Perth Long Term Ocean Outlet Monitoring (PLOOM) Program

2016 Summer Water Quality Surveys

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This report has been prepared for Water Corporation by BMT Oceanica Pty Ltd, June 2016, Report Number 1120_001_01/1_RevB.

Document history

Distribution

Revision	Author	Recipients	Organisation	No. copies & format	Date
A	M Lourey	G Shiell	BMT Oceanica	1 x docm	31/05/16
B	M Lourey	M Nener	Water Corporation	1 x pdf	07/06/16

Review

Revision	Reviewer	Intent	Date
A	G. Shiell	Technical Review	31/05/16

Status
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1. Introduction

1.1 Background

Water Corporation operates major wastewater treatment plants (WWTPs) at Beenyup, Subiaco and Woodman Point (Figure 1.1). The WWTPs treat domestic wastewater and employ an activated sludge treatment process with high nitrogen removal capacity producing and discharge advanced secondary treated wastewater. Treated wastewater from each plant is discharged to the sea through ocean outlets at Ocean Reef, Swanbourne and Sepia Depression, respectively (Figure 1.1 and Table 1.1). The Discharge from the Beenyup and Subiaco WWTPs consists almost entirely of domestic secondary treated wastewater. A small volume of primary treated wastewater (~10% of the final flow) and wastewater from industry (the Jervoise Bay Groundwater Recovery Scheme and the Kwinana Wastewater Reclamation Plant) (5% of final discharge) is added to the wastewater from Woodman Point WWTP prior to discharge.

Table 1.1 Ocean outlet characteristics

Wastewater source	Outlet Location	Depth	Distance offshore	Diffuser length
Beenyup WWTP	Ocean Reef	~10 m (outlet A)	1.6 km	195 m
		~10 m (outlet B)	1.8 km	195 m
Subiaco WWTP	Swanbourne	~11 m	1.1 km	91 m
Woodman Point WWTP Point Peron WWTP Industry	Sepia Depression	~20 m	4.2 km	324 m

Licence conditions for the operation of the WWTPs in Perth's metropolitan region and discharge of treated wastewater to the marine environment at Ocean Reef and Sepia Depression require an annual summer water quality survey. Although not formally required, Water Corporation completes an additional survey at Swanbourne for consistency.

The purpose of the annual summer water quality surveys is to:

- provide data on water quality in the vicinity of the outlets
- assess the performance of each outlet by determining the dilution and dispersion characteristics of the treated wastewater
- examine the extent of influence of the plumes
- allow for the ongoing assessment of the environmental impact of the wastewater discharge in relation to the marine water quality and beneficial uses of the area
- allow for the ongoing assessment of the level of public health risk associated with ocean disposal of treated wastewater.

This report presents the results of the 2016 summer water quality surveys at Ocean Reef (9 February 2016), Swanbourne (16 February 2016) and Sepia Depression (2 February 2016).

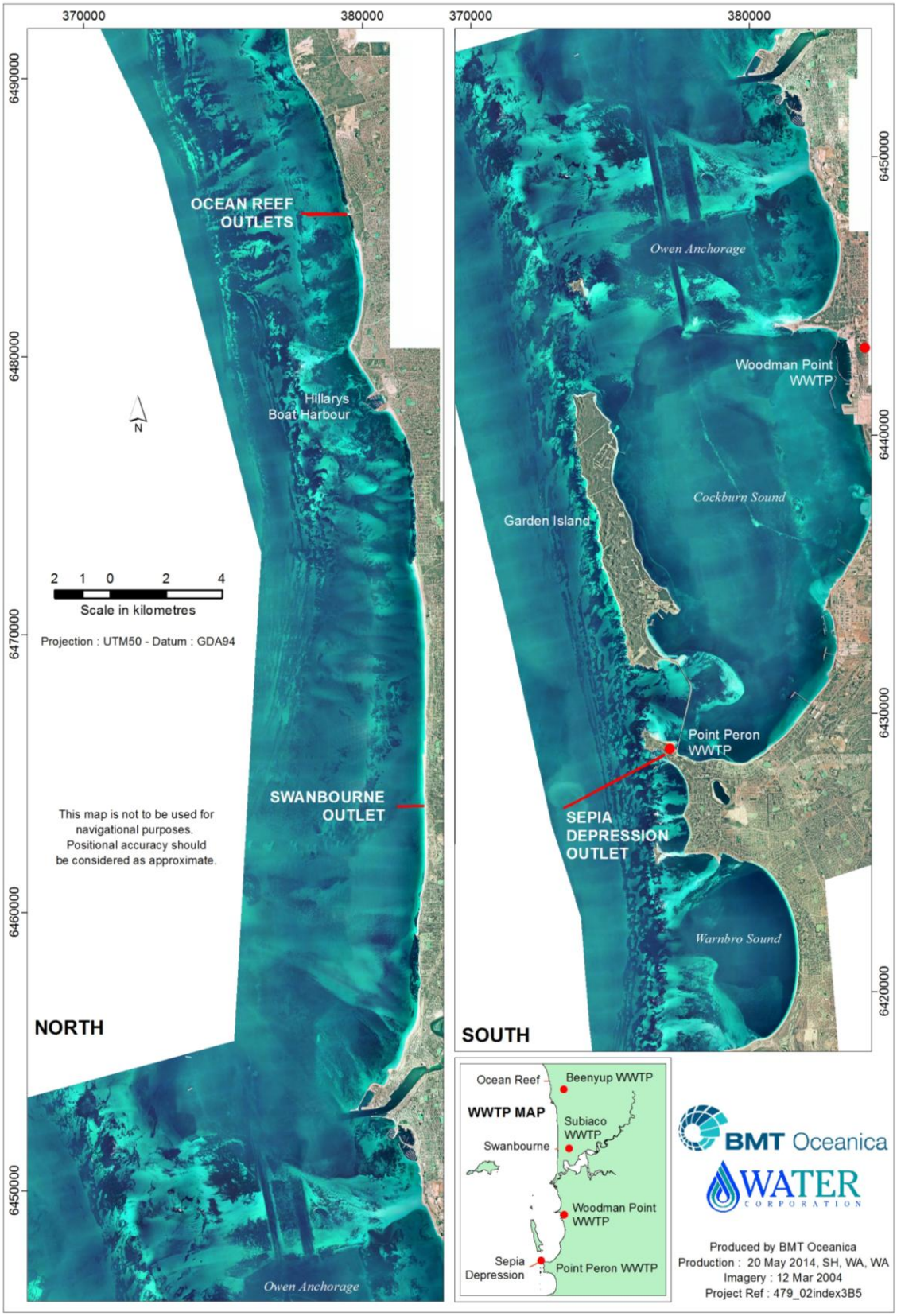


Figure 1.1 Treated wastewater ocean outlet locations, Perth

1.2 Water quality criteria

In 2000, the Environmental Protection Authority (EPA) established an Environmental Quality Management Framework (EQMF) for Perth's coastal waters (EPA (2000). First implemented practically in Cockburn Sound, the Framework was applied informally elsewhere until 2015 when it was formally applied to all the state's coastal waters (EPA 2015a). The summer surveys predate the EPA's Environmental Quality Management Framework and while there is some overlap, the design of the program not consistent with the framework and the results cannot be evaluated against the EQMF criteria. The results are therefore generally compared to the older ANZECC & ARMCANZ (2000) criteria.

1.2.1 Physical and chemical stressors

ANZECC & ARMCANZ (2000) default marine guidelines

Physical and chemical stressors are evaluated against the ANZECC & ARMCANZ (2000) default trigger values for physical and chemical stressors. The default trigger guidelines are conservative low-risk guidelines and an exceedance should be regarded as an 'early warning' of a potential problem rather than evidence of an issue. The 'inshore marine waters' guidelines are applicable to Perth coastal waters (Table 1.2).

Table 1.2 Summary of default water quality guidelines (trigger values) applicable to south-west Australian coastal waters

Parameter	Inshore marine waters trigger value[1]
Total ammonia nitrogen (µg/L)	5
Ortho-phosphate (µg/L)	5
Nitrate+nitrite (µg/L)	5
Total phosphorus (µg/L)	20
Total nitrogen (µg/L)	230
Chlorophyll-a (µg/L)	0.7

Notes:
1. From ANZECC & ARMCANZ (2000)

Comparison with background/reference sites

Previous surveys suggest 'background' ortho-phosphate concentrations are naturally higher than the ANZECC & ARMCANZ (2000) default guidelines. Low-risk trigger values based on the local reference condition can provide more locally relevant guidelines for naturally occurring stressors (ANZECC & ARMCANZ 2000). Trigger values for physical and chemical stressors in slightly-to-moderately disturbed ecosystems are based on the 80th and/or 20th percentile values[1] from appropriate background or reference data. 'Background concentrations' were collated from the surface and bottom concentrations measured at sampling sites located upstream of the outlet at the time of each summer water quality over the last 18 years (1999–2016)[2] (Table 1.3).

[1] *A percentile is a value on a scale of one hundred that indicates the percent of a distribution that is equal to or below it. For example, the 80th percentile is greater than or equal to 80% of all values – conversely, 80% of all values are less than or equal to the 80th percentile.*

[2] *These years were selected on the basis that the same laboratory (Marine and Freshwater Research Laboratory) has been responsible for undertaking water quality analysis over this period, thereby minimising the potential for between-laboratory differences within the dataset (see DALSE 2004).*

Table 1.3 Median and 80th percentile values for the nutrients and chlorophyll a at reference sites near each ocean outlet

	Total ammonium nitrogen (µg/L)	Ortho-phosphate (µg/L)	Nitrate+ nitrite (µg/L)	Total phosphorus (µg/L)	Total nitrogen (µg/L)	Chlorophyll-a (µg/L)
Ocean Reef – surface waters						
median	<3	7	8	18	107	0.3
80th percentile	4	8	12	34	138	0.5
Ocean Reef – bottom Waters						
median	<3	7	7	16	110	0.3
80th percentile	3	8	11	33	130	0.5
Swanbourne – surface waters						
median	<3	4	<2	14	110	0.3
80th percentile	4	8	11	34	138	0.5
Swanbourne – bottom waters						
median	<3	4	<2	14	118	0.3
80th percentile	3	8	11	33	130	0.5
Sepia Depression – surface waters						
median	<3	4	3	14	110	0.4
80th percentile	6	6	4	31	137	0.6
Sepia Depression – bottom waters						
median	<3	3	3	13	110	0.4
80th percentile	4	5	4	31	147	0.7

Note:
1. Values in this table are rounded.

Applying the criteria

The median concentration of samples collected within 250 m of the diffuser was compared to the relevant guideline values (ANZECC & ARMCANZ (2000) default and locally derived). This distance nominally represents the region encapsulating the initial stages of treated wastewater mixing, as indicated by historical initial dilution modelling. For comparison the median concentration of samples greater than 250 m from the diffuser were also calculated and compared to the guidelines. Concentrations at individual sites can also be compared to the default guidelines and the 80th percentile of reference values but for contextual purposes only.

1.2.2 Recreational contact

The ANZECC & ARMCANZ (2000) water quality guidelines for primary and secondary contact recreation in marine waters (Table 1.4) are exceeded if the median of the impact sites exceeds the guideline. The median concentrations of *Enterococci* spp. were calculated for sites located within 250 m of the diffuser and greater than 250 m from the diffuser at Ocean Reef and Swanbourne. At Sepia Depression, the median concentrations of *Enterococci* spp. were calculated for sites inside and outside the formal management zones that apply at that outlet (referred to as the post-upgrade boundary).

Table 1.4 Guidelines for primary and secondary contact recreation in marine waters

Type of recreation contact	Guidelines from ANZECC & ARMCANZ (2000)
Primary contact recreation	35 MPN/100 mL
Secondary contact recreation	230 MPN/100 mL

Notes:
1. The guidelines are for median values
2. MPN = Most Probable Number

1.2.3 Seafood for human consumption

The Department of Health (DoH) discourages the public from taking wild shellfish, recommending that only shellfish harvested commercially and under strict monitoring programs are consumed. Regardless, the EPA (2015b) has published Environmental Quality Criteria (Table 1.5) that serve as a measure of the potential threat to human health for those who wish to collect and consume wild shellfish. The criteria are primarily concerned with the highest risk consumption of raw shellfish (filter feeding bivalve molluscs, e.g. oysters, mussels, clams, pipis, scallops, cockles and razor clams) rather than other forms of seafood (e.g. fin fish, abalone and crayfish).

Table 1.5 Environmental Quality Criteria for the maintenance of seafood safe for human consumption

Thermotolerant coliforms	Environmental Quality Criteria from EPA (2015b)
EQG[1]	14 CFU/100 mL
EQS[2]	70 CFU/100 mL

Notes:
1. The EQG is based on median values with no more than 10% of the samples exceeding 21 CFU/100 mL
2. The EQS is based on median values with no more than 10% of the samples exceeding 85 CFU/100 mL
3. CFU = Colony Forming Units

2. Methods

2.1 Physics

2.1.1 Wind, wave and tides

Wind conditions (wind speed and direction) at Ocean Reef[3], Swanbourne[4] and Sepia Depression[5] immediately prior to and for the duration of each summer water quality survey were provided by the Bureau of Meteorology. Significant wave height and wave period were from the Department of Transport (DoT) wave rider buoy south-west of Rottnest Island. However, attenuation of the wave energy, due to refraction and diffraction processes around the offshore reefs, will cause the wave height near the outlets to be considerably lower than that observed offshore. Water surface elevations were obtained from the DoT gauge in the Fremantle Fishing Boat Harbour.

2.1.2 Currents

At the commencement of each survey, a drogue was released over the centre of the operational outlet diffuser (Outlet B for Ocean Reef). The location of the drogue was recorded at intervals throughout the survey using an on-board global positioning system (GPS). Drogue tracking provides an estimate of mean surface current speed and direction for the initial dilution modelling and determined which sampling grid was used at each outlet (DAL 2001).

2.1.3 Dilution

Initial dilution modelling

VPLUMES is an initial dilution model developed by the United States Environmental Protection Agency. Initial dilution occurs from the point of discharge to a point of maximum rise or fall (e.g. reaching the surface of the water body) of the plume.

These numerical models are designed to model the near-field (the region where the plume first jets into the surrounding waters and then (in the case of positively buoyant plumes) rises and mixes with the surrounding waters) behaviour of plumes. These models capture simple features of the surrounding environment such as depth at point of discharge, net current and wind speed. However, because the models do not take into account broader scale bathymetry and hydrodynamics, they generally do not accurately predict the far-field behaviour (after the plume has reached the surface or is fully mixed in the water column). Three-dimensional baroclinic or barotropic hydrodynamic models are required to better estimate far-field behaviour.

The UM3 initial dilution model, which is part of the Visual Plumes (VPLUMES) suite of dilution models (Frick et al. 2001), was applied to the discharges from each outlet under ambient conditions and treated wastewater flows at the time of the surveys.

Model set-up

Model set-up parameters were selected to represent the outlet diffuser, flows and ambient conditions at Ocean Reef, Swanbourne and Sepia Depression, respectively, at the time of the surveys (Table 2.1).

[3] *Bureau of Meteorology Site Number 009214.*
[4] *Bureau of Meteorology Site Number 009215.*
[5] *Bureau of Meteorology Site Number 009256 (Garden Island).*

Table 2.1 Initial dilution model set-up parameters for ocean outlets at Ocean Reef, Swanbourne and Sepia Depression

Diffuser characteristics	Ocean Reef (outlet A) 9/02/2016	Ocean Reef (outlet B) 9/02/2016	Swanbourne 16/02/2016	Sepia Depression 2/02/2016
Port diameter (m)	0.125	0.16	0.17	0.135
Port elevation (m)	0.76	0.84	1	0.75
Number of open ports	50	48	20	68
Port spacing (m)[1]	4	4	5	4.65
Port orientation	Alternating horizontal	Alternating horizontal	Tee discharge horizontal, aligned N-S	Alternating horizontal
Water depth (m)	9.8	9.8	11	20
Ambient conditions at the time of sampling				
Temperature (°C)[3]	23.91	23.91	23.10	22.23
Salinity[3]	35.35	35.35	36.31	36.15
Surface current (m/s)(based on drogue movement)	0.041	0.041	0.13	0.26
Discharge characteristics				
Flow (ML/day)	55.75	55.75	63.6	142.47
Temperature (°C)	28.3	28.3	30.3	28.7
Salinity (psu)	0.54	0.54	0.66	0.47

Notes:
1. In the case of alternate ports, they are all assumed to be on one side of the diffuser and 'port spacing' is the distance between each port irrelevant of the actual position on either side of the diffuser. For T-shaped risers, it is assumed that all ports are on the one side of the diffuser with the spacing equal to half of the spacing between the risers.
2. Ambient conditions have been taken from sites 64 for Ocean Reef and Sepia depression and site 48 for Swanbourne.

Vertical velocity profiles were derived from mean surface currents assuming a linear decrease in current speeds from the surface to the seabed[6] of ~1.2% per metre at Ocean Reef/Swanbourne and ~3.8% per metre depth at Sepia Depression (Pattiaratchi et al. 1995).

2.2 Wastewater sampling

Flow-proportionate composite samples of treated wastewater were collected from each of the WWTPs over the 24-hour period prior to and during the annual summer water quality survey at each outlet and the characteristics of the treated wastewater samples determined.

2.3 Ocean sampling

2.3.1 Sampling locations

Water samples were collected from 35 offshore sites at each outlet (34 at Sepia Depression) within a rectangular sampling grid appropriate for the prevailing flow conditions on the day of the survey (Appendix B; DAL 2001). The sampling grid was chosen after 4–6 drogue readings to determine the predominant flow direction. The actual position of each sampling site was recorded using an on-board GPS.

[6] *Two sets of ambient conditions are set in the model, one at the surface (0 m) and one at ~1 m above the seabed. The current speed is set to linearly decrease to zero from this depth to the seabed.*

Nine shoreline sites located along the coast adjacent to each ocean outlet were sampled at each outlet.

2.3.2 Water samples

Offshore samples were collected from the surface (1 m depth) and the bottom (~2 m above the seafloor) at each site using electric bilge pumps. At each site, the pumps were operated for ~30 s to flush the delivery hose prior to collecting the sample. The following samples were collected into sample rinsed (with the exception of pre-sterilised sample bottles used for the microbiological analysis) containers:

- two 125 mL unfiltered samples for total phosphorus and total nitrogen analysis
- two 10 mL filtered samples (onsite through a 45 µm filter) for ortho-phosphate, ammonia and nitrate+nitrite analysis
- one 10 mL sample for fluorometric chlorophyll-a analysis
- one 250 mL sample for thermotolerant coliforms and faecal streptococci analysis.

During each survey, three replicate samples for nutrients were obtained from surface waters at a single offshore site in the sampling grid to identify small-scale spatial variability and variability associated with laboratory analyses.

All the samples were placed on ice and in the dark and returned to the laboratory.

Shoreline samples were collected in waist-deep water by directly filling the sample containers.

2.3.3 Water column structure

A multi-parameter water quality sensor was lowered through the water column at seven or eight of the offshore sites at each of the outlet to provide information on the physical structure of the water column, i.e. vertical profiles of temperature, salinity and dissolved oxygen. Sites were arranged along a north–south transect through the middle of each sampling grid, with additional sites around the diffuser.

2.3.4 Laboratory analysis

The nutrient and primary production analyses were undertaken using the analytical methods identified in Table 2.2. For the purposes of calculating statistics and data presentation, nutrient, chlorophyll a and microbial concentrations below the reporting limit were assumed to be half the reporting limit (e.g. <3 µg/L becomes 1.5 µg/L).

Table 2.2 Analytical methods and reporting limits

Parameter	Analytical method	Reporting limit	Unit
Nutrient			
Total phosphorus	Lachat automated flow injection analyser (Valderrama 1981)	5[1]	µg P/L
Ortho-phosphate	Lachat automated flow injection analyser (Johnson & Petty 1982)	2[1]	µg P/L
Total nitrogen	Lachat automated flow injection analyser (Valderrama 1981)	50[1]	µg N/L
Total ammonia nitrogen	Lachat automated flow injection analyser (Switala 1993)	3[1]	µg N/L
Nitrate+nitrite	Lachat automated flow injection analyser (Johnson & Petty 1983)	2[1]	µg N/L
Primary production			
Chlorophyll-a	Fluorometric	0.1[2]	µg/L
Chlorophyll-a	Acetone extraction	0.1[1]	µg/L
Phaeophytin	Acetone extraction	0.1[1]	µg/L
Microbiological indicators			
Thermotolerant coliforms	Membrane filtration	Dilution dependent[3]	CFU/100 mL
Faecal streptococci (as *Enterococci* spp.)	Enterolert Defined Substrate Technology	Dilution dependent[3]	MPN/100 mL

Notes:
1. The reporting limit is calculated as the constituent concentration that produces a signal ten standard deviations above the reagent water blank.
2. Instrument reporting limit.
3. The lower assay limit for thermotolerant coliforms and faecal streptococci are dependent on the dilution of the original sample.

3. Swanbourne

3.1 The survey

The annual summer water quality survey at Swanbourne was completed on 16 February 2016.

3.2 Discharge

A 24-hour composite sample of treated wastewater was collected from the Subiaco WWTP on 16 February 2016 (prior to and during the ocean survey) (Table 3.1). At the time of the survey there were 20 ports open on the outlet.

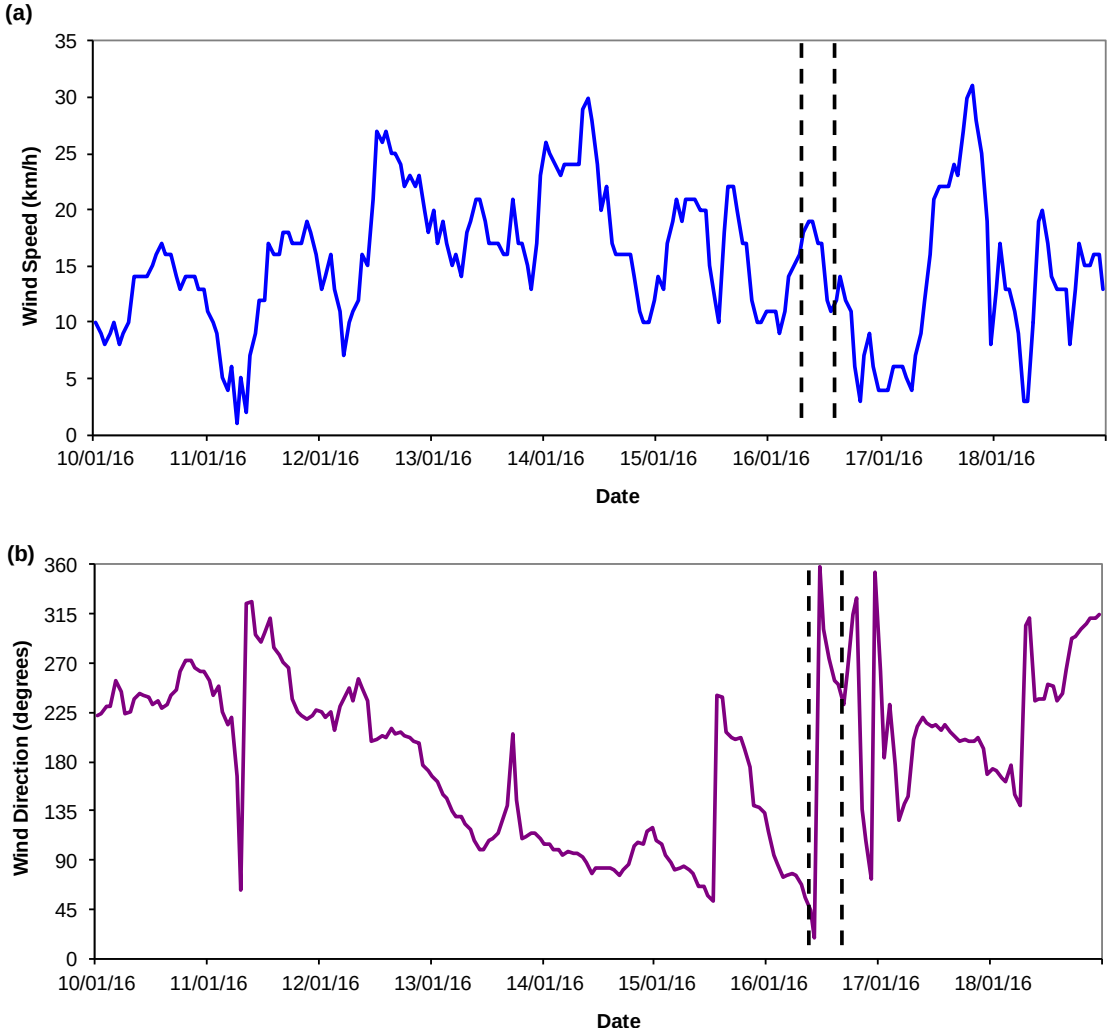
Table 3.1 Subiaco treated wastewater characteristics on 16 February 2016

Parameter	Concentration
Total phosphorus	6.1 mg/L
Total nitrogen	13 mg/L
Total ammonia nitrogen	0.61 mg/L
Nitrate+nitrite	8 mg/L
Thermotolerant coliforms	640 000 CFU/100 mL
Enterococci spp.	>24 000 MPN/100 mL
Total suspended solids	20 mg/L
Biological oxygen demand	8 mg/L
Total flow	63.6 ML/d

3.3 Environmental characteristics

3.3.1 Wind

For 24 hours prior to the survey, the winds at Swanbourne were gentle easterlies (averaging 17.6 km/h) swinging to gentle southerlies (average 15.7 km/h) and back to easterlies (average 13.12 km/h) in the 8 hours prior to sampling. During sampling, the gentle winds shifted from the east at the beginning of sampling to the west towards the end (averaging 12.25 km/h) (Figure 3.1).



Note:
1. Dashed lines (- -) show approximate timing of the summer water quality survey.
2. a = wind speed
3. b = wind direction

Figure 3.1 Wind speed and direction at Swanbourne

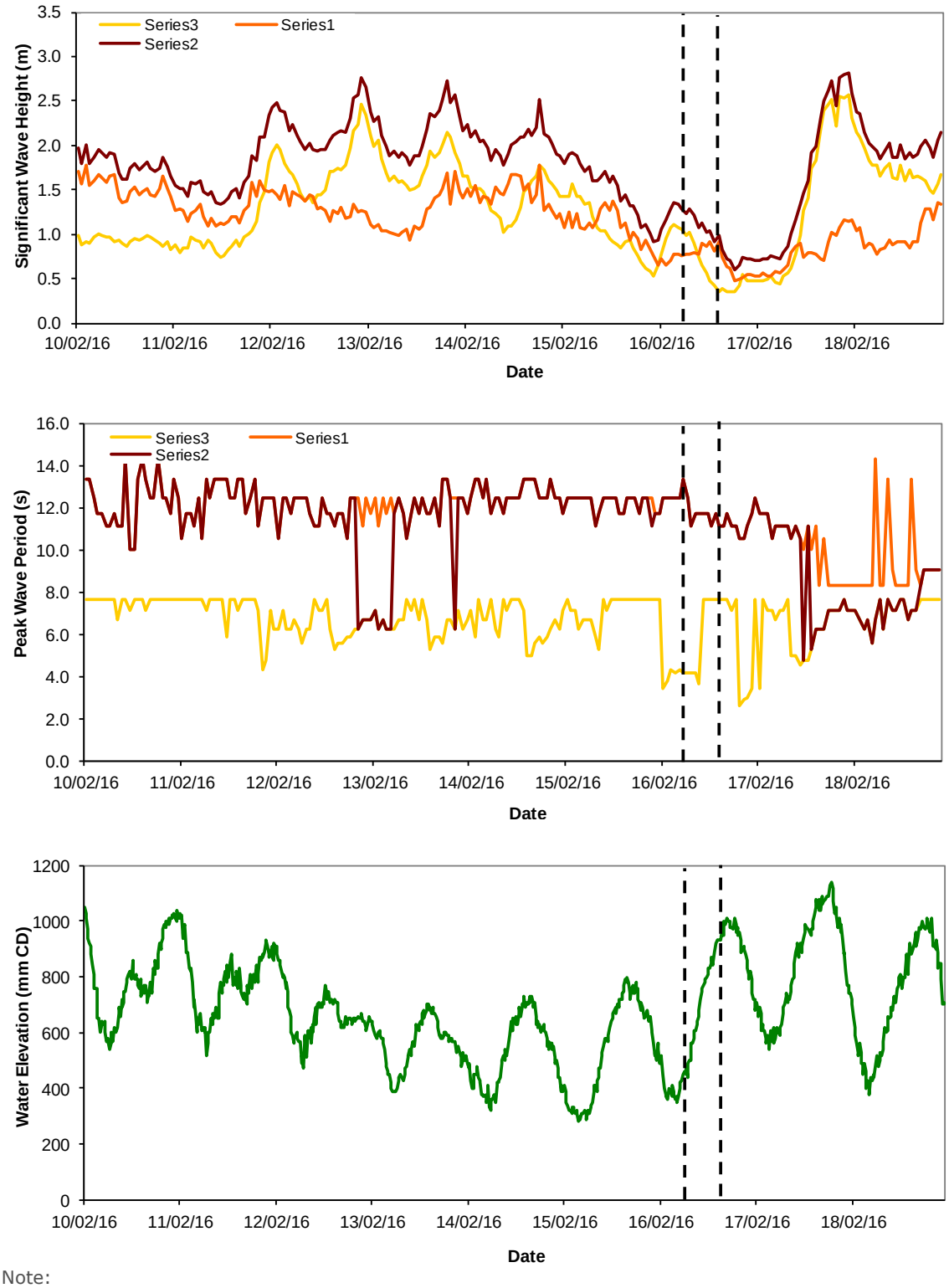
3.3.2 Waves and tide

For 24 hours prior to the survey, the average significant wave height[7] offshore from Rottnest Island was 1.4 m, with an average peak wave period[8] of 12.2 s (Figure 3.2).

[7] *The significant wave height (in metres) is defined as the average height of the highest one-third of waves recorded (source: http//www.dpi.wa.gov.au/)*

[8] *The wave period (in seconds) is the time between consecutive wave crests. The peak wave period is the wave period of those waves that are producing the most energy in a wave record*

During the survey the average offshore significant wave height was 1.2 m and the average peak wave period of 12.0 s. The survey was completed during a rising tide (Figure 3.2).



Note:
1. Dashed lines (- -) show approximate timing of the survey.

Figure 3.2 Significant wave heights (offshore Rottnest Island), peak wave periods (offshore Rottnest Island) and water level elevation (Fremantle Fishing Boat Harbour)

3.3.3 Currents

The surface drogue, released at the centre of the diffuser at the beginning of the survey, drifted in a south westerly direction for the duration of its passage. The average velocity of the drogue over the route was 0.13 m/s. At the time of the survey and based on drogue movements, it is expected that discharged treated wastewater would be travelling in a south westerly direction and offshore of the diffuser (Figure 3.3).

