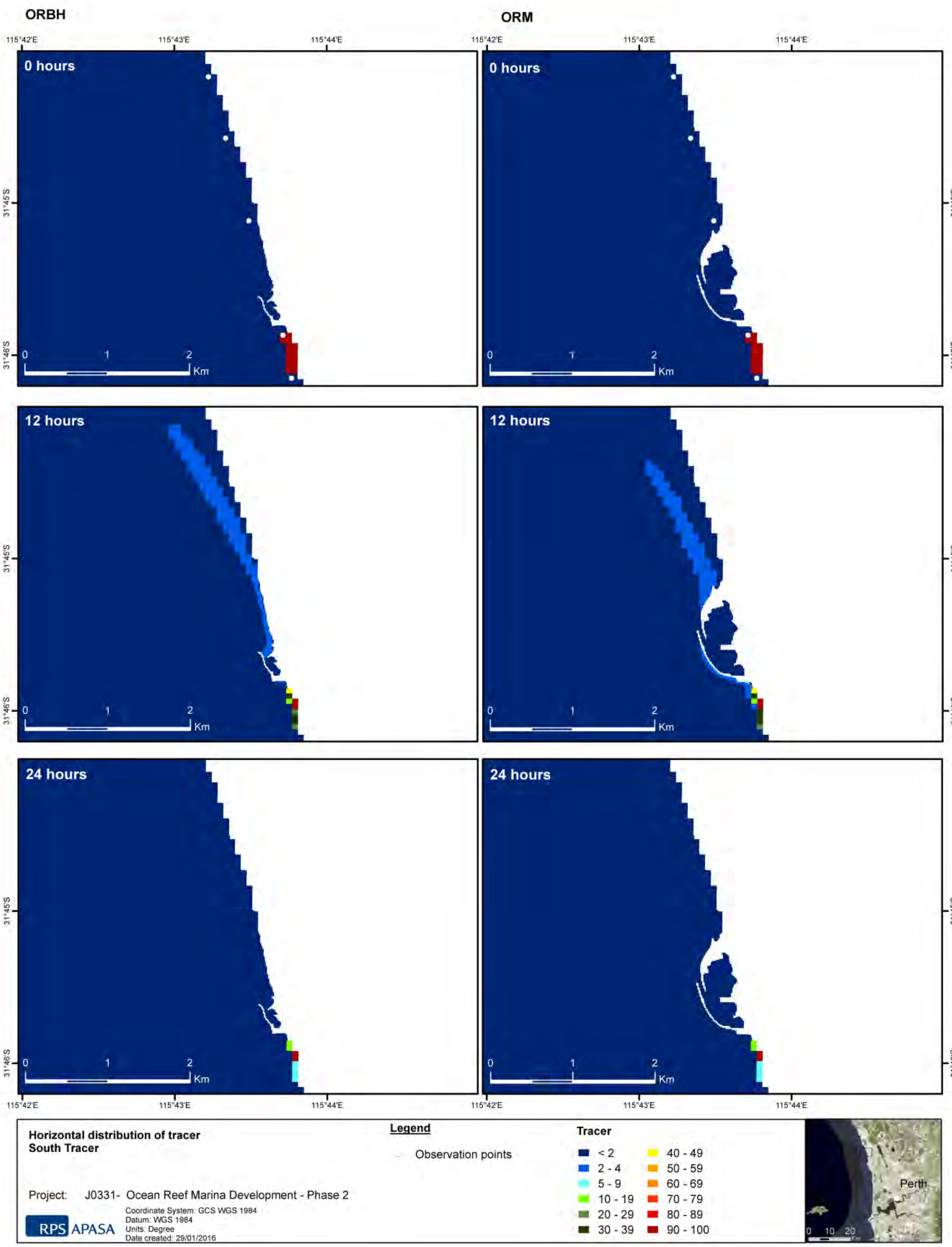

Figure 9.22: Maps showing spatial variations in surface layer tracer concentrations at selected time instances for a 15-day scenario commencing 9 Jan 13. The upper left panels shows the initial southern tracer release area.

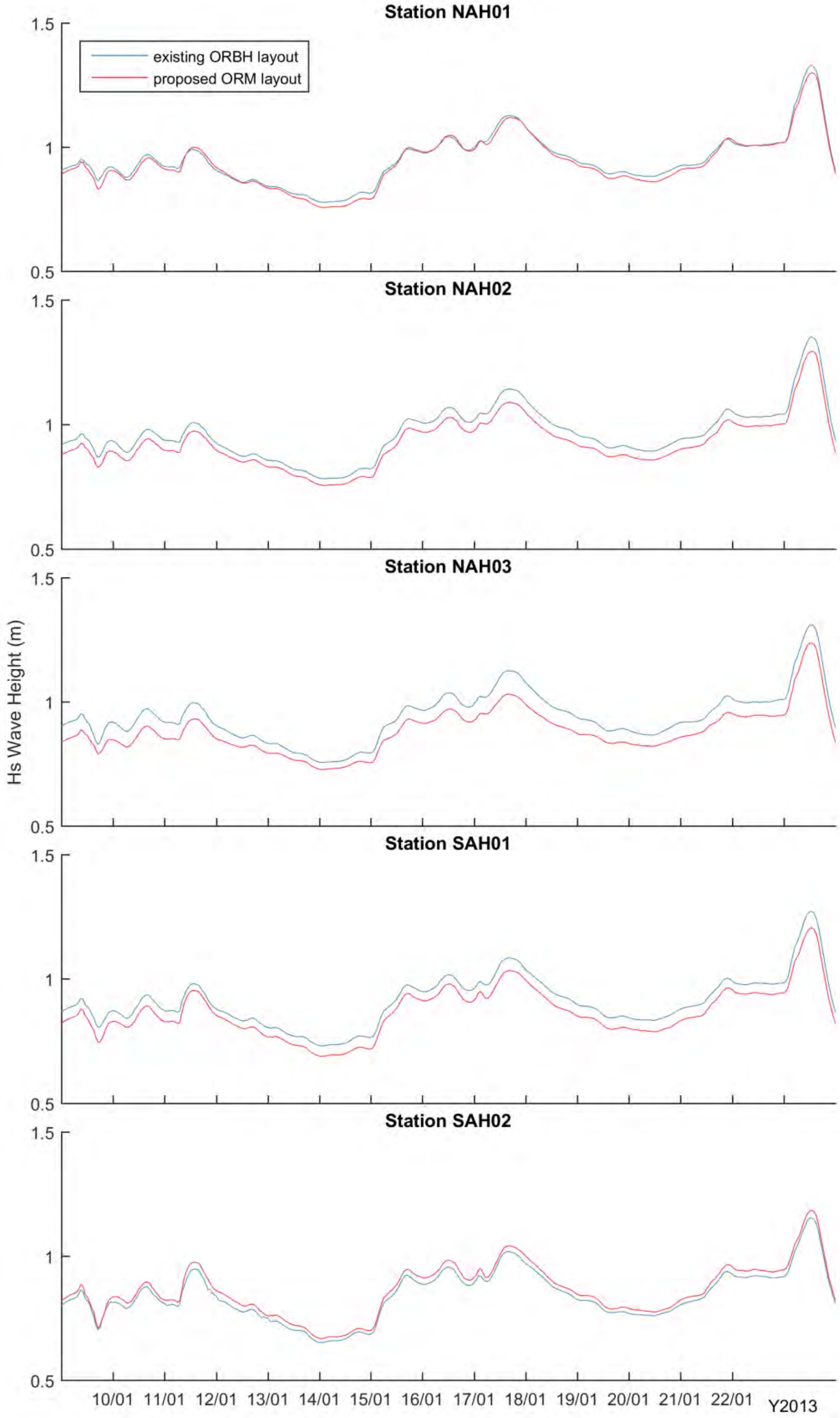

Figure 9.23: Time series of representative summer season wave heights at 5 coastal monitoring stations near to ORM (see Figure 9.1). The blue lines indicate wave heights generated at each station with the existing ORBH model grid, red lines indicate wave heights generated with the proposed ORM model grid. The simulations commenced 9 Jan 2013

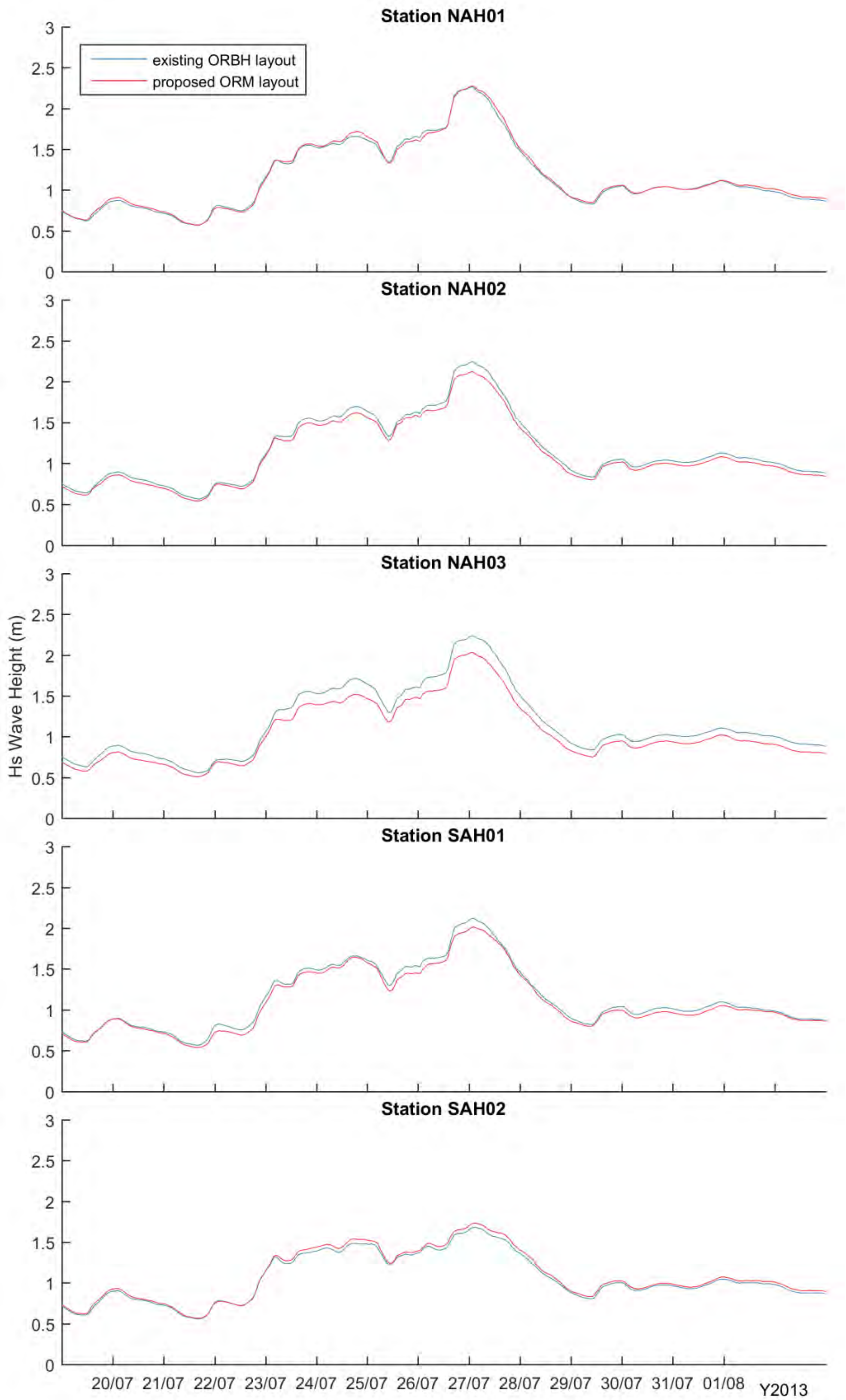

Figure 9.24: Time series of representative winter season wave heights at 5 coastal monitoring stations near to ORM (see Figure 9.1). The blue lines indicate wave heights generated at each station with the existing ORBH model grid, red lines indicate wave heights generated with the proposed ORM model grid. The simulations commenced 19 Jul 2013.

Table 9.2: Impact of a conservative tracer released within ORM on nearby abalone habitat, with the habitat sampled at 5 representative monitoring stations (see for Figure 9.1 locations). For each station and each simulation period, time to first arrival of tracer above threshold (2% of the initial release concentration), time of last departure of tracer above threshold and maximum tracer concertation at any time (% of initial value) is shown. The results show tracer concentrations averaged over depth.

Station	Season	Summer	Summer	Autumn	Autumn	Winter	Winter	Spring	Spring
	Cycle	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap
	Start Date	9 Jan 13	12 Feb 13	8 Apr 12	21 Mar 12	19 Jul 13	9 Aug 13	24 Oct 14	1 Nov 14
NAH01	Start 2% (hrs)	12	6	36	24	24	N/A	24	24
	End 2% (hrs)	204	134	168	216	96	N/A	180	168
	Max. Conc. (%)	8.5	12.3	4.8	4.6	6.5	0.7	15.1	8.9
NAH02	Start 2% (hrs)	24	62	132	120	60	N/A	72	72
	End 2% (hrs)	72	142	156	180	72	N/A	144	156
	Max. Conc. (%)	3.8	7.2	4.0	3.8	2.1	0.3	5.5	4.6
NAH03	Start 2% (hrs)	24	76	144	144	N/A	N/A	96	96
	End 2% (hrs)	84	148	168	180	N/A	N/A	144	156
	Max. Conc. (%)	3.1	4.4	2.9	2.9	0.9	0.3	4.2	3.6
SAH01	Start 2% (hrs)	N/A	N/A	N/A	N/A	84	N/A	N/A	144
	End 2% (hrs)	N/A	N/A	N/A	N/A	96	N/A	N/A	144
	Max. Conc. (%)	1.5	1.8	1.4	1.0	3.6	1.0	0.2	2.6
SAH02	Start 2% (hrs)	N/A	N/A	N/A	N/A	96	N/A	N/A	N/A
	End 2% (hrs)	N/A	N/A	N/A	N/A	168	N/A	N/A	N/A
	Max. Conc. (%)	1.3	<0.1	0.2	0.8	2.7	1.0	<0.1	0.6

N/A: the threshold of 2% of the initial tracer release concentration was not exceeded

Table 9.3: Predicted effect of the proposed ORM on flushing dynamics along the nearby coastal margin. For both the proposed ORM and the existing ORBH model layouts, conservative tracers were released in two separate areas directly north and south of the proposed ORM (see Figure 9.21 and Figure 9.22). For each station the time to first arrival of tracer above threshold (2% of the initial release concentration), time of last departure of tracer above threshold and maximum tracer concertation at any time (% of initial value) is shown. The results are averaged over depth.

Station	Season	Summer	Summer
	Start Date	9 Jan 13	9 Jan 13
	Layout	ORBH	ORM
NAH01	Start 2% (hrs)	0	0
	End 2% (hrs)	1	7.5
	Max. Conc. (%)	100	100
NAH02	Start 2% (hrs)	3.5	4.3
	End 2% (hrs)	21.3	38.5
	Max. Conc. (%)	49.6	47.7
NAH03	Start 2% (hrs)	12.3	12.8
	End 2% (hrs)	40.2	52.3
	Max. Conc. (%)	15.9	19.6
SAH01	Start 2% (hrs)	0	0
	End 2% (hrs)	11.3	13.0
	Max. Conc. (%)	100	100
SAH02	Start 2% (hrs)	N/A	N/A
	End 2% (hrs)	N/A	N/A
	Max. Conc. (%)	0	0

N/A: the threshold of 2% of the initial tracer release concentration was not exceeded

10.0 Sediment Fates Modelling

A major component of the environmental studies for the proposed ORM development is the assessment of any potential impacts on the ecology of the surrounding marine environment from the transport and fate of sediments that could be suspended by breakwater construction, land reclamation and dredging activities. Of particular concern is the potential for any impact on several abalone habitat zones that have been identified within the study area (BMT Oceanica, 2015).

Detailed sediment fate modelling of the breakwater and reclamation construction, and the dredging operations was conducted to predict the suspended sediment load and likely sedimentation within the surrounding marine environment. This section presents the methodology applied to assess these factors and the resulting outcomes.

10.1 Construction and Dredging Project Description and Model Operational Assumptions

10.1.1 Summary of Proposed Construction Operations

The construction activities that are anticipated to produce sediment sources of sufficient magnitude to require assessment are the material dumping for the construction of the core of the northern and southern marina breakwaters, and to a lesser degree the construction of the core of the internal northern and peninsula reclamation bunds. The location of the breakwaters and reclamation areas are presented on Figure 10.1. It is proposed that the core construction method would involve end tipping from trucks, to progressively build the core out into the water from the shoreline (MPRA, 2015a).

Based on the anticipated construction schedule provided by MPRA (2015c) the northern and southern breakwaters are proposed to be constructed in parallel, with the northern and peninsula reclamation bunds then constructed consecutively once a large proportion of the outer breakwaters have been constructed. Construction is assumed to occur only during daylight hours, 10 hours a day for the duration of the work. Start and end dates, total weeks to construct and core volumes to be placed for each marina component modelled, are outlined in Table 10.1 based on information provided by MPRA (2015b, 2015c, 2015d). Note the use of 2012 to 2013 dates in the table represents the modelled periods, which were selected based on these being representative of typical wave and current conditions at the site.

Table 10.1: Construction timing and volumes for each of the marina components modelled (MPRA, 2015b, 2015c, and 2015d).

