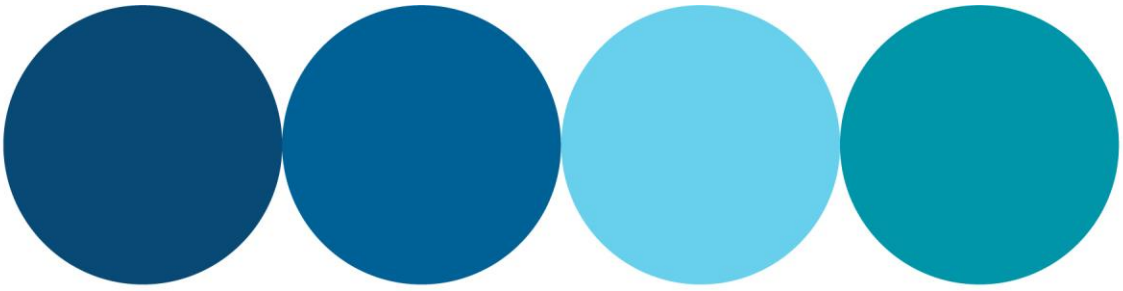
Perth Long Term Ocean Outlet Monitoring (PLOOM) Program

2019 Summer Water Quality Surveys



WATER CORPORATION

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Quality Assurance

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BMT Western Australia Pty Ltd has prepared this report in accordance with our Integrated Management System, in compliance with OHSAS18001, ISO14001 and ISO9001

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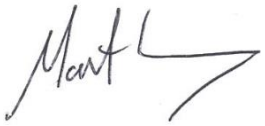

Author
Date: 28/08/18

Director (or delegate)
Date: 28/08/19

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Introduction

Water Corporation operates major water resource recovery facilities (WRRFs) at Beenyup, Subiaco and Woodman Point (Figure 1). Treated wastewater from each plant is discharged to the sea through ocean outlets at Ocean Reef, Swanbourne and Sepia Depression, respectively (Figure 1 and Table 1). The Discharge from the Beenyup and Subiaco WRRFs consists almost entirely of domestic secondary treated wastewater. A small volume of primary treated wastewater (from the Point Peron Wastewater Treatment Plant (WWTP)) and industrial wastewater (from the Kwinana Wastewater Reclamation Plant) is added to the Woodman Point WRRF wastewater stream prior to discharge.

Table 1 Ocean outlet characteristics

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

Water Corporation completes annual summer water quality surveys at each outlet to:

- provide data on water quality near 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
- ongoing assessment of potential environmental impacts from wastewater discharge in relation to the marine water quality and beneficial uses of the area
- ongoing assessment of potential public health risk associated with ocean disposal of treated wastewater.

This report presents the results of the 2019 summer water quality surveys at Ocean Reef (5 February 2016), Swanbourne (22 January 2019) and Sepia Depression (19 February 2019).