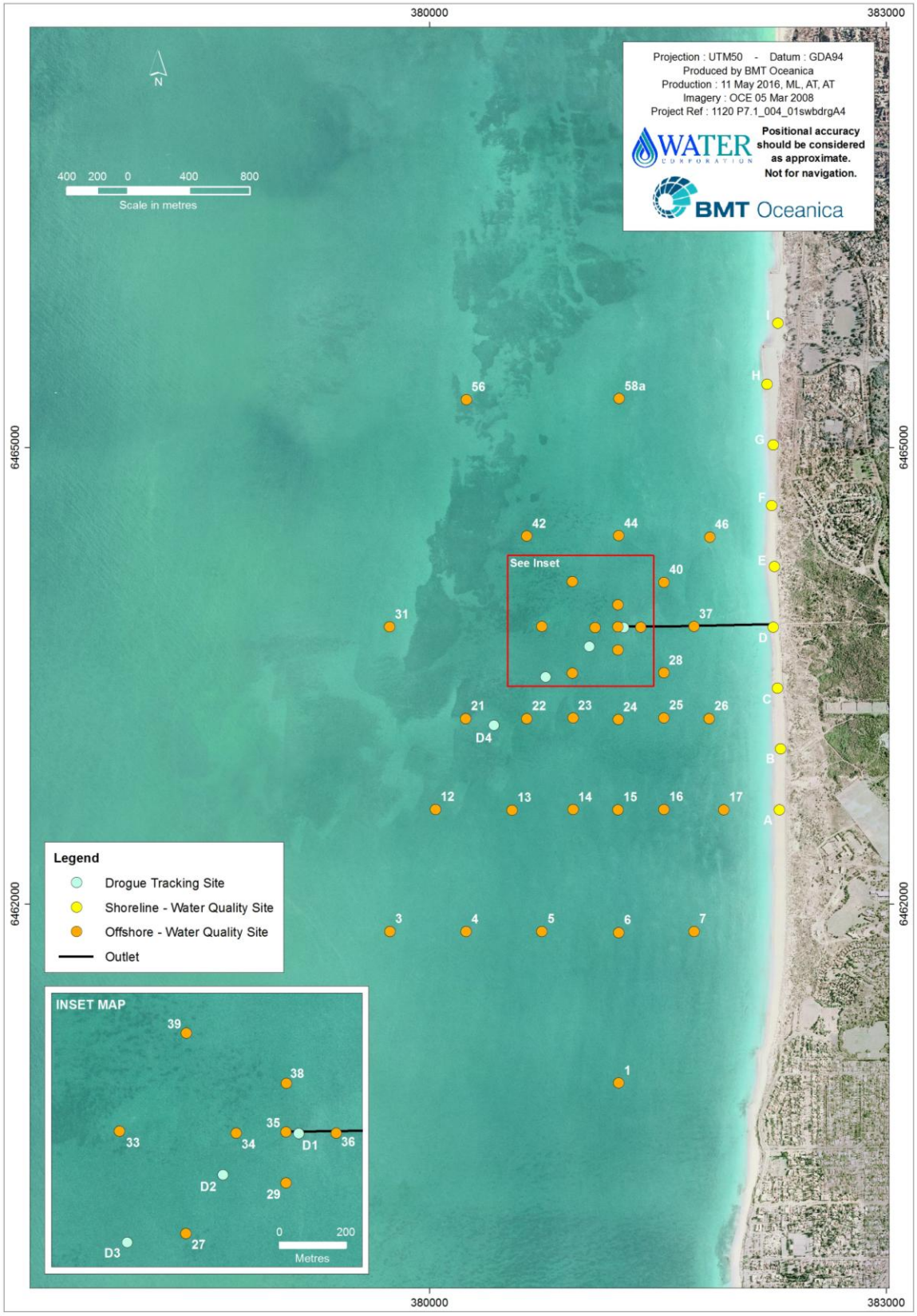
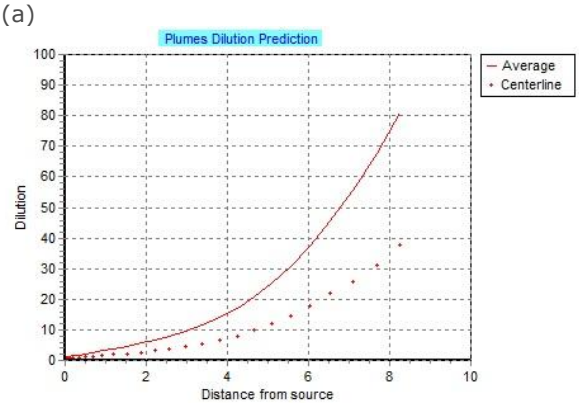


Figure 3.3 Swanbourne drogue tracking locations, 16 February 2016

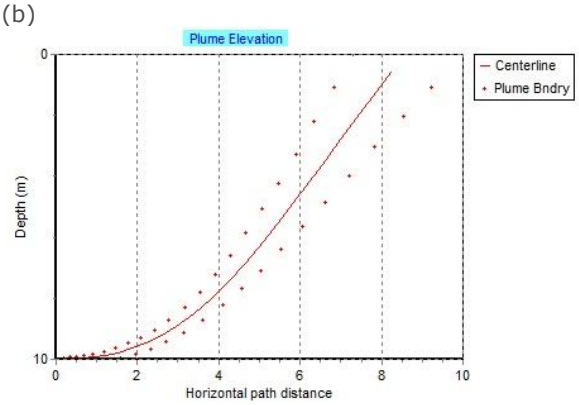
3.3.4 Initial dilution

For conditions at the time of the Swanbourne survey, the modelling predicted average initial dilution of 1:129 and centreline dilutions of 1:53 (Figure 3.4a). The plume was predicted to first reach the surface within ~9 m (horizontal distance) from the discharge point (see the ambient boundary[9] of the plume in Figure 3.4b). The full model output is included in Appendix C.

(a)



(b)



Notes:
1. a = predicted average and centreline dilution
2. b = predicted plume elevation

Figure 3.4 Predicted average and centreline dilutions and predicted plume elevation trajectory at Swanbourne

3.4 Water column structure

Water temperature from 8 sites profiled ranged from 23.10°C to 23.62°C, salinity ranged from 36.12 to 36.63 and dissolved oxygen varied from 6.49 mg/L to 6.90 mg/L (equivalent to 93.5–99.6% saturation) (Figure 3.5 and Figure 3.6). There was no thermocline evident at any site and salinity was typically constant with depth at most sites, with the exception of site 34 where a layer of lower salinity water was evident at the surface, which may indicate the presence of the treated wastewater plume (Figure 3.5 and Figure 3.6). Dissolved oxygen was not depleted by the treated wastewater plume or any other process at any site (Figure 3.5 and Figure 3.6).

[9] *The ambient boundary corresponds to the plume boundary at which concentrations are estimated to be equal to ambient conditions.*

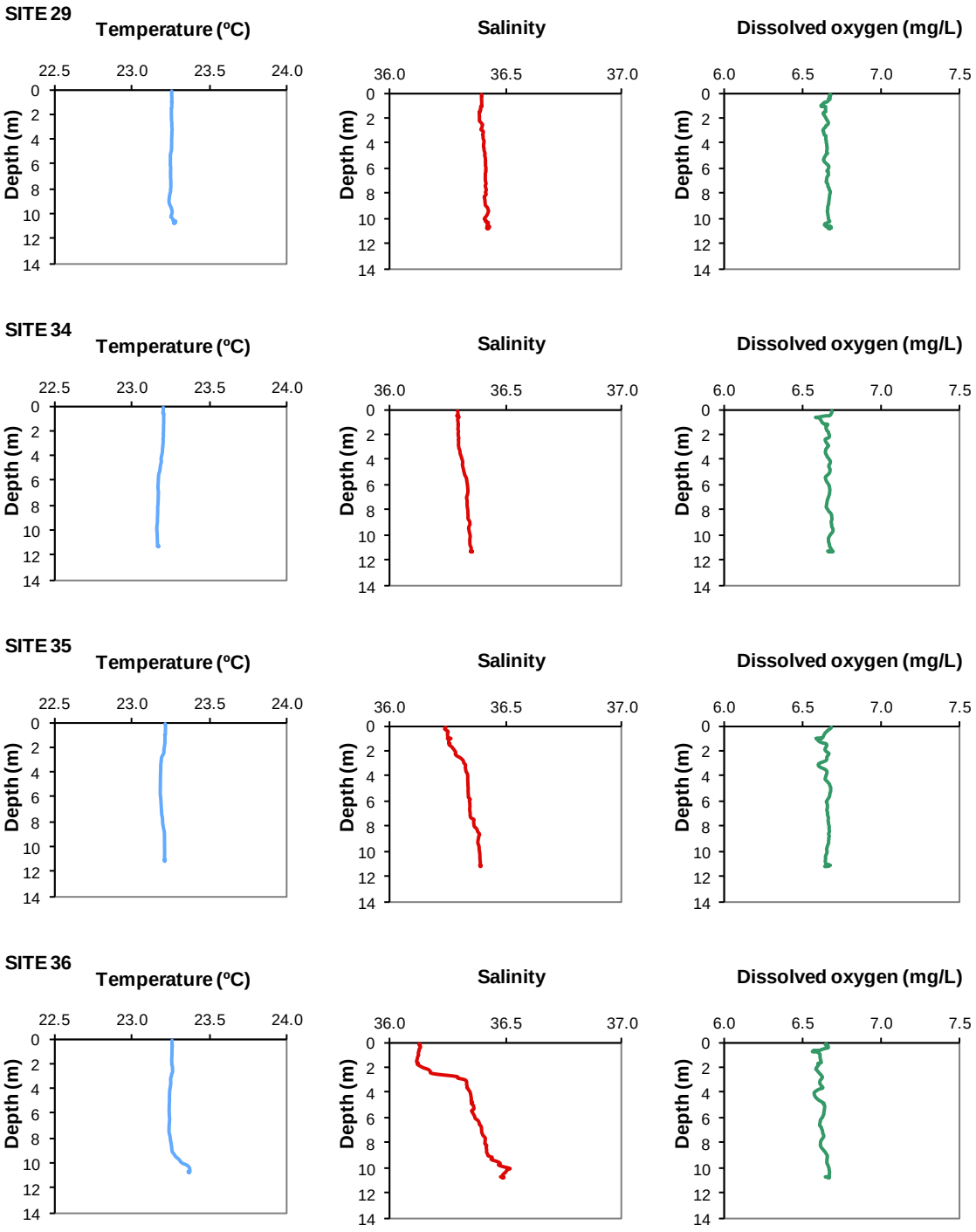


Figure 3.5 Temperature, salinity and dissolved oxygen vertical profiles at Swanbourne

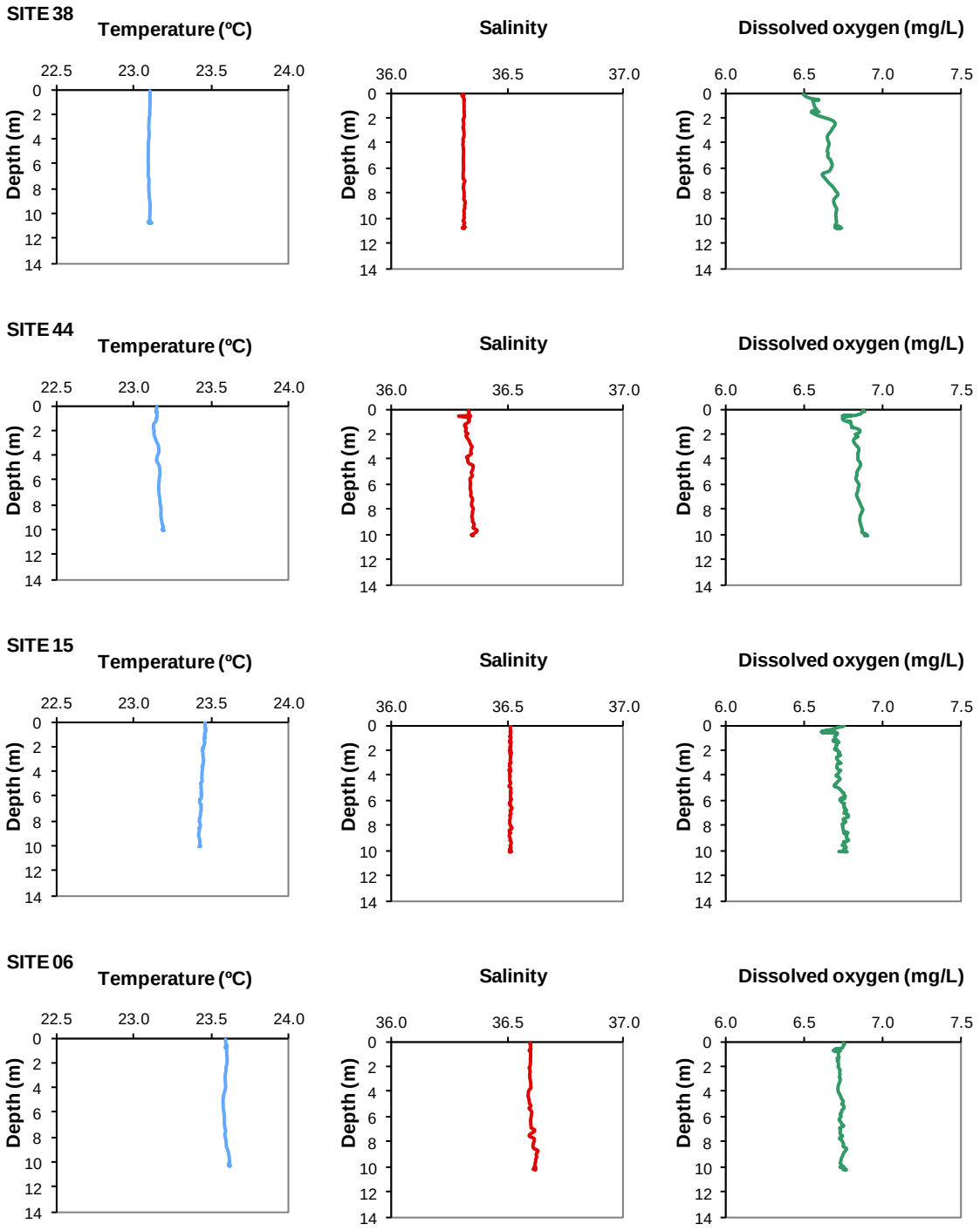


Figure 3.6 Temperature, salinity and dissolved oxygen vertical profiles at Swanbourne

Water temperature decreased with increasing distance downstream of the diffuser with the highest temperatures observed at the site 29 up current of the diffuser (Figure 3.7a). Vertical stratification was not evident from water temperature, but there appears to be a layer of lower salinity/density water at the surface down current of the diffuser (Figure 3.7b). This layer was more evident at sites well removed from the diffuser (44 and 53) than close to the discharge point (sites 35 and 38) (Figure 3.7c).

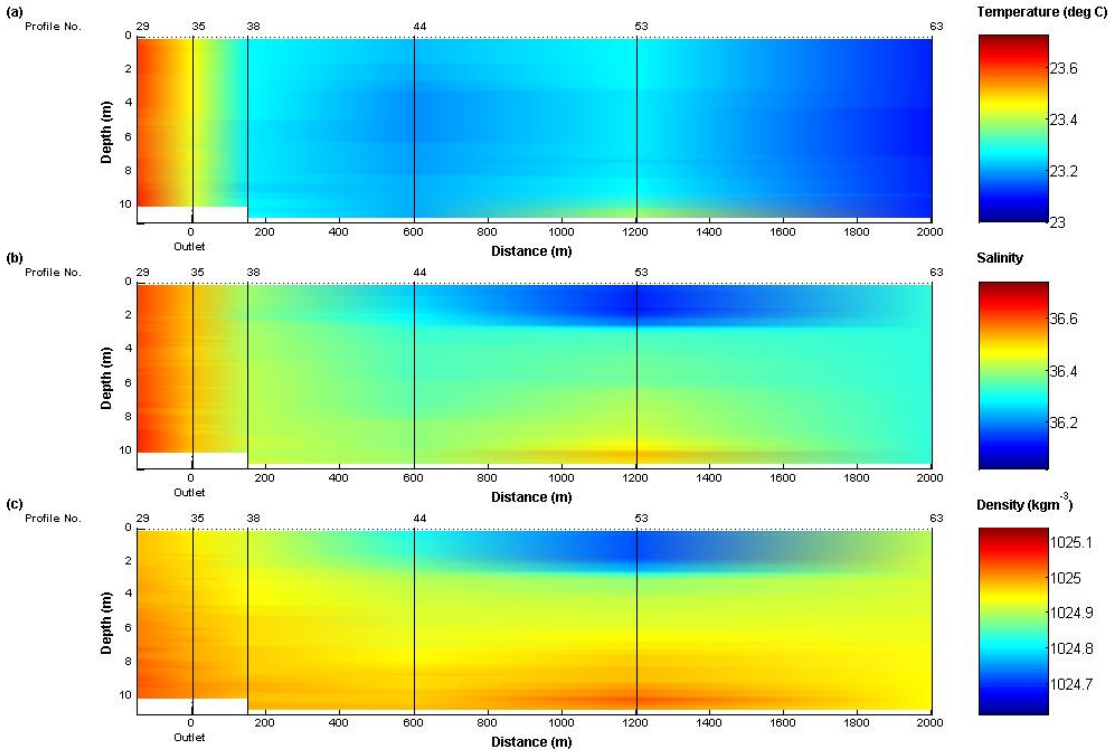


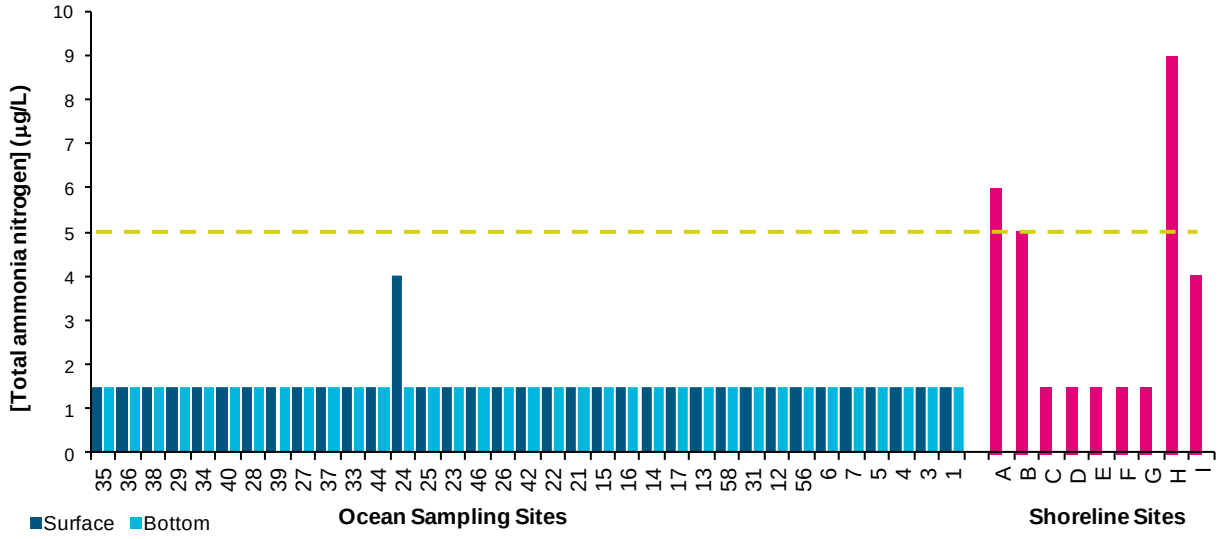
Figure 3.7 Temperature (a), salinity (b) and density (c) transect at Swanbourne

3.5 Nutrients

Total Ammonia Nitrogen ($HN_4^+ + NH_3$)

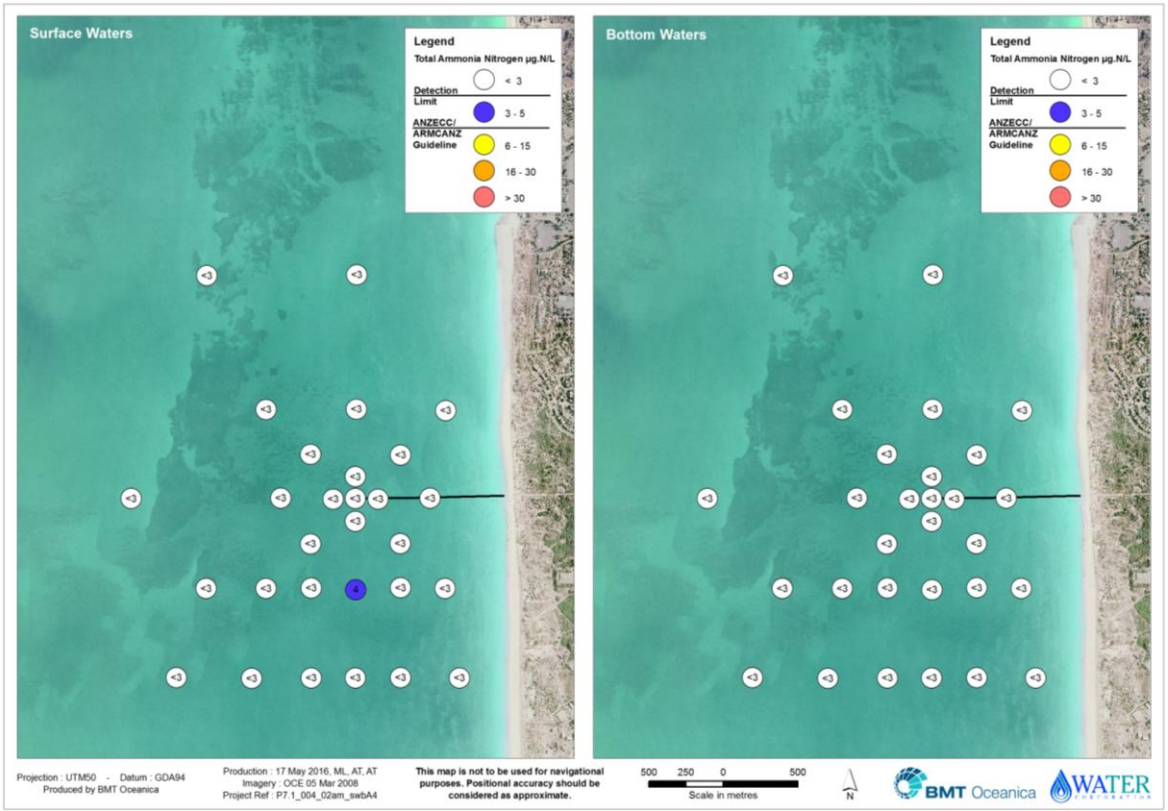
With the exception of a single surface sample well removed (~610 m) from the Swanbourne diffuser, all offshore surface and bottom ammonia concentrations were at the limit of reporting (3 µg/L) (Figure 3.8 and Figure 3.9). Median concentrations (surface and bottom, both within and outside 250 m of the diffuser) were below the ANZECC & ARMCANZ (2000) default guideline and 80th percentile of reference concentrations (Table 3.3).

Ammonia concentrations at two shoreline locations exceeded the ANZECC & ARMCANZ (2000) default guideline (Figure 3.8 and Figure 3.9). Isolated pockets of elevated ammonia concentrations at this distance from the diffuser are likely from terrestrial sources rather than the influence of the outlet. Nevertheless, median shoreline concentrations still meet the ANZECC and ARMCANZ (2000) default guideline (Table 3.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 3.8 Total ammonia nitrogen concentrations at Swanbourne



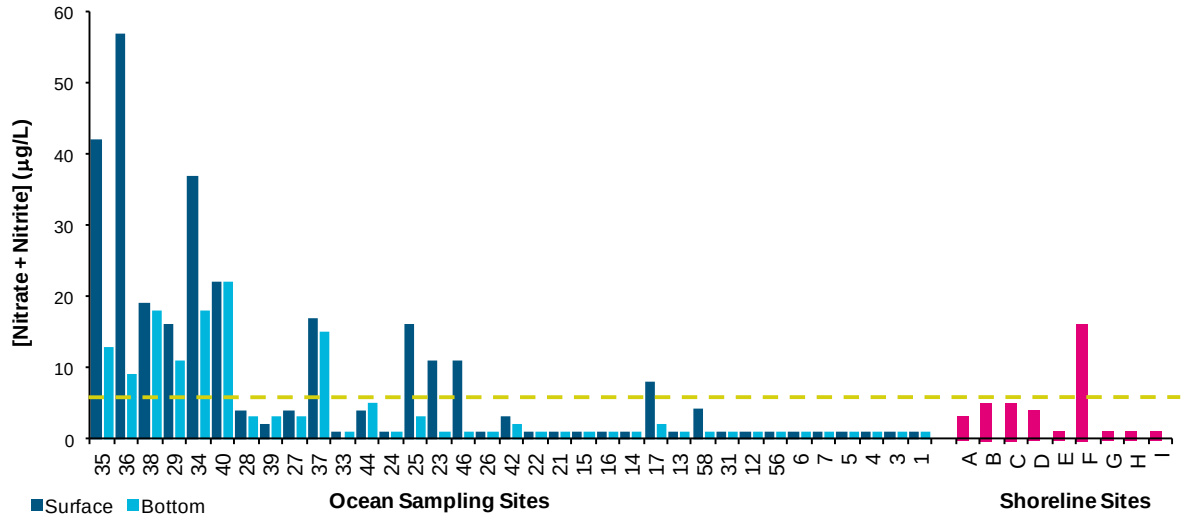
Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.9 Spatial distribution of total ammonia nitrogen at Swanbourne

Nitrate+nitrite (NO_2^-+NO_3^-)

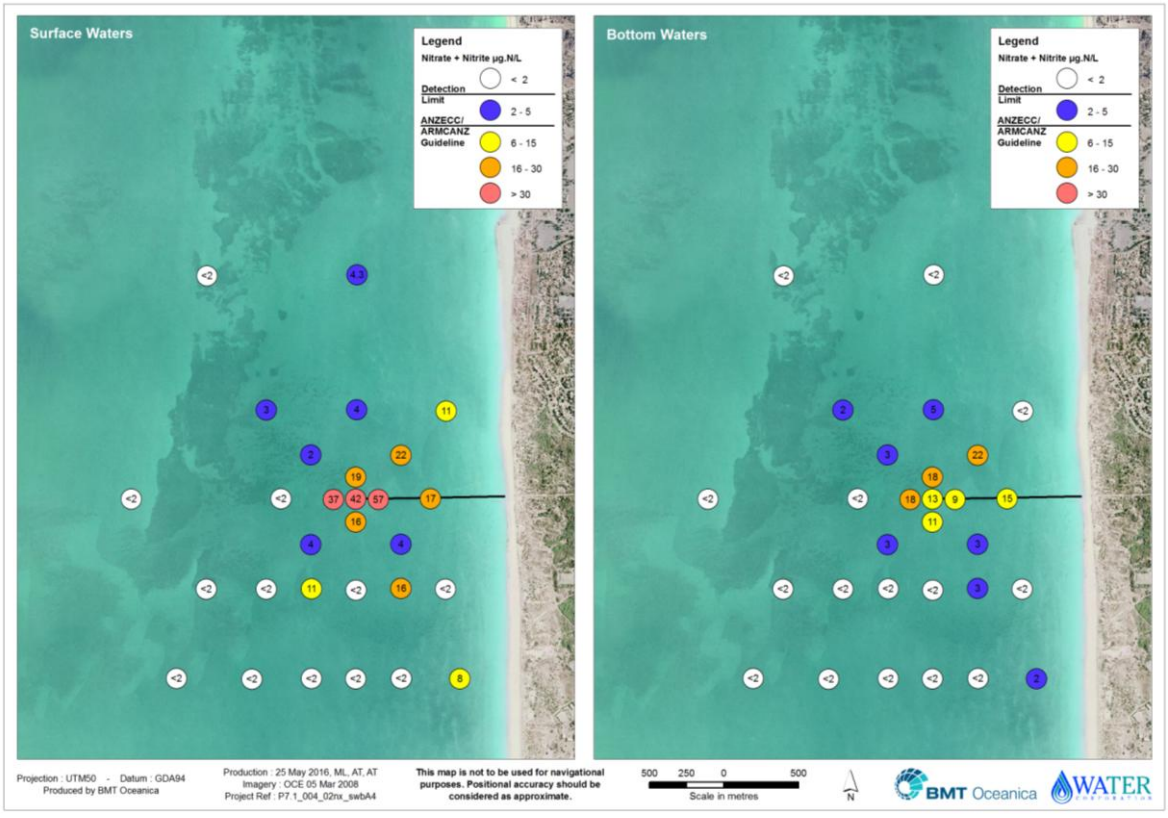
Offshore, 11 (31%) surface and 7 (20%) of bottom sample concentrations exceeded the ANZECC & ARMCANZ (2000) guideline, while 8 (23%) surface and 5 (14%) bottom sample concentrations exceeded the 80th percentile of reference site concentrations

(Figure 3.10 and Figure 3.11. The median concentration of nitrate + nitrite within 250 m of the outlet exceeded the ANZECC & ARMCANZ (2000) guideline (Table 3.3). The median concentration of samples>250 m from the diffuser were below the ANZECC & ARMCANZ (2000) guideline (Table 3.3). Median nitrate + nitrite concentration from the shoreline stations were below the ANZECC & ARMCANZ (2000) guideline (Table 3.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 3.10 Total nitrate+nitrite concentrations at Swanbourne

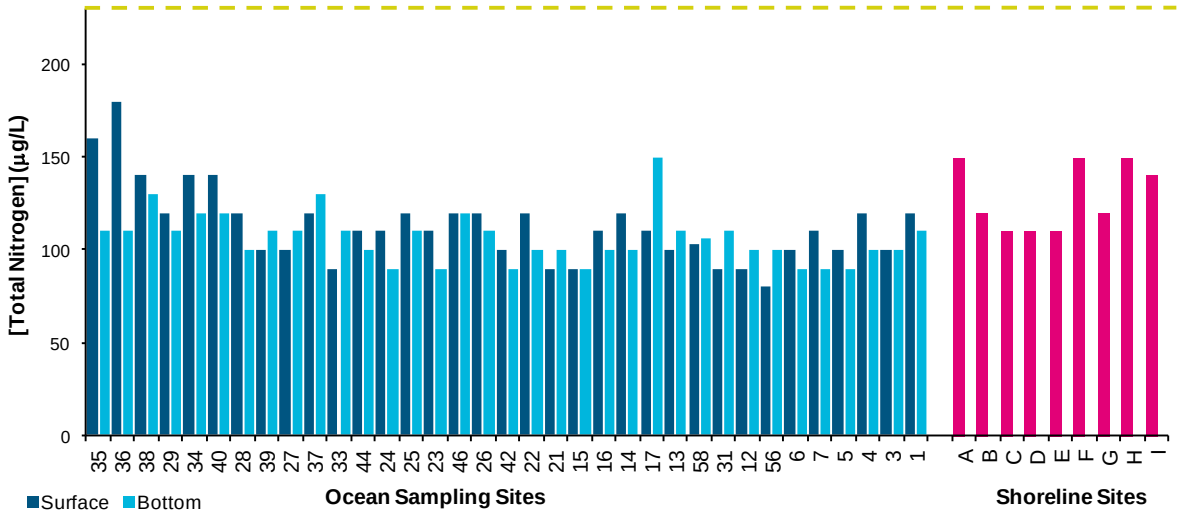


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.11 Spatial distribution of nitrate+nitrite at Swanbourne

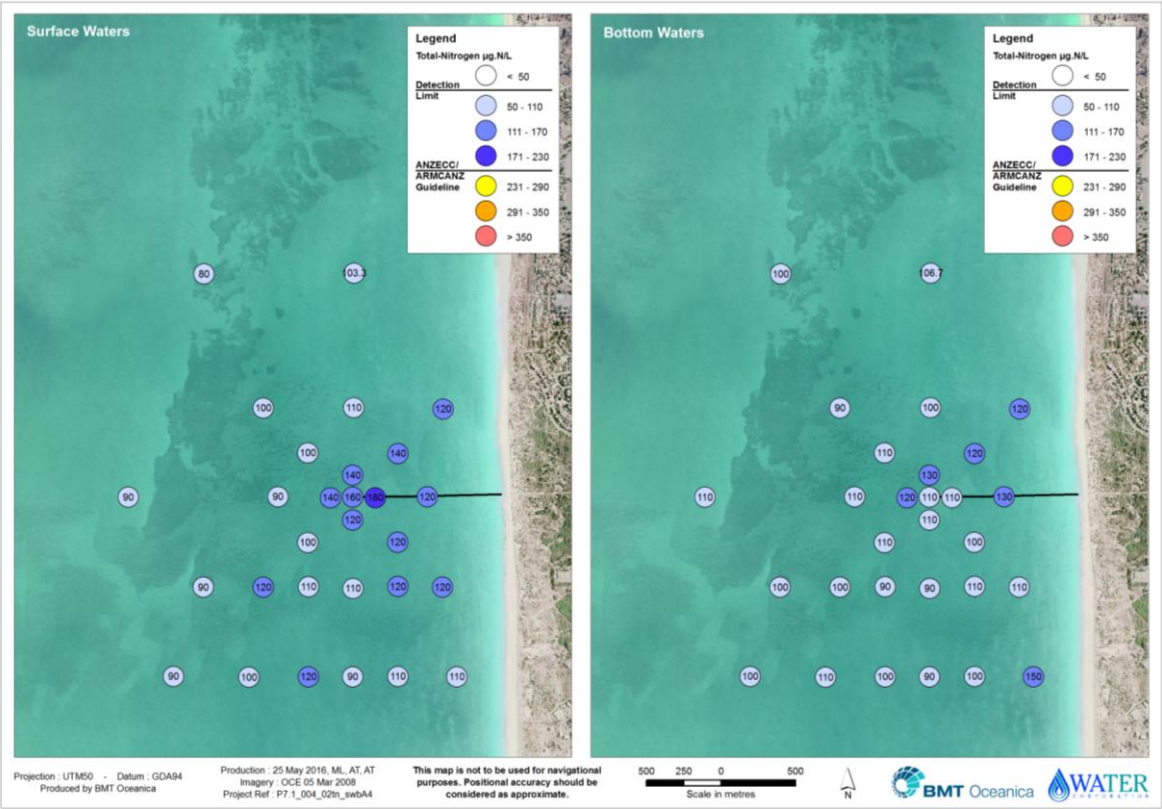
Total nitrogen

Total nitrogen concentrations at all offshore and shoreline sites were lower than the ANZECC and ARMCANZ (2000) guideline value (Figure 3.12 and Figure 3.13). The 80th percentile of reference site concentrations were more conservative, and were exceeded by 5 (14%) surface samples and 1 (3%) bottom sample (Figure 3.12 and Figure 3.13). Median surface concentrations <250 m of the outlet exceeded the 80th percentile of reference site concentrations (Table 3.3). Median bottom concentrations <250 m of the outlet concentrations and both surface and bottom median concentrations >250 M from the outlet were below the percentile based guideline (Table 3.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline .

Figure 3.12 Total nitrogen concentrations at Swanbourne

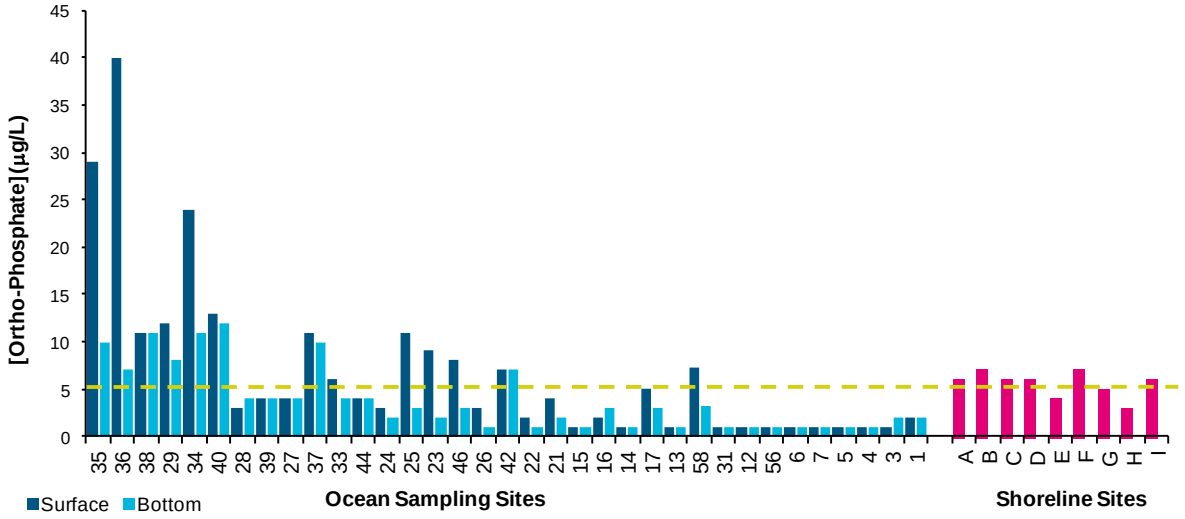


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.13 Spatial distribution of total nitrogen at Swanbourne

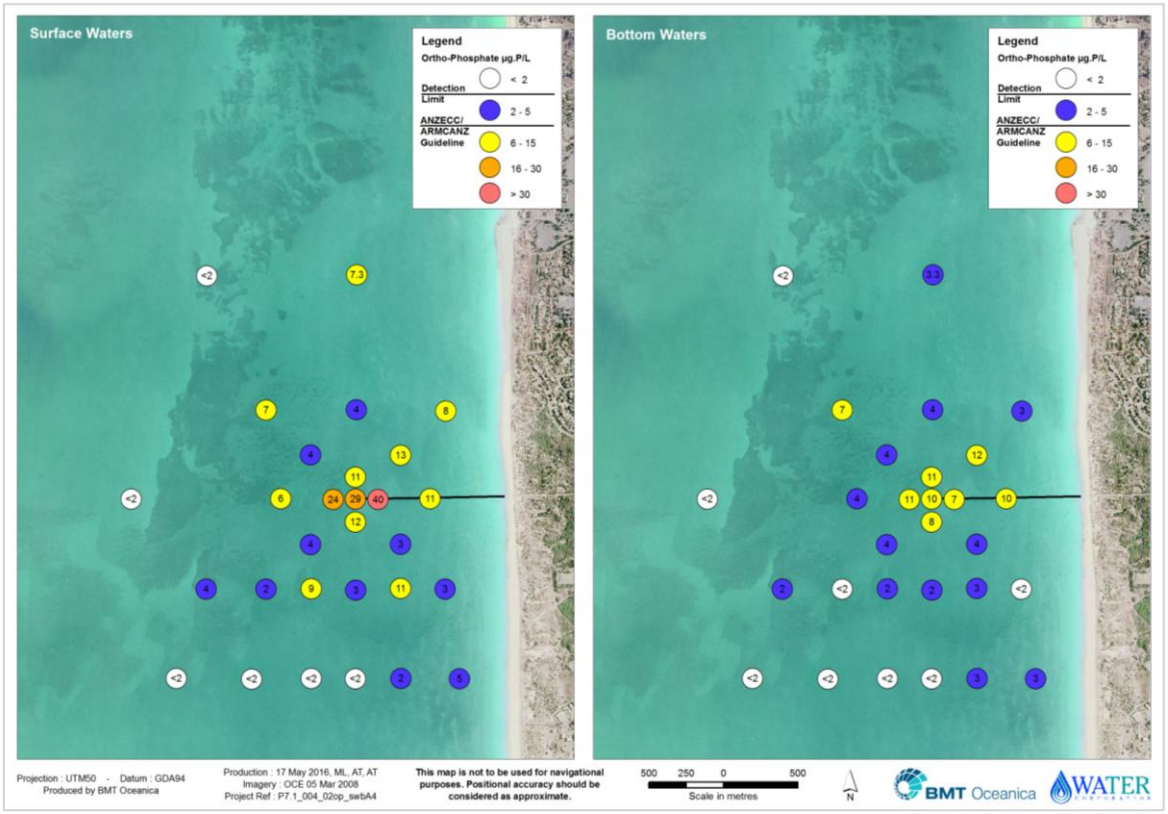
Orthophosphate

Offshore, 13 (37%) of surface and 8 (23%) of bottom sample concentrations exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 3.14 and Figure 3.15). The ANZECC & ARMCANZ (2000) guideline is conservative relative to the 80th percentile of background but 9 (26%) of surface and 5 (14%) of samples exceeded the 80th percentile of reference concentrations (Figure 3.14 and Figure 3.15). Median concentrations of orthophosphate at the surface and near the bottom were higher than both guidelines <250 m from the outlet but below both guidelines >250 m from the outlet (Table 3.3). Six of the 8 shoreline sites exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 3.14 and Figure 3.15).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 3.14 Ortho-phosphate concentrations at Swanbourne



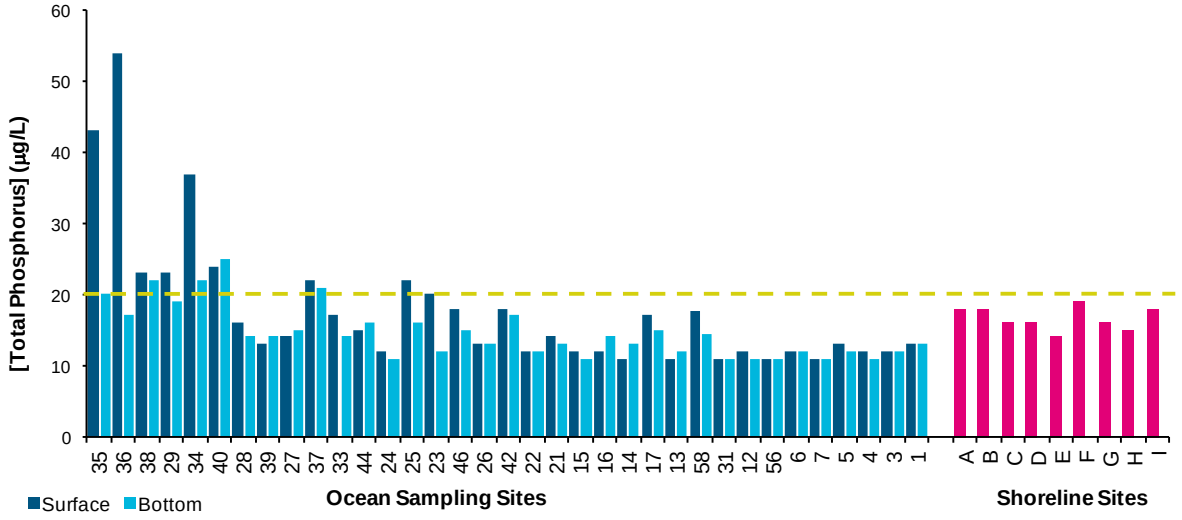
Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.15 Spatial distribution of ortho-phosphate at Swanbourne

Total Phosphorus (TP)

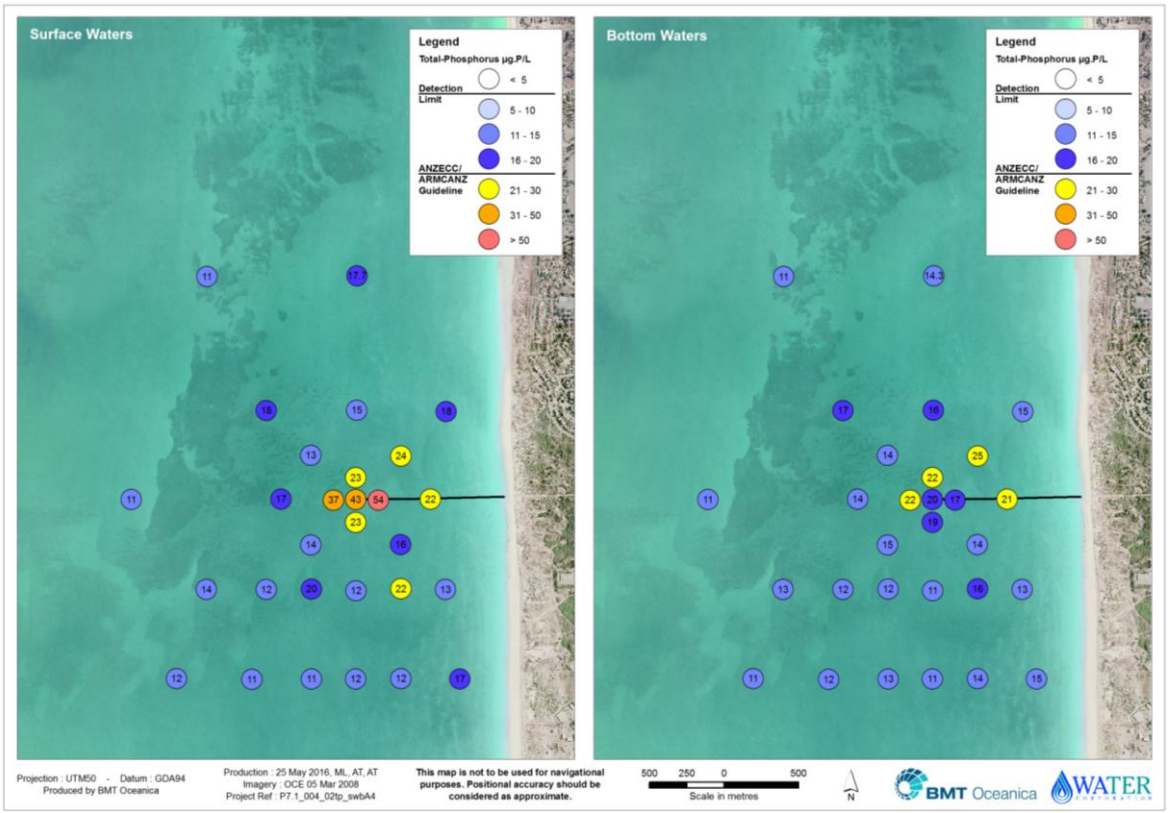
8 (23%) surface samples and 4 (11%) bottom samples exceeded the ANZECC & ARMCANZ (2000) guideline, while 3 (9%) surface and no bottom samples exceeded the 80th percentile of reference concentrations (Figure 3.16 and Figure 3.17). Shoreline

concentrations did not exceed the ANZECC & ARMCANZ (2000) guideline (Figure 3.16 and Figure 3.17). Only the median concentrations at the surface inside 250 m exceeded the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference concentrations (Table 3.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 3.16 Total phosphorus concentrations at Swanbourne

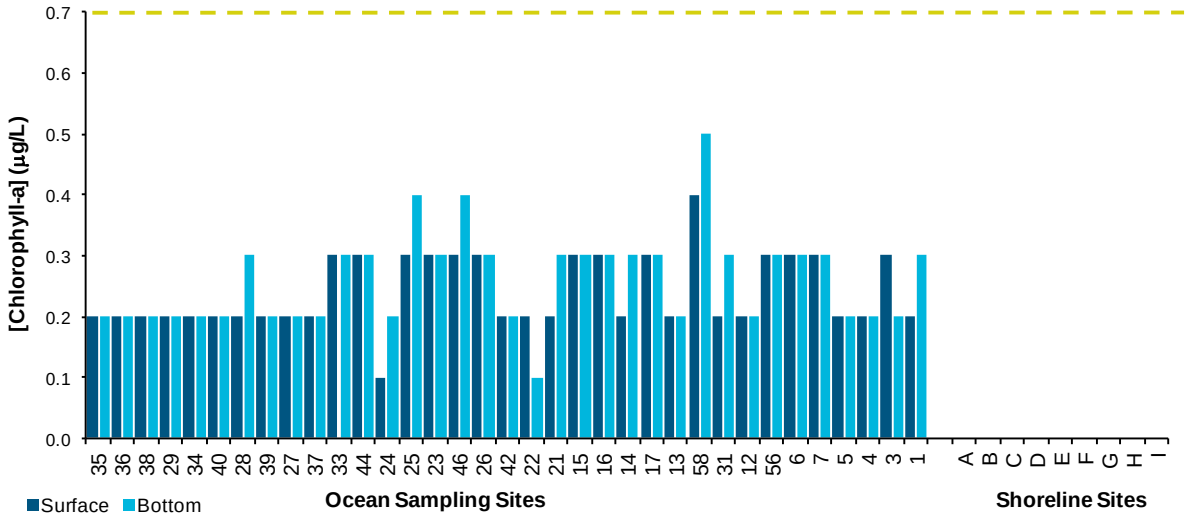


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.17 Total phosphorus concentrations at Swanbourne

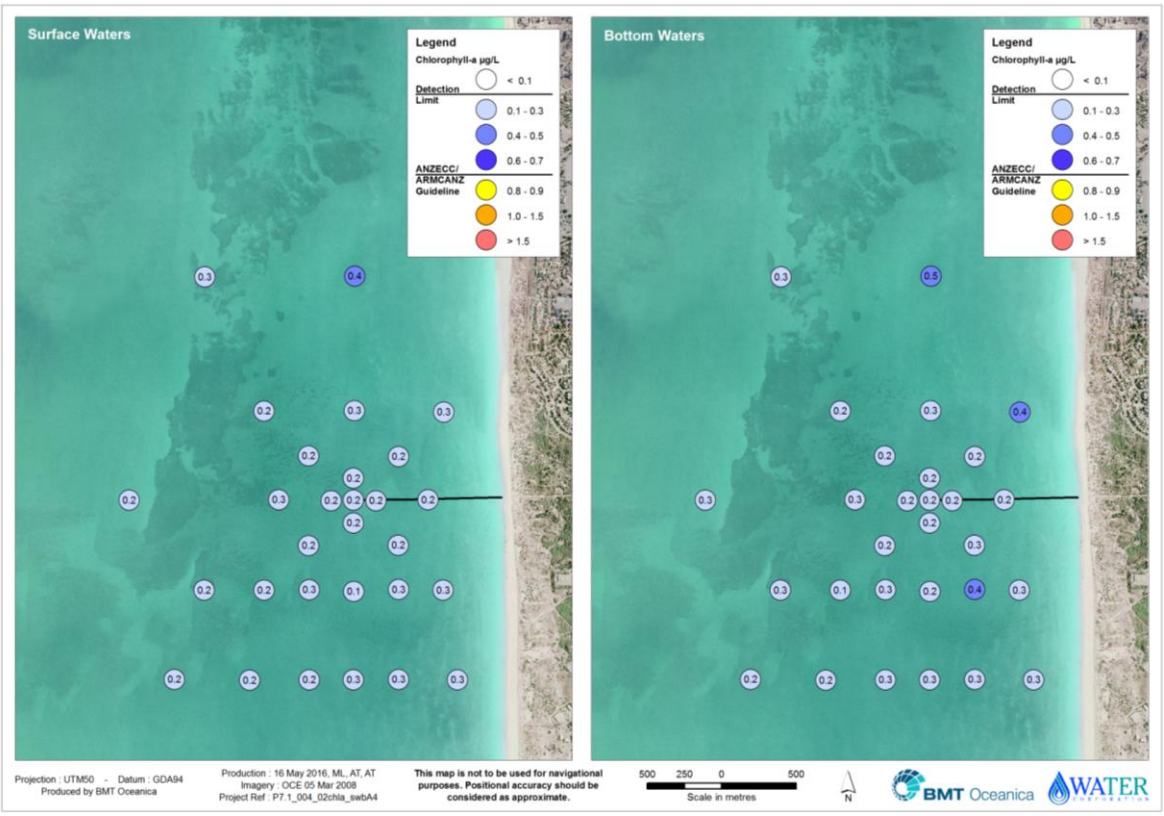
3.6 Chlorophyll

No individual samples and therefore, no median concentrations exceeded the ANZECC & ARMCANZ (2000) guideline for chlorophyll or the 80th percentile of reference concentrations (Figure 3.18, Figure 3.19 and Table 3.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline.

Figure 3.18 Chlorophyll-a concentrations at Swanbourne

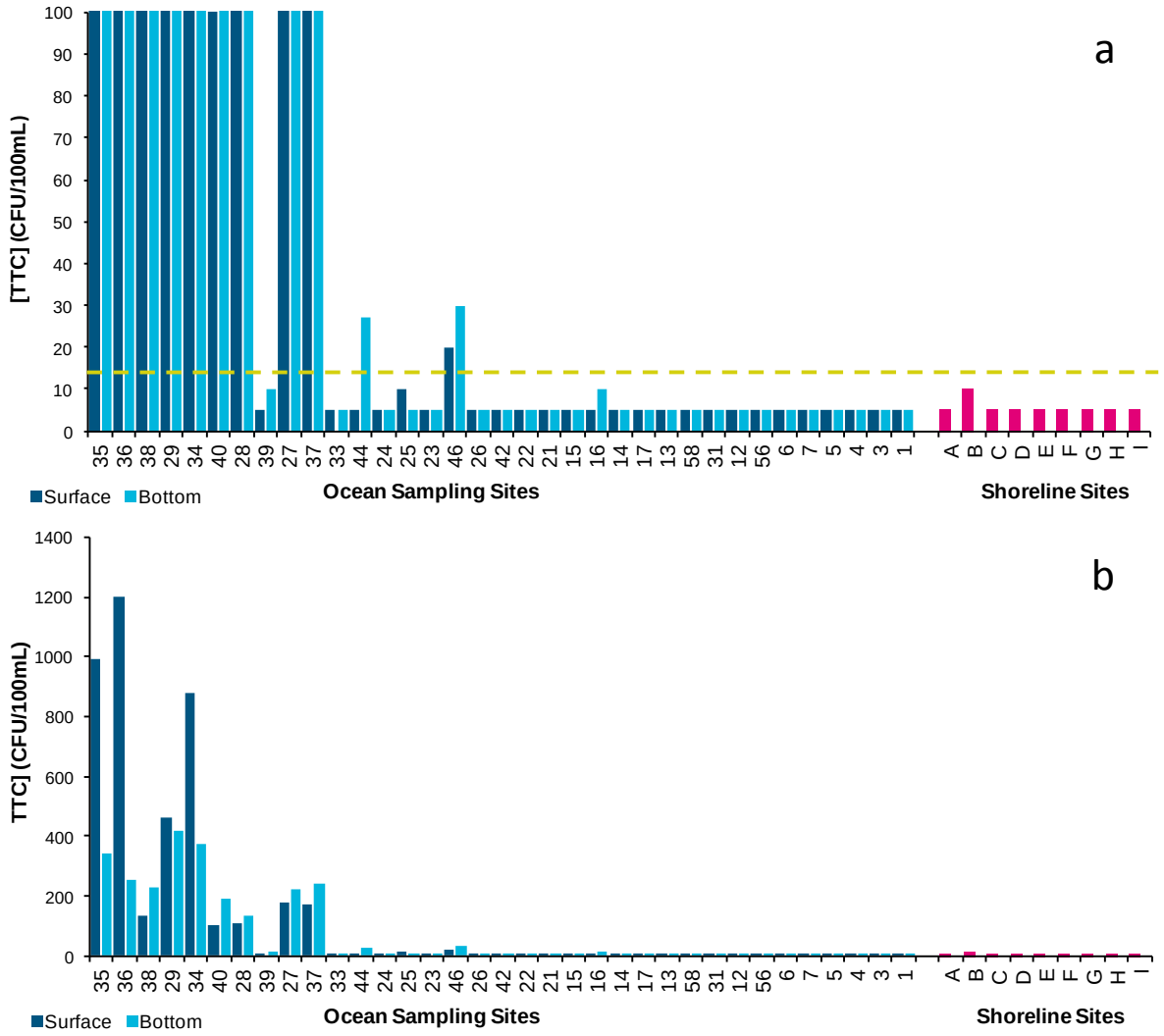


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.19 Spatial distribution of chlorophyll-a concentrations at Swanbourne

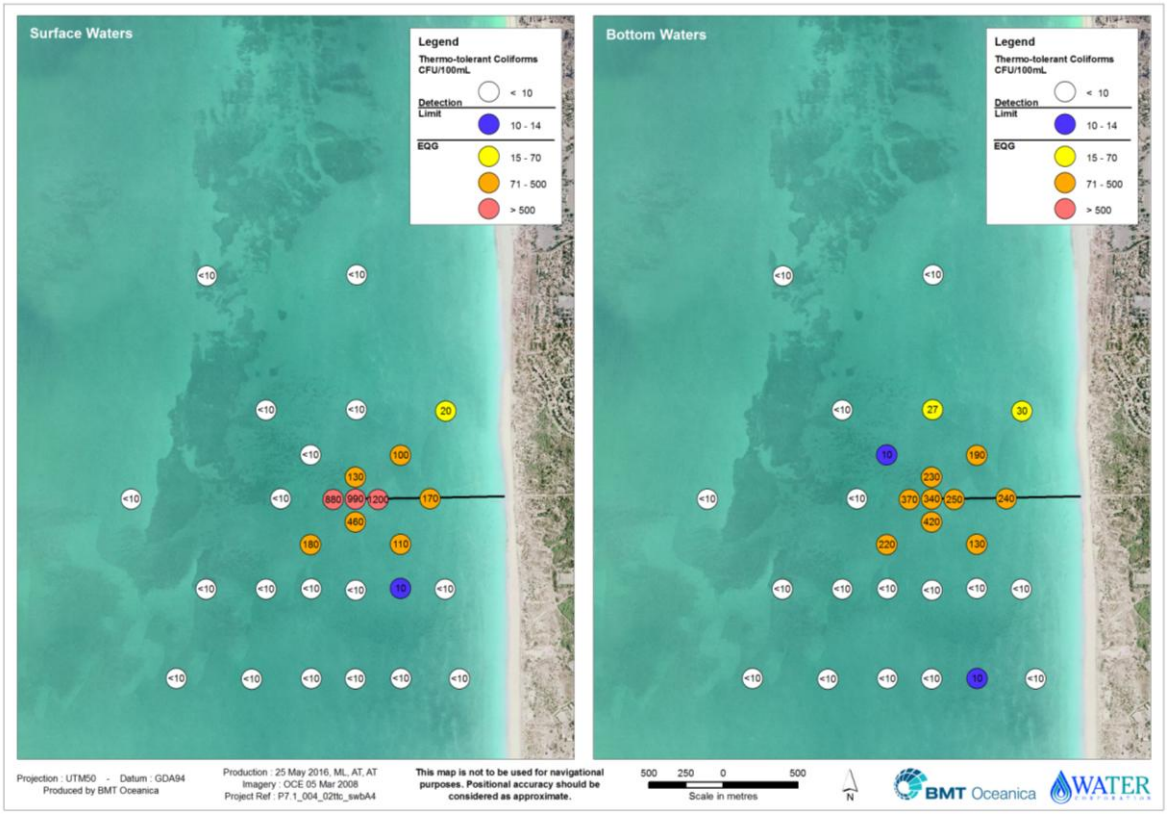
3.7 Microbial community

TTC concentrations with 250 m of the diffuser ranged between 130 and 1200 CFU/100 ml (Figure 3.20 and Figure 3.21). The median surface and the bottom concentrations from sites <250 m from the diffuser both exceeded the EPA (2015b) EQG trigger (Table 3.3). Beyond 250 m, surface and bottom median concentrations were equivalent to the limit of detection and the EQG trigger was met (Table 3.3).



Note:
1. Dashed line indicates EQG (EPA 2015b) guideline

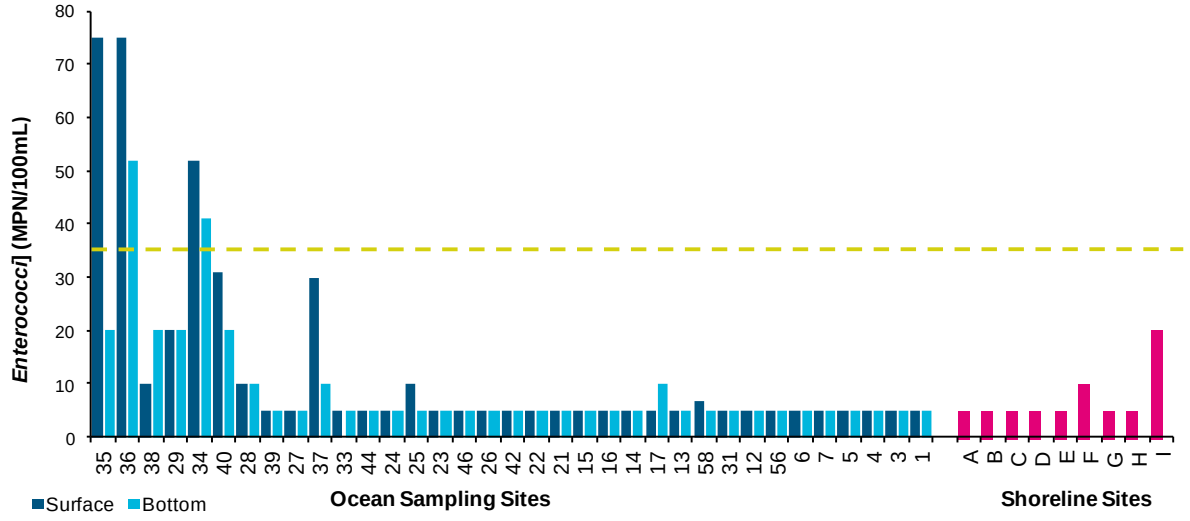
Figure 3.20 Thermotolerant coliform concentrations at Swanbourne



Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or EQG.

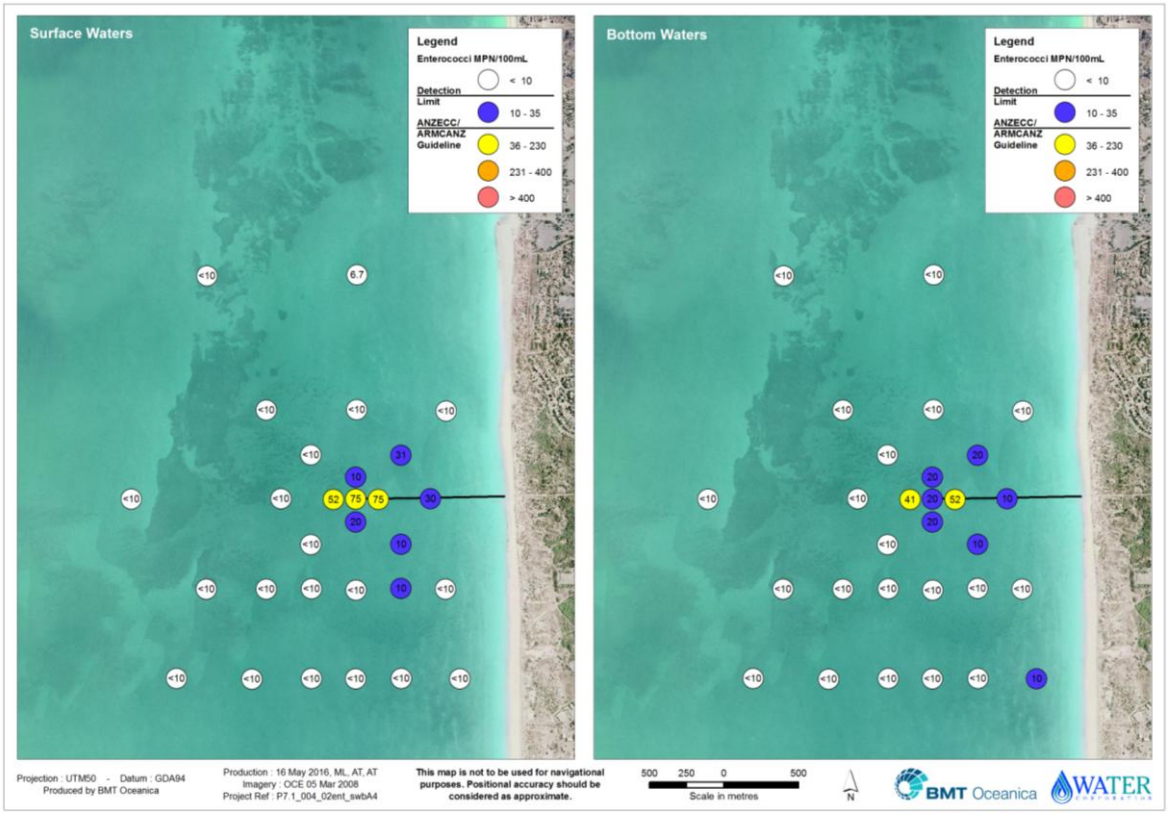
Figure 3.21 Spatial distribution of thermotolerant coliform concentrations at Swanbourne

The highest *Enterococci* spp. concentrations were at the surface sites nearest the diffuser (Figure 3.22 and Figure 3.23) Median concentrations of *Enterococci* spp. at the surface within 250 m of the diffuser exceed the ANZECC & ARMCANZ (2000) trigger (Table 3.3). Median concentrations at the bottom <250 m from the diffuser and at the surface and the bottom >250 m from the diffuser meet the criteria (Table 3.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 3.22 *Enterococci* spp. concentrations at surface Swanbourne



Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 3.23 Spatial distribution of *Enterococci* spp. at Swanbourne

3.8 Summary

The summer water quality surveys were not specifically designed for comparison with the ANZECC/ARMCANZ (2000) guidelines or with 80th percentile of reference values but comparisons were made for sites located <250 m and >250 m from the diffuser as an indicator rather than a means of assessing 'compliance. Despite elevated concentrations at some individual sites outside the immediate zone of influence of the outlet, the guidelines for demonstrating ecosystem protection and public health criteria were met (Table 3.2).

During the survey, the treated wastewater plume was initially buoyant (as indicated by the lower salinity and slightly higher concentrations of nutrients and microbiological indicators in surface waters than in bottom waters) and was advecting in a south westerly direction. Surface nutrients were typically elevated within 250 m of the diffuser but median concentrations were diluted to below the guidelines beyond 250 m (Table 3.2). There was no indication that the wastewater nutrients were stimulating detectable increases in phytoplankton (chlorophyll) within or outside the 250 m area around the diffuser (Table 3.2).

Median *Enterococci* spp. and thermotolerant coliform (TTC) concentrations were below their respective guidelines for recreation contact and the maintenance of seafood safe for human consumption, respectively in surface and bottom waters >250 m from the diffuser (Table 3.2) suggesting that these waters are maintained for recreation and

seafood quality. Shoreline monitoring found no indication of contamination of adjacent beaches (Table 3.2)

Table 3.2 Summary Swanbourne

Parameter	Inside the mixing zone (sites <250 m from diffuser)		Outside the mixing zone (sites >250 m from diffuser)		Shoreline
	Surface	Bottom	Surface	Bottom	
ANZECC/ARMCANZ (2000) guideline values					
Total ammonia nitrogen					
Ortho-phosphate					
Nitrate+nitrite					
Total phosphorus					
Total nitrogen					
Chlorophyll-a					
Enterococci spp.[3]					
80th percentile of reference values					
Total ammonia nitrogen					
Ortho-phosphate					
Nitrate+nitrite					
Total phosphorus					
Total nitrogen					
Chlorophyll-a					
Environmental Quality Guideline (EPA 2015b)					
Thermotolerant coliforms[4]					

Notes:

1. Green = median values ≤ ANZECC/ARMCANZ (2000) guideline values , ≤80th percentile reference values or ≤ EQG.
2. Red = Median values > ANZECC/ARMCANZ (2000) guideline values , >80th percentile reference values or > EQG
3. For the maintenance of seafood safe for human consumption
4. For primary contact recreation

Table 3.3 Summary statistics for Swanbourne

Parameter	depth	lowest		highest		Median		number (%) below the guideline		number (%) below 80th percentile of reference	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Ammonia (NH_4)	All	<3	<3	4	<3	<3	<3	35 (100)	35 (100)	35 (100)	35 (100)
	Inside 250 m	<3	<3	<3	<3	<3	<3				
	Outside 250 m	<3	<3	4	<3	<3	<3				
	Shoreline	<3		9		<3		7 (78)			
Nitrate + nitrite	All	<2	<2	57	22	<2	<2	24 (69)	28 (80)	27 (77)	30 (86)
	Inside 250 m	16	9	57	18	37	13				
	Outside 250 m	<2	<2	22	22	<2	<2				
	Shoreline	<2		16		3		8 (89)			
Total nitrogen	All	80	90	180	150	110	106.7	35 (100)	35 (100)	30 (86)	34 (97)
	Inside 250 m	120	110	180	130	140	110				
	Outside 250 m	80	90	140	150	110	100				
	Shoreline	110		150		120		9 (100)			
Ortho-phosphate	All	1	1	40	12	4	3	22 (63)	27 (77)	26 (74)	30 (86)
	Inside 250 m	11	7	40	11	24	10				
	Outside 250 m	1	1	13	12	3	2				
	Shoreline	3	0	7	0	6	0	3 (33)			
Total phosphorus	All	11	11	54	25	14	14	27 (77)	31 (89)	32 (91)	35 (100)
	Inside 250 m	23	17	54	22	37	20				
	Outside 250 m	11	11	24	25	13	13				
	Shoreline	14		19		16		9 (100)			
Chlorophyll *a*	All	0.1	0.1	0.4	0.5	0.2	0.3	35 (100)	35 (100)	35 (100)	35 (100)
	Inside 250 m	0.2	0.2	0.2	0.2	0.2	0.2				
	Outside 250 m	0.1	0.1	0.4	0.5	0.2	0.3				
	Shoreline										
Thermotolerant coliforms	All	<10	<10	1200	420	<10	<10				
	Inside 250 m	130	230	1200	420	880	340				
	Outside 250 m	<10	<10	180	240	<10	<10				
	Shoreline	<10		10		<10					
Enterococci spp.	All	<10	<10	750	52	<10	<10				
	Inside 250 m	10	20	750	52	52	20				
	Outside 250 m	<10	<10	31	20	<10	<10				
	Shoreline	<10		20		<10					

4. Ocean Reef

4.1 The survey

The annual summer water quality survey at Ocean Reef was completed on 9 February 2016.