Marina Component	Core Volume (m^3)	Start date	End date	Total number of weeks
Northern Breakwater	194,000	1/11/2012	15/3/2013	19*
Southern Breakwater	300,000	1/11/2012	25/4/2013	25*
Northern Reclamation	54,000	7/1/2013	4/2/2013	4
Peninsula Reclamation	43,100	4/2/2013	4/3/2013	4

*total includes a 2 week non-working break for the Christmas period.

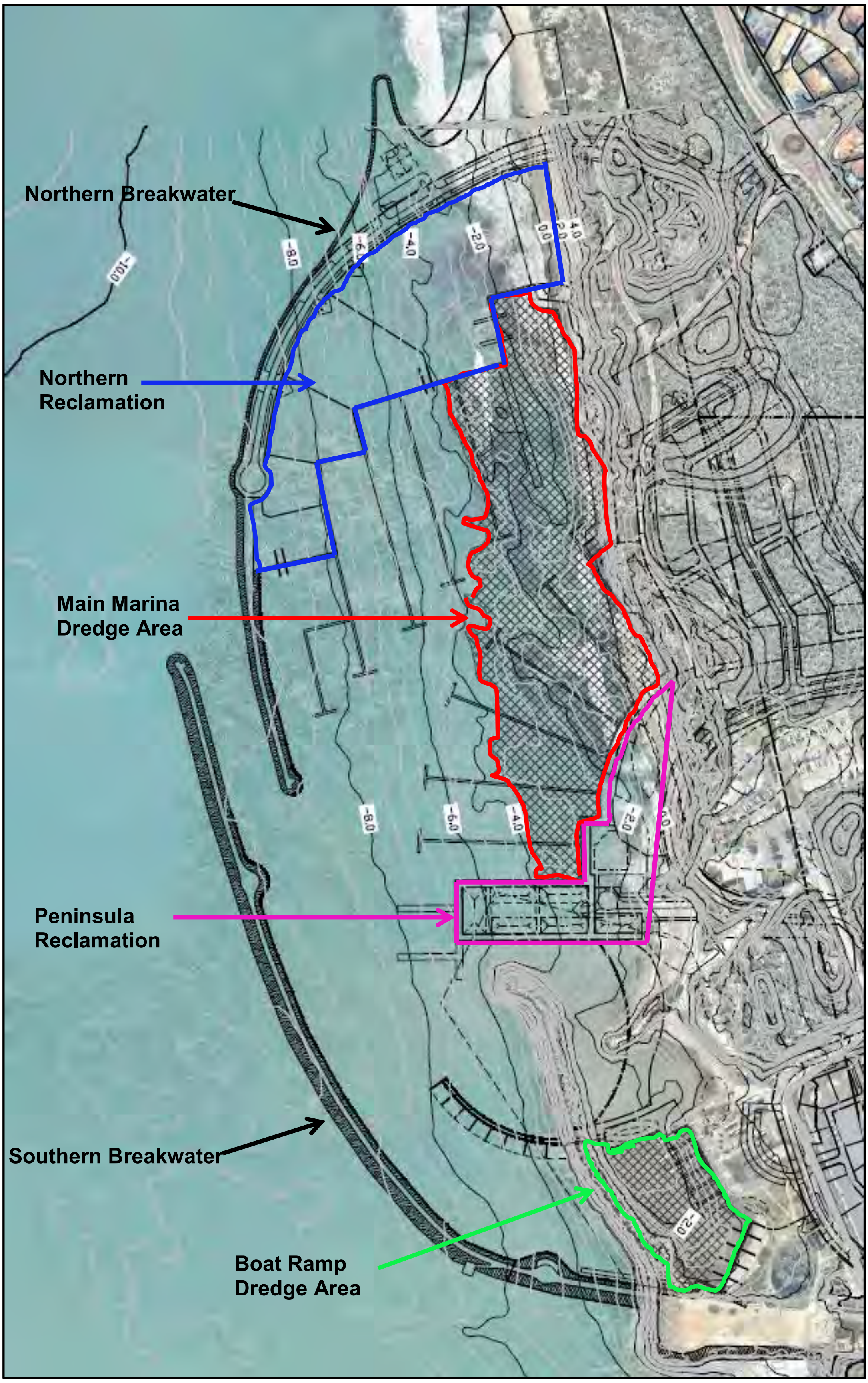

Figure 10.1: Construction and dredging areas to be modelled overlain on the Ocean Reef Marina – Concept 7.2A – Layout and dredge areas drawing (MPRA, SK1252-04/09/15-1a).

10.1.2 Summary of Proposed Dredging Operations

There are two separate areas that will need to be dredged to a depth of -3.5 mAHD within the proposed marina layout; these are the main marina area and the area bounded by the existing breakwater and boat ramp. The footprint of each area is outlined in Figure 10.1.

The dredging is proposed to be completed using a hydraulic excavator working from a series of temporary bunds (MPRA, 2015a). The temporary bunds are proposed to be constructed by the end tipping of core material with the bund removed with the dredging works (MPRA, 2015a). Both the construction and removal of the bunds have been included as sources of suspended sediment in the modelling. MPRA (2015a) have advised that a typical long reach excavator can excavate approximately 15 m either side of the bund centreline, therefore a bund spacing of 30m has been assumed for modelling purposes.

The in situ rock is proposed to be broken initially with a hydraulic rock breaker or excavator and then removed with an open excavator bucket along with the overlying sand and bund material. The dredged material will be loaded onto trucks and transported to the reclamation area. MPRA (2015a) has advised that overflow from the material placement in the reclamation area is not anticipated.

For modelling purposes, it has been assumed that the dredging operations will start after the construction of the northern and southern breakwaters are complete (MPRA, 2015b). It is assumed that dredging procedures would be managed such that all of the relevant environment controls and protection procedures are in place prior to any dredge operations commencing. Furthermore, the proposed methodology includes the placement of one or more silt curtains across the constructed marina entrance to limit the release of material during dredging. Modelling has included a representation of a silt curtain barrier but with the potential for fine material to wash over the barrier.

Dredging will be conducted during daylight hours, 10 hours a day, with dredging of both areas to begin simultaneously, with one dredge working each area. Start and end dates, total weeks and volumes to be dredged for each dredge area, are outlined in Table 10.2 and are based on information provided by MPRA (2015a, 2015c). All dates are based on the assumed construction period.

Table 10.2: Timing and volumes for each of the dredge areas to be modelled (MPRA, 2015a, 2015c).

Dredge Area	Rock Volume (m^3)	Sand Volume (m^3)	Total Volume (m^3)	Start date	End date	Total number of weeks
Main Marina	75,300	10,500	85,800	25/04/2013	27/11/2013	32
Boat Ramp	4,000	10,000	14,000	25/04/2013	12/06/2013	7

10.1.3 Sediment Sources

To accurately represent the core construction and dredging operations in DREDGEMAP a range of information was provided including methodology, material types, volumes and production/flow rates. The following section outlines how the provided information was used to represent the core construction and dredging operations in the model and any assumptions that were made to supplement the provided information.

It is evident from the proposed core construction and dredging operation methodology that there will be eight individual sources of suspended sediment plumes. The eight sources are:

1. Direct loss of material during core dumping for the southern breakwater core construction.
2. .Direct loss of material during core dumping for the northern breakwater core construction.
3. Direct loss of material during core dumping for the northern reclamation bund core construction.
4. Direct loss of material during core dumping for the peninsula reclamation bund core construction.
5. Direct loss of material during core dumping for the creation of the working bunds during dredging of the main marina dredge area.
6. Direct loss of material during excavation of the dredged material and working bunds of the main marina dredge area.
7. Direct loss of material during core dumping for the creation of the working bunds during dredging of the boat ramp dredge area.
8. Direct loss of material during excavation of the dredged material and working bunds of the boat ramp dredge area.

These eight sources can be grouped into two main source types that require alternative representations in the model, the core dumping sources (source 1, 2, 3, 4, 5 and 7) and the dredging sources (source 6 and 8). The two main source types will require different source strengths, vertical distributions of sediment and sediment grain-size distributions within the model and these are outlined in the following sections.

10.1.3.1 Representation of Sediment Plume for Core Construction

MPRA (2015a) have stated that the breakwater core material is likely to be specified as well graded limestone rubble with a D_{50} of approximately 0.5 tonnes, having not more than 20% less than 0.35 m diameter and ranging up to approximately 1.5 tonnes (~1 m diameter). Based on measurements from a similar limestone breakdown construction at Rous Head, MPRA (2015a) stated that the amount of quarry material less than 100 mm in the core material was typically in the order of 5% of the volume. Therefore a conservative loss rate of the full 5% of the total volume of core material dumped was applied in the modelling. The 5% of the total core volume sets the maximum volume of material that is available for resuspension; however, the particle size distribution within that 5% is also an important input to the model.

For sediment fate modelling the breakdown of the 5% fine core material into the five SSFATE particle size classes (Table 3.1) is required. In particular, the proportion of material that is lower than 130 µm is an important specification, as this is the proportion of the material that will not settle out immediately and has the potential to remain suspended. Based on material testing from previous projects, the volume of quarried core material less than 130 µm is typically in the order of 2%. Table 10.3 presents the particle size distribution (PSD) that was applied in the model for the core dumping sources. The size composition of the material is dominated by coarse sand and greater size particles with the 2% finer material assumed to be evenly spread over the four smaller model material classes.

Table 10.3: Particle size distribution for sediments released into the marine environment from dumping of core material for breakwater construction, based on initial testing measurements from previous projects.

Material Class	Size Range (µm)	Cumulative %	% of Total
Clay	< 7	0.5	0.5
Fine Silt	7 to 35	1.0	0.5
Coarse Silt	35 to 75	1.5	0.5
Fine Sand	75 to 130	2.0	0.5
Coarse Sand	> 130	100	98

As the core will be end tipped from trucks the material will move through the whole water column as it falls to the seabed. Therefore a uniform vertical distribution through the water column has been assumed for modelling of the core dumping sources (Table 10.4). As the depth varies along the breakwaters and reclamation bunds, the depths for the vertical distribution in the model inputs also vary, an example distribution at a depth of 9 m is provided in Table 10.4. The process of bund removal was also represented in the model.

Table 10.4: Initial vertical distribution of sediments in the water column setup by the dumping of core material.

Elevation above seabed (m)	Example Elevation above seabed for a depth of 9 m (m)	% of sediments
1 * depth	9	20
0.8 * depth	7.2	20
0.6* depth	5.4	20
0.4* depth	3.6	20
0.2* depth	1.8	20

Construction of the northern and southern breakwaters will start from the land and move progressively seaward as the core is built, and therefore the sources in the model move progressively outwards along the centreline of the breakwaters as construction progresses (Figure 10.1). Similarly the modelled source for the northern reclamation bund moves progressively out from the land along the outline of the northern reclamation. The peninsula reclamation bund source starts at the northern land portion, working south and then outwards along the outline of the reclamation. All construction and source progression was based on the construction program provided by MPRA.

10.1.3.2 Representation of Sediment Plume from Dredging

The dredging operations for both the main marina and boat ramp dredge areas involve periods of dredging interspersed with periods of bund construction. For the periods of bund construction the source is represented as outlined in Section 10.1.3.1. For the periods of dredging and bund removal the representation of the source in the model is as outlined in this section.

PSDs for the overlying sediment within the main marina and boat ramp dredge areas at a range of locations and depths were provided along with estimates of volumes of rock and sediment to be dredged for each area. The main marina dredge area is comprised of a relatively thin layer of sediment overlying rock, while the boat ramp dredge area has a thicker layer of sediment overlying rock (Table 10.5).

The PSDs provided for the project area were averaged over each dredge area and combined into the five SSFATE material classes for use in the modelling. The averaged PSDs for each area are presented in Table 10.5. It is evident from the PSDs that the overlying sediments within the existing boat ramp area have a significantly higher proportion of very fine material when compared to the main marina dredge area.

Limited geotechnical information has been collected regarding the underlying rock and therefore it was not possible to accurately anticipate the PSDs that would result after the rock was broken up for removal. As such, the overlying sediment PSDs has been used for the total volume to be dredged. As Table 9.5 shows, 4% of all dredged material is considered to comprise particles with diameters less than 130 µm in the Marina dredge area, with this value rising to around 57% in the Boat Ramp dredge area.

It was also considered that the rock material in both areas could be assumed to have the same PSD as the breakwater core material (Table 9.3), which would have resulted in 2% of dredged sediments having diameters less than 130 µm. However, the approach taken was considered to be more conservative as it would release a greater volume of finer material into the water column, potentially contributing to a more prominent visible plume during rock excavation than may actually be the case. Given the shallowness of the water, the bulk of the finer material is expected to settle relatively quickly, and the reduced wave energy within the marina once the breakwaters are in place means the bulk of the deposited material is unlikely to be resuspended.

Table 10.5: Particle size distribution for sediments released into the marine environment from dredging of sediments and rock material from the main marina and boat ramp dredge areas.

Material Class	Size Range (µm)	Main Marina Dredge Area		Boat Ramp Dredge Area	
		Cumulative %	% of Total	Cumulative %	% of Total
Clay	< 7	0.2	0.2	2.9	2.9
Fine Silt	7 to 35	1.5	1.3	22.4	19.5
Coarse Silt	35 to 75	2.9	1.4	40.8	18.4
Fine Sand	75 to 130	4.0	1.1	56.6	15.8
Coarse Sand	> 130	100	96.0	100	43.4

It is anticipated that the dredging will be conducted using a large excavator arm fitted with an open bucket, working from a series of temporary bunds, with the dredged material being placed into waiting trucks. Past observations of this dredging method have shown that material is suspended from the seabed due to the initial grab action of the excavator with further loss occurring as sediment overflows from the bucket while the bucket is lifted through the water column and as the bucket breaks free of the water surface.

Suspension of sediment is assumed to occur close to uniformly throughout the water column, but with slightly higher initial concentrations at the bottom, due to the seabed disturbance, and at the top, due to turbid water draining as the bucket clears the water (Hayes & Wu 2001, Anchor Environmental 2003). Table 10.6 shows the anticipated vertical distribution of sediments released into the water column during the excavator dredging operations; note that the highest proportion of sediments released are expected at the seabed and water surface.

Published sediment loss rates from an excavator bucket were found to vary from 0.1% to 10%, with a mean of 2.1% (Anchor Environmental, 2003). The reported sediment loss rates vary due to factors such as the size and type of bucket, the nature of the bed material, current speed and depth of water, in addition to the dredging approach of the operator (Hayes and Wu 2001, Anchor Environmental, 2003). Therefore, in the absence of site and equipment specific measurements, the mean published loss rate of 2.1% was assumed for this study. This sediment loss rate is in line with values that have been applied for other validated dredge plume models in Australia.

Table 10.6: Initial vertical distribution of sediments in the water column due to dredging with an excavator bucket.

Elevation above seabed (m)	Example Elevation above seabed for a depth of 1.75 m (m)	% of sediments
1 * depth	1.75	25
0.8 * depth	1.4	18
0.6* depth	1.05	14
0.4* depth	0.7	18
0.2* depth	0.35	25

As stated previously we have been advised that a bund spacing of approximately 30m will be applied for the dredging operations. The bunds are assumed to be built out from the land to approximately 15 m from the outer extent of the dredging area, therefore in order to model the dredging operations a series of 30 m spaced bund source lines were developed to cover the two main dredge areas (Figure 10.2). The sediment source for both dredge areas will begin at the bund line at the northern extent of the dredge area and work southwards to each bund line in turn. For each bund line the source will first move offshore along the line as the bund is constructed and then return along the same line as the dredging of the area around that bund line is completed.

Figure 10.2: Location of the temporary bund line sources used to model the dredging operation in the sediment fate modelling.

10.2 Model Domain and Bathymetry

DREDGEMAP was set up over a domain that extended approximately 30 km (north - south) by 18 km (west – east; Figure 10.3). The DREDGEMAP model grid covers the section of the Perth Coastline from Alkimos in the north to Scarborough in the south. This region is within the grid domain of Delft3D hydrodynamic model that provides the currents to DREDGMAP. A grid resolution of 30 m by 30 m was selected so that existing features of the domain as well as the proposed Marina layout were adequately defined.

The existing bathymetry was based on a DoT LiDAR topography set (~5 m resolution), supplemented with digitized chart information. A set of 6 staged model bathymetry grids were set up to represent the evolving Marina layout as construction activities were progressively completed. A description of the 6 staged bathymetry grids is outlined below, with Figure 10.3 showing each of the staged grids:

1. Existing bathymetry and coastline – applied during the first month of construction.

2. December 2012 – representative of the portion of the northern and southern breakwaters that are expected to be complete after one month of construction.

3. January 2013 – representative of the portion of the northern and southern breakwaters that are expected to be complete after two months of construction.

4. February 2013 – representative of the portion of the northern and southern breakwaters that are expected to be complete after three months of construction, and the portion of the northern reclamation that is expected to be complete after one month of construction.

5. March 2013 – representative of the completed northern breakwater, the completed northern and peninsula reclamations and the portion of the southern breakwater that is expected to be complete after four months of construction.

6. Final construction layout – representative of the completed northern and southern breakwaters and the completed northern and peninsula reclamations. This layout was used for all marina dredging operations modelling and has the existing bathymetry inside the marina prior to dredging.