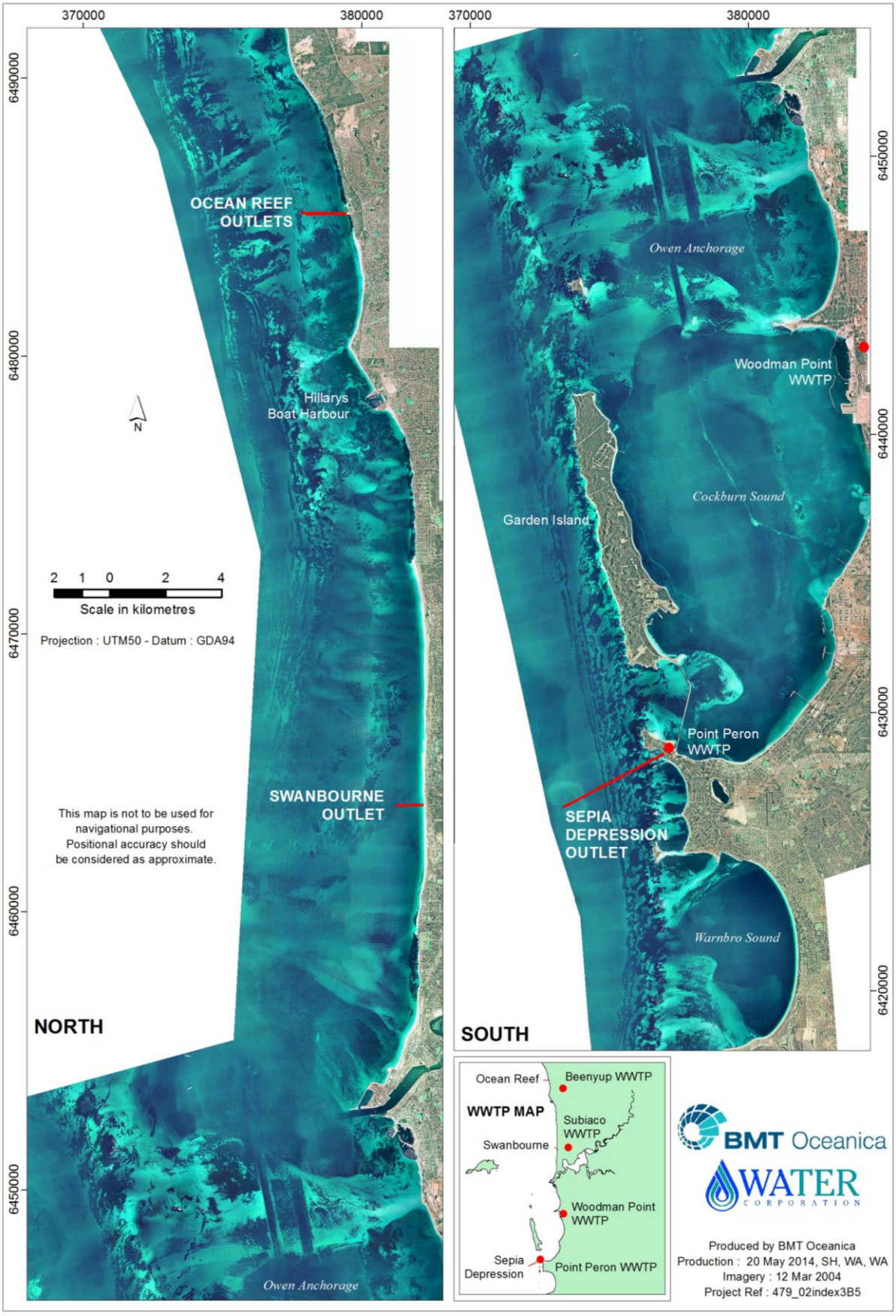


Figure 1 **Treated wastewater ocean outlet locations, Perth**

Physics

Wind speed and direction at Ocean Reef, Swanbourne and Sepia Depression prior to and during each summer water quality survey were provided by the Bureau of Meteorology. In the 24 hours prior to the Ocean Reef survey, winds were relatively consistent averaging a moderate 7.0 m/s (Figure 2). Initially winds were from the east, swinging towards the south and then back to the east (Figure 2). During the survey, winds were predominantly easterly and averaged 6.4 m/s (Figure 2). At Swanbourne, southerly winds abated from moderate (~6 m/s) to light (~2 m/s) over the 24-hours prior to commencement (Figure 2). Winds averaging 4 m/s out of the SSW persisted for the duration of the survey (Figure 2). For the 24 hours prior to the survey, the winds at Sepia Depression were gentle easterlies (~5 m/s), increasing to fresh southerlies (~10 m/s) and easing back to gentle southerlies (~4 m/s) immediately prior to sampling (Figure 2). During sampling, the southerlies built from 3.6 to 7.8 m/s (Figure 2).