4.2 Discharge

A discrete sample of treated wastewater was collected from the Beenyup WWTP on 9 February 2016 (during the ocean survey) (Table 4.1). At the time of the survey there were 50 ports open on Outlet A and 48 ports on Outlet B. Discharge was evenly split between the outlets.

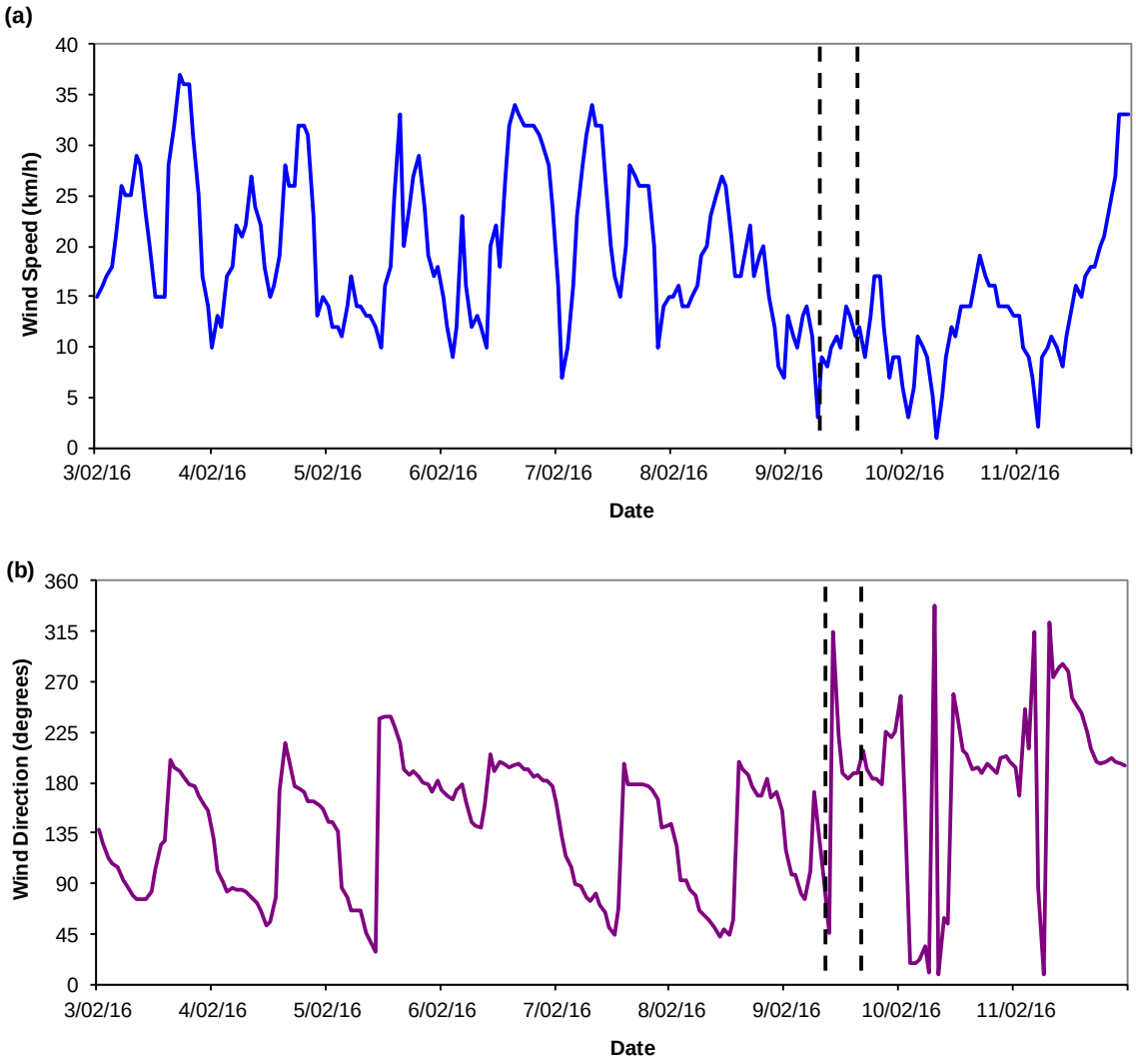
Table 4.1 Beenyup treated wastewater characteristics on 9 February 2016

Parameter	Concentration
Total phosphorus	5.8 mg/L
Total nitrogen	13 mg/L
Total ammonia nitrogen	2.8 mg/L
Nitrate+nitrite	7.6 mg/L
Thermotolerant coliforms	10 000 CFU/100 mL
Enterococci spp.	660 MPN/100 mL
Total suspended solids	8 mg/L
Biological oxygen demand	<5 mg/L
Total flow (combined outlet A and B)	111.5 ML/d

4.3 Environmental characteristics

4.3.1 Wind,

For 24 hours prior to the survey, the winds at Ocean Reef abated from moderate easterlies (averaging 22.7 km/h), to gentle southerlies (average 15.6 km/h) and back to light easterlies (average 12.0 km/h). During sampling, the light winds shifted from the east at the beginning of sampling to the south towards the end (averaging 10.8 km/h) (Figure 4.1).



Note:
1. a = wind speed
2. b = wind direction
3. Dashed lines (- -) show approximate timing of the summer water quality survey.

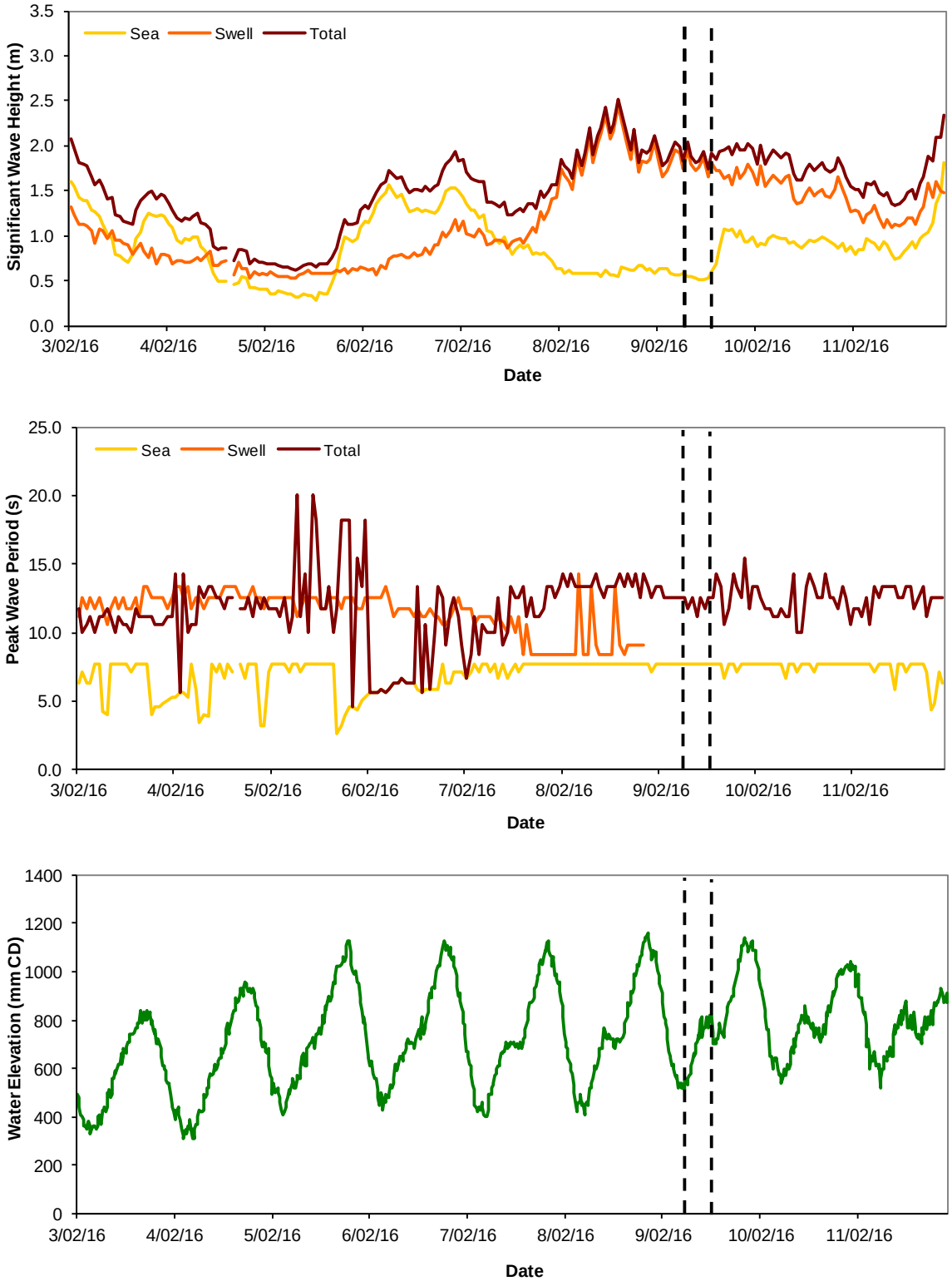
Figure 4.1 Wind speed and wind direction at Ocean Reef

4.3.2 Waves and tide

For 24 hours prior to the survey, the average significant wave height[10] offshore from Rottnest Island was 2.1 m, with an average peak wave period[11] of 13.3 s (Figure 4.2). During the survey the average offshore significant wave height was 1.9 m and the average peak wave period of 12.2 s. The survey was completed during a rising tide (Figure 4.2).

[10] *The significant wave height (in metres) is defined as the average height of the highest one-third of waves recorded (source: http//www.dpi.wa.gov.au/)*

[11] *The wave period (in seconds) is the time between consecutive wave crests. The peak wave period is the wave period of those waves that are producing the most energy in a wave record*



Note:
1. Dashed lines (- -) show approximate timing of the survey

Figure 4.2 Significant wave heights (offshore Rottnest Island), peak wave periods (offshore Rottnest Island) and water level elevation (Fremantle Fishing Boat Harbour)

4.3.3 Currents

The surface drogue, released at the centre of the diffuser at the beginning of the survey, initially drifted in a northerly direction for ~130 and gradually shifted to the west and then southwest during its passage. The average velocity of the drogue over the route was 0.04 m/s. At the time of the survey and based on drogue movements, it is expected that discharged treated wastewater would overall be travelling in a north westerly direction and offshore of the diffuser (Figure 4.3).

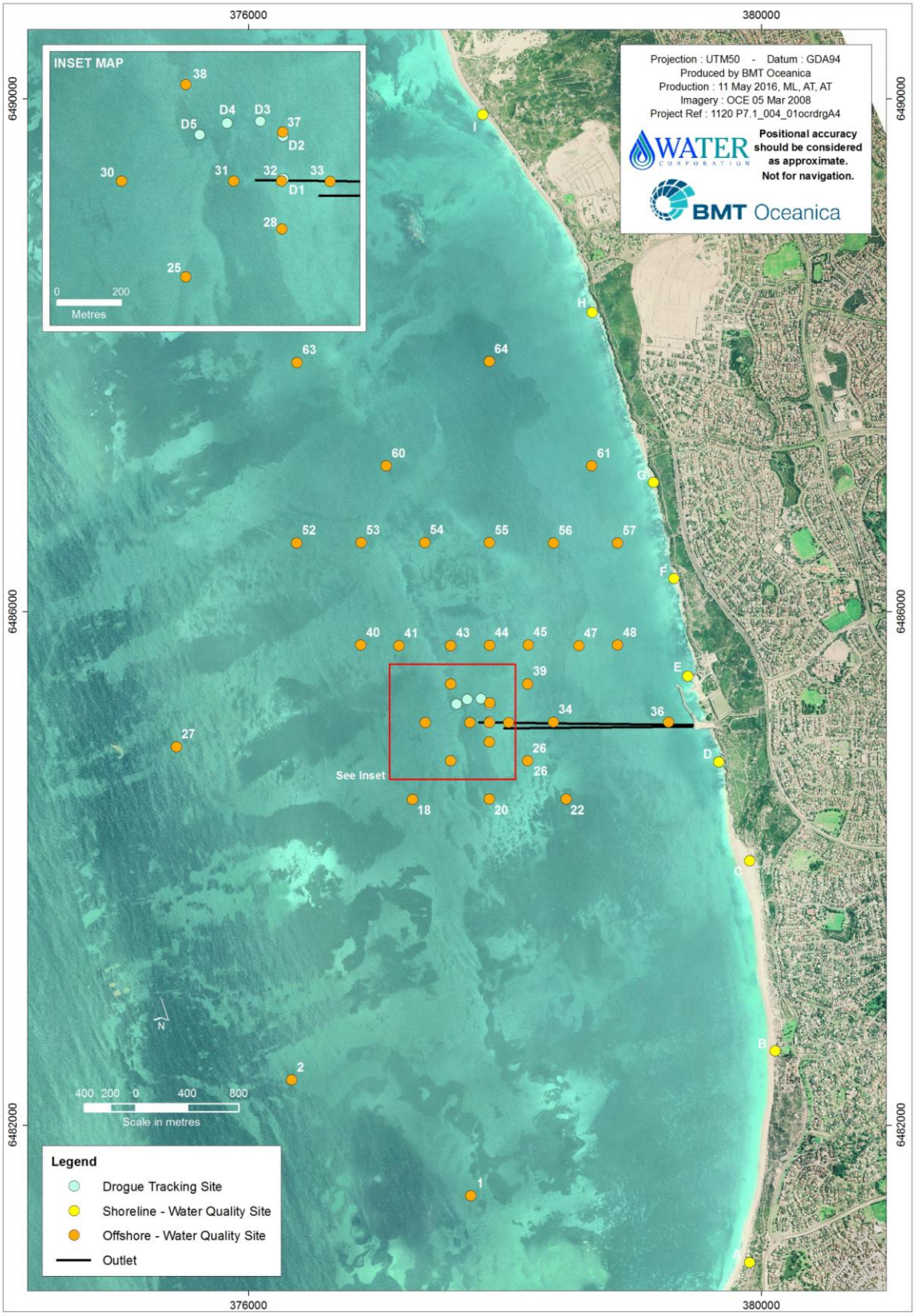
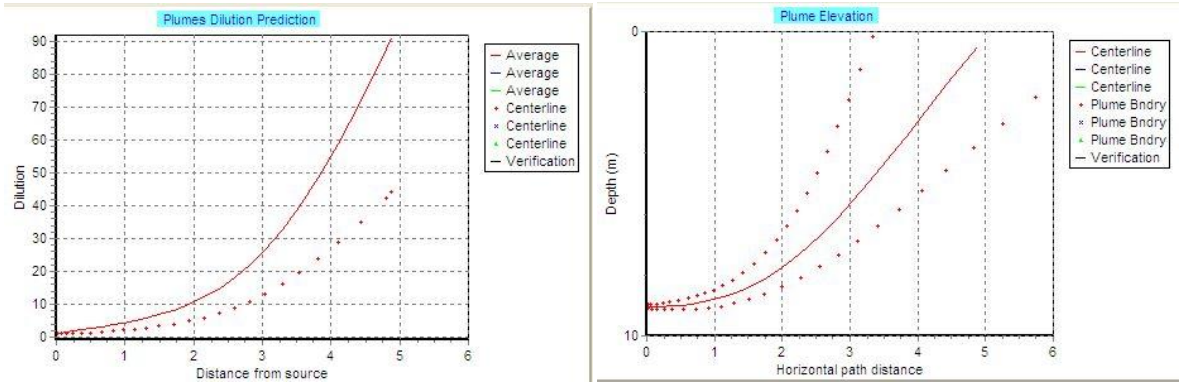


Figure 4.3 Ocean Reef drogue tracking locations, 9 February 2016

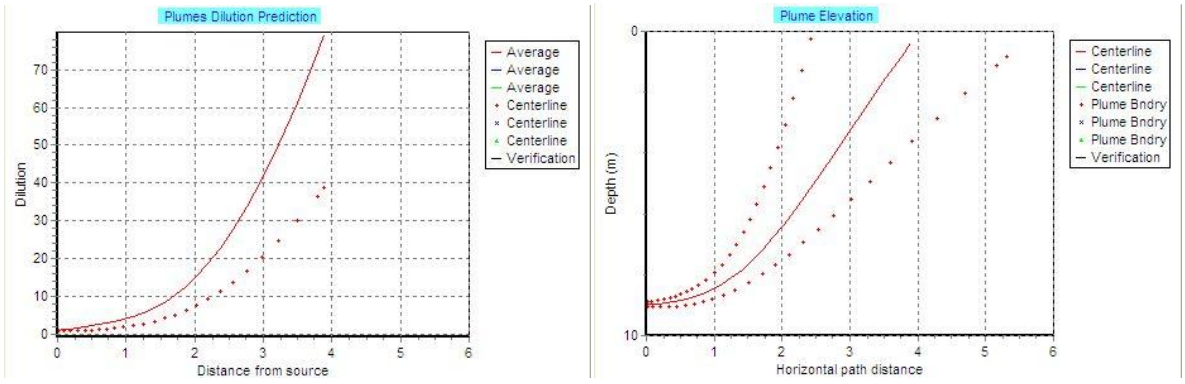
4.3.4 Initial dilution

For ambient conditions at the time of the Ocean Reef survey, the modelling predicted average initial dilutions of 1:91 for Outlet A and 1:79 for Outlet B with centreline dilutions of 1:45 for Outlet A and 1:39 for Outlet B (Figure 4.4a and Figure 4.5a). The plume was predicted to first reach the surface within ~5–8 m (horizontal distance) from the discharge point (see the ambient boundary[12] of the plume in Figure 4.4b and Figure 4.5b). The full model output is included in Appendix C**Error! Reference source not found.**.



Notes:
1. a = predicted average and centreline dilution
2. b = predicted plume elevation

Figure 4.4 Predicted average and centreline dilutions and predicted plume elevation trajectory for Outlet A at Ocean Reef



Notes:
1. a = predicted average and centreline dilution
2. b = predicted plume elevation

Figure 4.5 Predicted average and centreline dilutions and predicted plume elevation trajectory for Outlet B at Ocean Reef

4.4 Water column structure

Water temperature from 8 sites profiled ranged from 23.43°C to 25.11°C, salinity ranged from 36.00 to 36.46 and dissolved oxygen varied from 6.62 mg/L to 7.37 mg/L (equivalent to 96.5–107% saturation) (Figure 4.6 and Figure 4.7). Thermoclines were evident at sites furthest from the outlet while salinity was slightly reduced at the surface relative too deeper waters near the diffuser (Figure 4.6 and Figure 4.7). Dissolved

[12] *The ambient boundary corresponds to the plume boundary at which concentrations are estimated to be equal to ambient conditions.*

oxygen was not depleted by the treated wastewater plume or any other process at any site (Figure 4.6 and Figure 4.7).

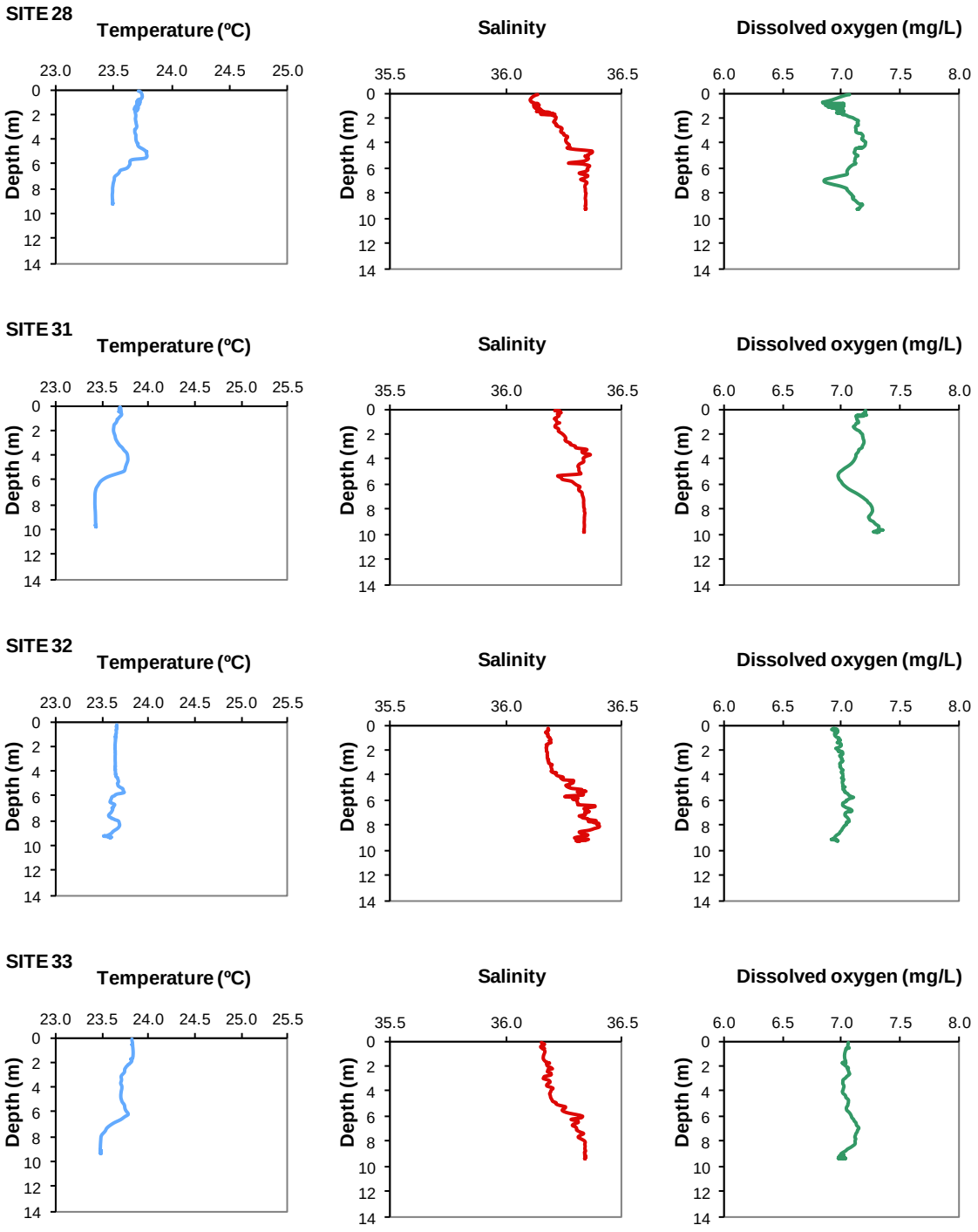


Figure 4.6 Temperature, salinity and dissolved oxygen vertical profiles at Ocean Reef

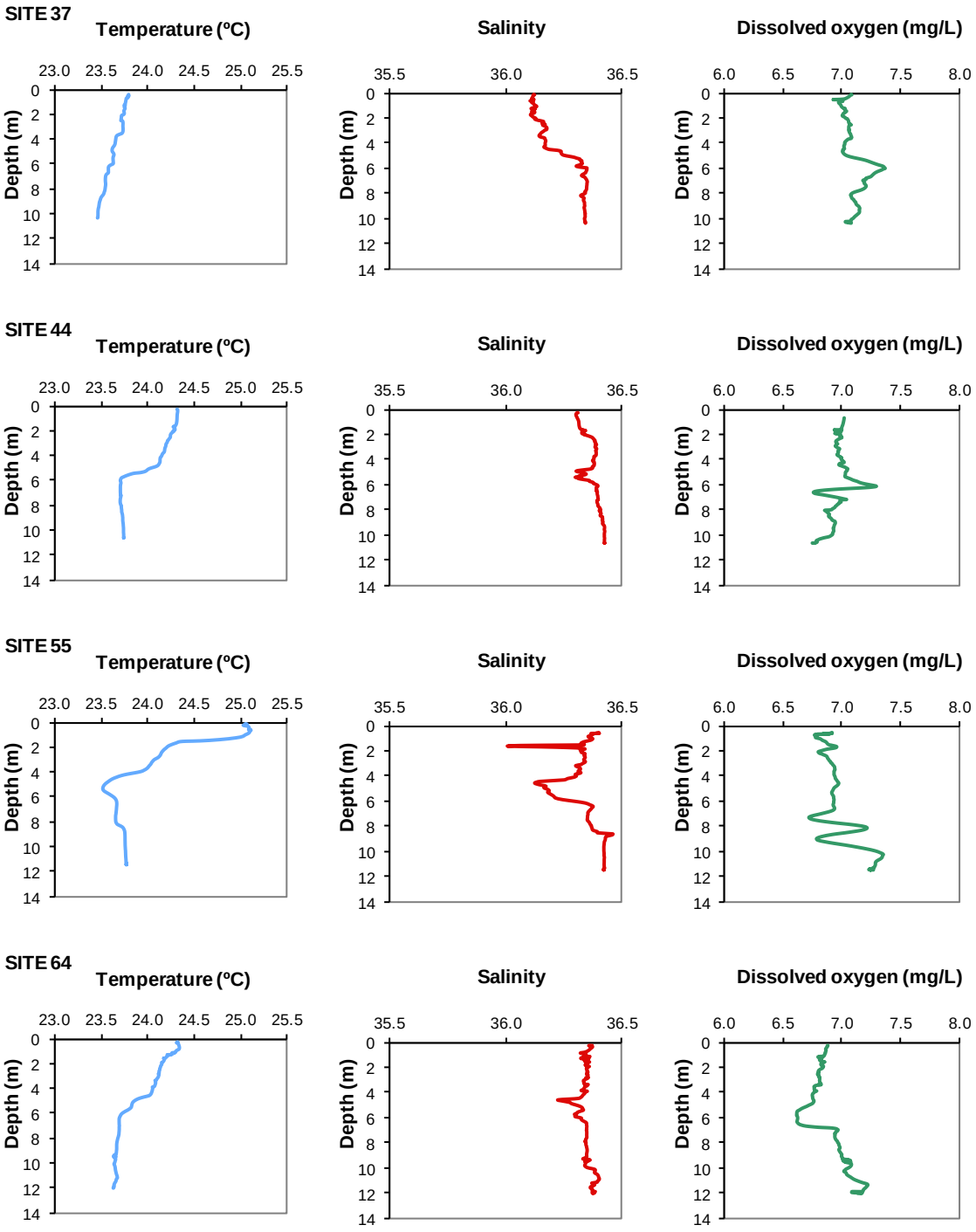


Figure 4.7 Temperature, salinity and dissolved oxygen vertical profiles at Ocean Reef

A layer of warmer water at the surface was most evident well downstream of the diffuser (site 55) and not necessarily related to the discharge (Figure 4.8). There was a salinity gradient between the surface (lower salinity) and deeper (higher salinity) waters near the outlet that may reflect the discharge but it was evident in both an up and down current direction and could also reflect natural variability (Figure 4.8). The salinity gradient is not evident at station 44 down current of the diffuser (Figure 4.8).