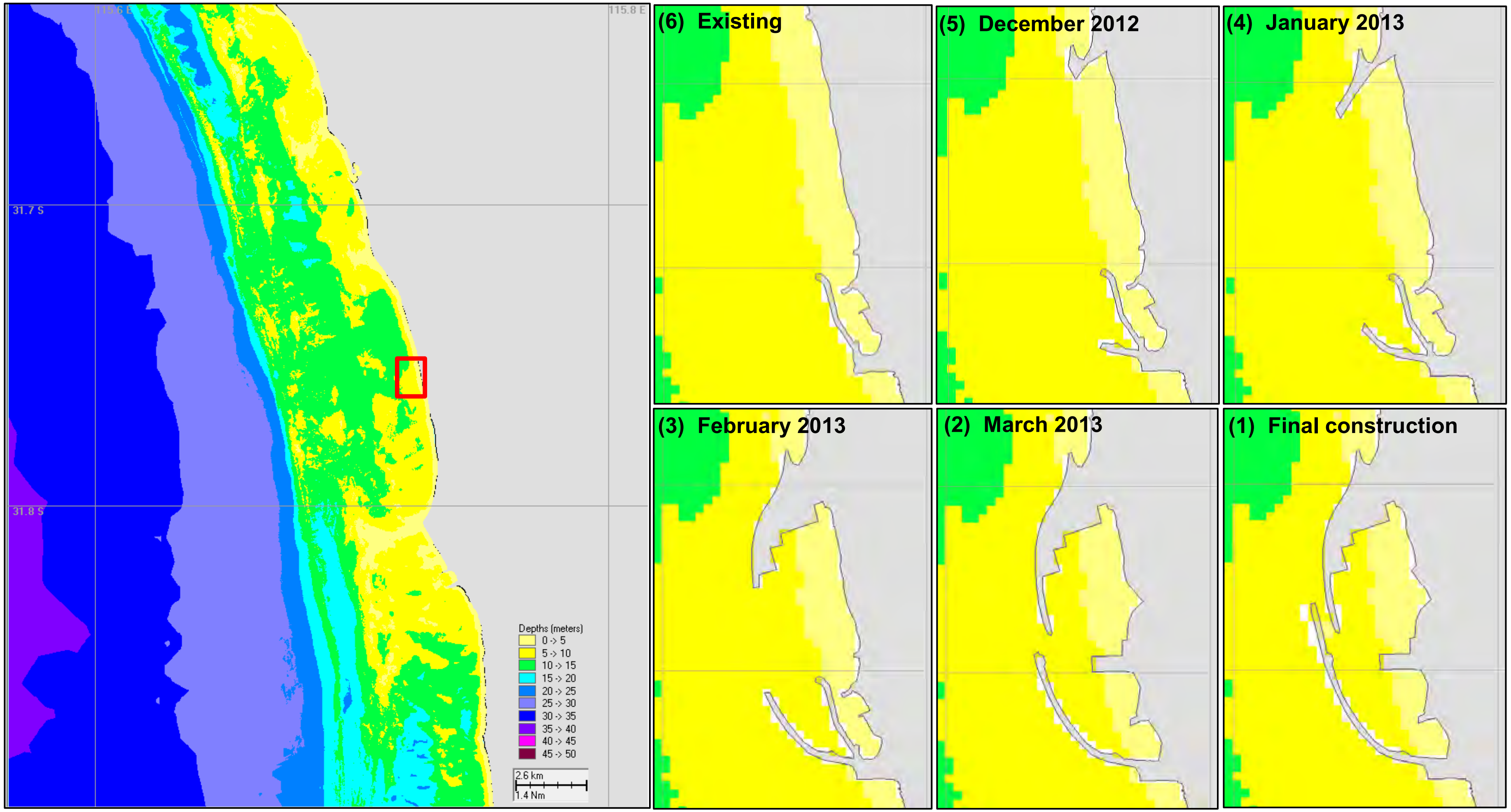

Figure 10.3: Domain and bathymetry (left) with zoomed views of the marina area bathymetry for the 6 staged bathymetry grids (right panels), zoom area indicated by the red box on left panel.

10.3 Simulation Scenario

Simulation of the sediment fate was completed for one scenario, spanning the period from the beginning of November 2012 through to the end of November 2013. The construction and dredging period modelled was therefore 13 months in duration, with the modelling time period selected on the basis of being representative of the typically expected conditions at the site. Breakwater and reclamation construction activities were assumed to be complete towards the end of April in 2013, with the dredging operations commencing immediately thereafter.

10.4 Model Results

The results of the 3D sediment fate model were output hourly over the model domain, for the duration of the construction period modelled. Post-processing was completed to derive maximum total suspended solids (TSS) concentration through the water column, which were used to predict the extent of potential plume movement, as well as possible visible plume signatures by comparing to notional thresholds based on levels applied in previous projects of a similar nature. Potential sediment deposition remote from the immediate construction zone was also assessed by analysing maximum bed coverage of settled material and also the temporal behaviour during the construction period.

The use of the maximum TSS through the water column as an indicator of likely plume extent is likely to be a conservative approach, since sediment is expected to gradually settle towards the seabed. Remote from the construction zone, higher concentrations are expected near the seabed, even following resuspension by sufficiently strong wave and current conditions.

The following sections present discussion based on results indicating excess TSS or sedimentation generated by dredging and general construction activities. The influence of the natural background values is not included and therefore any presented threshold values can be considered as elevations above ambient levels.

10.4.1 General Plume Behaviour

Processing has been completed for each of the separate construction phases (breakwater/reclamation and dredging) as well as the full construction period. This was done to allow the potential effect of each of the processes to be compared and also placed into context with the results predicted over the full period.

The statistical results presented herein can be further developed in monthly subsets, as the modelling was conducted month by month. Where relevant below, samples of these cases are presented graphically in the discussion, however monthly percentile maps are included in an Appendix to this report.

10.4.1.1 Breakwater Construction Period

During the breakwater construction period, sediment sources arise from the dumping of core material during as the breakwaters progress seaward from the shoreline. Although the magnitude of the source is relatively small, and much of the material is relatively coarse, the construction face is relatively exposed to incident wave conditions and prevailing currents.

Figure 10.4 presents the 99th percentile of maximum TSS concentration resulting from the breakwater and reclamation construction phase, which occurs during the first 6 months of the program. While this plot does not present snapshots of the expected plume (visible or not) at any one time, it does provide detail of the level of effect that is predicted to be exceeded 1% of the time or less. Based on Figure 10.4, the area outside of a 70 m buffer zone from the ORM that had a total suspended sediment concentration above 2 g/m^2 at any time during breakwater construction was 1,642 m^2.

The highest concentrations outside of the direct footprint are expected to the immediate north, likely resulting from the initial core placement as part of the northern breakwater construction. Figure 10.6 shows the 99th percentile map from the initial month, clearly showing the effect of the dual construction fronts on local suspended sediment elevations.

In terms of the 6- month analysis period, 1% of the time equates to less than 2 days, and less than 8 hours over any month. The results therefore predict that high TSS concentrations are likely to be very localised and short-lived.

10.4.1.2 Marina Excavation

At the commencement of the marina excavation, a silt curtain barrier is proposed to be placed across the opening of the new marina breakwaters. This barrier will prevent a large proportion of fine material escaping into the external marine environment, however at times material may be discharged. Modelling of the barrier has assumed that only the finest material present in the upper portion of the water column would have the potential to wash over the barrier, given suitable conditions for this to occur. The model construct is idealised, and not intended to be an exact model of the process, given that should the silt curtain be installed and maintained effectively, there may be little to no discharge of sediment at all.

Figure 10.7 shows the 99th percentile contour of maximum TSS derived from analysis of the full dredging period. The results show that the discharge of any significant concentration of suspended sediment is expected to occur less than 1% of the time, with the sediment expected to be contained within the marina. TSS concentrations are shown to be locally higher within the marina due to dredging when compared to the breakwater construction and reclamation process, as expected. Suspended sediment will gradually settle within the marina and would then be unlikely to be resuspended by natural processes.

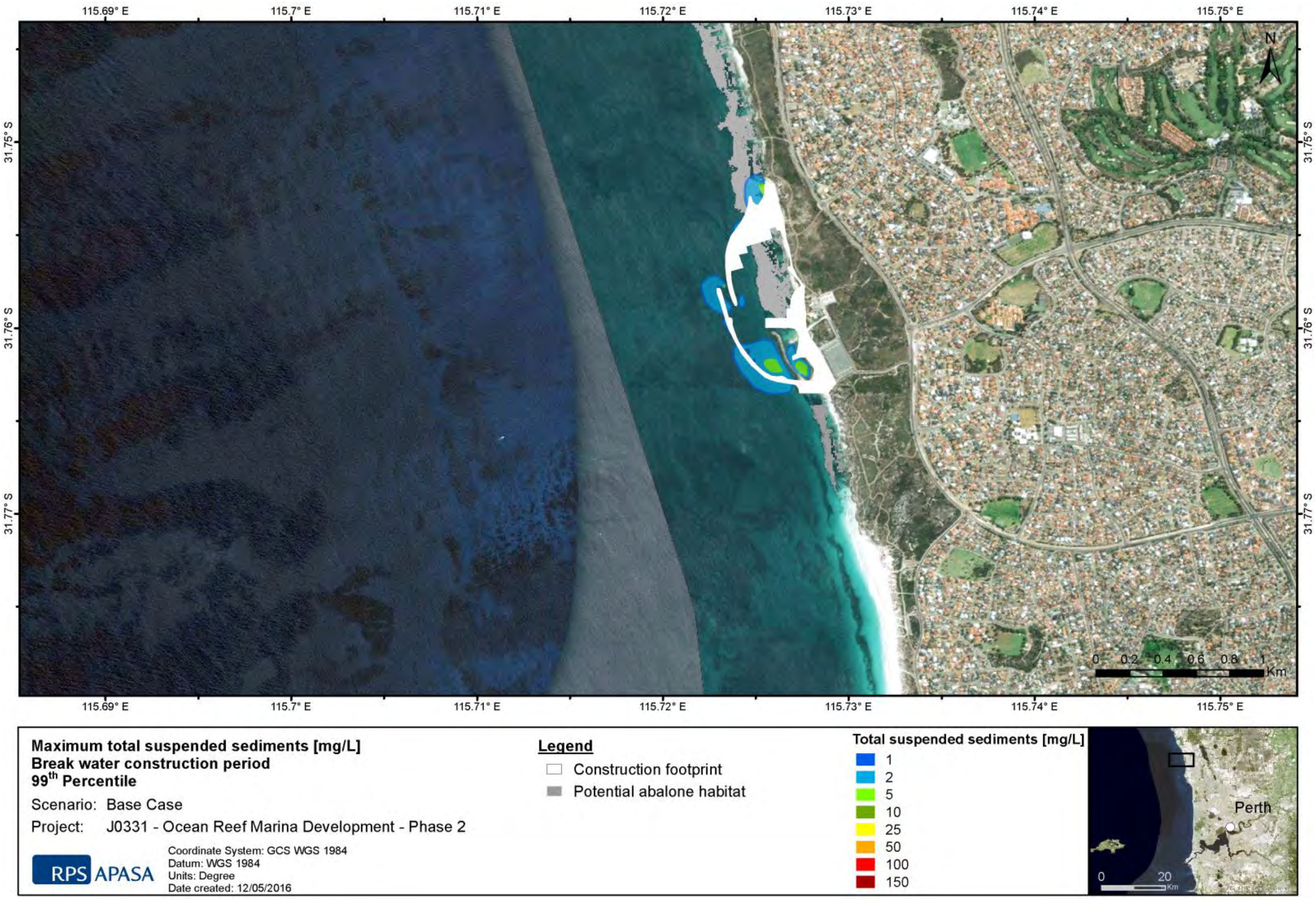

Figure 10.4 Map of the 99th percentile of maximum TSS concentrations (any depth) during the breakwater/reclamation construction period (first 6 months).

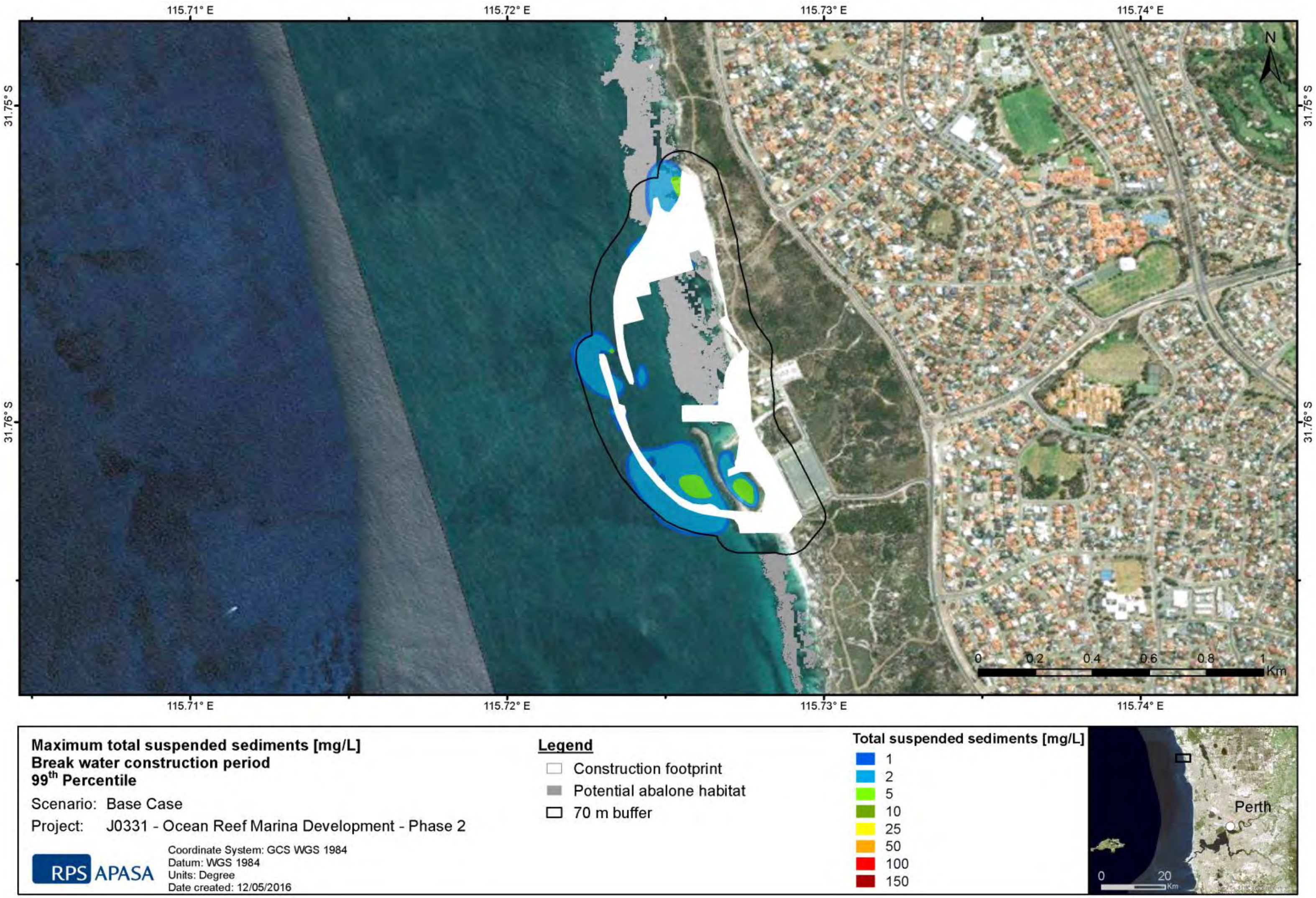

Figure 10.5 Zoom view map of the 99th percentile of maximum TSS concentrations (any depth) during the breakwater/reclamation construction period (first 6 months), with the boundary of a 70 m buffer zone indicated.

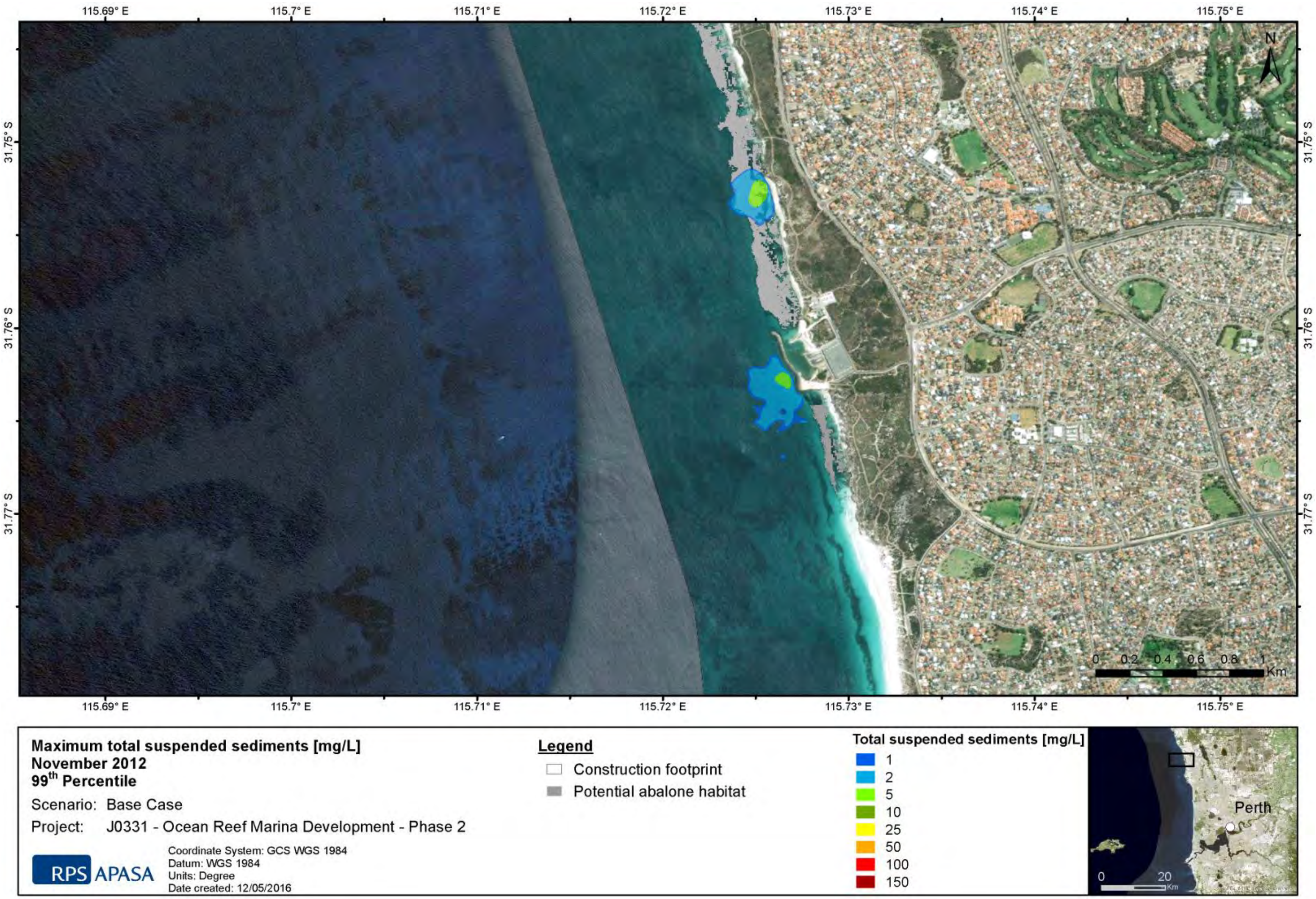

Figure 10.6 Map of the 99th percentile of maximum TSS concentrations during the first month of the breakwater/reclamation construction period.