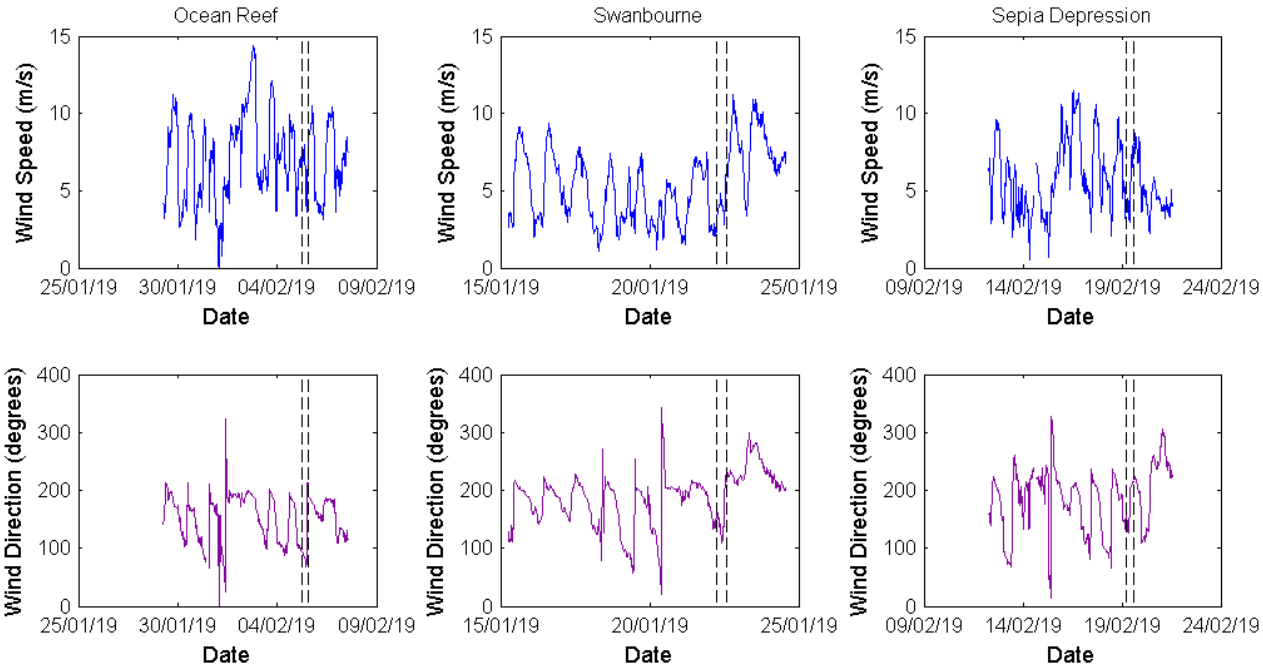


Figure 2 Wind speed and direction prior to and during each ocean outlet survey

Water surface elevations were obtained from the Department of Transport's(DoT) gauge in Fremantle Fishing Boat Harbour. Significant wave height and wave period are from the DoT wave rider buoy south-west of Rottnest Island. Attenuation of the wave energy by refraction and diffraction around offshore reefs will reduce the wave height near the outlets below that observed offshore. For 24 hours prior to the surveys, the average significant wave height[1] offshore from Rottnest Island was 1.8, 2.4 and 1.5 m at Ocean Reef, Swanbourne and Sepia Depression, respectively (Figure 3). During the surveys the average offshore significant wave height had fallen to 1.4 m at Ocean Reef, 2.0 m at Swanbourne and 1.3 m at Sepia Depression (Figure 3). The average peak wave period was also shorter during the surveys than the prior 24-hour period (Figure 3). Each survey was completed during a rising tide (Figure 3).