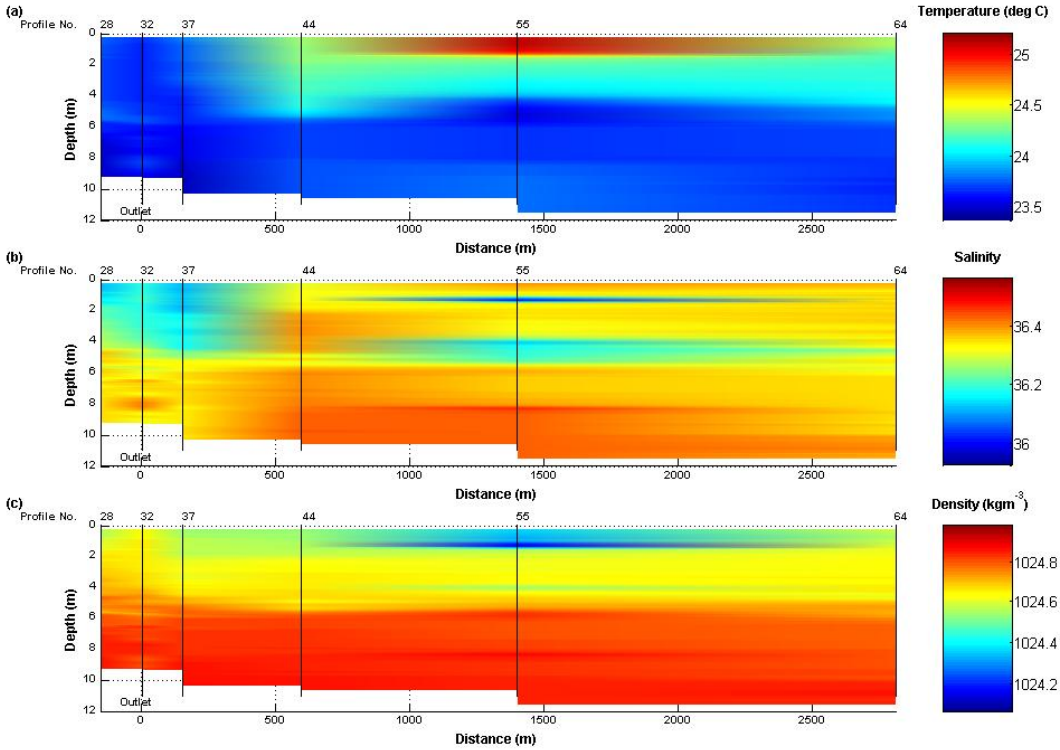
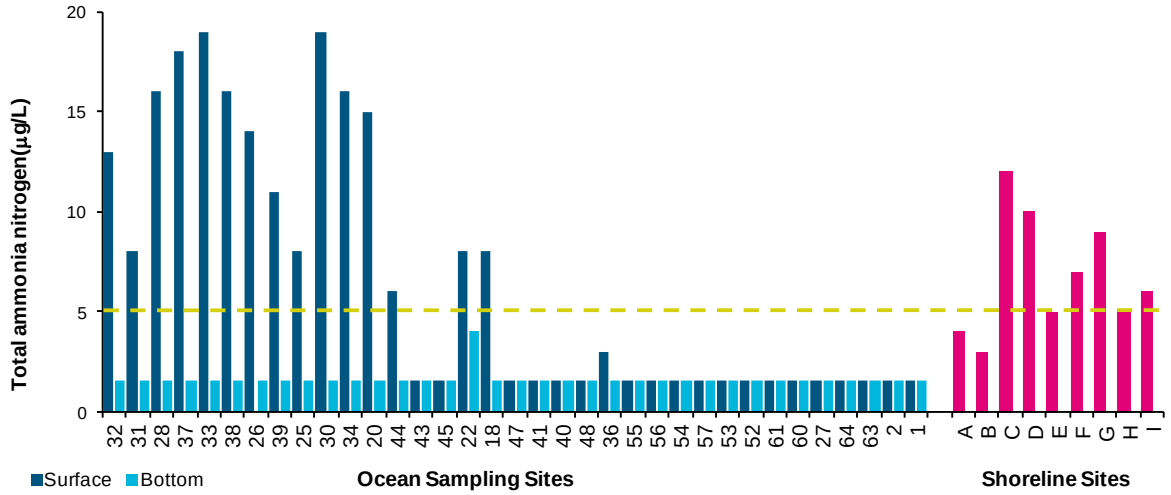


Figure 4.8 Temperature (a), salinity (b) and density (c) transect at Ocean Reef

4.5 Nutrients

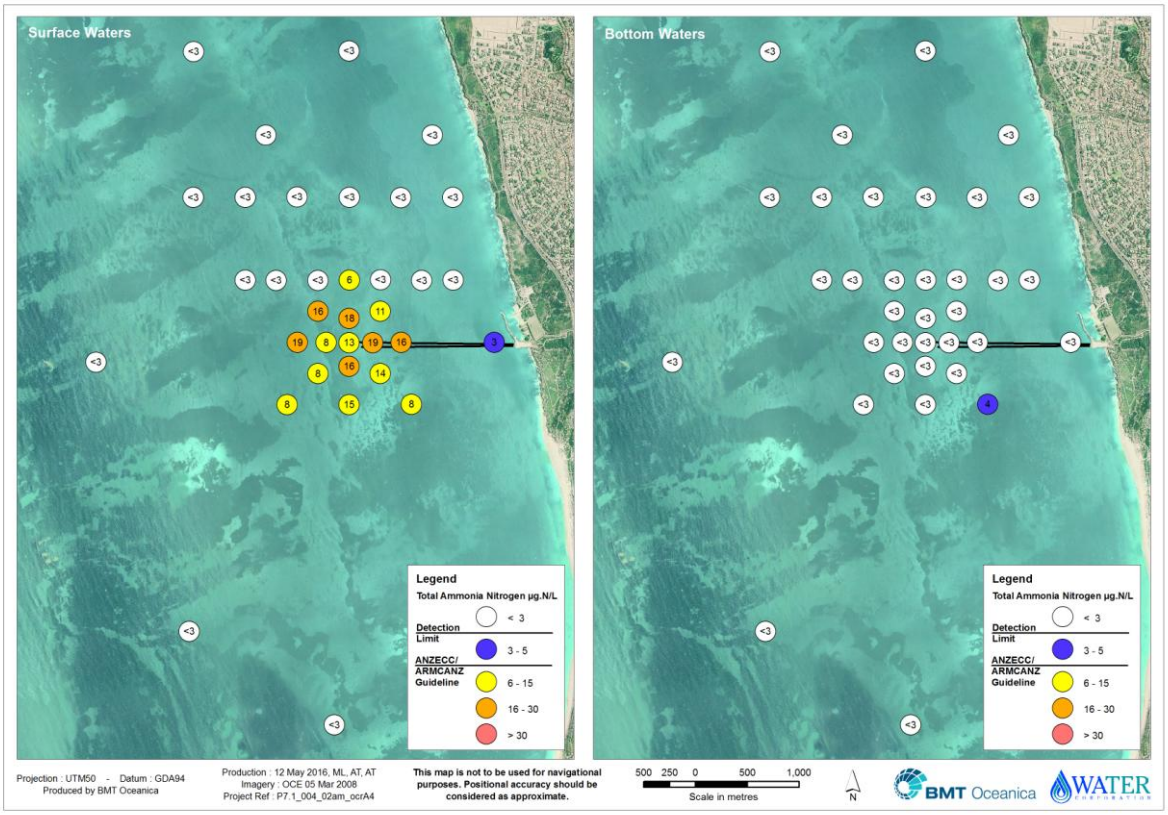
Total Ammonia Nitrogen ($HN_4^+ + NH_3$)

A total of 15 (43%) surface samples exceeded the ANZECC & ARMCANZ (2000) guideline and the 80th percentile of reference concentrations (Figure 4.9 and Figure 4.10). None of the bottom water samples exceeded the ANZECC & ARMCANZ (2000) guideline but 1 sample (3%) exceeded the 80th percentile of reference concentrations (Figure 4.9 and Figure 4.10). Five (56%) of the shoreline sites exceeded the ANZRCC and ARMCANZ (2000) trigger (Figure 4.9). Median ammonia concentration at the surface within 250 m of the diffuser exceeded the ANZACC and ARMCANZ (2000) guideline as did median concentrations at the shoreline (Table 4.3). Median concentrations at the bottom <2450 m from the diffuser and at the surface and bottom >250 m from the diffuser were all below the guideline (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 4.9 Total ammonia nitrogen concentrations at Ocean Reef

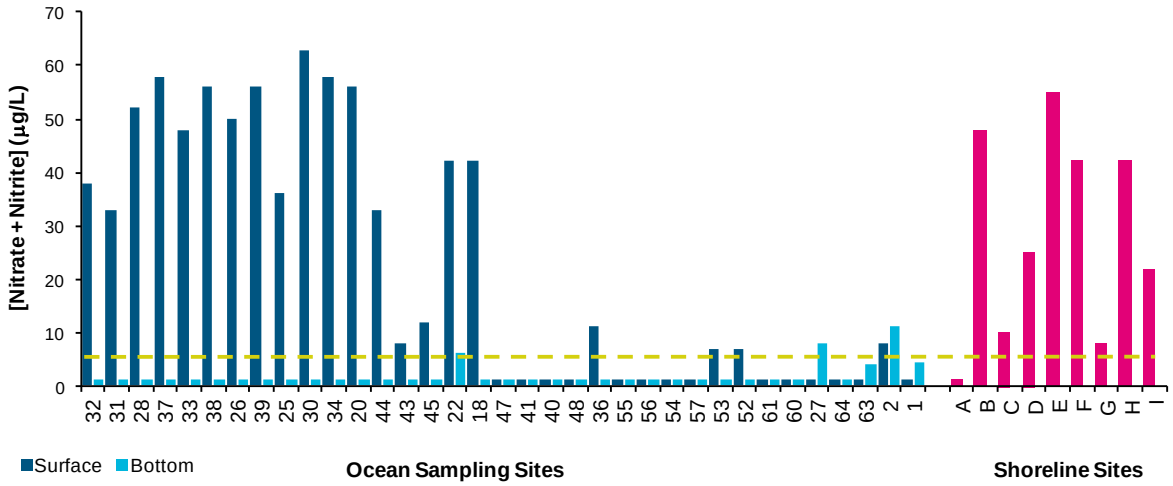


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.10 Spatial distribution of total ammonia nitrogen at Ocean Reef

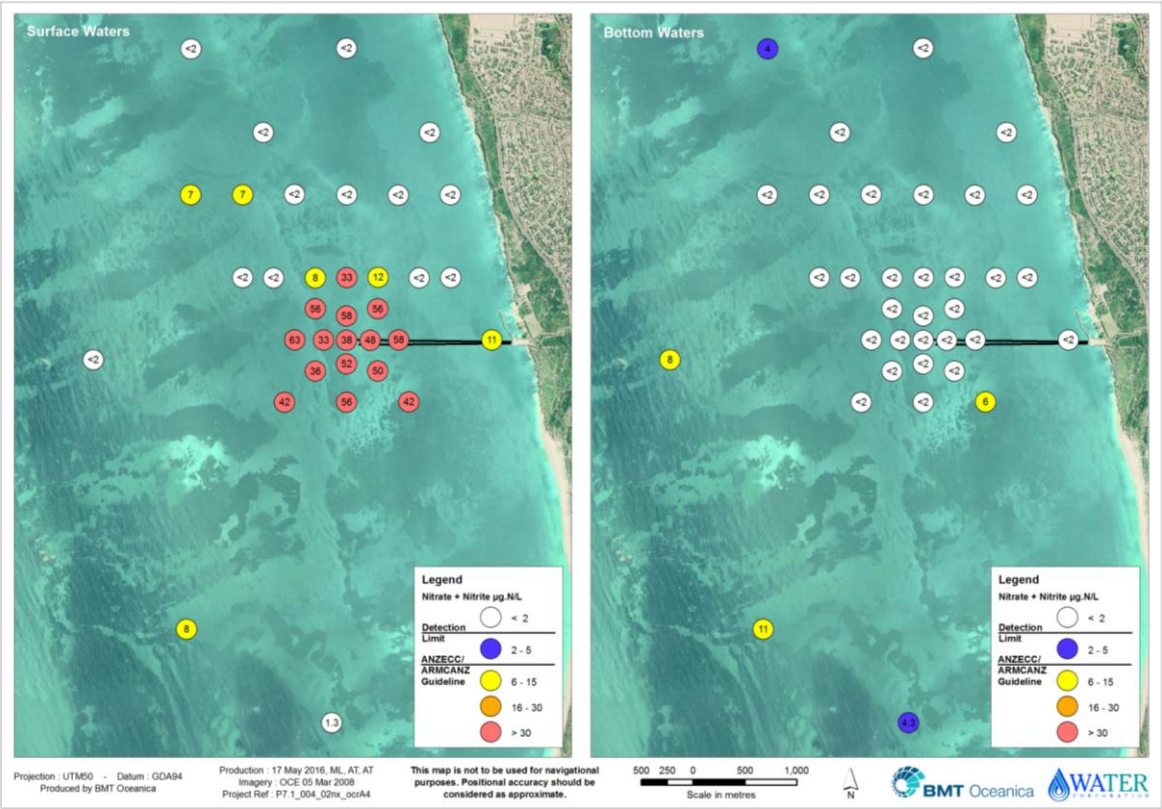
Nitrate+nitrite (NO_2^-+NO_3^-)

At the surface, 21 (60%) samples exceeded the ANZECC & ARMCANZ (2000) guideline with only 3 (9%) of bottom samples exceeding (Figure 4.11Figure 4.12). Nitrate + nitrite in the background is naturally high relative to the ANZECC & ARMCANZ (2000) figure so the 80th percentile of reference site data is higher and was exceeded by only 15 (43%) surface and no bottom samples (Figure 4.11 and Figure 4.12. Eight out of nine (89%) shoreline samples exceeded the ANZECC & ARMCAZ (2000) guideline (Figure 4.11). Median concentrations at the surface inside and outside 250 m of the diffuser both exceeded the ANZECC & ARMCANZ (2000) guideline but only surface median concentrations <250 m from the diffuser exceeded the 80th percentile of reference data as well (Table 4.3). Median concentrations at the shoreline exceeded both triggers but these sites are far from the identifiable effect of the outlet and likely elevated by terrestrial sources (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 4.11 Total nitrate+nitrite concentrations at Ocean Reef

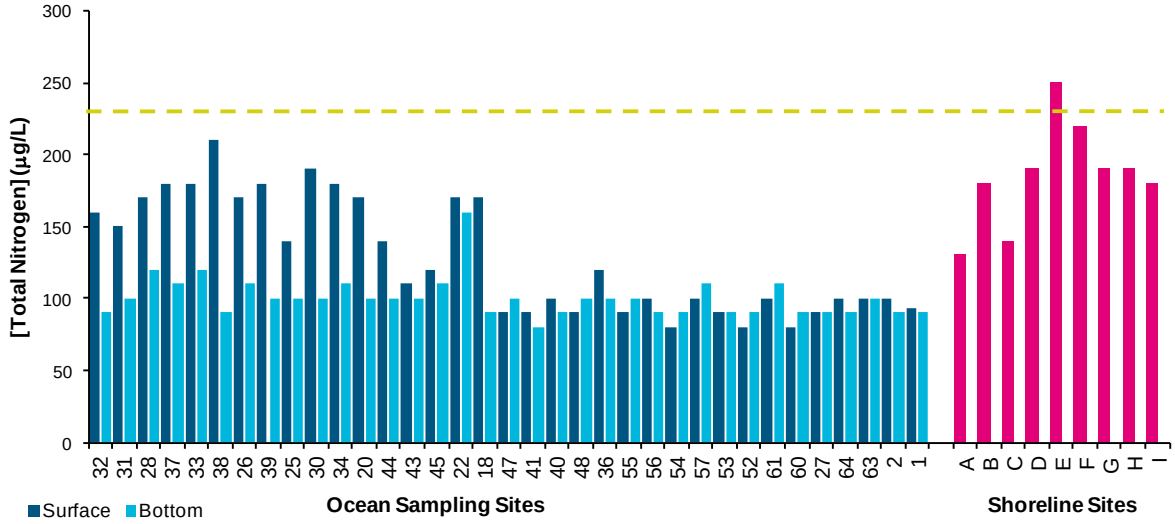


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.12 Spatial distribution of nitrate+nitrite at Ocean Reef

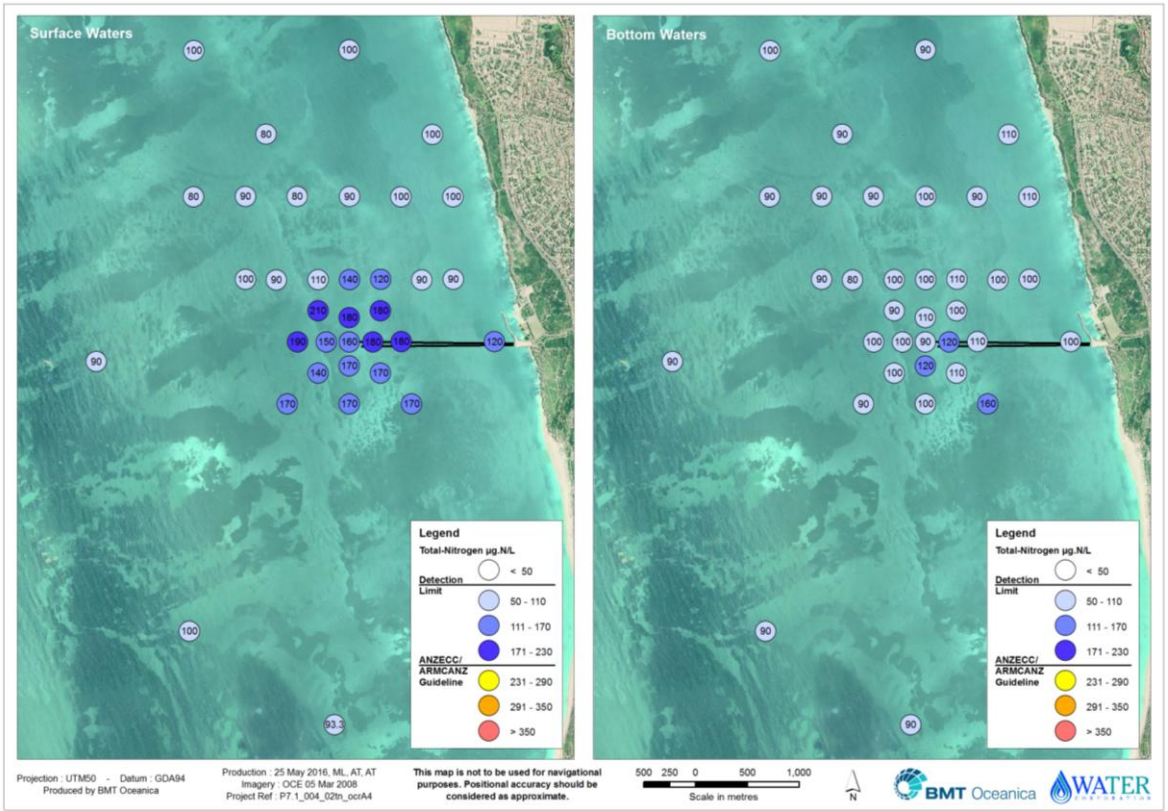
Total nitrogen

Total nitrogen concentrations exceeded the ANZECC & ARMCANZ (2000) guideline at only one (11%) of the nine shoreline sites (Figure 4.13 and Figure 4.14). The 80th percentile of reference site concentrations was more conservative and exceeded by 15 (43%) surface and 1 (35) bottom samples (Figure 4.13 and Figure 4.14). No median concentrations exceeded the ANZECC & ARMCANZ (2000) guideline (Table 4.3). Median concentrations at the surface inside 250 m and at the shoreline exceed the 80th percentile of reference concentrations (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 4.13 Total nitrogen concentrations at Ocean Reef



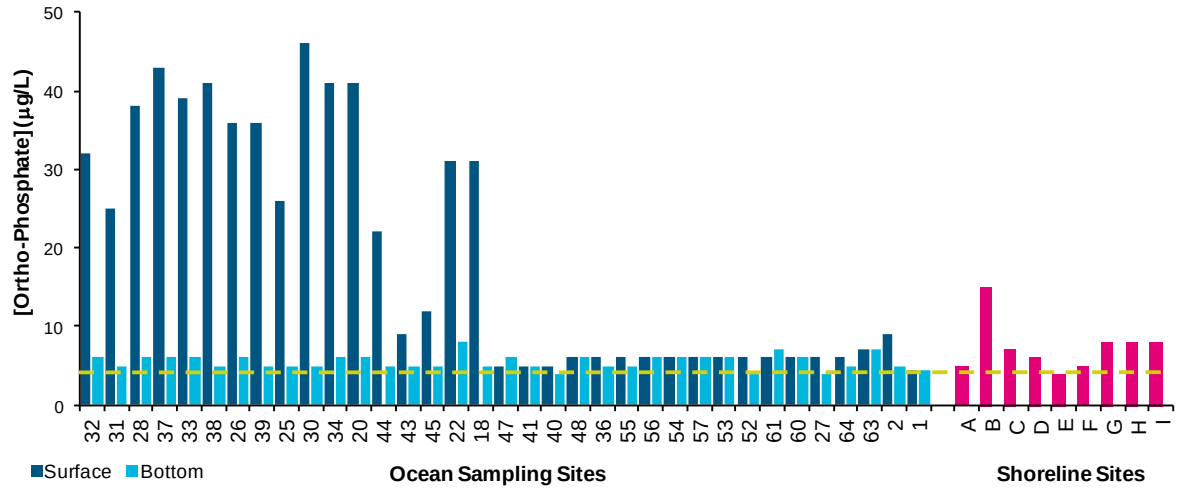
Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.14 Spatial distribution of total nitrogen at Ocean Reef

Orthophosphate

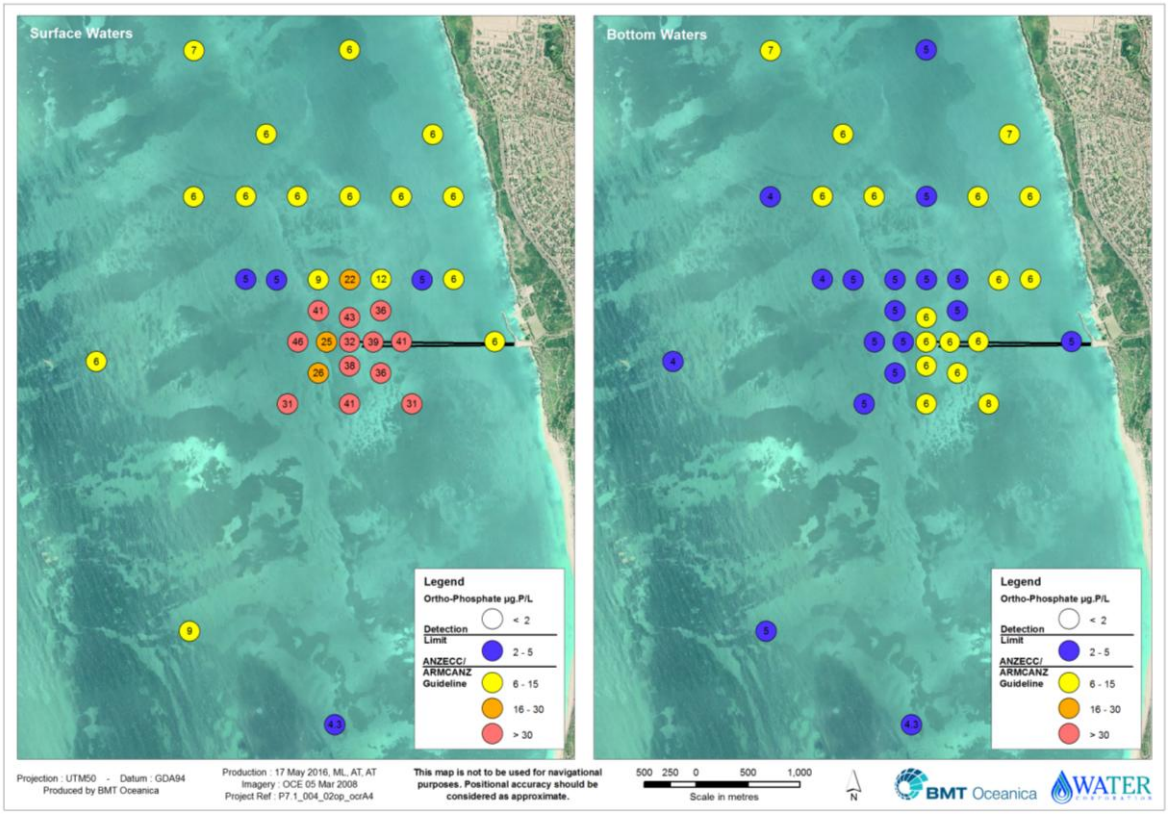
Most (31 (89%)) surface samples and almost half (17 (49%)) the bottom samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 4.15 and Figure 4.16). The

80th percentile of reference site concentrations was higher and exceeded by half (18 (51%)) the samples at the surface and by no individual samples at the bottom (Figure 4.15 and Figure 4.16). Two thirds (6 (67%)) of the shoreline samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 4.15). As a result, median surface concentrations <250 m and at the shore line exceeded the ANZECC & ARMCANZ (2000) guideline but only median surface concentrations <250 m from the diffuser exceeded the 80th percentile of reference site concentrations (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 4.15 Ortho-phosphate concentrations at Ocean Reef



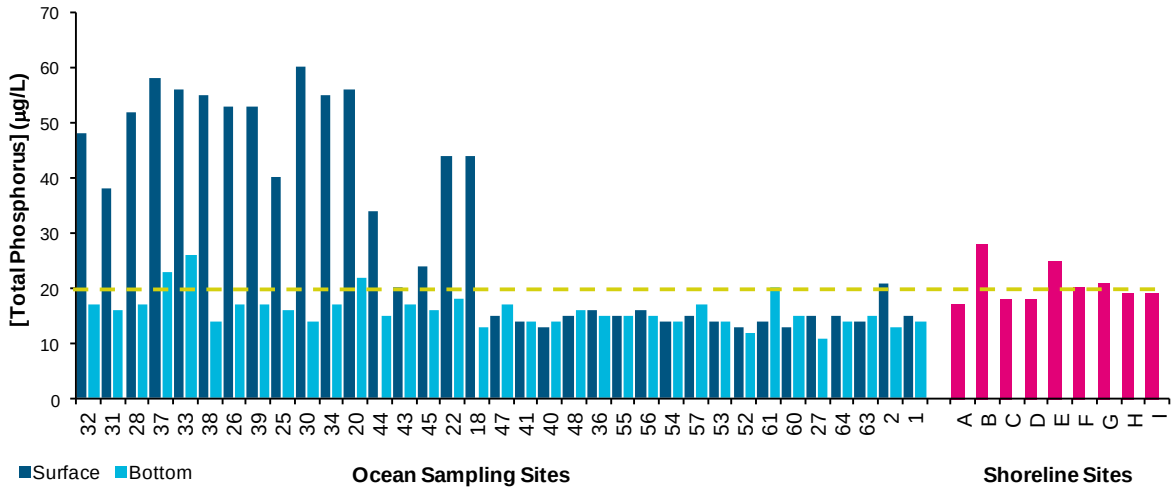
Notes:
1. Site locations have been exaggerated for visual clarity

2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.16 Spatial distribution of ortho-phosphate at Ocean Reef

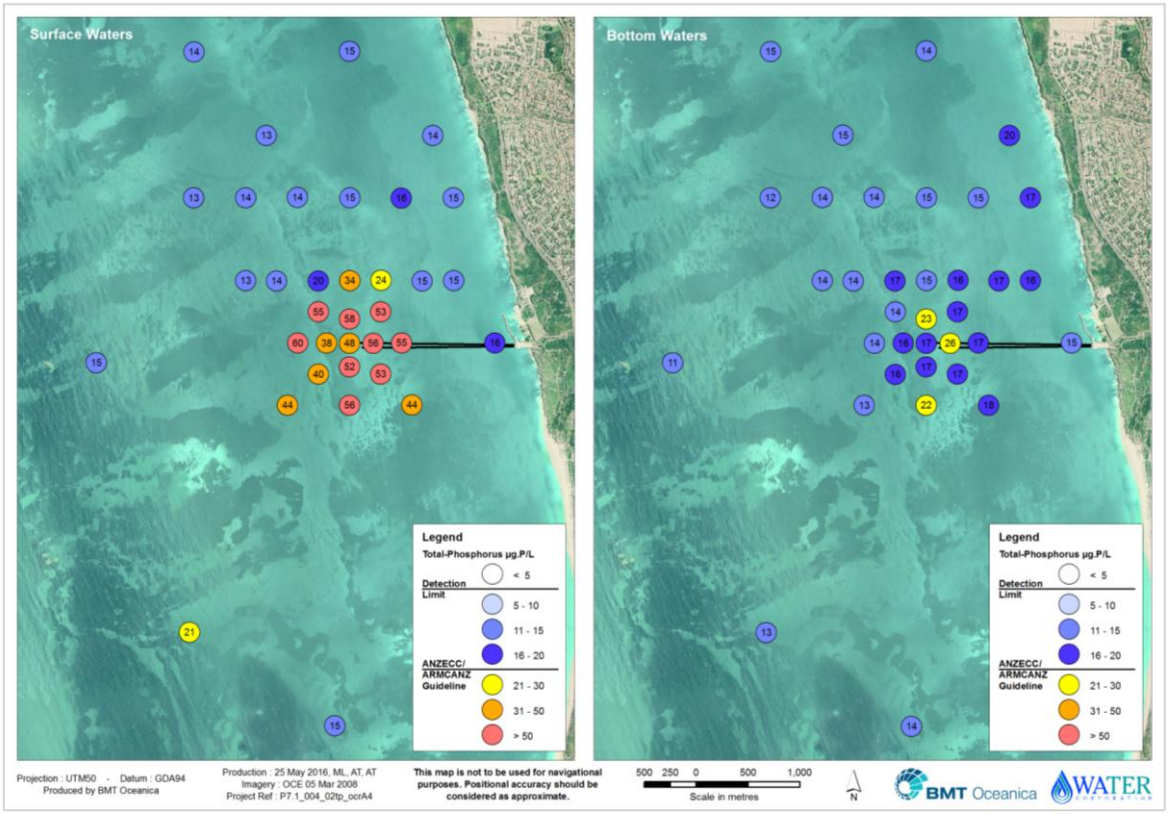
Total Phosphorus (TP)

Seventeen (49%) surface and 3 (9%) bottom samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 4.17 and Figure 4.18). The 80th percentile was exceeded by 14 (40%) and 0 surface and bottom samples, respectively (Figure 4.17 and Figure 4.18). One third of shoreline samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 4.17). Only median concentrations at the surface <250 m from the diffuser exceeded the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference site data (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 4.17 Total phosphorus concentrations at Ocean Reef

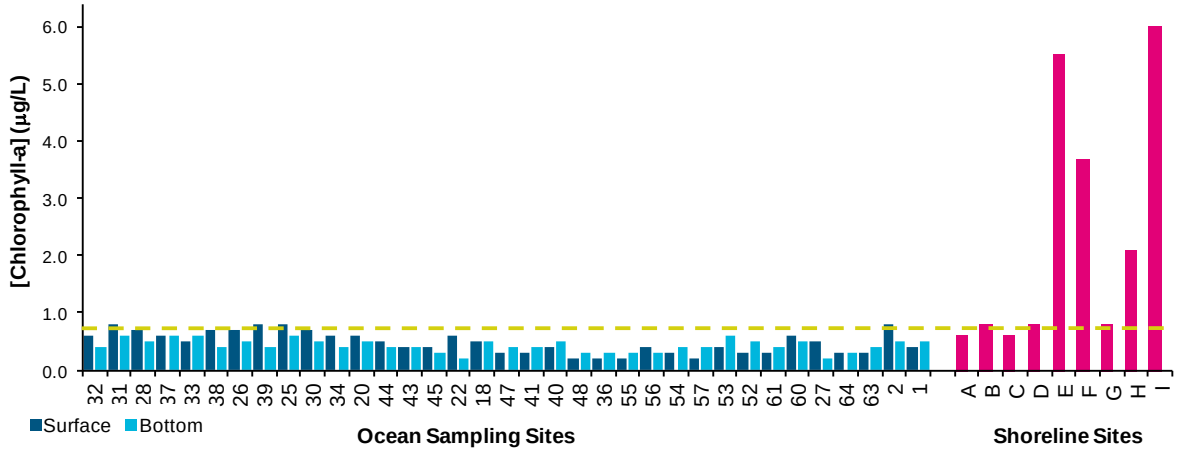


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.18 Total phosphorus concentrations at Ocean Reef

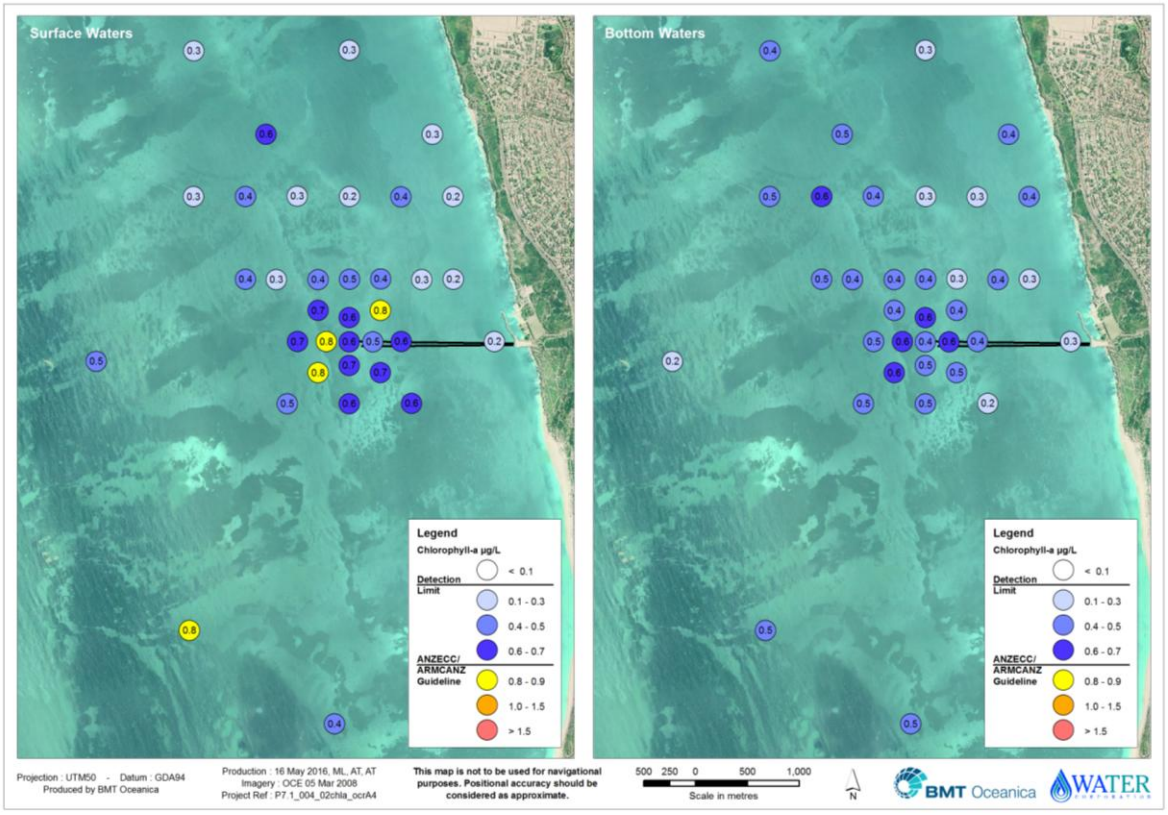
4.6 Chlorophyll

Four (11%) surface samples and 7 (78%) of shoreline samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 4.19 and Figure 4.20). Shoreline sites included some very high concentrations (up to 6 mg/L) (Figure 4.19). The long-term 80th percentile concentration at the reference sites is lower than the ANZECC & ARMCANZ (2000) guideline and was exceeded at 14 (40%) surface sites and 5 (14%) bottom sites (Table 4.3). Only shoreline median concentrations exceeded the ANZECC & ARMCANZ (2000) guideline but median concentrations at the surface and bottom within 250 m exceed the 80th percentile of reference site concentrations as well as the shoreline sites (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline.