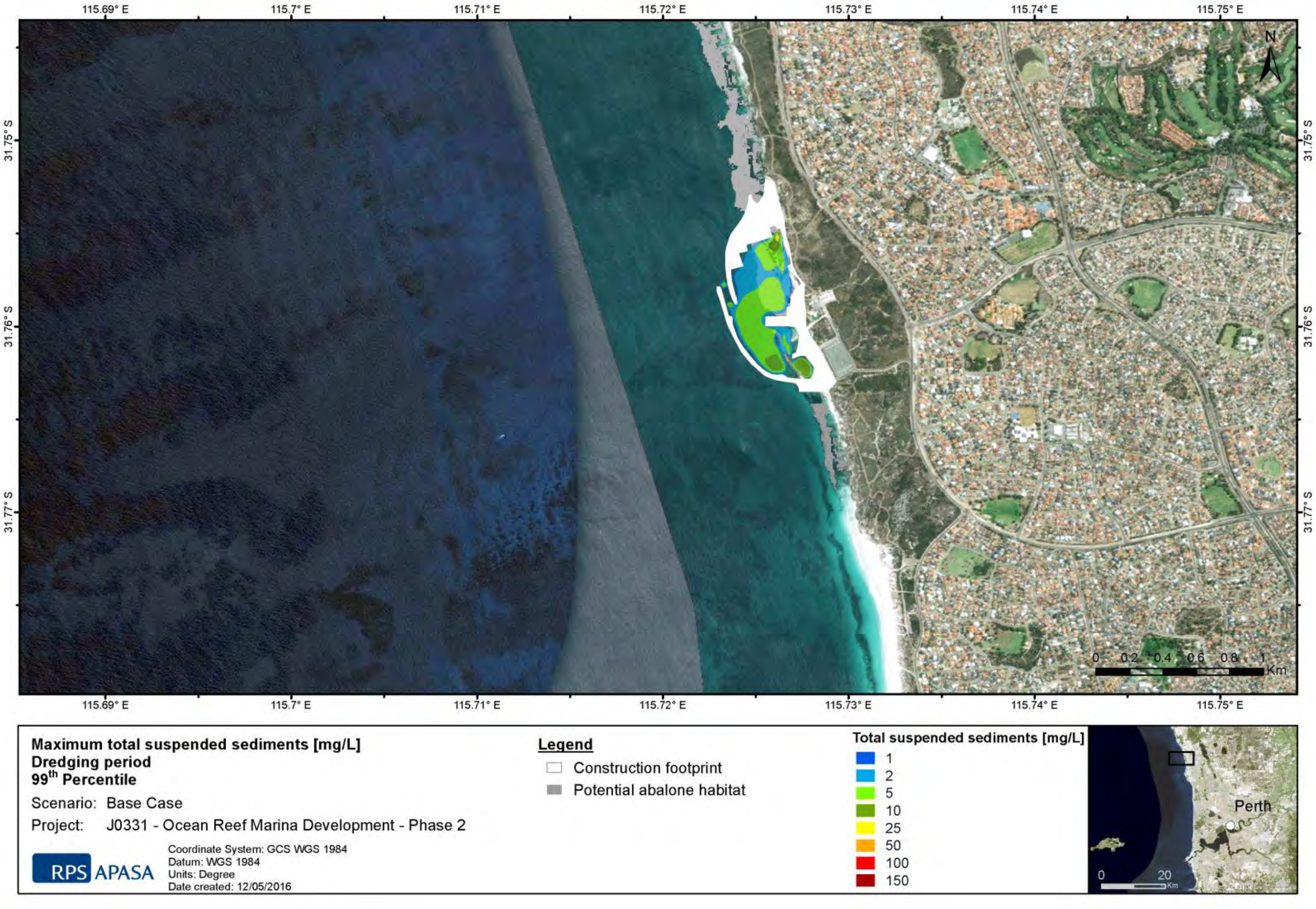

Figure 10.7 Map of the 99th percentile of maximum TSS concentrations during the dredging period (final 7 months).

10.4.1.3 Full Construction Period

Figure 10.8 shows the composite 99th percentile of maximum TSS for the full construction period. This figure highlights the localised levels that are expected to be exceeded 1% or less over the full 13 month period, which equates to approximately 4 days in total. The only area external to the marina showing any TSS elevation when evaluated at this threshold is immediately adjacent and to the north of the marina. This is likely due to persistent low levels of TSS during the initial months of the construction period, which is further highlighted below.

10.4.1.4 Time-series at Reference Locations

To aid understanding of the time-varying nature of the behaviour of any released plume, time-series maximum TSS results have been extracted at a series of reference locations (Figure 10.9). The resulting time-series at the locations for the full construction period are given in Figure 10.10.

The time-series results show the clear delineation between the respective construction phases, with elevated TSS concentrations occurring generally at the marina locations from late April through to November. The highest concentrations are expected within the marina due to dredging activities, with lower and more sporadic signals at the affected sites during the early breakwater construction phase.

Of the reference sites within the Abalone habitat zones, only site Abalone North 1 shows any persistence in expected TSS impact, which is predicted to occur primarily during the initial month of construction. This is expected since the construction of both breakwaters commences from the shoreline, extending outward. During this period, the general drift direction is expected to be northward for the most part, and episodic elevations of local TSS are expected. The maximum TSS elevation predicted by the model at this location is approximately 11 mg/L. Further north, the effect is likely to be significantly diminished (see results for site Abalone North 2).

At the southern habitats, site Abalone South 2 shows small episodic elevations in TSS primarily during the initial two months of construction. The maximum elevation of TSS predicted by the model during this period is approximately 5 mg/L.

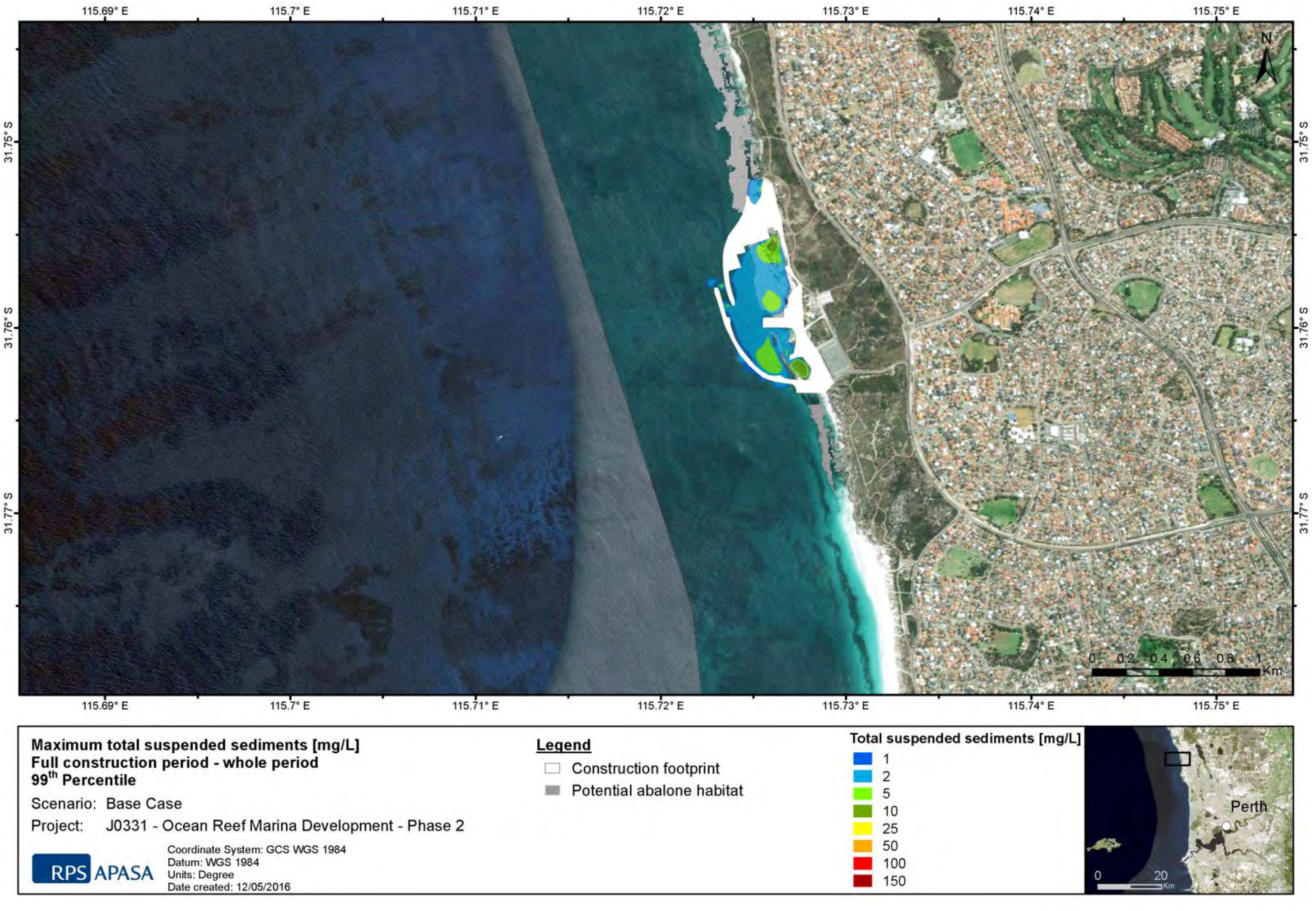

Figure 10.8 Map of the 99th percentile of maximum TSS concentrations during the full construction period.

Figure 10.9 Location of reference sites used for time-series presentation of maximum TSS.

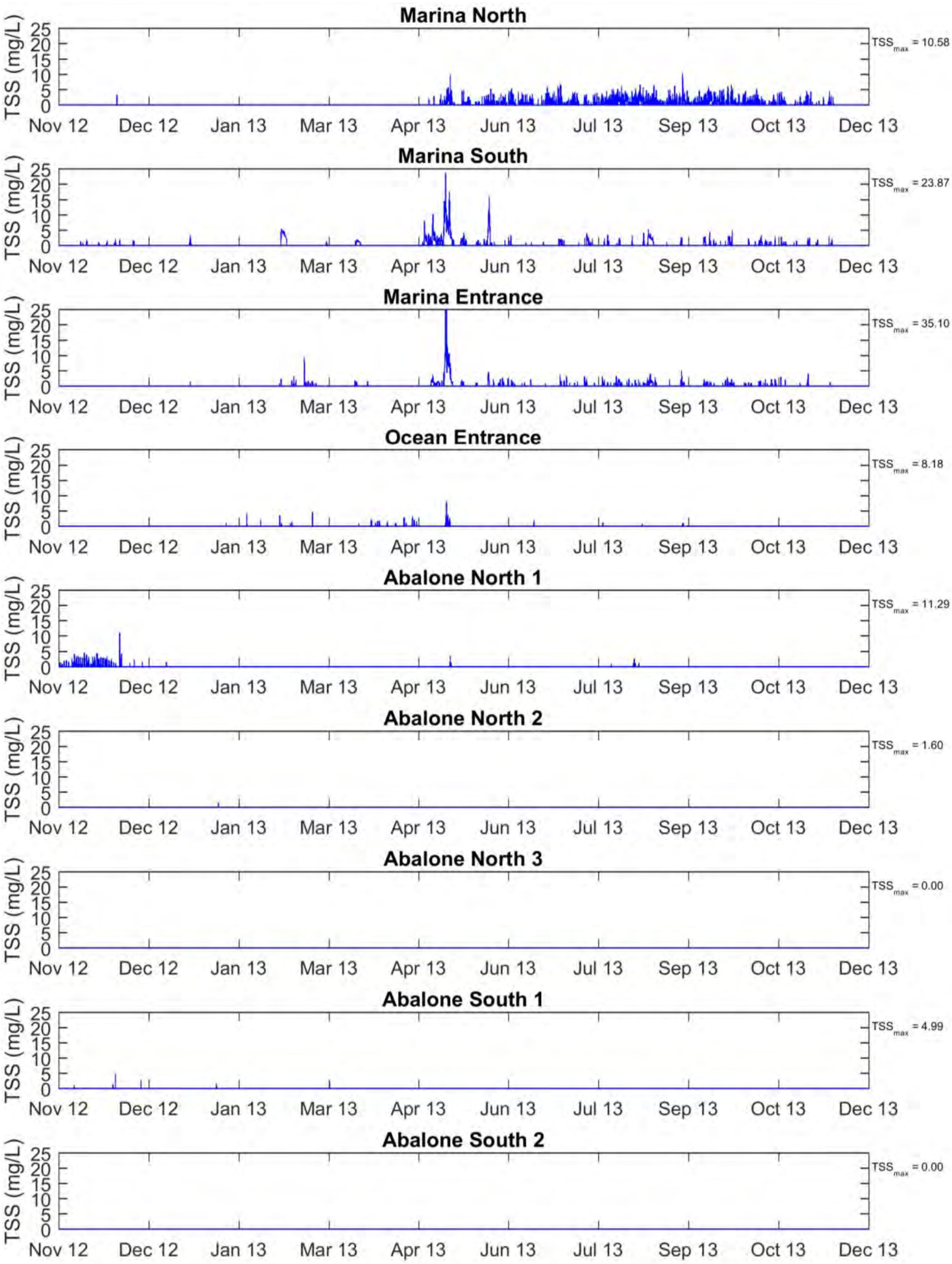

Figure 10.10 Time-series of maximum TSS in the water column at assessed reference locations (refer to Figure 10.9).

10.4.2 Potential Visible Plume Extent

The extent of the visible plume in these relatively clear waters is expected to be where the combined TSSC of the dredge-generated plume and background suspended sediment concentration is above approximately 4 mg/l. Previous studies (DEP, 1996) have identified background TSSC values for Perth Coastal Waters of the order of 2 - 3 mg/l; therefore a dredge-generated TSSC threshold of 2 mg/l was applied as an indicator of the likely extent of the visible plume. The present guidelines (EAG7; EPA, 2011) suggest that the extent of a visible plume represents a broad definition of the potential Zone of Influence related to the proposed construction and dredging activities.

The predicted extent of the visible plume is presented in Figure 10.11 – Figure 10.13, where mapping of a 2 mg/L elevation at any time, and anywhere in the water column, has been applied to define the potentially affected region. The figures show results for the complete dredging period, as well as the composite periods of the breakwater construction (~ months 1 through 6), and the marina dredging period (final 7 months). Overall, the higher level of sediment disturbance resulting from dredging within the marina is expected to result in a potentially larger visible plume footprint. This is expected to result from episodic fine sediment release during energetic conditions, such as winter storms and where sufficient outflow is occurring from the marina.

It should be noted that the maps do not show where the visible plume may be seen at one moment in time, it represents the summation of maximum values over the entire dredging program. A visible plume may be present at varying persistence over this zone, and is generally expected to be confined to the near vicinity of the construction site.

Figure 10.11 Map of the potential extent of the area where visible plumes may occur during the dredging and construction periods (at any particular time, the plume would only cover fraction of this area). Analysis based on TSS elevation of 2 mg/L above background occurring at any time and at any level in the water column.

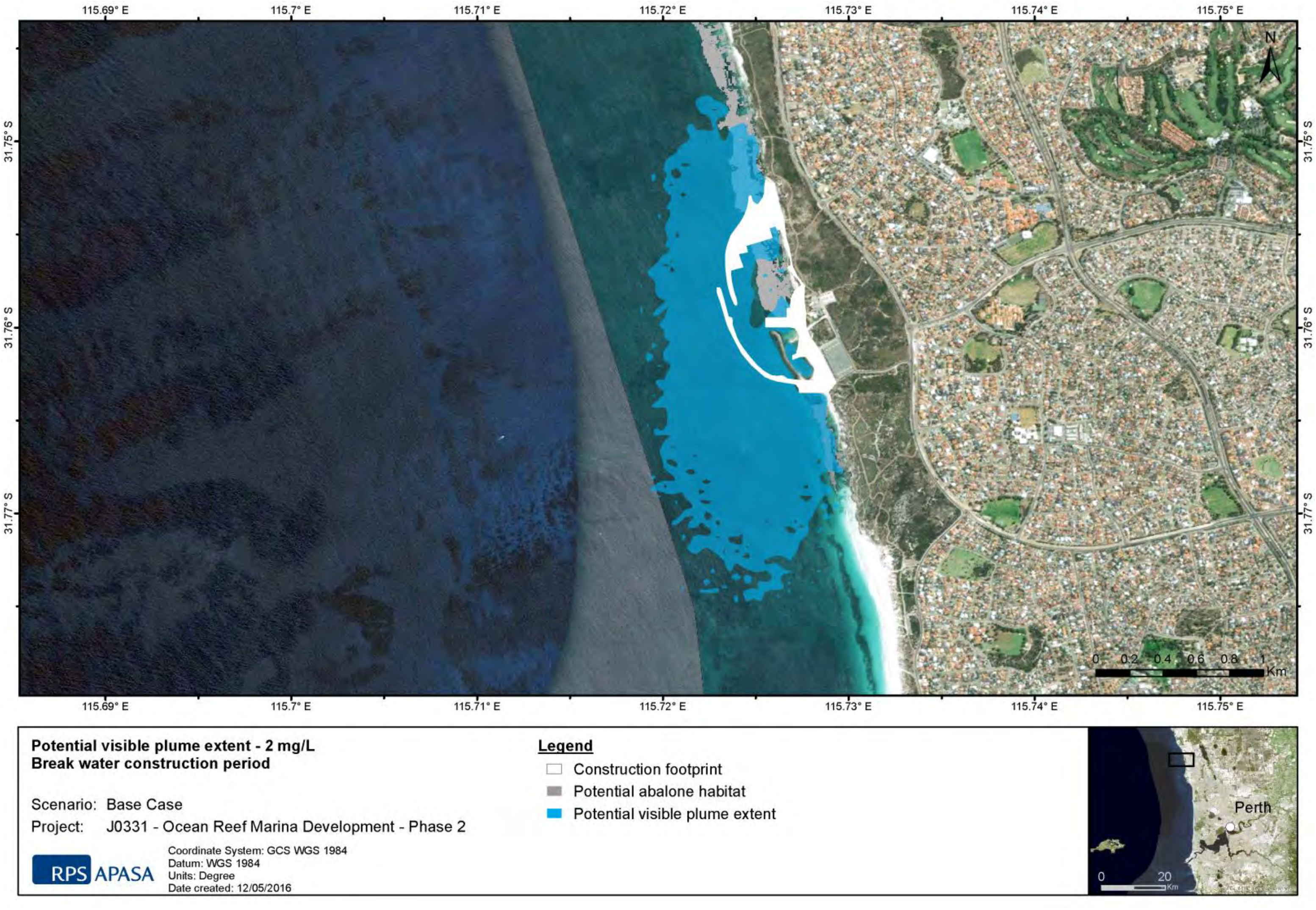

Figure 10.12 Map of the potential extent of the area where visible plumes may occur during the construction phase at any time (at any particular time, the plume would only cover fraction of this area). Analysis based on TSS elevation of 2 mg/L above background occurring at any time and at any level in the water column.

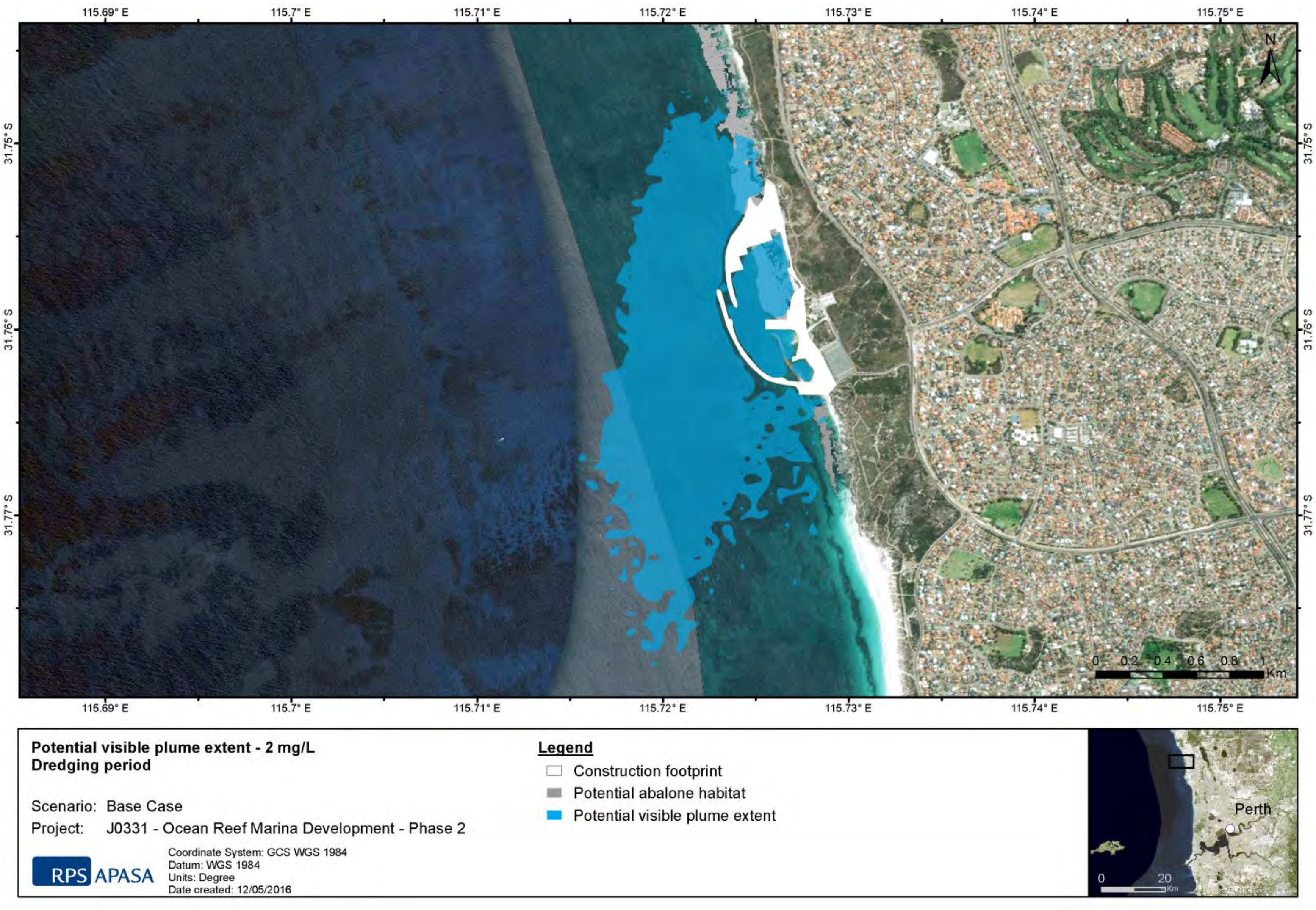

Figure 10.13 Map of the potential extent of the area where visible plumes may occur during the dredging phase at any time (at any particular time, the plume would only cover fraction of this area). Analysis based on TSS elevation of 2 mg/L above background occurring at any time and at any level in the water column.

10.4.3 Potential Seabed Deposition

Deposition of suspended sediment may have the potential to affect the environment over time through direct burial of habitats or substrates. In shallow water zones exposed to wave action, the finer sediment that is able to disperse larger distances from the source location tends to be readily resuspended, resulting in little residual depositional impact both during and following construction. In reviewing the modelling results, which only considered the sediments directly attributable to the dredging and construction (i.e. above background), we find this to be the predicted outcome of this construction program.

The dynamic nature of the deposition and resuspension cycling is demonstrated by the time-series extracted at reference site Abalone North 1 for the initial two months of construction (Figure 10.14). The time-series shows irregular deposition and then resuspension events occurring every 1 to 2 days at this particular site. The persistence of any deposition is predicted to be very short, typically in the order of a few hours, even when larger depositional events occur (for example as simulated at the beginning of December, 2012).

The results are consistent with the expectation that only very fine sediment is likely to be dispersed away from the marina site; material that can be readily resuspended given exposure to wave energy incident to the local coastline and reef system.

Figure 10.15 presents a map showing the maximum predicted bottom concentration (in units of g/m^2) at any time during the modelled construction period (Figure 10.5 presents a zoomed view of the same results). The image does not represent a static situation, rather the maximum levels taken from all time-steps simulated. As indicated above, external to the marina zone, the conditions are dynamic enough to ensure that any settled material is quickly resuspended and dispersed into the background environment. The area of the region that was outside of a 100 m buffer zone from the marina, and that had a bottom concentration greater 1000 g/m^2 was 749 m^2.

The maximum bottom concentration map shows that beyond the immediate vicinity of the marina, seabed deposition is expected to be less than 100 g/m^2 at any time, and less than 1 g/m^2 further than approximately 500 m away from the construction activities. At these levels, there is some contact expected on the reefs to the immediate north and south of the marina where potential abalone habitat has been identified.

To place these levels in context, assuming a typical sediment bulk density 2,600 kg/m^3 and settled porosity of 0.5 (bulked up volume is doubled prior to consolidation), 100 g/m^2 equates to a deposited thickness of approximately 0.1 mm. Levels of environmental concern are expected to be greater than this value.

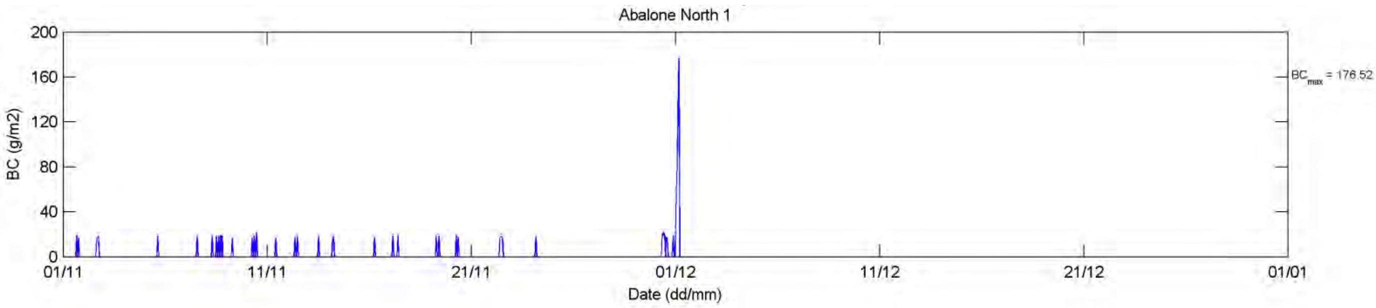

Figure 10.14 Time-series of seabed sediment deposition above background (g/m^2) at the Abalone North 1 reference site during the initial two months of construction (Nov/Dec 2012).

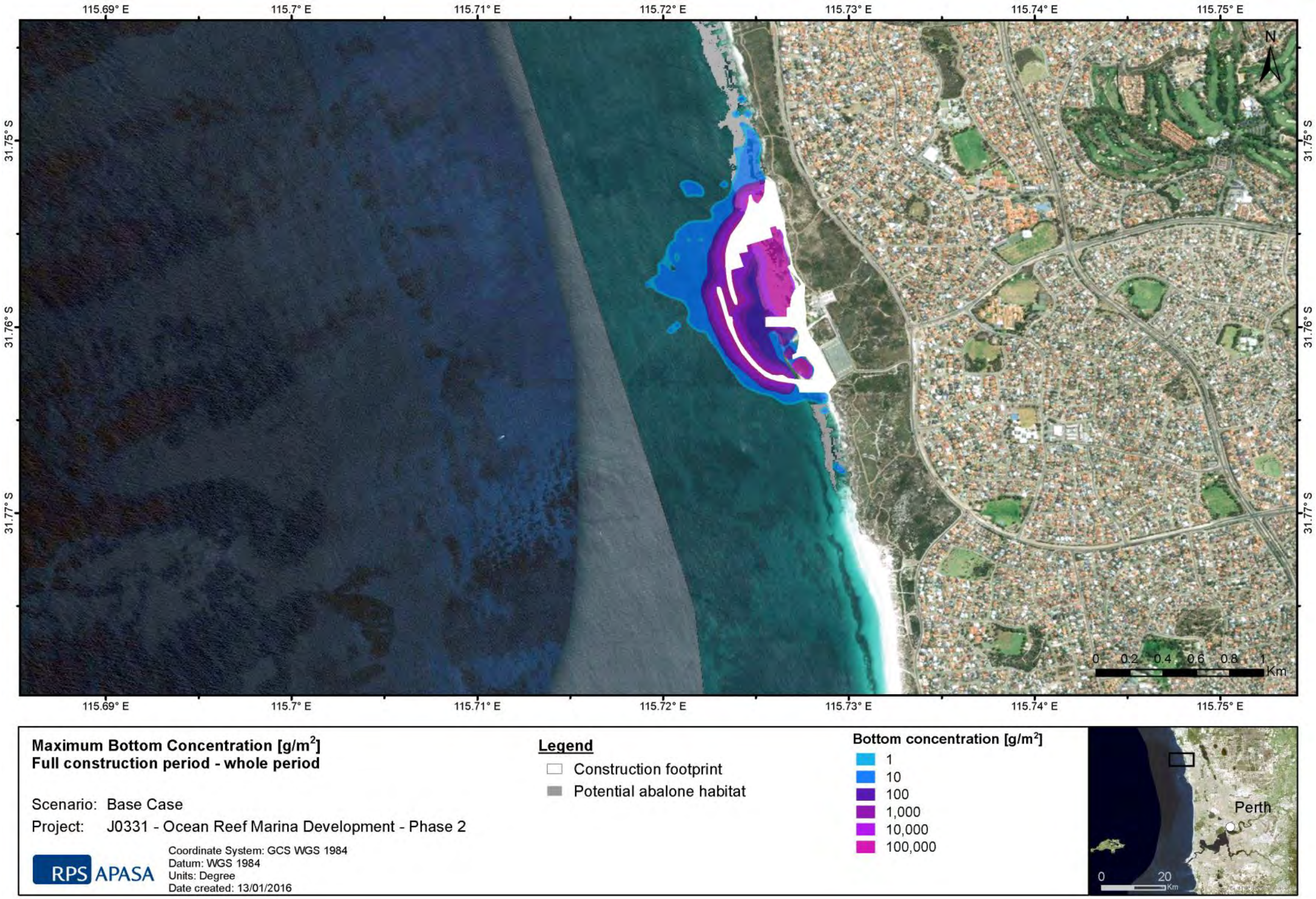

Figure 10.15 Map of the potential extent of the area where bottom deposition above model thresholds is expected to occur during the full construction period. Analysis based on bottom concentration above background occurring at any time regardless of persistence.

11.0 Climate Change Scenarios

Anthropogenic climate change has the potential to impact water quality within ORM during the coming century. The most foreseeable mechanism for adverse impact is an increase to the natural flushing time due to higher sea level and/or reduced groundwater discharge into ORM. In this component of the water quality assessment the hydrodynamic model framework is used to test the sensitivity of the ORM flushing characteristics to plausible combinations of changes in sea level and ground water flows.

It can be noted in parenthesis that predictions of sea level changes for the next century are considered to be more robust than the predictions of groundwater changes because the latter is a more localised phenomenon. Modelled groundwater reductions are based on the assumption of reduced recharge due to decreased rainfall and/or increased groundwater abstraction. These potential influences can be reasonably forecast out to the year 2040 but are very difficult to forecast reliably beyond that.

11.1 Method

Two climate change scenarios were considered for this assessment. The first climate change scenario represents a forecast for the year 2040. Groundwater discharge to the ORM for this scenario was forecast to reduce from the base case by 8% and 6% for summer and winter respectively (Rockwater 2015), based on an assumed 20% reduction in groundwater recharge. The sea level is predicted to increase by 0.13 m above 2015 levels based on Western Australian government guidelines for coastal infrastructure (Department of Transport, 2010).

The second climate change scenario represents a long term forecast to the year 2115. The sea level for this scenario was forecast to increase by 0.9 m above 2015 levels, again based on WA government guidelines for coastal infrastructure (Department of Transport, 2010). As changes in groundwater discharge couldn’t be reliably estimated, they were assumed to reduce by 40% relative to the base case values. This is intended to serve as an extreme estimate given the uncertainty.

Two particular simulation periods that were identified as having the longest flushing times under current climate conditions were remodelled for the two climate change scenarios. The periods identified were the autumn neap tide period commencing on 21 March 12 and the winter spring tide period commencing 19 July 2013. For each period and each scenario the flushing times were calculated using the same methodology detailed in Section 7.0.

11.2 Results for Climate Change Scenarios

The e-folding results for the climate change scenarios are summarised and contrasted against their respective base case results in Table 11.1. The results for the year 2040 scenarios indicate that the maximum e-folding times are forecast to increase by around 24 to 36 hours, depending on the period considered. The median e-folding time in both the March and July periods increased from approximately 6 days to approximately 7 days. As with the base climate scenarios flushing is dependent on winds and tides.

The results for 2115 scenario indicate maximum flushing times increasing by approximately 2 to 3 days, depending on the period. The median flushing time was forecast to increase from approximately 6 days to approximately 8 days for the July period and from 7 days to 9 days for the March period.