Figure 4.19 Chlorophyll-a concentrations at Ocean Reef



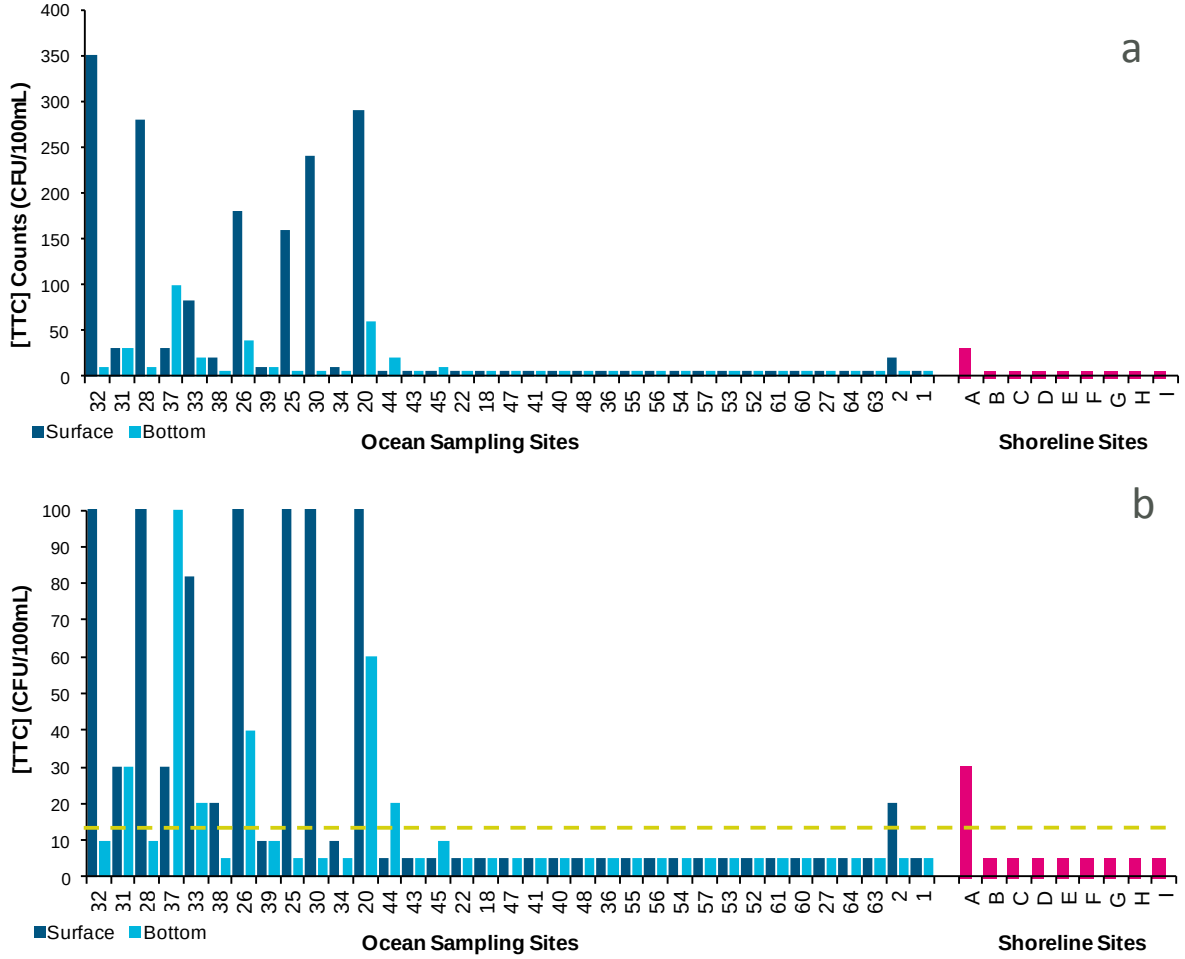
Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.20 Spatial distribution of chlorophyll-a concentrations at Ocean Reef

4.7 Microbial community

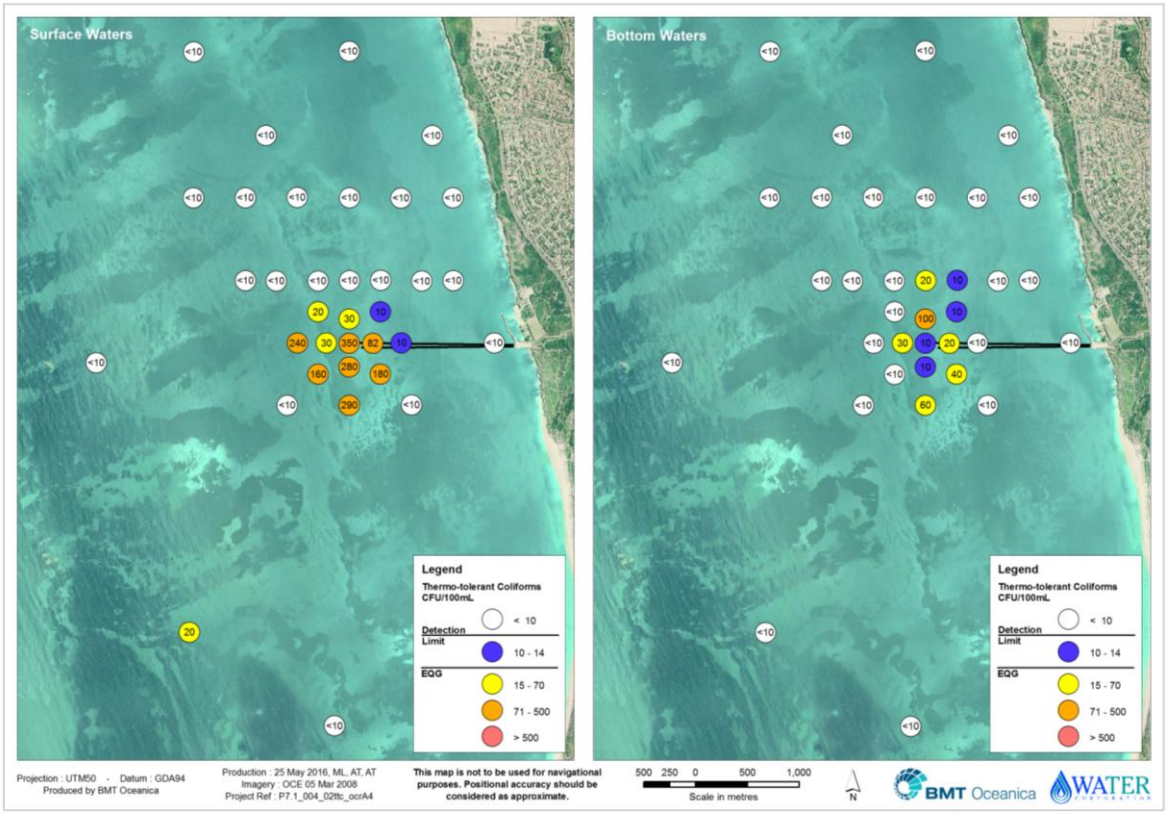
Surface TTC concentrations were elevated around the diffuser for a distance of around 600 m (Figure 4.21 and Figure 4.22). Median concentrations exceeded the EPA (2015b) EQG trigger at both the surface and bottom within 250 m of the diffuser. Median

concentrations at the surface and bottom >250 m from the outlet and at the shoreline met the guideline (Table 4.3).



Note:
1. Dashed line indicates EQG (EPA 2015b) guideline

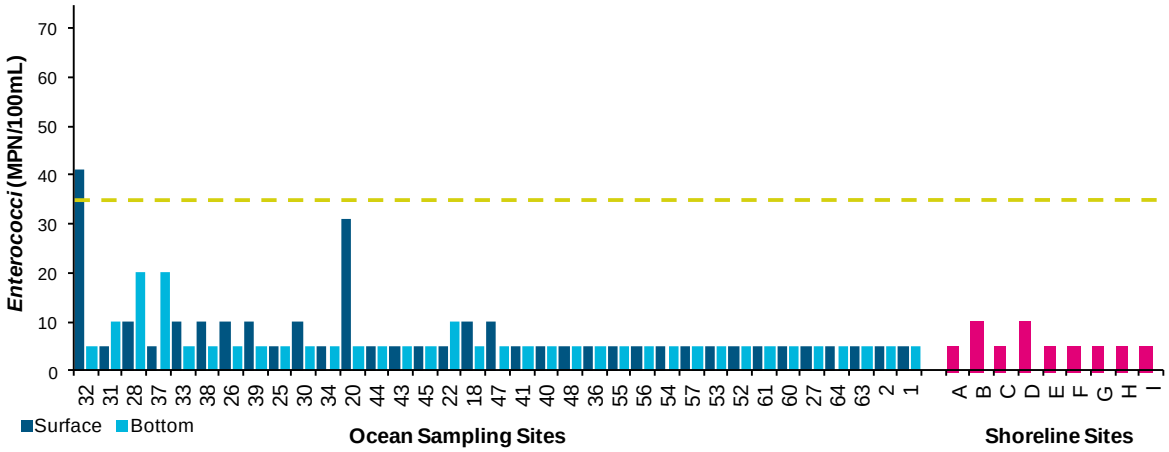
Figure 4.21 Thermotolerant coliform concentrations at Ocean Reef



Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or EQG.

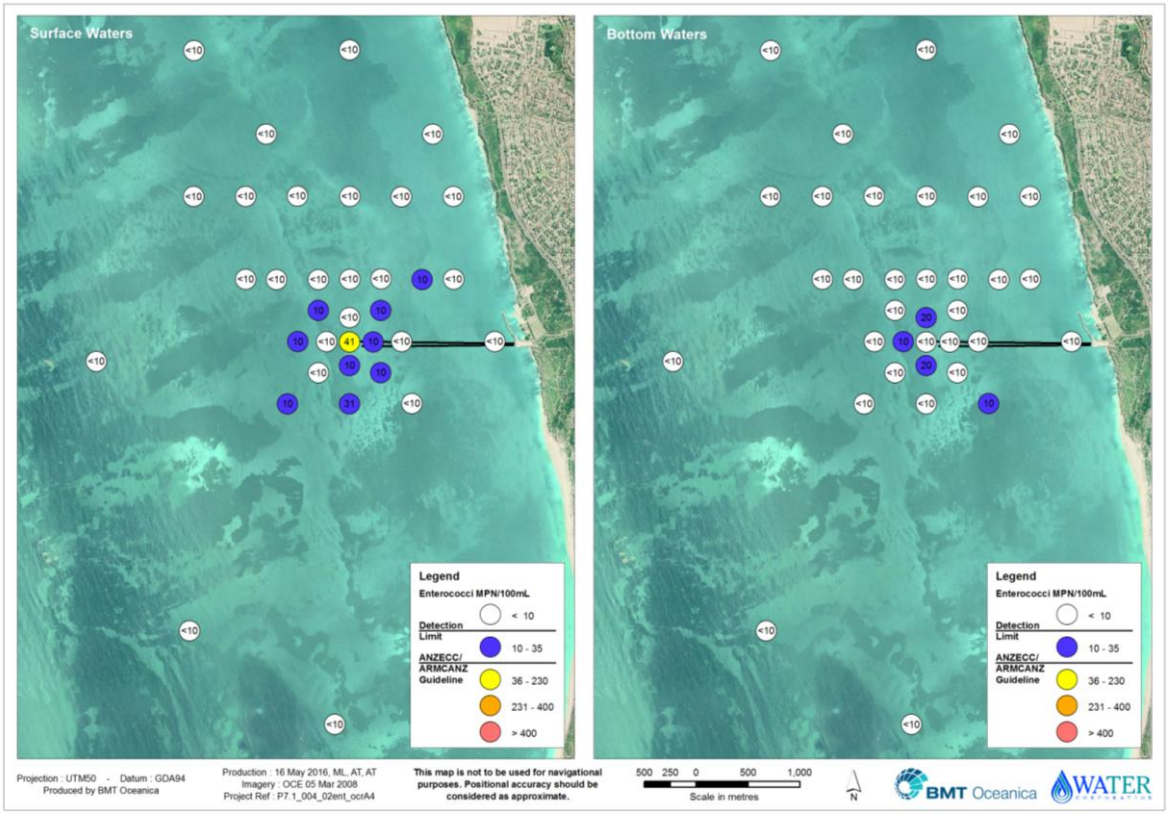
Figure 4.22 Spatial distribution of thermotolerant coliform concentrations at Ocean Reef

Enterococci spp. concentrations exceeded the ANZECC & ARMCANZ (2000) guideline in only one sample (from the surface at the site closest to the diffuser) (Figure 4.23 and Figure 4.24). Median concentrations were therefore all below the ANZECC & ARMCANZ (2000) guideline (Table 4.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 4.23 *Enterococci* spp. concentrations at Ocean Reef



Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 4.24 Spatial distribution of *Enterococci* spp. at Ocean Reef

4.8 Summary

The summer water quality surveys were not designed for comparison with the ANZECC $ ARMCANZ (2000) guidelines or with 80th percentile of reference values but comparisons were made for sites located <250 m and >250 m from the diffuser as an indicator rather than a means of assessing compliance. Despite elevated concentrations at some individual sites outside the immediate zone of influence of the outlet, the guidelines for demonstrating ecosystem protection and public health criteria were met (Table 4.2).

During the survey, the treated wastewater plume was initially buoyant (as indicated by the lower salinity and slightly higher concentrations of nutrients and microbiological indicators in surface waters than in bottom waters) and was advecting in first a northerly and then westerly direction. Surface nutrients were elevated above the 80th percentile of reference site concentrations within 250 m of the diffuser median concentrations were diluted to below the 80th percentile of reference site concentrations beyond 250 m (Table 4.2). There was no indication that the wastewater nutrients were increasing chlorophyll outside the 250 m area around the diffuser (Table 4.2).

Median *Enterococci* spp. concentrations were below the guidelines for recreation contact in surface and bottom samples collected within and outside 250 m from the diffuser (Table 4.2). Thermotolerant coliform (TTC) concentrations exceeeded the guideline for the maintenance of seafood safe for human consumption near the diffuser but surface and bottom waters >250 m from the diffuser are maintained for seafood quality.

Shoreline monitoring found no indication of contamination of adjacent beaches (Table 4.2)

Table 4.2 Summary Ocean Reef

Parameter	Inside the mixing zone (sites <250 m from diffuser)		Outside the mixing zone (sites >250 m from diffuser)		Shoreline
	Surface	Bottom	Surface	Bottom	
ANZECC/ARMCANZ (2000) guideline values					
Total ammonia nitrogen					
Ortho-phosphate					
Nitrate+nitrite					
Total phosphorus					
Total nitrogen					
Chlorophyll-a					
Enterococci spp.[3]					
80th percentile of reference values					
Total ammonia nitrogen					
Ortho-phosphate					
Nitrate+nitrite					
Total phosphorus					
Total nitrogen					
Chlorophyll-a					
Environmental Quality Guideline (EPA 2015b)					
Thermotolerant coliforms[4]					

Notes:

1. Green = median values ≤ ANZECC/ARMCANZ (2000) guideline values , ≤80th percentile reference values or ≤ EQG.
2. Red = Median values > ANZECC/ARMCANZ (2000) guideline values , >80th percentile reference values or > EQG
3. For the maintenance of seafood safe for human consumption
4. For primary contact recreation

Table 4.3 Summary statistics for Ocean Reef

Parameter	depth	lowest		highest		Median		number (%) below the guideline		number (%) below 80th percentile of reference	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Ammonia (NH4)	All	1.5	1.5	19	4	1.5	1.5	20 (57)	35 (100)	20 (57)	34 (97)
	Inside 250 m	8	1.5	19	1.5	16	1.5				
	Outside 250 m	1.5	1.5	19	4	1.5	1.5				
	Shoreline	3	0	12	0	6	0	4 (44)			
Nitrate + nitrite	All	1	1	63	11	8	1	14 (40)	32 (91)	20 (57)	35 (100)
	Inside 250 m	33	1	58	1	48	1				
	Outside 250 m	1	1	63	11	7	1				
	Shoreline	1	0	55	0	25	0	20 (57)			
Total nitrogen	All	80	80	210	160	110	100	35 (100)	35 (100)	20 (57)	34 (97)
	Inside 250 m	150	90	180	120	170	110				
	Outside 250 m	80	80	210	160	100	100				
	Shoreline	130	0	250	0	190	0	8 (89)			
Ortho-phosphate	All	4.3	4	46	8	9	5	4 (11)	18 (51)	17 (49)	35 (100)
	Inside 250 m	25	5	43	6	38	6				
	Outside 250 m	4.3	4	46	8	6	5				
	Shoreline	4	0	15	0	7	0	3 (33)			
Total phosphorus (TP)	All	13	11	60	26	20	15	18 (51)	32 (91)	21 (60)	35 (100)
	Inside 250 m	38	16	58	26	52	17				
	Outside 250 m	13	11	60	22	15.5	15				
	Shoreline	17	0	28	0	19	0	21 (60)			
Chlorophyll a	All	0.2	0.1	0.8	0.6	0.5	0.4	31 (89)	35 (100)	21 (60)	30 (86)
	Inside 250 m	0.5	0.2	0.8	0.6	0.6	0.6				
	Outside 250 m	0.2	0.1	0.8	0.6	0.4	0.4				
	Shoreline	0.6	0	6	0	0.8	0	2 (22)			
Thermotolerant coliforms	All	5	5	350	100	5	5	20 (57)	35 (100)	20 (57)	34 (97)
	Inside 250 m	30	10	350	100	82	20				
	Outside 250 m	5	5	290	60	5	5				
	Shoreline	5	0	30	0	5	0	4 (44)			
Enterococci spp.	All	5	5	41	20	5	5				
	Inside 250 m	5	5	41	20	10	10				
	Outside 250 m	5	5	31	10	5	5				
	Shoreline	5	0	10	0	5	0				

5. Sepia Depression

5.1 The survey

The annual summer water quality survey at Sepia Depression was completed on 2 February 2016.

5.2 Discharge

A 24- hour composited sample of treated wastewater was collected from the Sepia depression Ocean Outlet Landline (SDOOL) on 9 February 2016 (prior to and during the ocean survey) (Table 3.1). At the time of the survey there were 50 ports open on the Outlet.

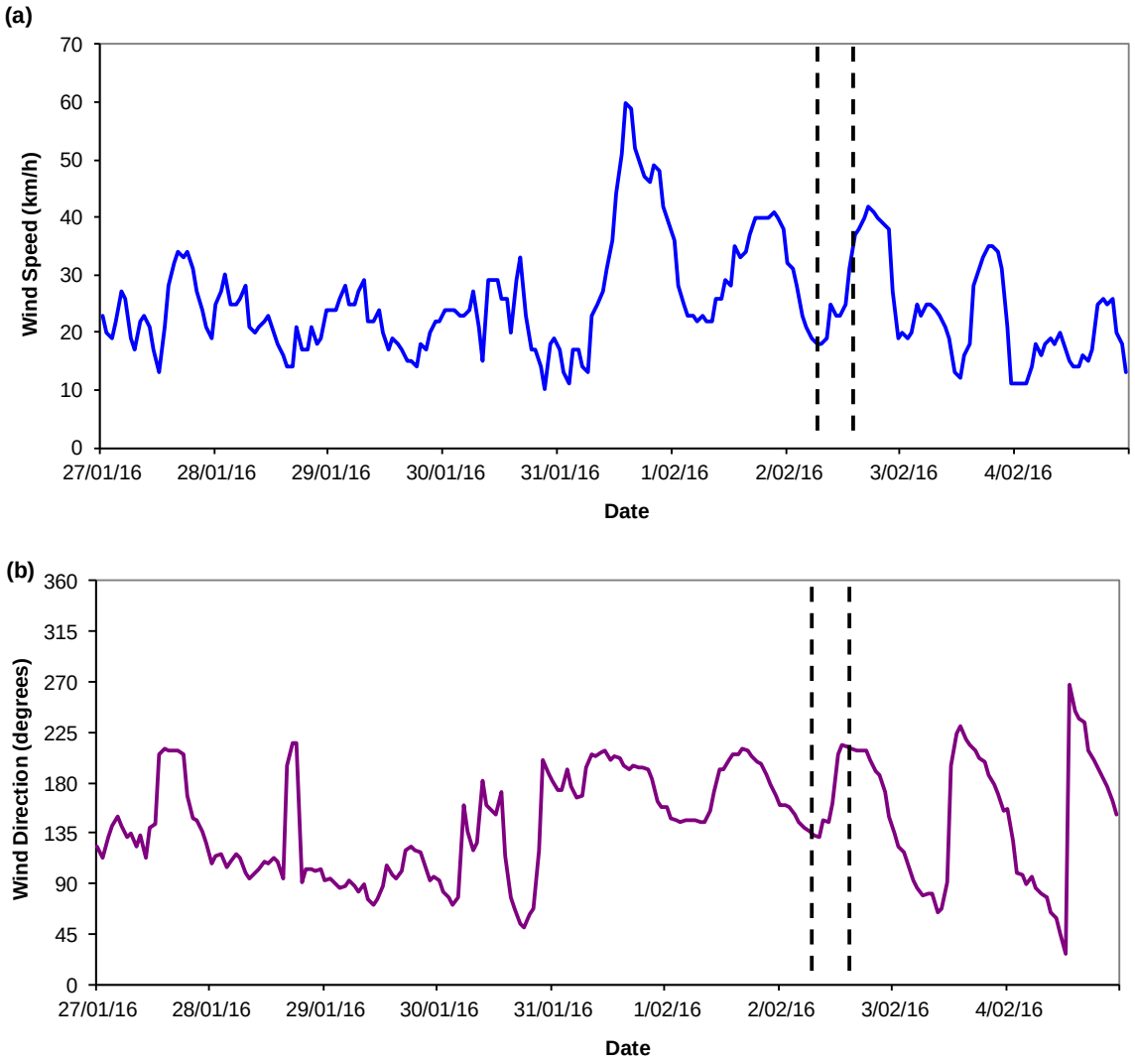
Table 5.1 SDOOL treated wastewater characteristics on 3 February 2015

Parameter	Concentration
Total phosphorus	5.9 mg/L
Total nitrogen	20 mg/L
Total ammonia nitrogen	0.59 mg/L
Nitrate+nitrite	3 mg/L
Thermotolerant coliforms	>1 000 000 CFU/100 mL
Enterococci spp.	>24 000 MPN/100 mL
Total suspended solids	66 mg/L
Biological oxygen demand	28 mg/L
Total flow	142.5 ML/d

5.3 Environmental characteristics

5.3.1 Wind

For 24 hours prior to the survey, the wind at Sepia Depression was typically a fresh southerly (averaging 32 km/h) abating gradually in the period immediately prior to the survey. Building, moderate southerly winds averaging 25.1 km/hr continued throughout the survey (Figure 5.1).



Note:
1. a = wind speed
2. b = wind direction
3. Dashed lines (- -) show approximate timing of the summer water quality survey.

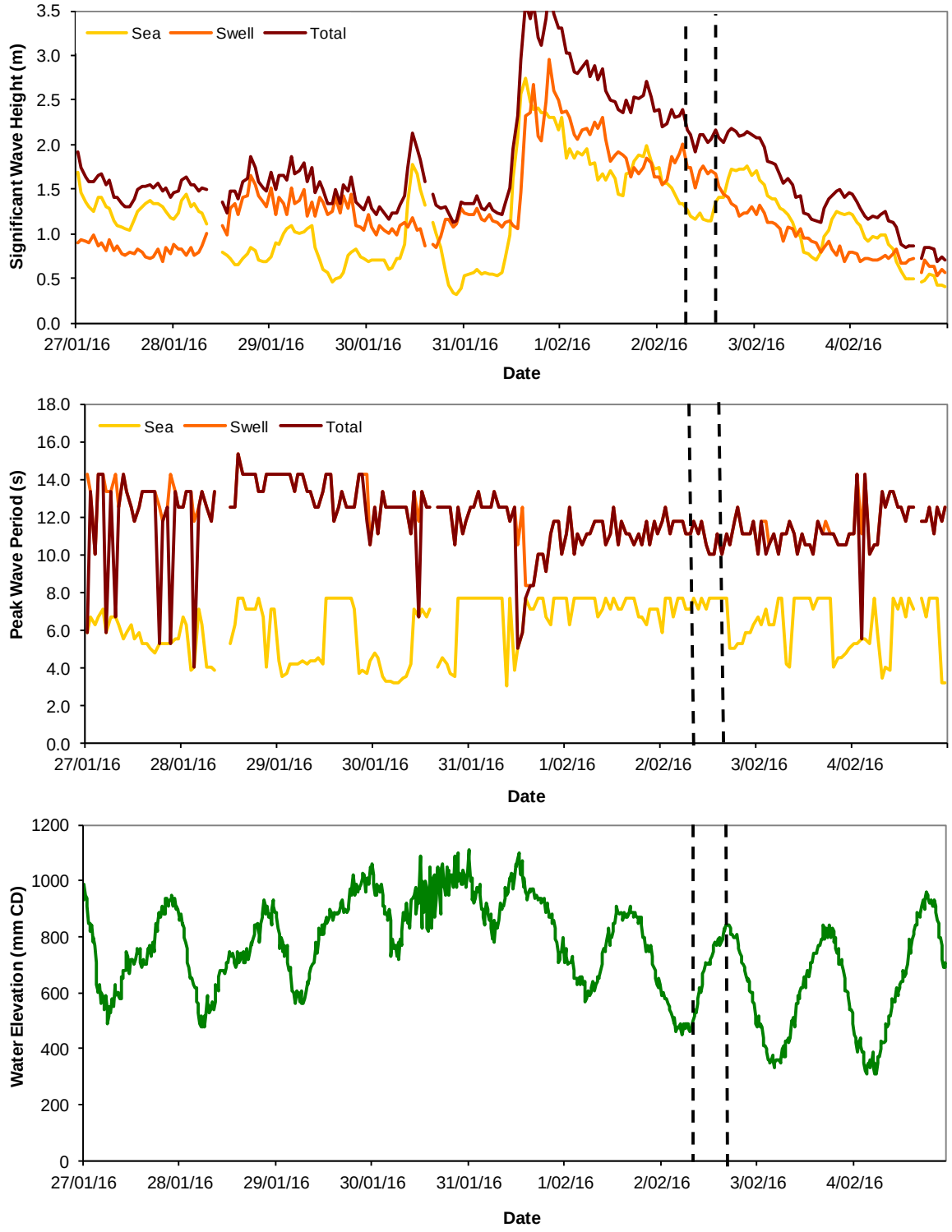
Figure 5.1 Wind speed and wind direction at Sepia Depression

5.3.2 Waves and tide

For 24 hours prior to the survey, the average significant wave height[13] offshore from Rottnest Island was 2.5 m, with an average peak wave period[14] of 11.4 s (Figure 5.2). During the survey the average offshore significant wave height was 2.1 m and the average peak wave period of 10.9 s. The survey was completed during a rising tide (Figure 5.2).

[13] *The significant wave height (in metres) is defined as the average height of the highest one-third of waves recorded (source: http//www.dpi.wa.gov.au/)*

[14] *The wave period (in seconds) is the time between consecutive wave crests. The peak wave period is the wave period of those waves that are producing the most energy in a wave record*



Note:
1. Dashed lines (- -) show approximate timing of the survey

Figure 5.2 Significant wave heights (offshore Rottnest Island), peak wave periods (offshore Rottnest Island) and water level elevation (Fremantle Fishing Boat Harbour)

5.3.3 Currents

The surface drogue, released at the centre of the diffuser at the beginning of the survey drifted in a north-north westerly direction for 2065 m. The average velocity of the

drogue over the route was 0.26 m/s. At the time of the survey and based on drogue movements, it is expected that discharged treated wastewater would overall be travelling in a north north westerly direction from the diffuser (Figure 5.3).

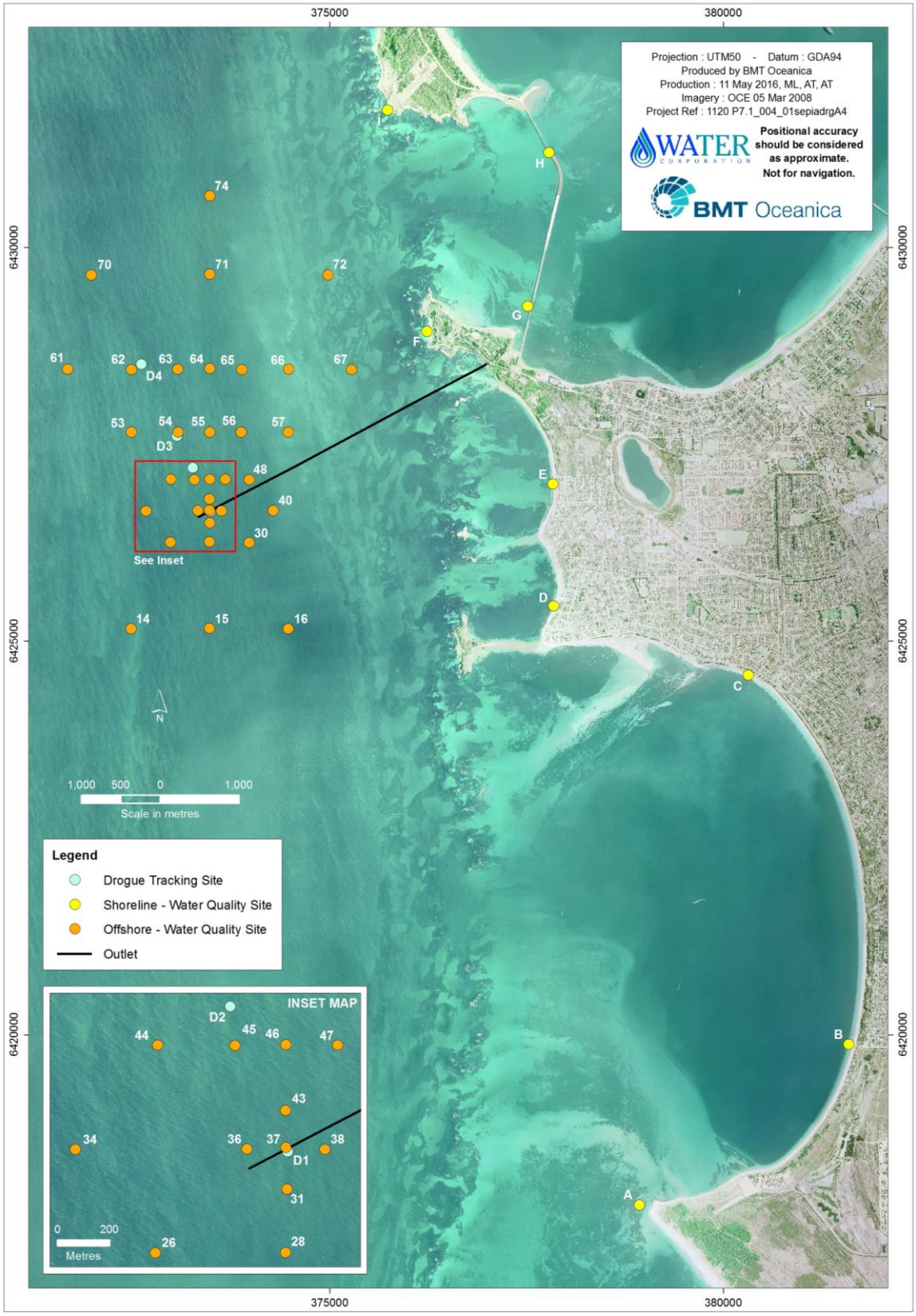
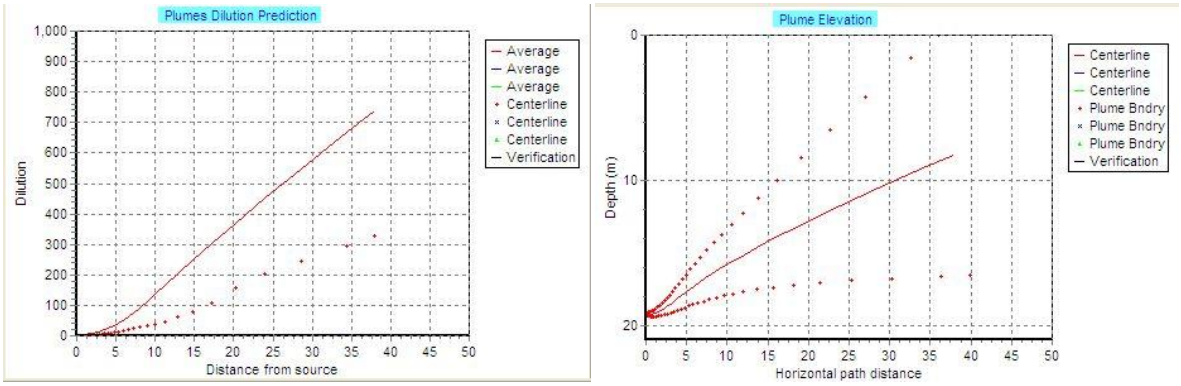


Figure 5.3 Sepia Depression drogue tracking locations, 2 February 2016

5.3.4 Initial dilution

For ambient conditions at the time of the Sepia Depression survey, the modelling predicted average initial dilution of 1:739 and centreline dilution of 1:332 (Figure 5.4a). The plume was predicted to first reach the surface within ~30 m (horizontal distance) from the discharge point (see the ambient boundary[15] of the plume in Figure 5.4b). The full model output is included in Appendix C.



Notes:
1. a = predicted average and centreline dilution
2. b = predicted plume elevation

Figure 5.4 Predicted average and centreline dilutions and predicted plume elevation trajectory for Sepia Depression

5.4 Water column structure

Water temperature from 8 sites profiled ranged from 21.93°C to 22.39°C, salinity ranged from 35.77 to 36.29 and dissolved oxygen varied from 6.38 mg/L to 6.67 mg/L (equivalent to 90.1–94.2% saturation) (Figure 5.5 and Figure 5.6). There was no thermocline evident at the diffuser and salinity was typically constant with depth. Down current of the diffuser (from site 38) a layer of cooler, lower salinity water typically sat above warmer, more saline water (Figure 5.5 and Figure 5.6). Dissolved oxygen was not depleted by the treated wastewater plume or any other process at any site (Figure 5.5 and Figure 5.6).