Table 11.1: Summary of e-folding times for base case and climate change scenarios

	Scenario	Base Year 2015	Year 2040	Year 2115	Base Year 2015	Year 2040	Year 2115	Median	Maximum
	Start Date	21 Mar	21 Mar	21 Mar	19 Jul	19 Jul	19 Jul		
Nth Retail	Surface	7.2	8.1	10.1	6.3	6.5	8.1	7.7	10.1
	Bottom	7.2	8.2	10.2	6.3	6.6	8.1	7.7	10.2
Restaurant	Surface	7.1	8.0	9.9	6.2	6.8	8.1	7.6	9.9
	Bottom	7.2	8.1	10.1	6.3	6.8	8.0	7.6	10.1
Nth Pens	Surface	7.1	8.0	9.8	5.6	6.4	8.2	7.6	9.8
	Bottom	7.3	8.2	10.3	6.4	6.8	8.1	7.7	10.3
Mid ORM Nth	Surface	5.9	7.1	9.5	5.6	6.3	8.2	6.7	9.5
	Bottom	6.7	7.6	9.5	6.4	6.9	8.1	7.3	9.5
Sth Retail	Surface	6.4	7.2	9.2	6.2	7.0	8.1	7.1	9.2
	Bottom	6.4	7.3	9.2	6.3	7.0	8.0	7.2	9.2
ORM Mouth	Surface	0.7	1.7	1.7	4.7	4.8	8.4	3.2	8.4
	Bottom	6.5	6.7	8.6	6.7	6.9	7.8	6.8	8.6
Tavern	Surface	6.0	6.2	8.8	5.6	7.1	8.2	6.7	8.8
	Bottom	6.1	6.4	8.8	6.0	7.1	8.0	6.8	8.8
Beach	Surface	5.1	6.2	7.9	5.7	8.1	8.1	7.1	8.1
	Bottom	5.2	6.2	7.9	5.9	8.0	8.0	7.1	8.0
Mid ORM Sth	Surface	4.2	5.8	7.7	5.0	8.3	8.5	6.8	8.5
	Bottom	5.4	6.2	8.6	6.5	8.0	8.0	7.3	8.6
Boat Ramp	Surface	4.9	6.2	7.8	5.8	8.1	8.2	7.0	8.2
	Bottom	5.0	6.2	7.9	6.1	8.1	8.2	7.1	8.2
Median	**All depths**	6.3	6.9	9.0	6.1	7.0	8.1		
Maximum	**All depths**	7.3	8.2	10.3	6.7	8.3	8.5		

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RPS APASA

Ocean Reef Marina Development

Phase 2: Appendix – Monthly Sediment Fate Results

18/01/2016

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IMPORTANT NOTE

A. Maximum TSS - Monthly Results

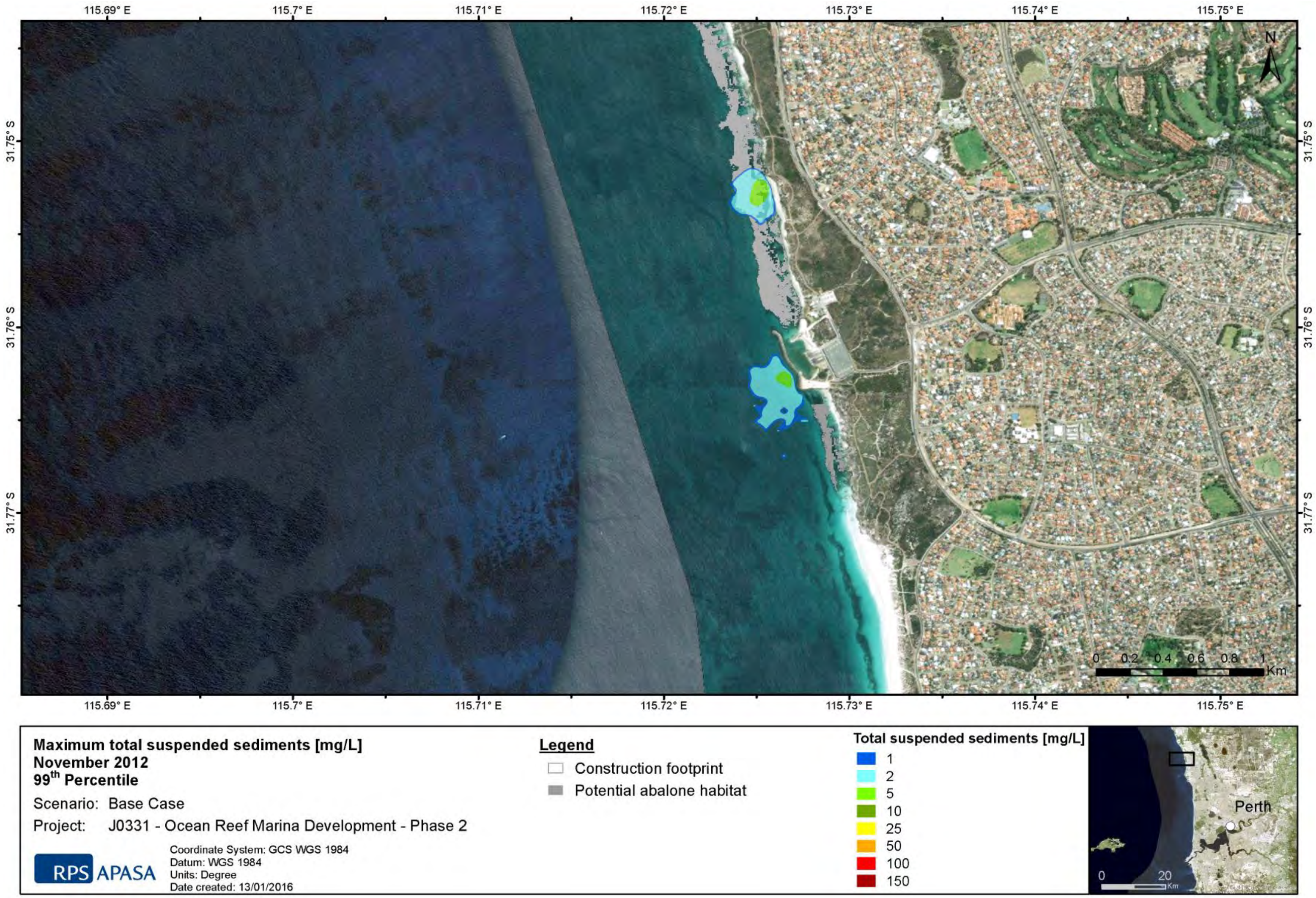

Figure A.1 Map of the 99th percentile of maximum TSS concentrations during November 2012.

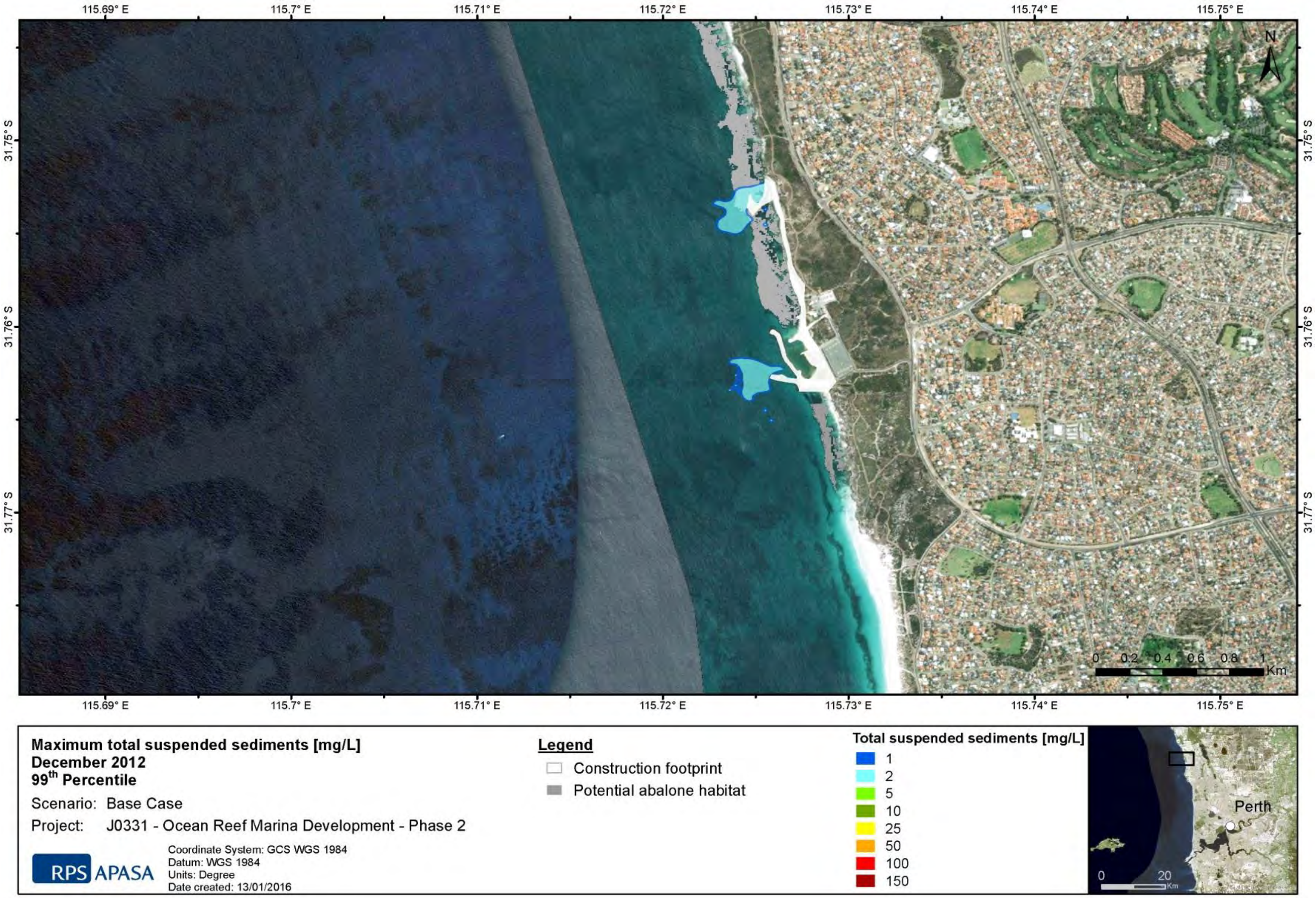

Figure.2 Map of the 99th percentile of maximum TSS concentrations during December 2012.

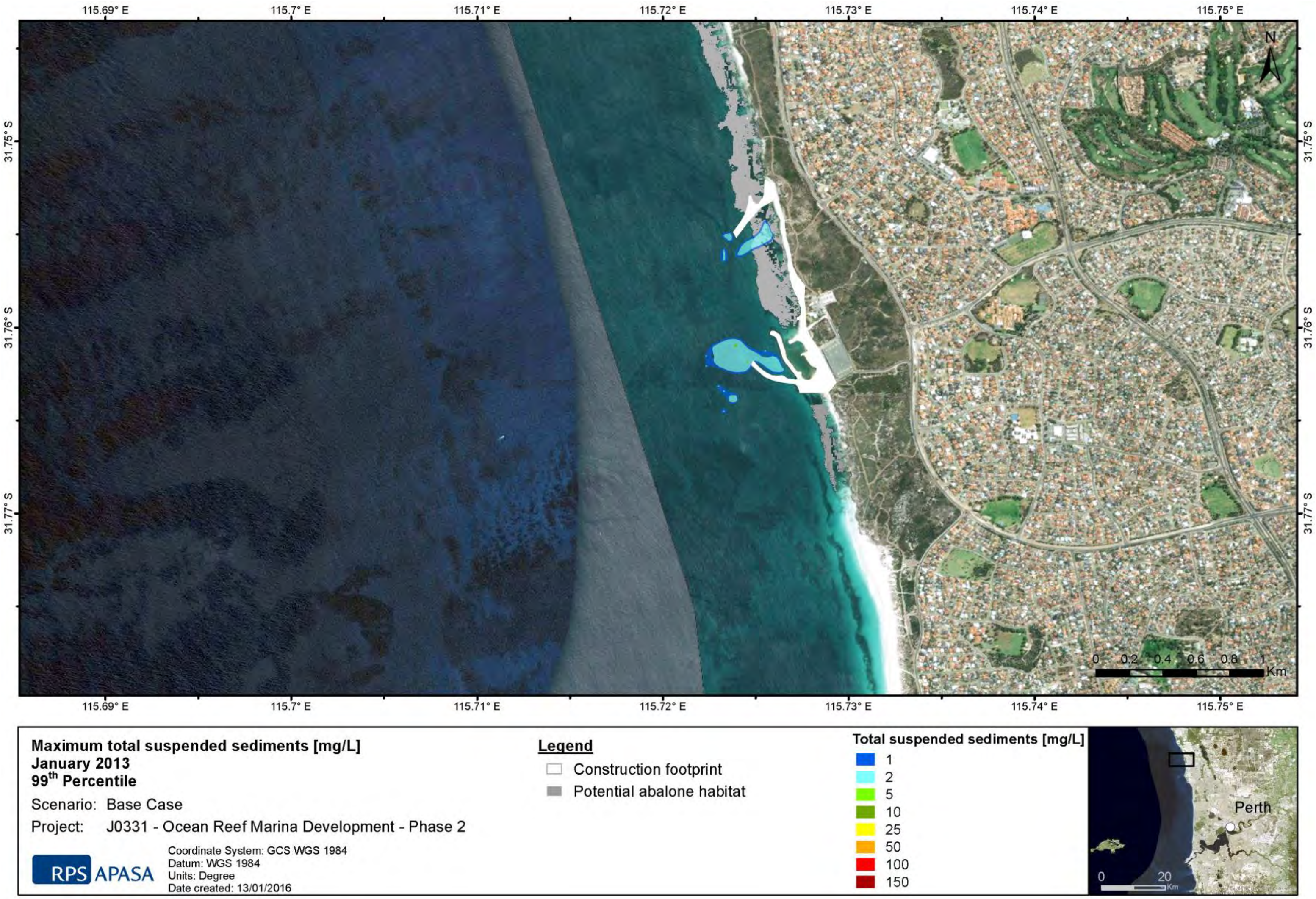

Figure A.3 Map of the 99th percentile of maximum TSS concentrations during the January 2013.

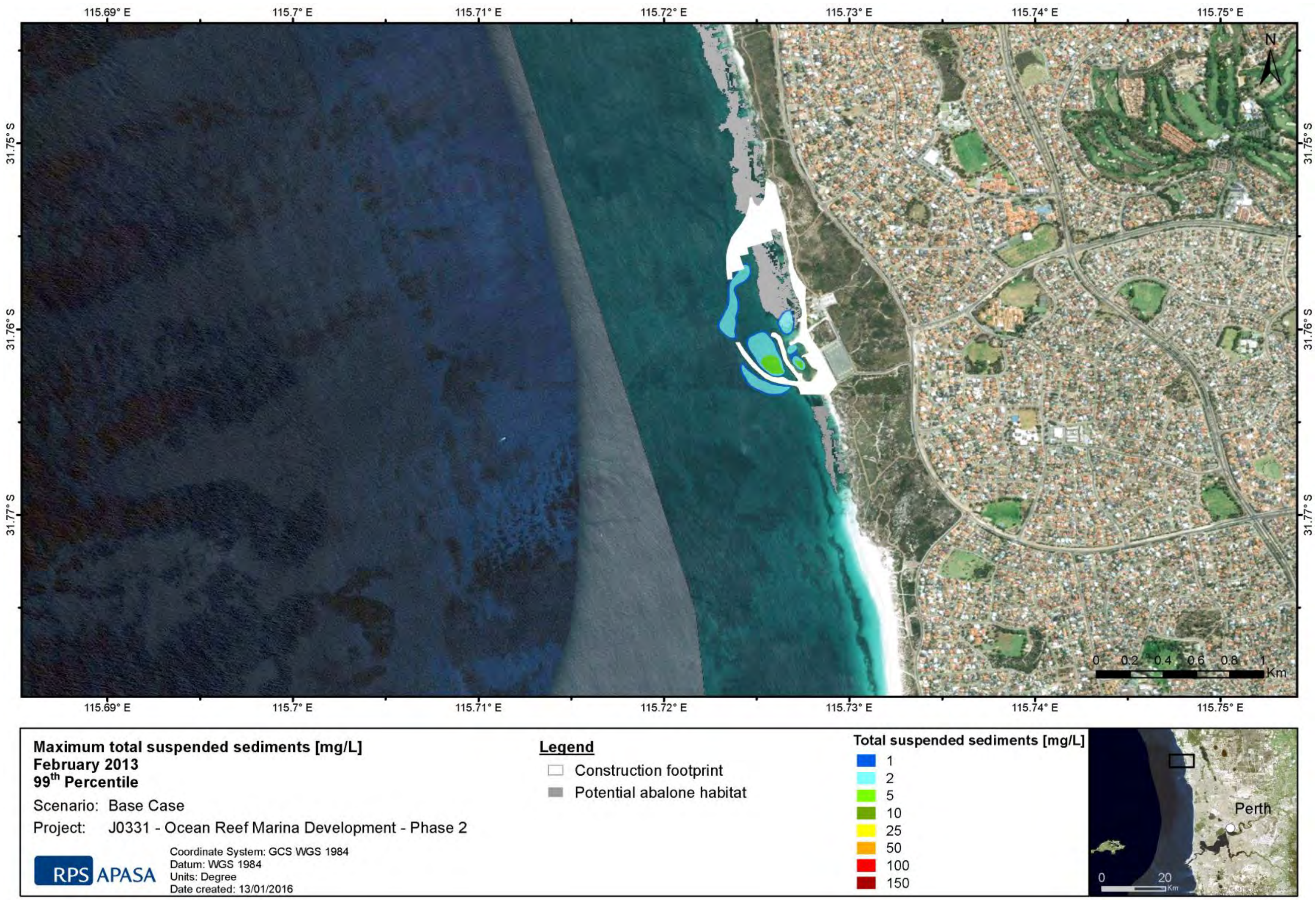

Figure A.4 Map of the 99th percentile of maximum TSS concentrations during February 2013.

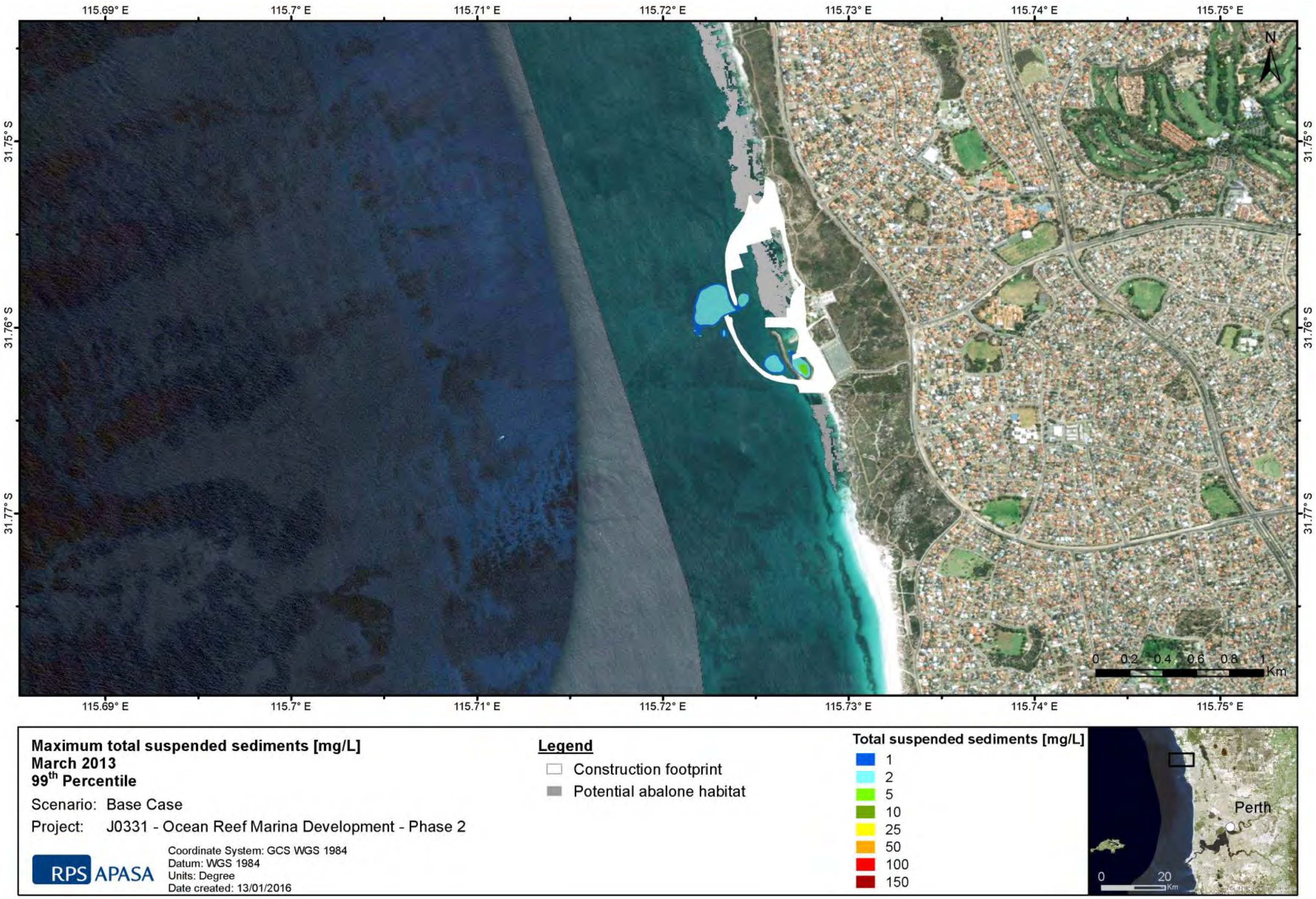

Figure A.5 Map of the 99th percentile of maximum TSS concentrations during March 2013.

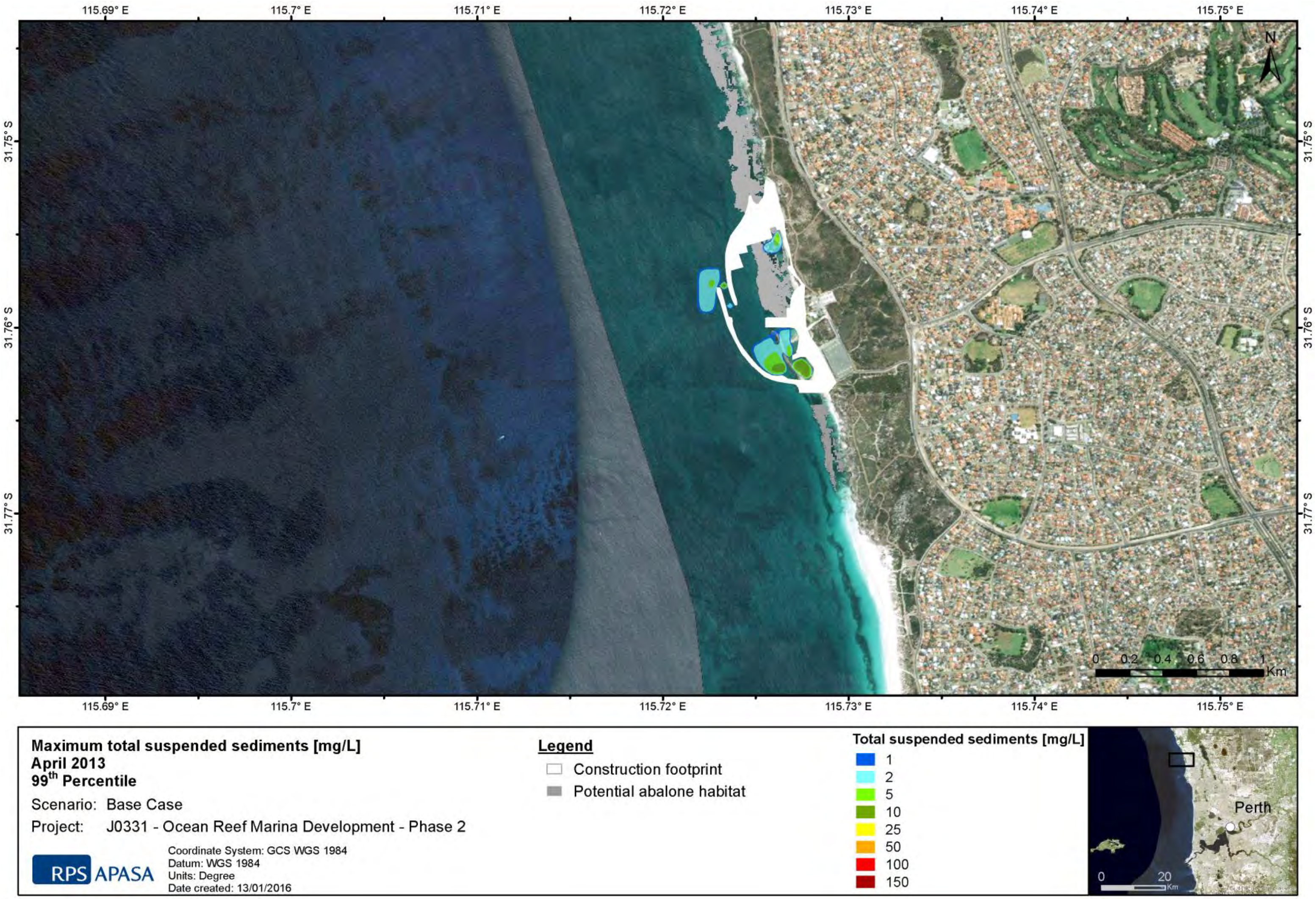

Figure A.6 Map of the 99th percentile of maximum TSS concentrations during the April 2013.

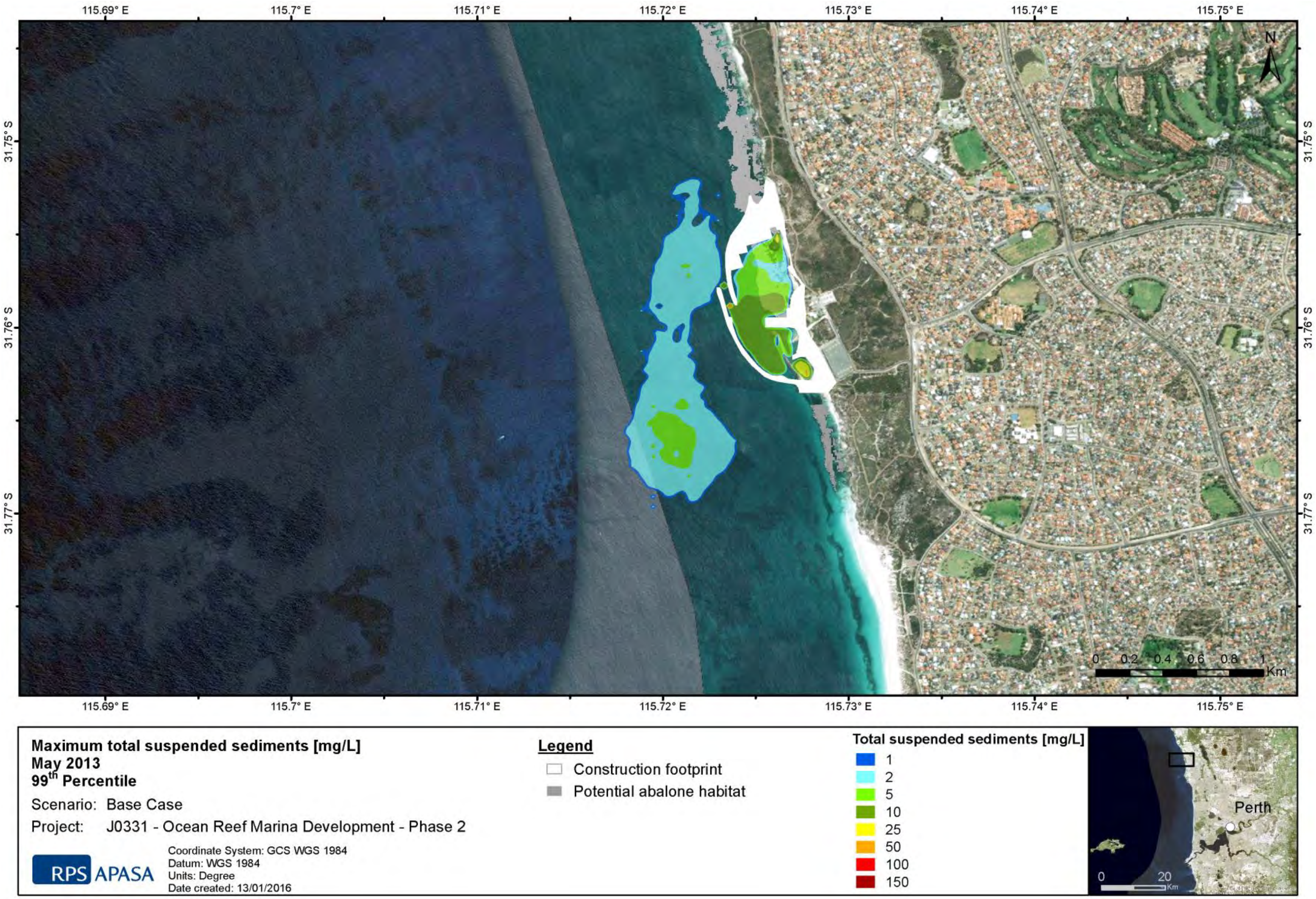

Figure A.7 Map of the 99th percentile of maximum TSS concentrations during the May 2013.

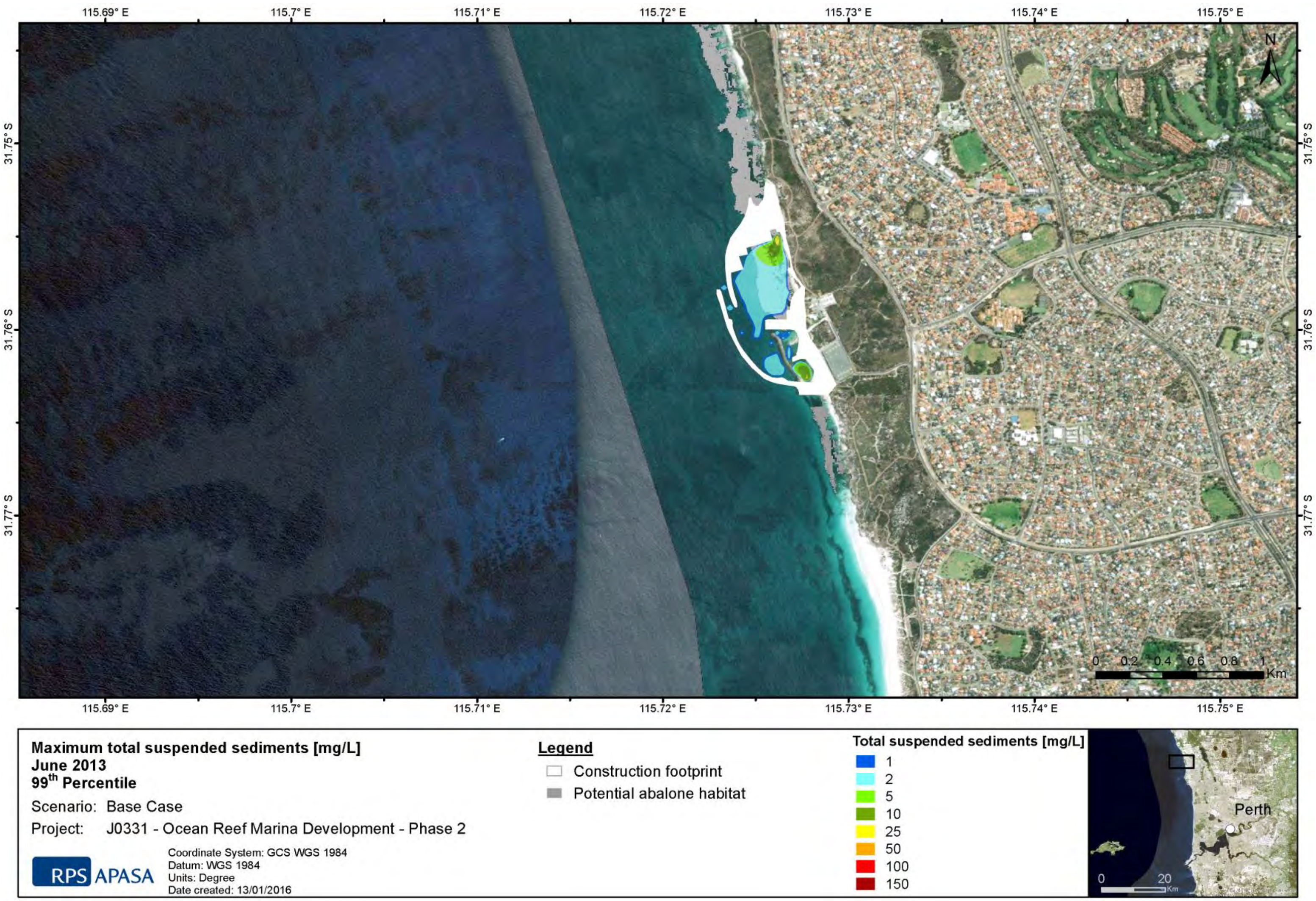

Figure A.8 Map of the 99th percentile of maximum TSS concentrations during June 2013.