[15] *The ambient boundary corresponds to the plume boundary at which concentrations are estimated to be equal to ambient conditions.*

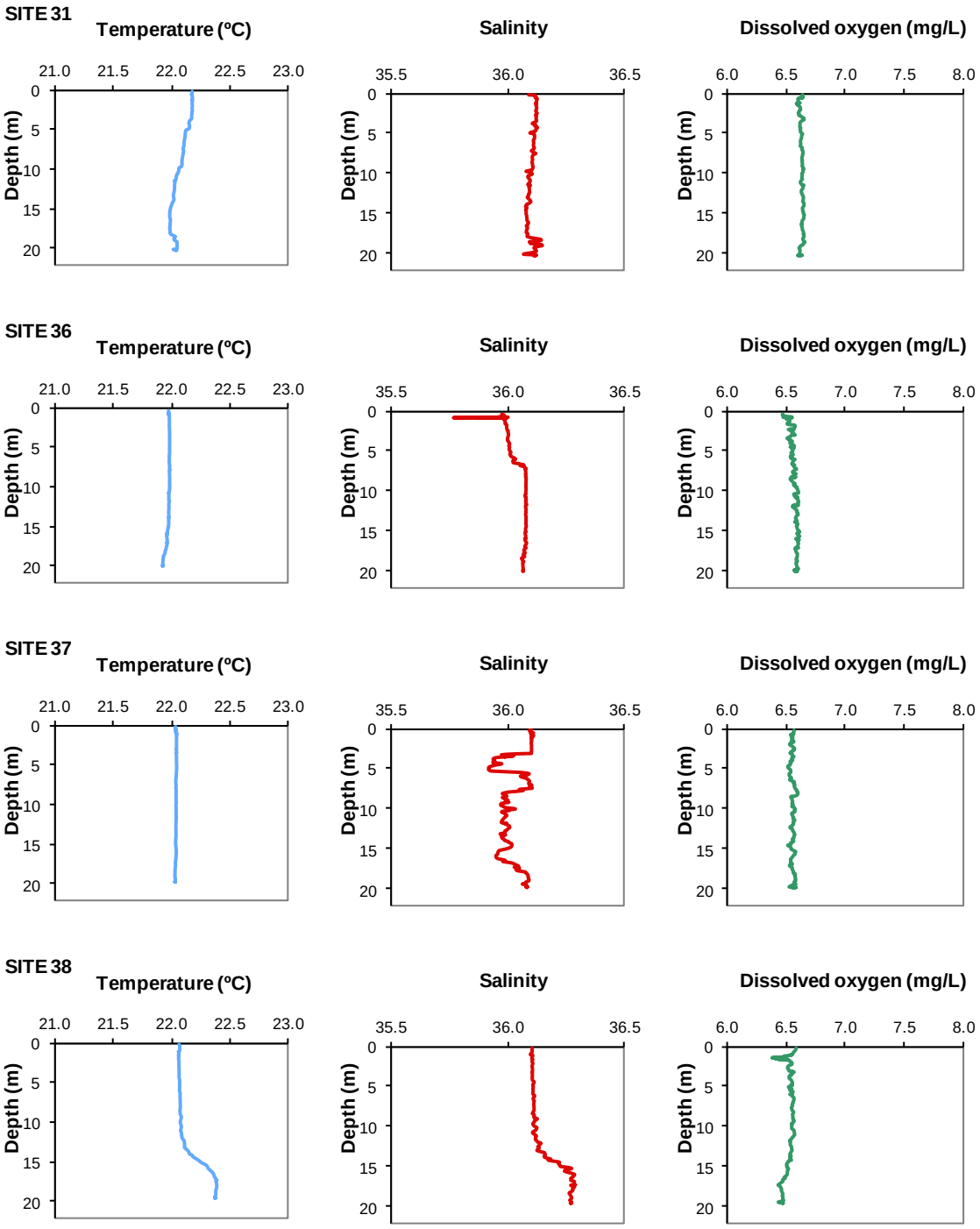


Figure 5.5 Temperature, salinity and dissolved oxygen vertical profiles at Sepia Depression

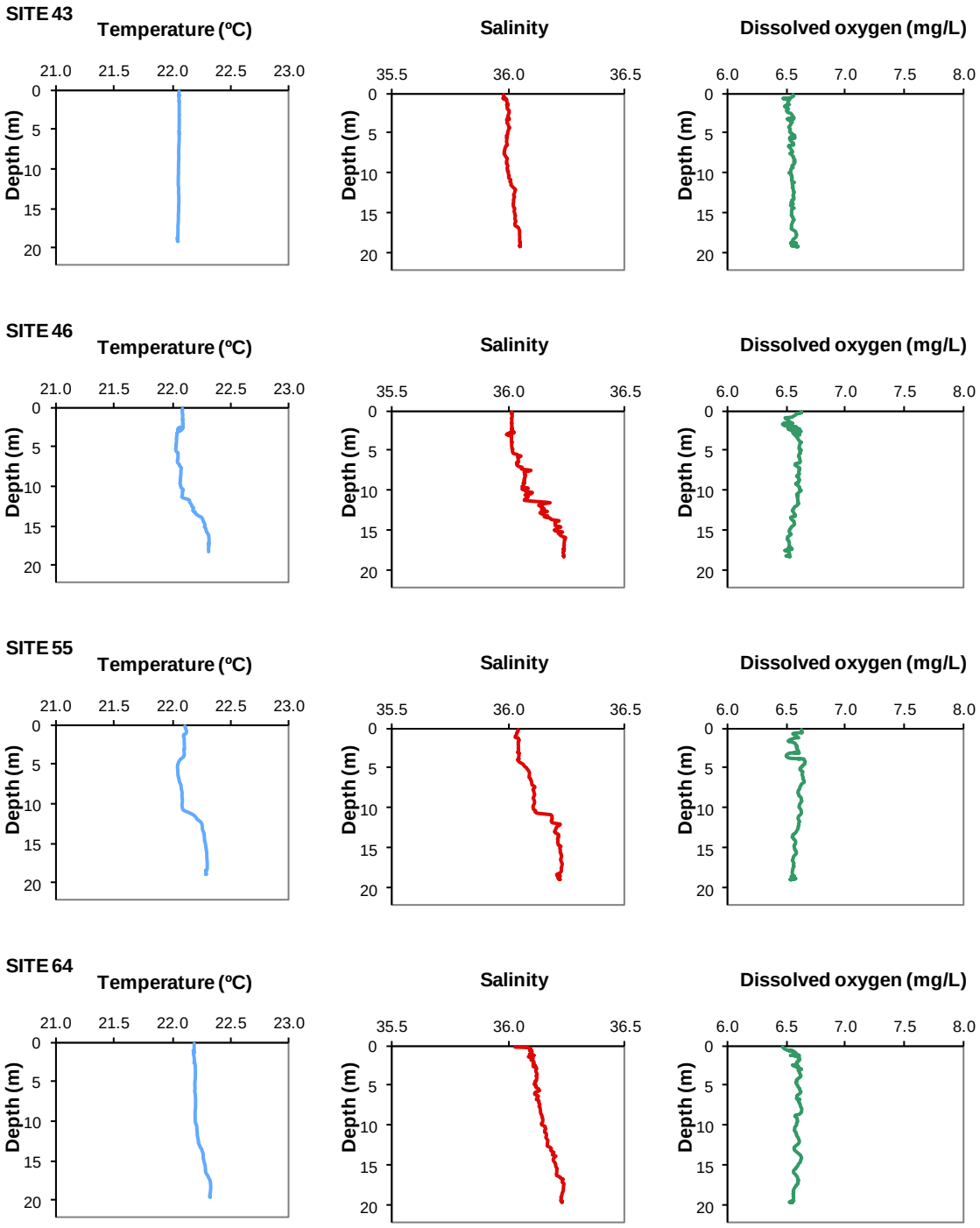


Figure 5.6 Temperature, salinity and dissolved oxygen vertical profiles at Sepia Depression

The wastewater stream is evident at the outlet as a plume of cool, low salinity water extending from the surface to bottom as the buoyant rises from the outlet to the surface after discharge (Figure 5.7). The discharge then forms a buoyant layer that overlies warmer more saline water at sites as it is advected further from the outlet (Figure 5.7).

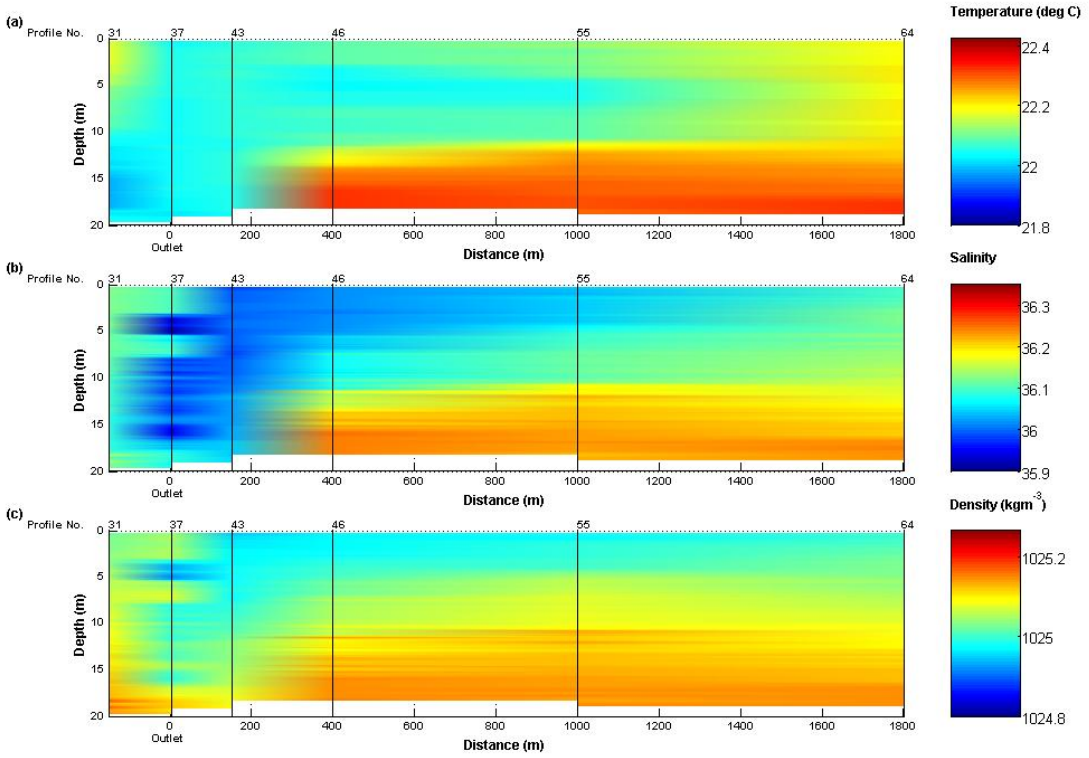
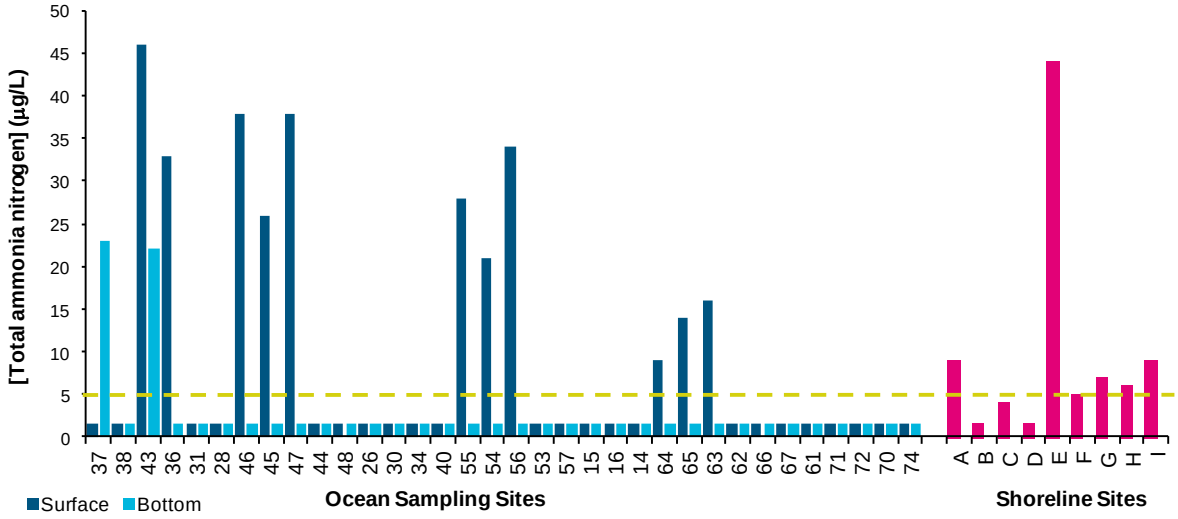


Figure 5.7 Temperature (a), salinity (b) and density (c) transect at Sepia Depression

5.5 Nutrients

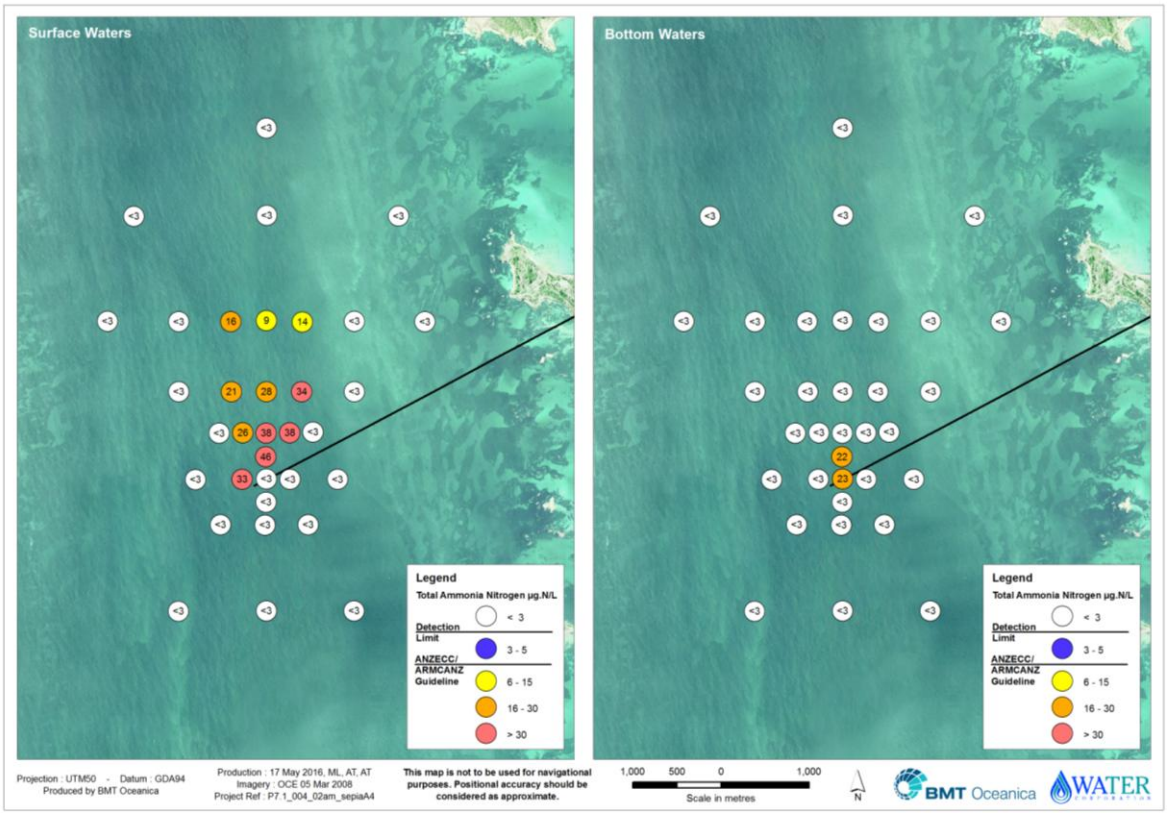
Total Ammonia Nitrogen (HN_4^+ + NH_3)

One third (11 for 32%) of surface and 2 (6%) bottom water samples exceeded the ANZECC & ARMCANZ (2000) guideline for ammonia and the 80th percentile of reference site concentrations (Figure 5.8 and Figure 5.9). Five (56%) of the shoreline samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 5.8). The highest concentrations were evident at the surface and were elevated to the north of the outlet (the direction of the prevailing current at the time (Figure 5.9). There is general reduction in concentration with increasing distance from the outlet (Figure 5.9). Median concentrations at the surface and bottom, both inside and beyond a distance of 250 m from the diffuser were all lower than the ANZECC & ARMCANZ (2000) and 80th percentile of reference site concentrations (Table 5.3). Median shoreline concentrations exceed the ANZECC & ARMCANZ (2000) guideline but do not appear to be related to the passage of the plume (Table 5.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 5.8 Total ammonia nitrogen concentrations at Sepia Depression



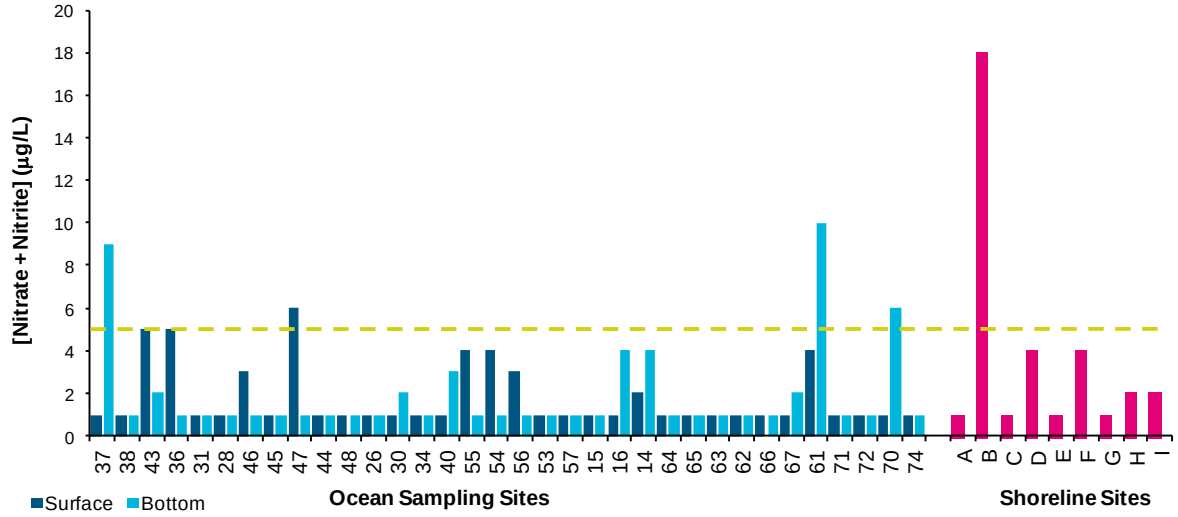
Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.9 Spatial distribution of total ammonia nitrogen at Sepia Depression

Nitrate+nitrite (NO_2^-+NO_3^-)

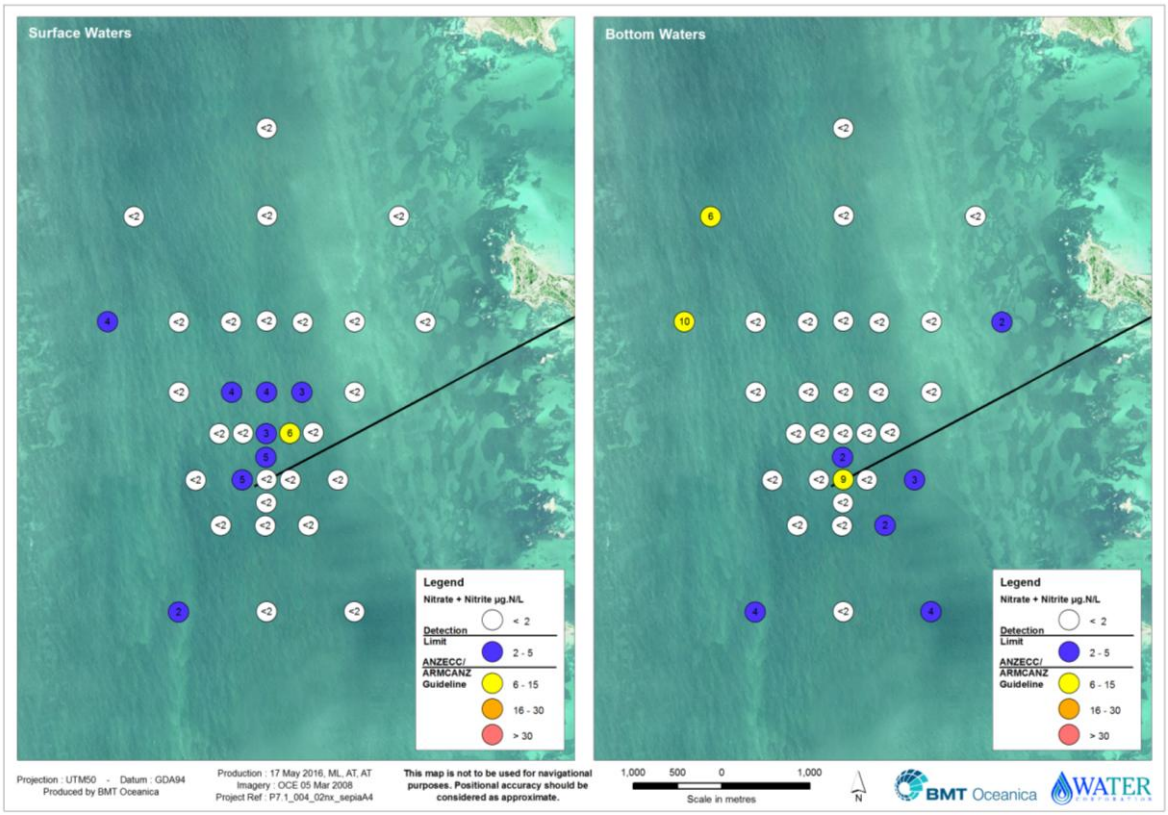
Only 1 (3%) surface and 3 (9%) bottom samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 5.10Figure 5.11). The 80th percentile of reference site concentrations is slightly lower and exceeded by 3 surface (9%) samples in addition to

the (9%) bottom samples that exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 5.10 and Figure 5.11). Concentrations at only 1 shoreline site exceeded the ANZECC & ARMCANZ (2000) guidelines but were particularly high in that location (18 µg/L) (Figure 5.10). All medians concentrations (i.e. combinations of surface and bottom, both within and outside 250 m from the diffuser as well as at the shoreline) were below the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference site concentrations (Table 5.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 5.10 Total nitrate+nitrite concentrations at Sepia Depression

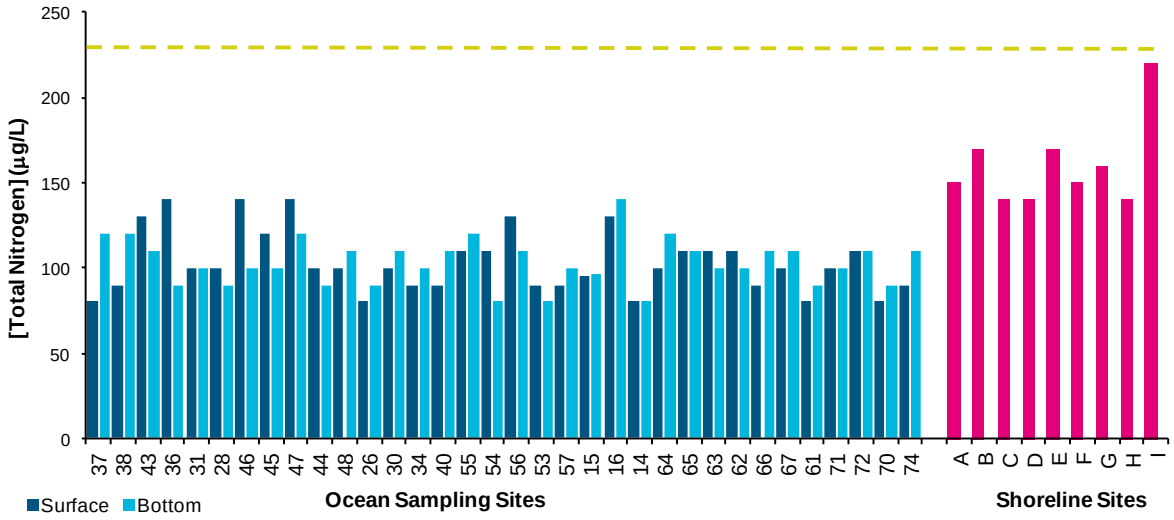


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.11 Spatial distribution of nitrate+nitrite at Sepia Depression

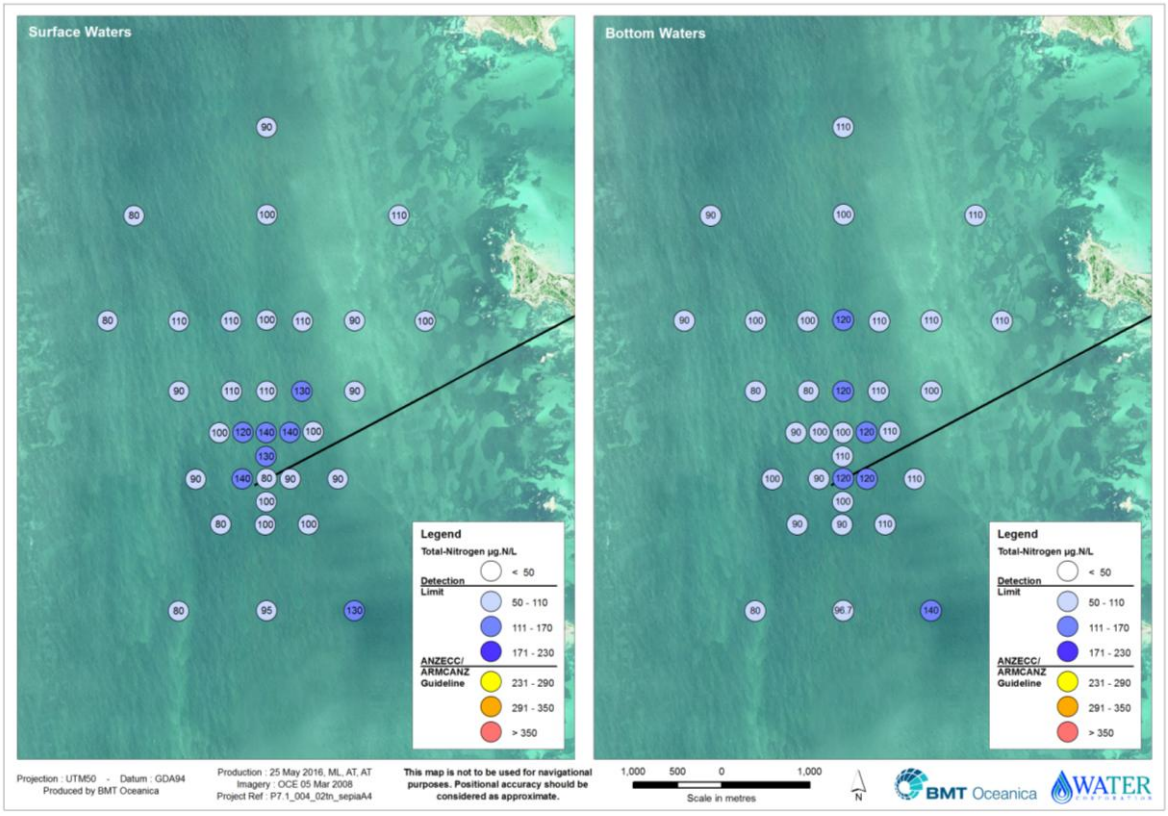
Total nitrogen

No surface or bottom sample concentrations exceeded the ANZECC & ARMCANZ (2000) total nitrogen guideline (Figure 5.12 and Figure 5.13). The 80th percentile of reference site concentrations is more conservative and exceeded by 3 (9%) surface samples (Figure 5.12 and Figure 5.13). No shoreline exceeded the ANZECC & ARMCANZ (2000) trigger (Figure 5.12). Median surface and bottom sample concentrations, inside and outside 250 m from the diffuser were below the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference site concentrations (Table 5.3). Median shoreline concentrations were below the ANZECC & ARMCANZ (2000) total nitrogen trigger (Table 5.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 5.12 Total nitrogen concentrations at Sepia Depression

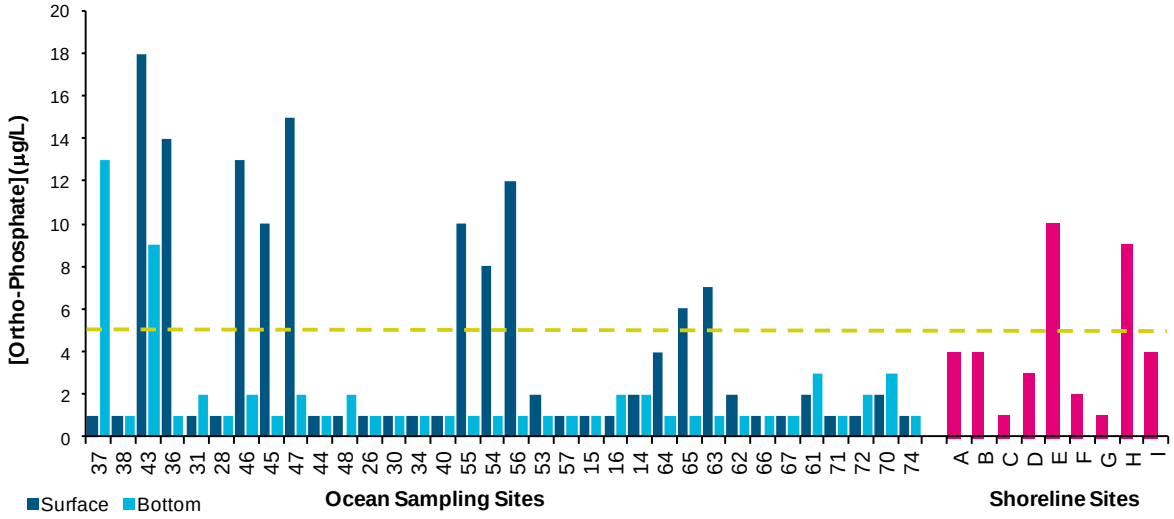


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.13 Spatial distribution of total nitrogen at Sepia Depression

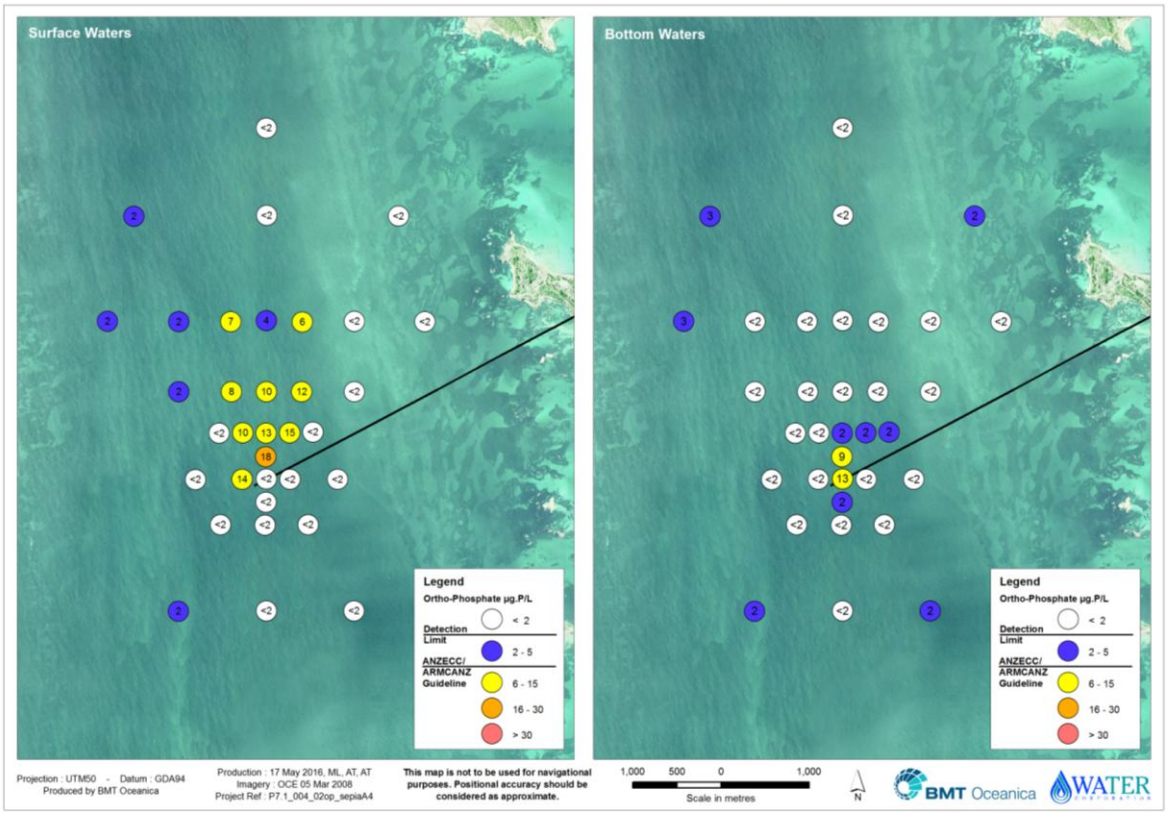
Orthophosphate

Concentrations of orthophosphate in 10 (29%) surface and 2 (6%) bottom samples exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 5.14 and Figure 5.15). One fewer surface samples (9 for 26%) exceeded 80th percentile of reference site concentrations (Figure 5.14 and Figure 5.15). Elevated surface concentrations extended to the north of the diffuser (in the direction of the prevailing current (Figure 5.15). Concentrations of orthophosphate in 2 of the 9 (22%) shoreline sites exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 5.14). Median concentrations of surface and bottom samples both within and outside 250 m from the diffuser as well as at the shoreline sites were below the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference site concentrations (Table 5.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 5.14 Ortho-phosphate concentrations at Sepia Depression



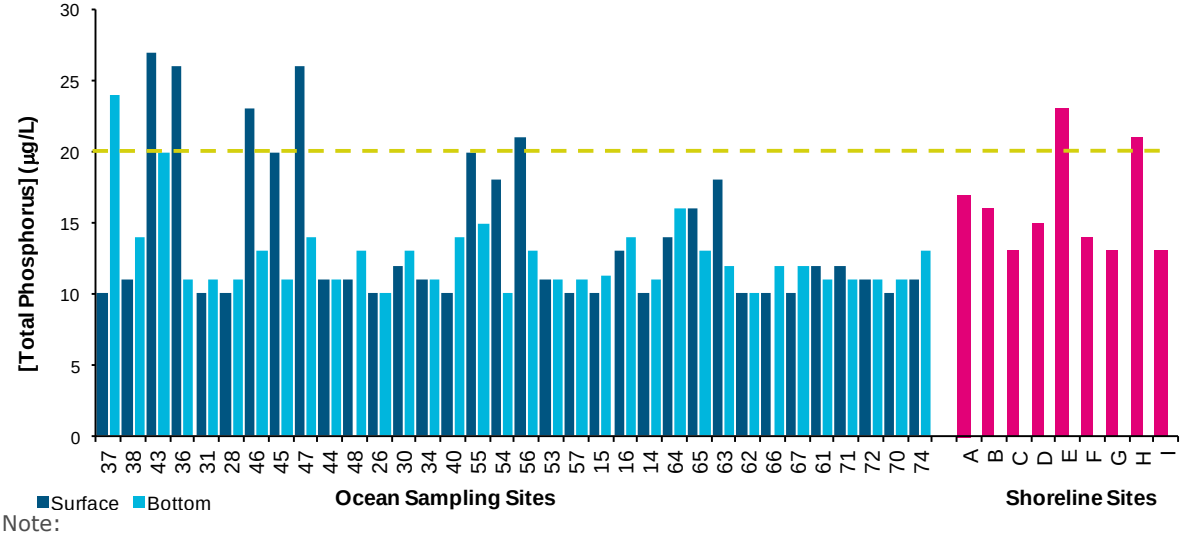
Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.15 Spatial distribution of ortho-phosphate at Sepia Depression

Total Phosphorus (TP)

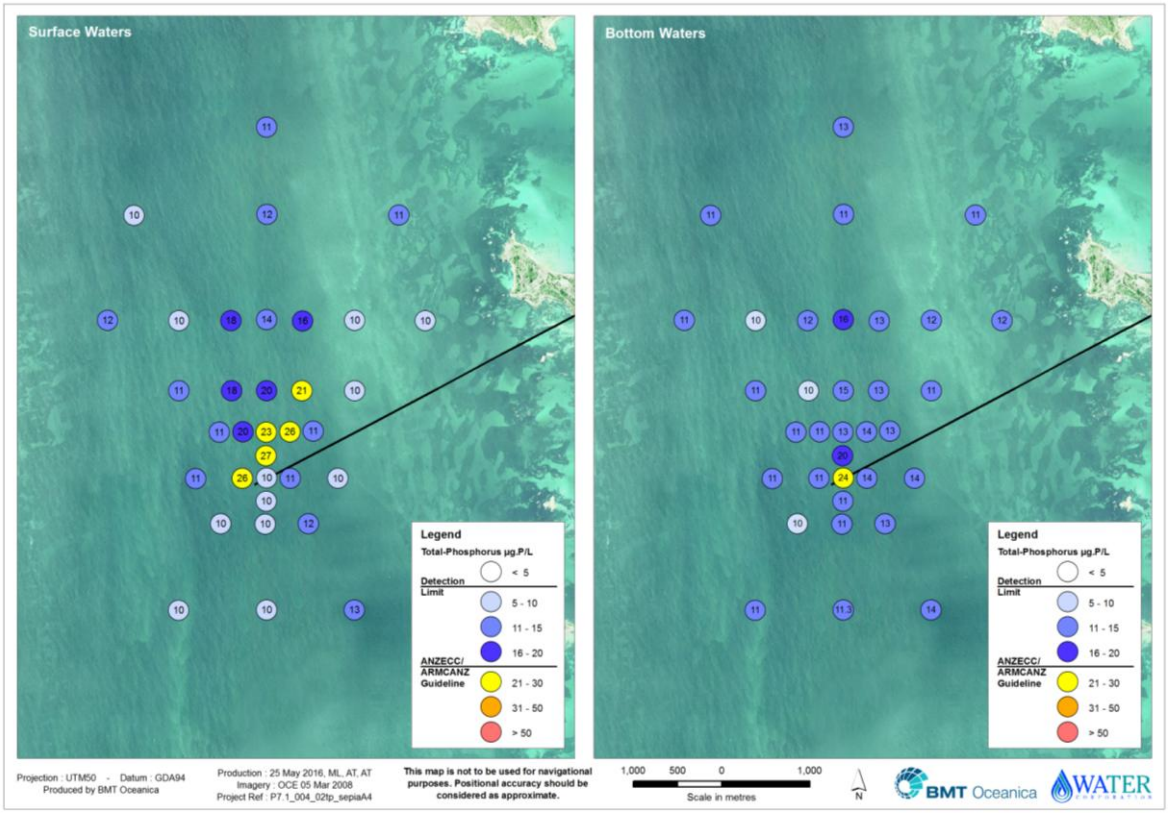
Total phosphorus concentrations exceeded the ANZECC & ARMCANZ (2000) guideline in 5 (15%) surface and 1 (3%) bottom samples (Figure 5.16 and Figure 5.17).

Concentrations did not exceed the 80th percentile of reference site concentrations in any sample (Figure 5.16 and Figure 5.17). A total of 2 (22%) shoreline sample concentrations exceeded the ANZECC & ARMCANZ (2000) guideline (Figure 5.16 and Figure 5.17). Median concentrations of surface and bottom samples < 250 m and >250 m from the diffuser and at the shoreline sites were below the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference site concentrations (Table 5.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 5.16 Total phosphorus concentrations at Sepia Depression

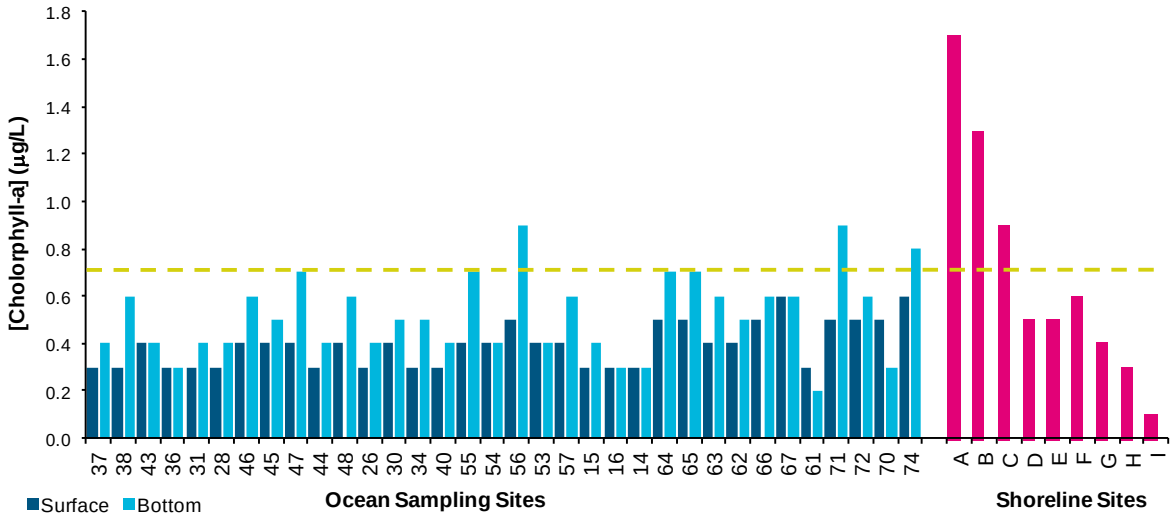


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.17 Total phosphorus concentrations at Sepia Depression

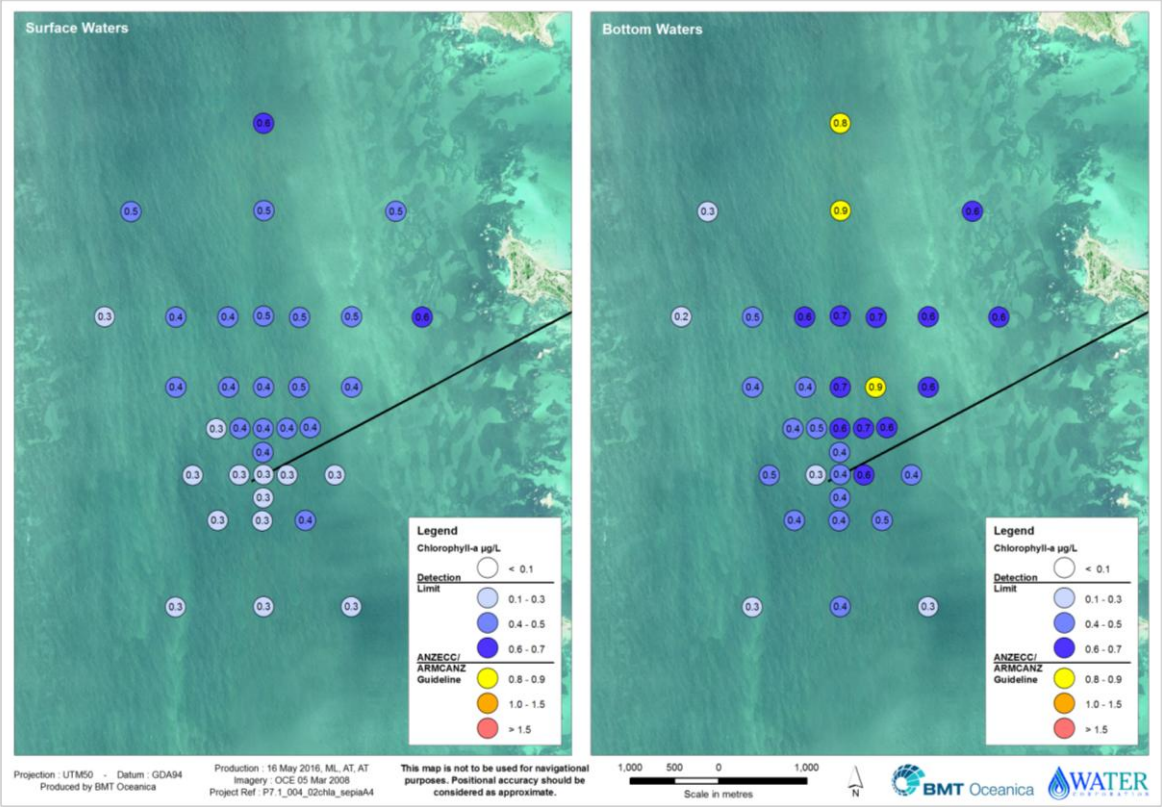
5.6 Chlorophyll

Chlorophyll *a* concentrations did not exceed either the ANZECC & ARMCANZ (2000) guideline or 80th percentile of reference site concentrations in any surface samples (Figure 5.18 and Figure 5.19). Concentrations in 3 (9%) bottom samples exceeded both triggers and concentrations at 3 (33%) shoreline sites exceeded the ANZECC & ARMCANZ (2000) (Figure 5.18 and Figure 5.19). Median concentrations of surface and bottom samples <250 and >250 m from the diffuser and at the shoreline sites were below the ANZECC & ARMCANZ (2000) guideline and 80th percentile of reference site concentrations (Table 5.3).



Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline.

Figure 5.18 Chlorophyll-a concentrations at Sepia Depression

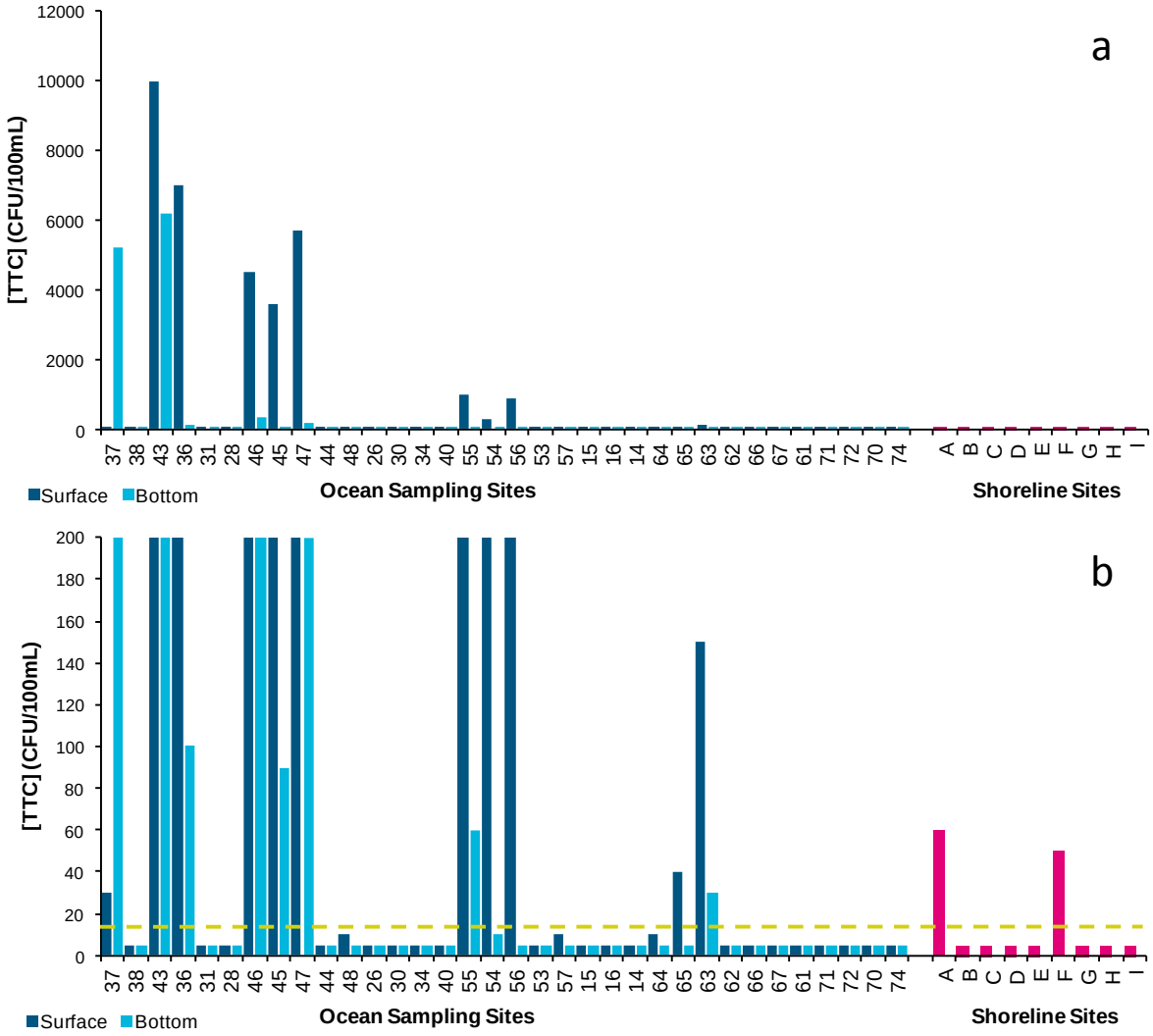


Notes:
1. Site locations have been exaggerated for visual clarity.
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.19 Spatial distribution of chlorophyll-a concentrations at Sepia Depression

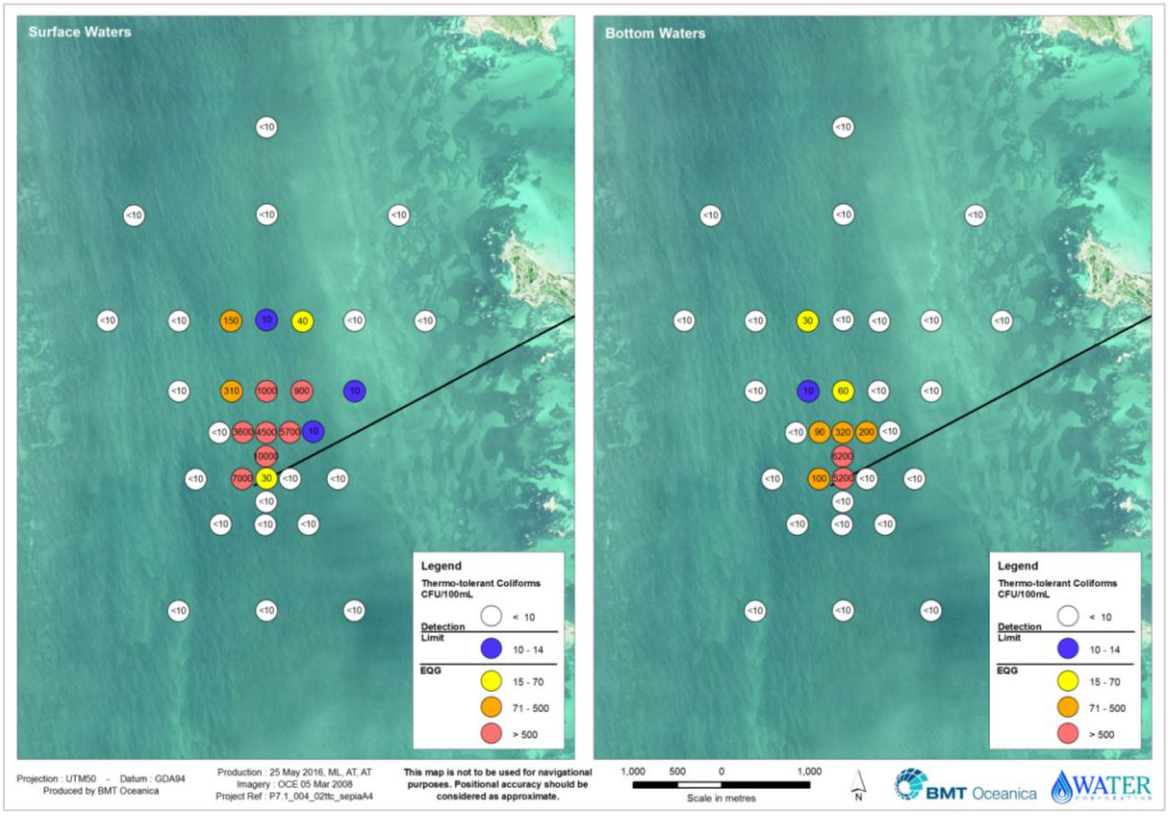
5.7 Microbial community

Surface and bottom TTC concentrations were elevated near the diffuser and surface and bottom median concentrations <250 m from the diffuser both exceeded the EPA (2015b) EQG trigger (Figure 5.20 and Figure 5.21). Surface concentrations remained elevated (although decreasing with distance) in samples collected in a northerly direction from the diffuser (the direction of the prevailing current) (Figure 5.21). Despite this, concentrations, median TTC concentrations >250 m from the diffuser were below the EPA (2015b) EQG trigger. TTC concentrations at 2 shoreline sites exceeded the EPA (2015b) EQG trigger, but overall median concentrations were below the guideline (Figure 5.20 and Table 5.3).



Note:
1. Dashed line indicates EQG (EPA 2015b) guideline

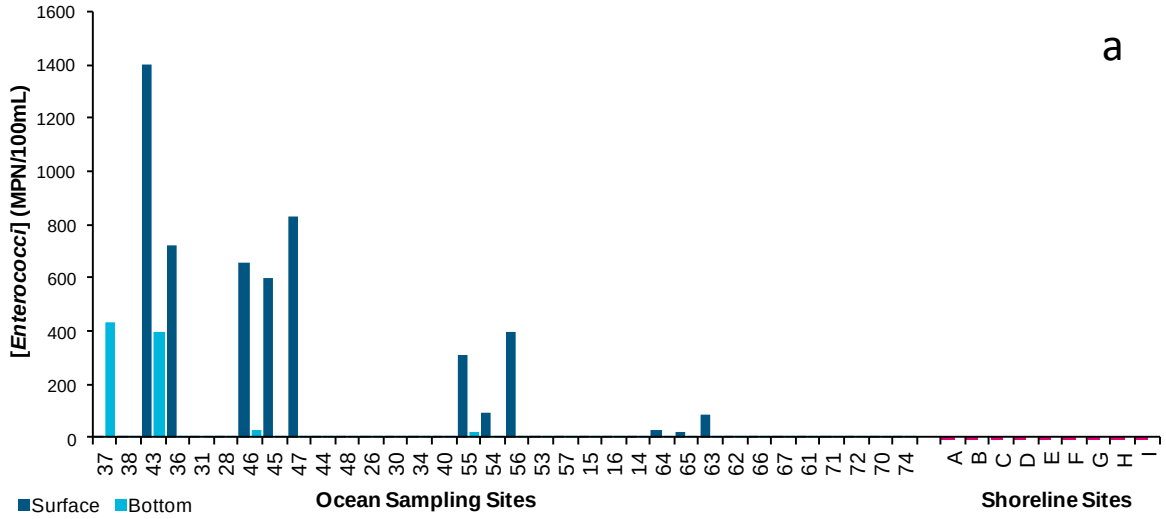
Figure 5.20 Thermotolerant coliform concentrations at Sepia Depression

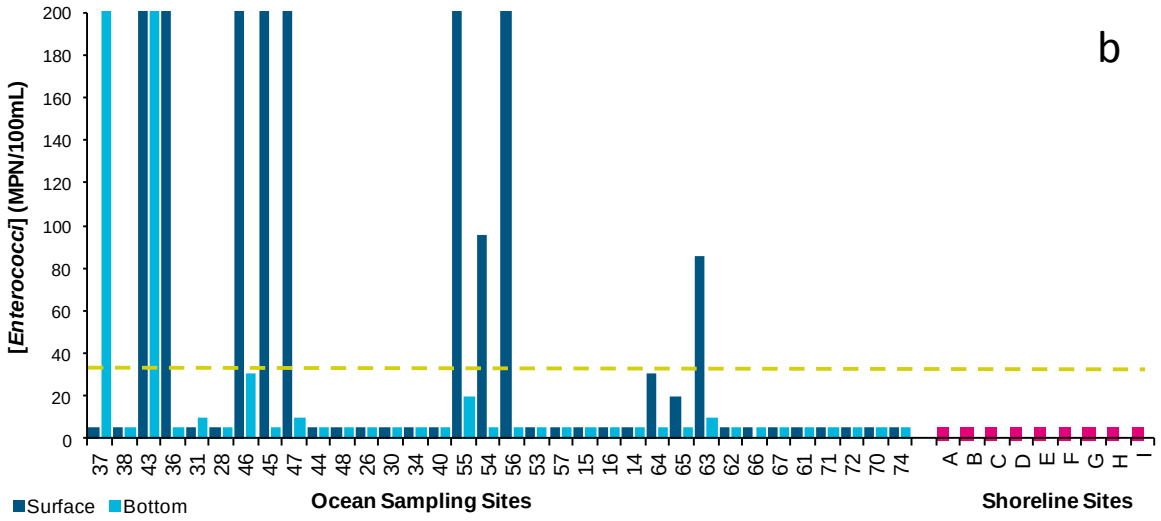


Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or EQG.

Figure 5.21 Spatial distribution of thermotolerant coliform concentrations at Sepia Depression

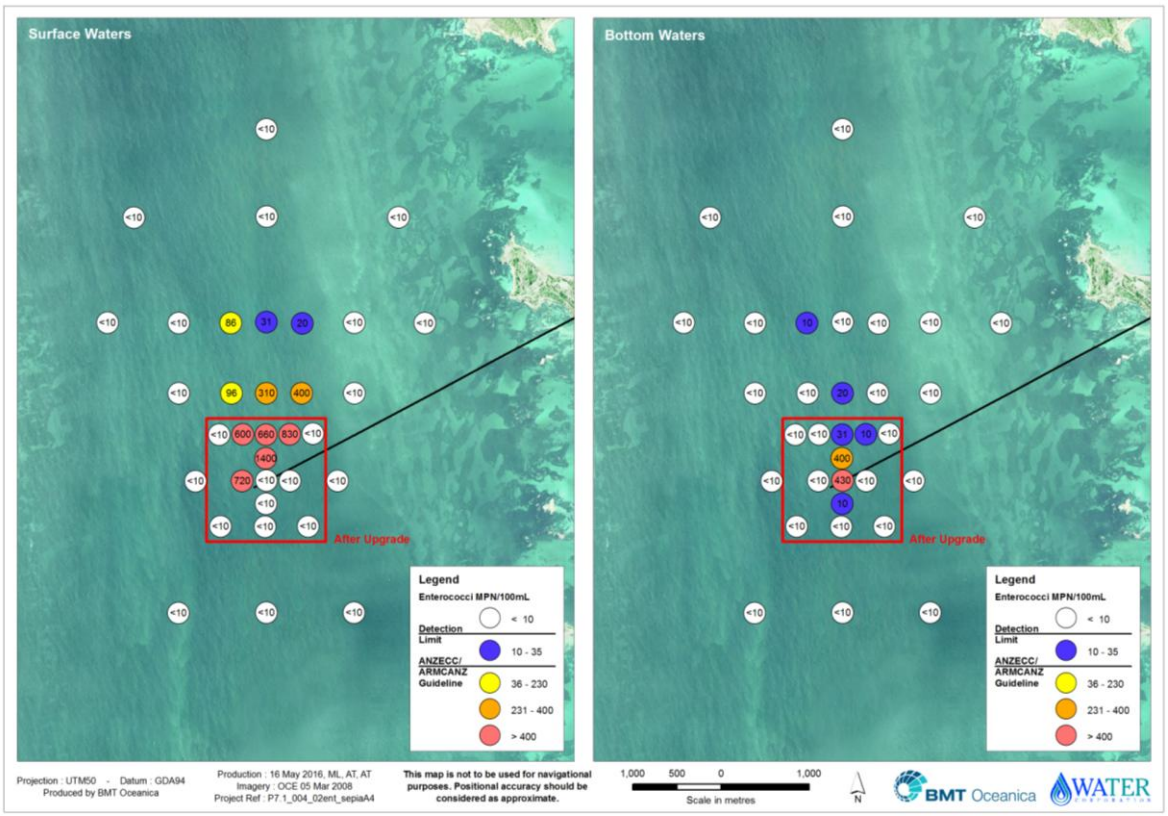
Like TTC, surface and bottom *Enterococci* spp. concentrations were elevated near the diffuser and remained elevated (although decreasing with distance) in samples collected away from the diffuser in the direction of the prevailing current (a northerly direction) (Figure 5.22 and Figure 5.23). However, median concentrations at the surface and bottom, both less than and greater than 250 m met the ANZECC & ARMCANZ (2000) trigger (Table 5.3). Concentrations did not exceed the ANZECC & ARMCANZ (2000) guideline at any of the shoreline sites (Figure 5.22).





Note:
1. Dashed line indicates ANZECC & ARMCANZ (2000) guideline

Figure 5.22 *Enterococci* spp. concentrations at Sepia Depression



Notes:
1. Site locations have been exaggerated for visual clarity
2. Breaks in the legend (solid lines) indicate concentrations above or below the detection limit or ANZECC & ARMCANZ (2000) guideline.

Figure 5.23 Spatial distribution of *Enterococci* spp. at Sepia Depression

5.8 Summary

The summer water quality surveys were not designed for comparison with the ANZECC & ARMCANZ (2000) guidelines or with 80th percentile of reference values but comparisons were made for sites located <250 m and >250 m from the diffuser as an indicator rather than a means of assessing compliance. Despite elevated concentrations at some individual sites outside the immediate zone of influence of the outlet, the guidelines for demonstrating ecosystem protection and public health criteria were met (Table 5.2).

During the survey, the treated wastewater plume was initially buoyant (as indicated by the lower salinity and higher concentrations of nutrients and microbiological indicators in surface waters than in bottom waters) and was advecting in a north-north westerly direction. Median concentrations of nutrients and chlorophyll a were typically below the guidelines both within and beyond 250 m from the outlet (Table 5.2) some elevated nutrients at the shoreline appear to be unrelated to the outlet (Table 5.2).

Median thermotolerant coliform (TTC) concentrations were below the maintenance of seafood safe for human consumption guideline in surface and bottom waters >250 m from the diffuser (Table 5.2) suggesting that these waters are maintained for seafood quality. Guidelines relating to recreation contact were met both within and outside 250 m of the diffuser (Table 5.2).

Table 5.2 Summary Sepia Depression

Parameter	Inside the mixing zone (sites <250 m from diffuser)		Outside the mixing zone (sites >250 m from diffuser)		Shoreline
	Surface	Bottom	Surface	Bottom	
ANZECC/ARMCANZ (2000) guideline values					
Total ammonia nitrogen					
Ortho-phosphate					
Nitrate+nitrite					
Total phosphorus					
Total nitrogen					
Chlorophyll-a					
Enterococci spp.[3]					
80th percentile of reference values					
Total ammonia nitrogen					
Ortho-phosphate					
Nitrate+nitrite					
Total phosphorus					
Total nitrogen					
Chlorophyll-a					
Environmental Quality Guideline (EPA 2015b)					
Thermotolerant coliforms[4]					

Notes:

1. Green = median values ≤ ANZECC/ARMCANZ (2000) guideline values , ≤80th percentile reference values or ≤ EQG.
2. Red = Median values > ANZECC/ARMCANZ (2000) guideline values , >80th percentile reference values or > EQG
3. For the maintenance of seafood safe for human consumption
4. For primary contact recreation

Table 5.3 Summary statistics for Sepia Depression

Parameter	depth	lowest		highest		Median		number (%) below the guideline		number (%) below 80th percentile of reference	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Ammonia (NH4)	All	1.5	1.5	46	23	1.5	1.5	23 (68)	32 (94)	23 (68)	32 (94)
	Inside 250 m	1.5	1.5	46	23	1.5	1.5				
	Outside 250 m	1.5	1.5	38	1.5	1.5	1.5				
	Shoreline	1.5	0	44	0	6	0	4 (44)			
Nitrate + nitrite	All	1	1	6	10	1	1	33 (97)	31 (91)	31 (91)	31 (91)
	Inside 250 m	1	1	5	9	1	1				
	Outside 250 m	1	1	6	10	1	1				
	Shoreline	1	0	18	0	2	0	31 (91)			
Total nitrogen	All	80	80	140	140	100	100	34 (100)	34 (100)	31 (91)	34 (100)
	Inside 250 m	80	90	140	120	100	110				
	Outside 250 m	80	80	140	140	100	100				
	Shoreline	140	0	220	0	150	0	9 (100)			
Ortho-phosphate	All	1	1	18	13	1	1	24 (71)	32 (94)	25 (74)	32 (94)
	Inside 250 m	1	1	18	13	1	2				
	Outside 250 m	1	1	15	3	1	1				
	Shoreline	1	0	10	0	4	0	7 (78)			
Total phosphorus (TP)	All	10	10	27	24	11	11.65	29 (85)	33 (97)	0 (100)	34 (100)
	Inside 250 m	10	11	27	24	11	14				
	Outside 250 m	10	10	26	16	11	11.3				
	Shoreline	13	0	23	0	15	0	0 (100)			
Chlorophyll a	All	0.3	0.1	0.6	0.9	0.4	0.5	34 (100)	31 (91)	34 (100)	31 (91)
	Inside 250 m	0.3	0.2	0.4	0.6	0.3	0.4				
	Outside 250 m	0.3	0.1	0.6	0.9	0.4	0.5				
	Shoreline	0.1	0	1.7	0	0.5	0	6 (67)			
Thermotolerant coliforms	All	5	5	10000	6200	5	5				
	Inside 250 m	5	5	10000	6200	30	100				
	Outside 250 m	5	5	5700	320	5	5				
	Shoreline	5	0	60	0	5	0				
Enterococci spp.	All	5	5	1400	430	5	5				
	Inside 250 m	5	5	1400	430	5	10				
	Outside 250 m	5	5	830	31	5	5				
	Shoreline	5	0	5	0	5	0				

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Appendix A – Wastewater Treatment Plant Licences

Appendix B – Sampling grids and coordinates

Appendix C – UM3Initial Dilution Model Output

Appendix D – Water Quality Sampling sites and Data

Appendix E - Sample replicates and QA/QC

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