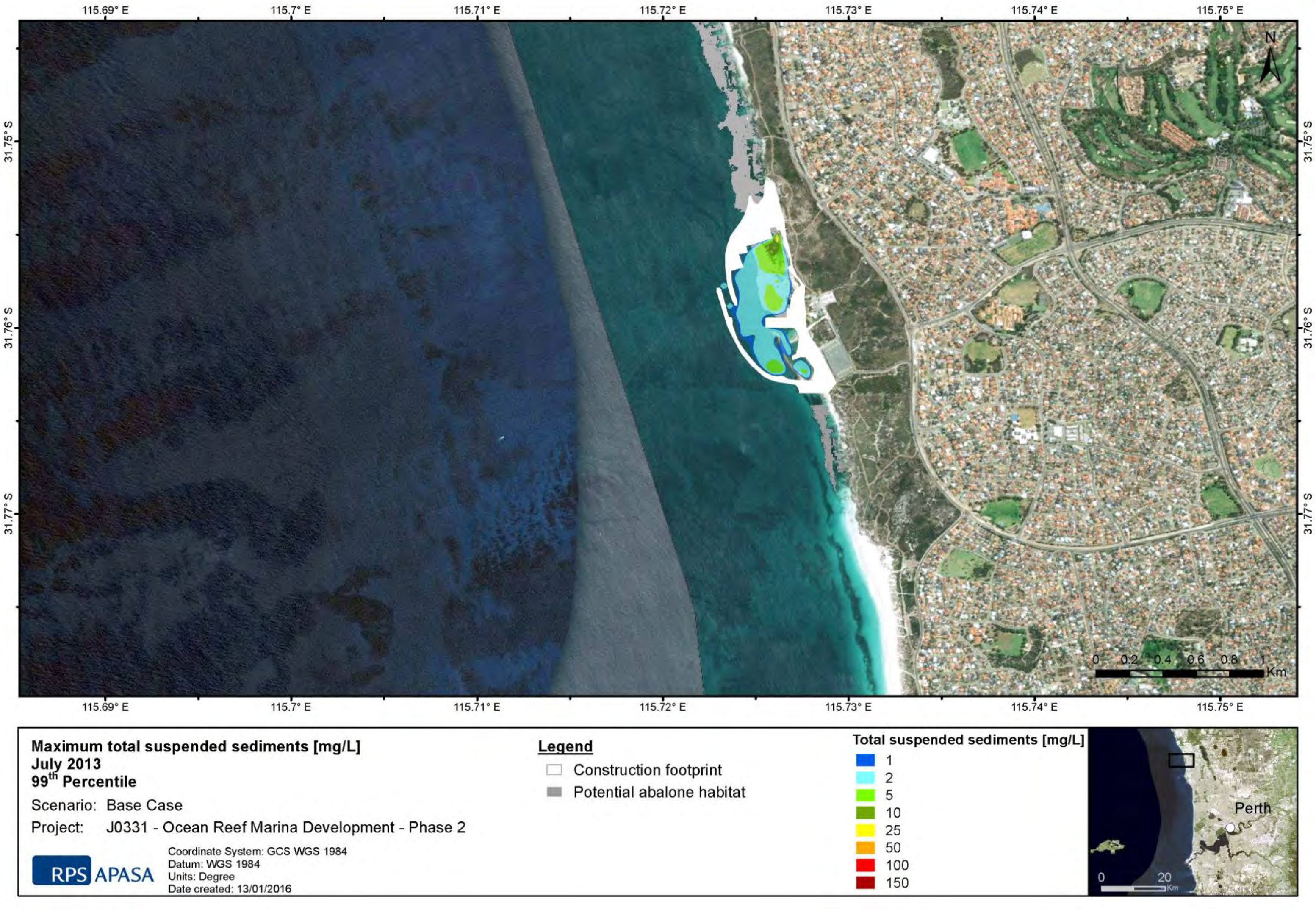

Figure A.9 Map of the 99th percentile of maximum TSS concentrations during July 2013.

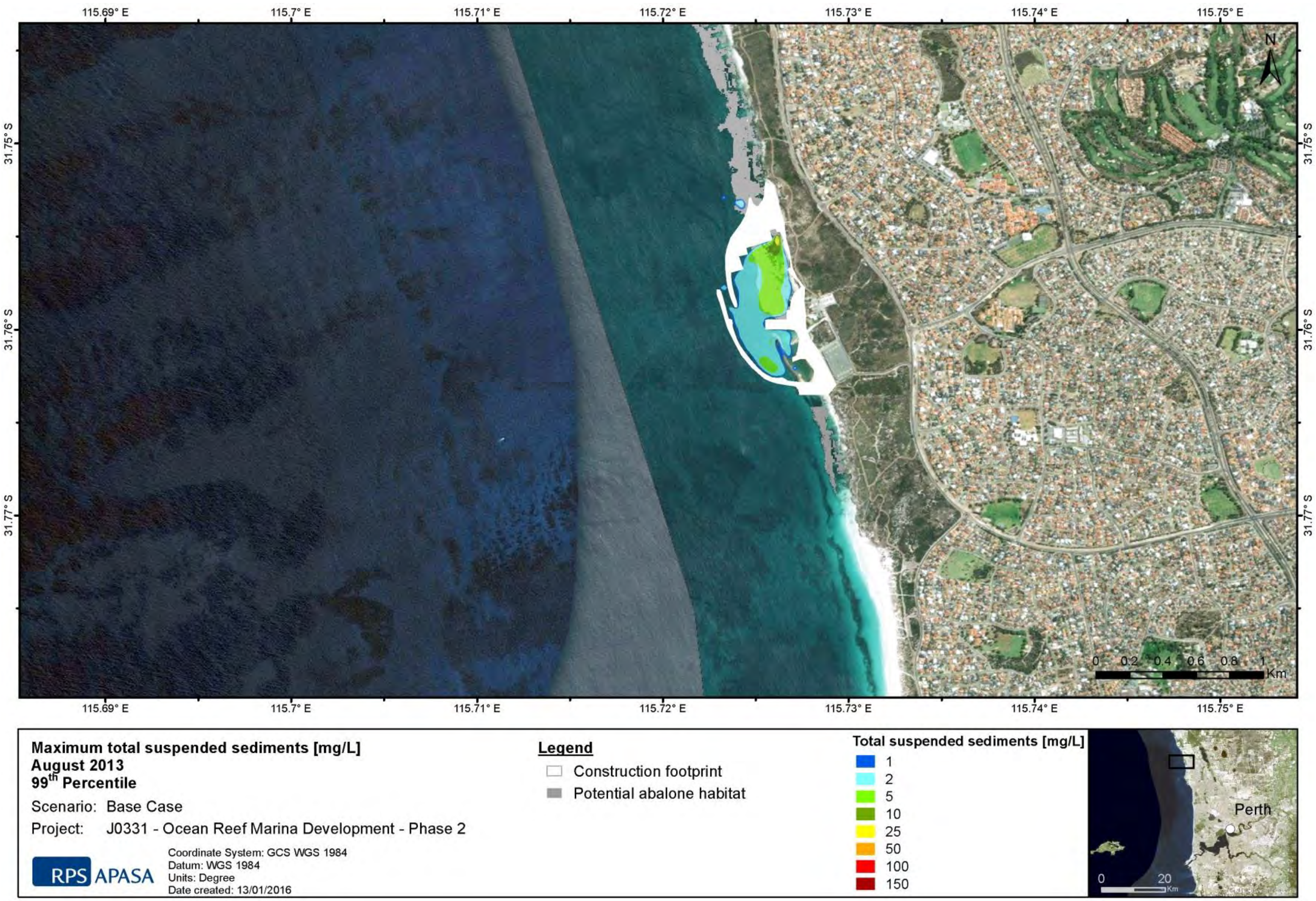

Figure A.10 Map of the 99th percentile of maximum TSS concentrations during the August 2013.

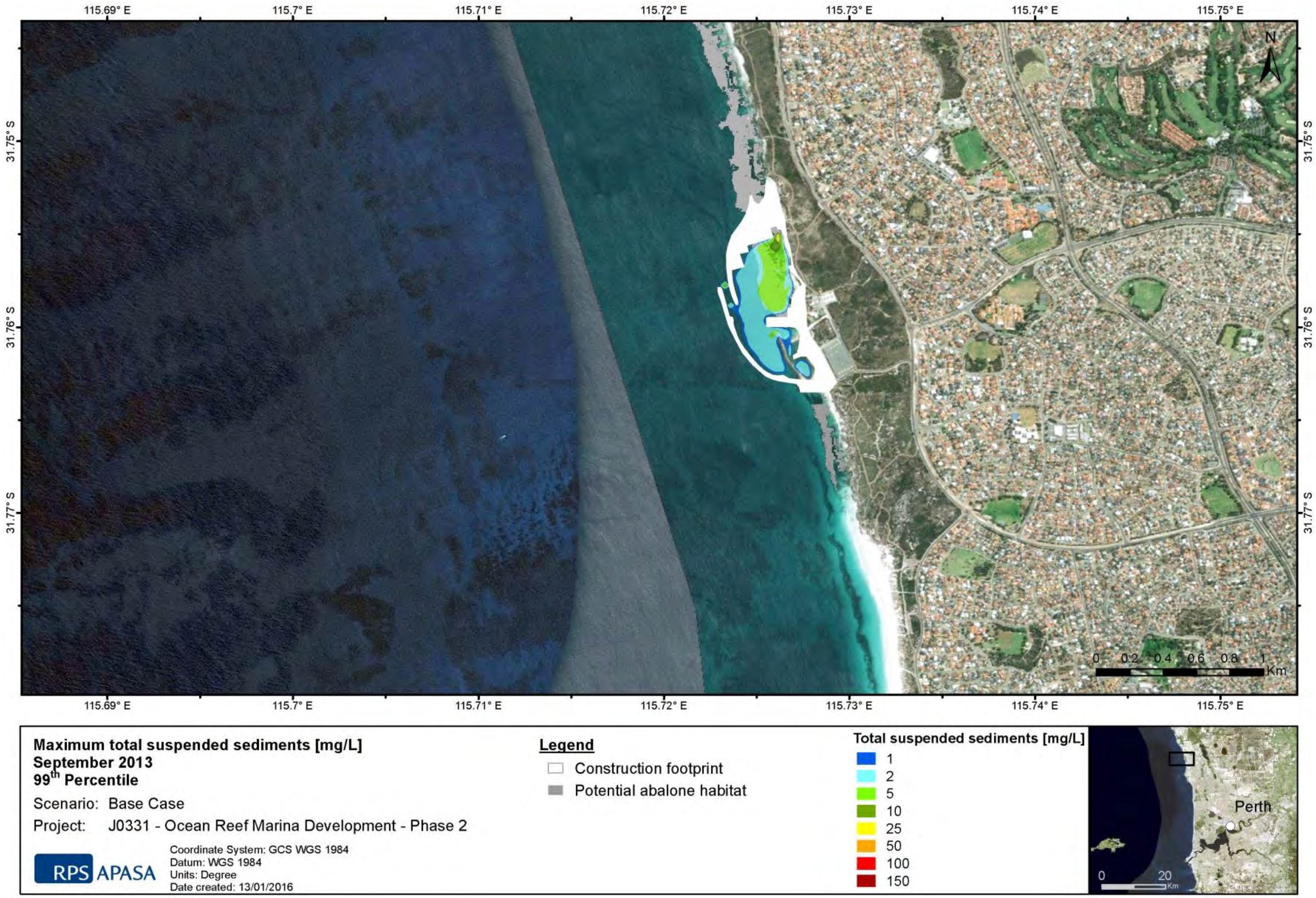

Figure A.11 Map of the 99th percentile of maximum TSS concentrations during the September 2013.

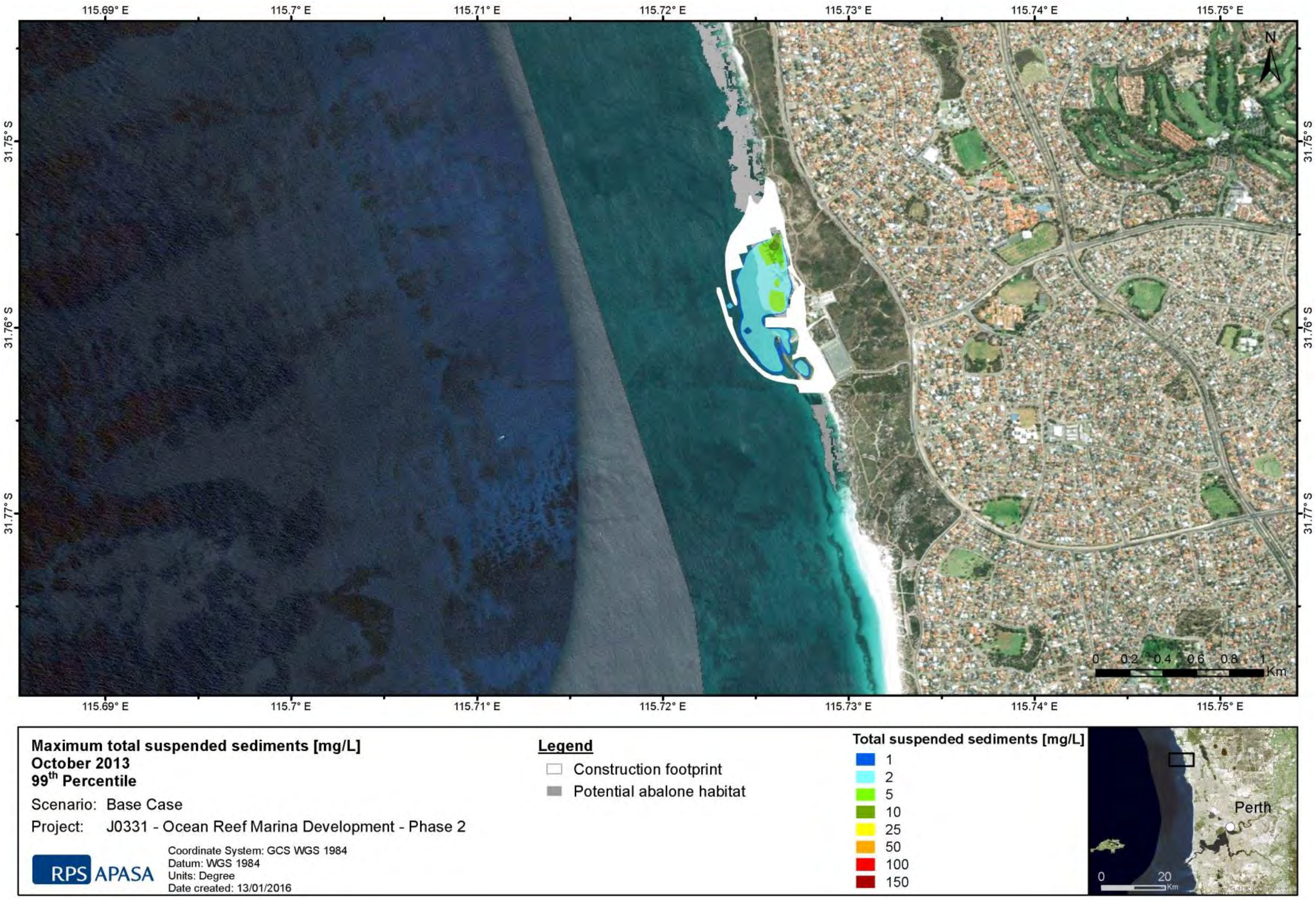

Figure A.12 Map of the 99th percentile of maximum TSS concentrations during October 2013.

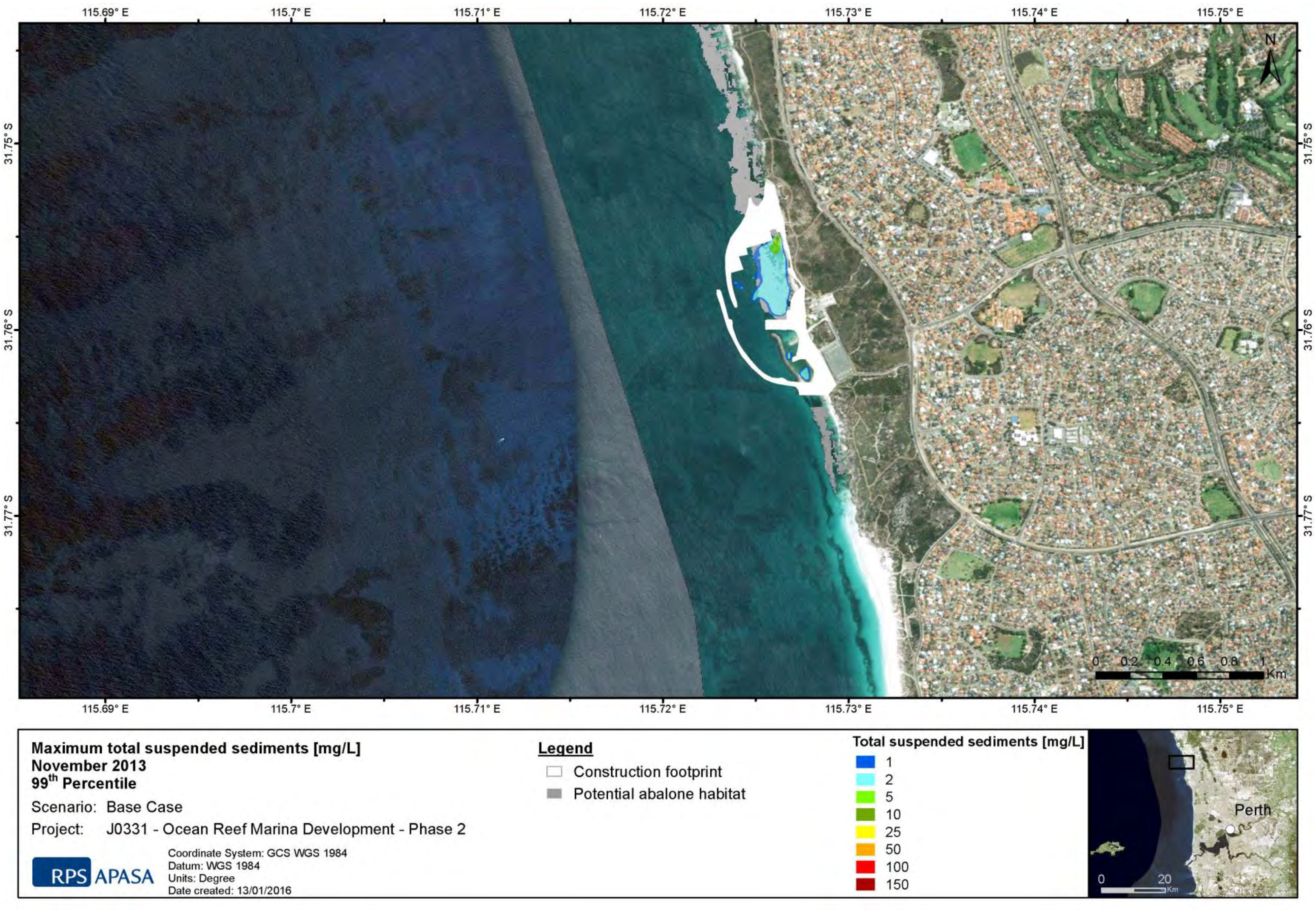

Figure A.13 Map of the 99th percentile of maximum TSS concentrations during November 2013