[1] *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/)*

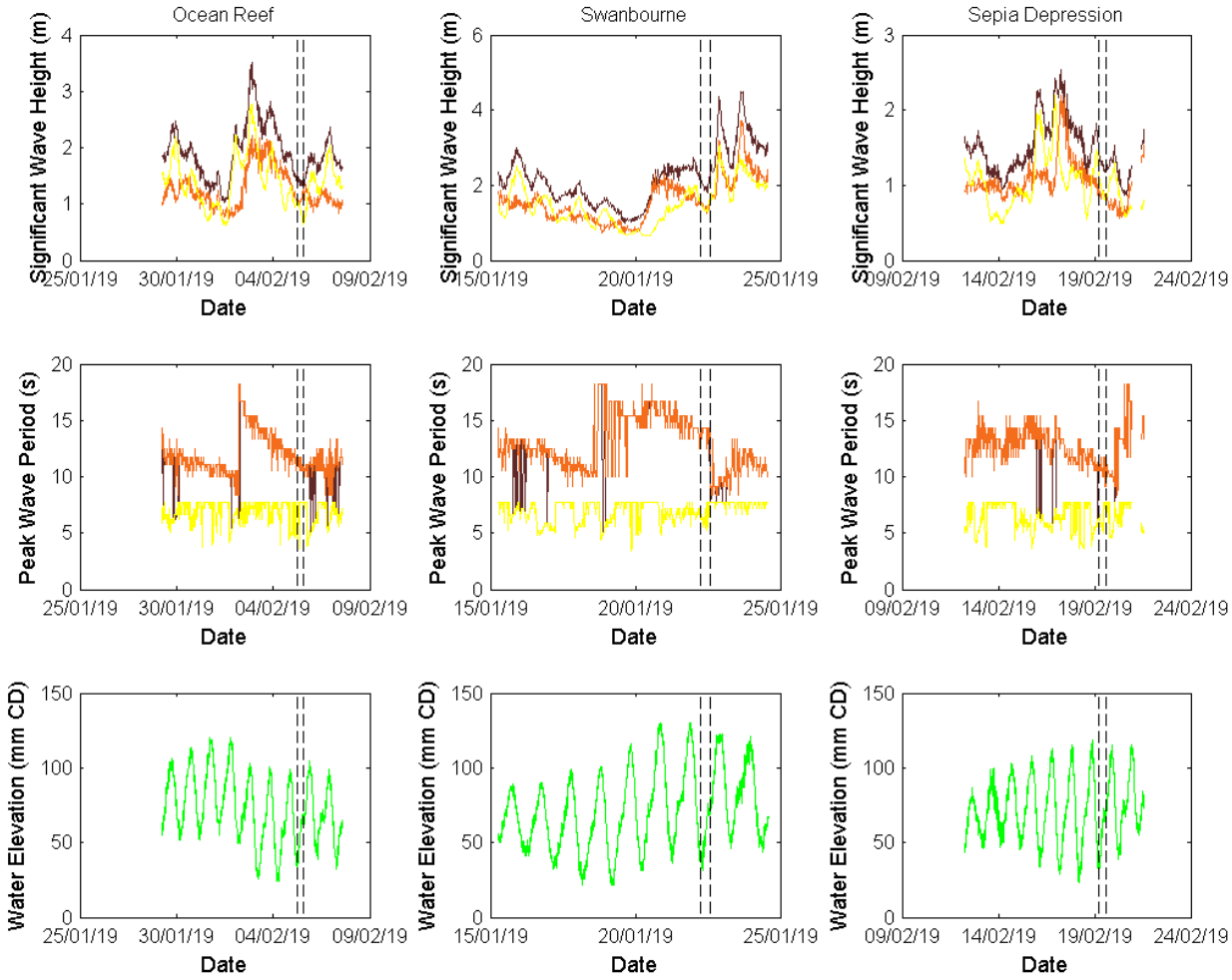


Figure 3 Significant wave heights (offshore Rottnest Island), peak wave periods (offshore Rottnest Island) and water level elevation (Fremantle Fishing Boat Harbour) prior to and during each ocean outlet survey

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). At Ocean Reef, the drogue travelled in a westerly direction (278º) at a velocity of 0.11 m/s (Figure 4). At Swanbourne, the drogue travelled in a north-north westerly direction (338º) at a velocity of 0.15 m/s (Figure 5). At Sepia Depression, the drogue travelled in a north westerly direction (324º) at a velocity of 0.19 m/s (Figure 6).

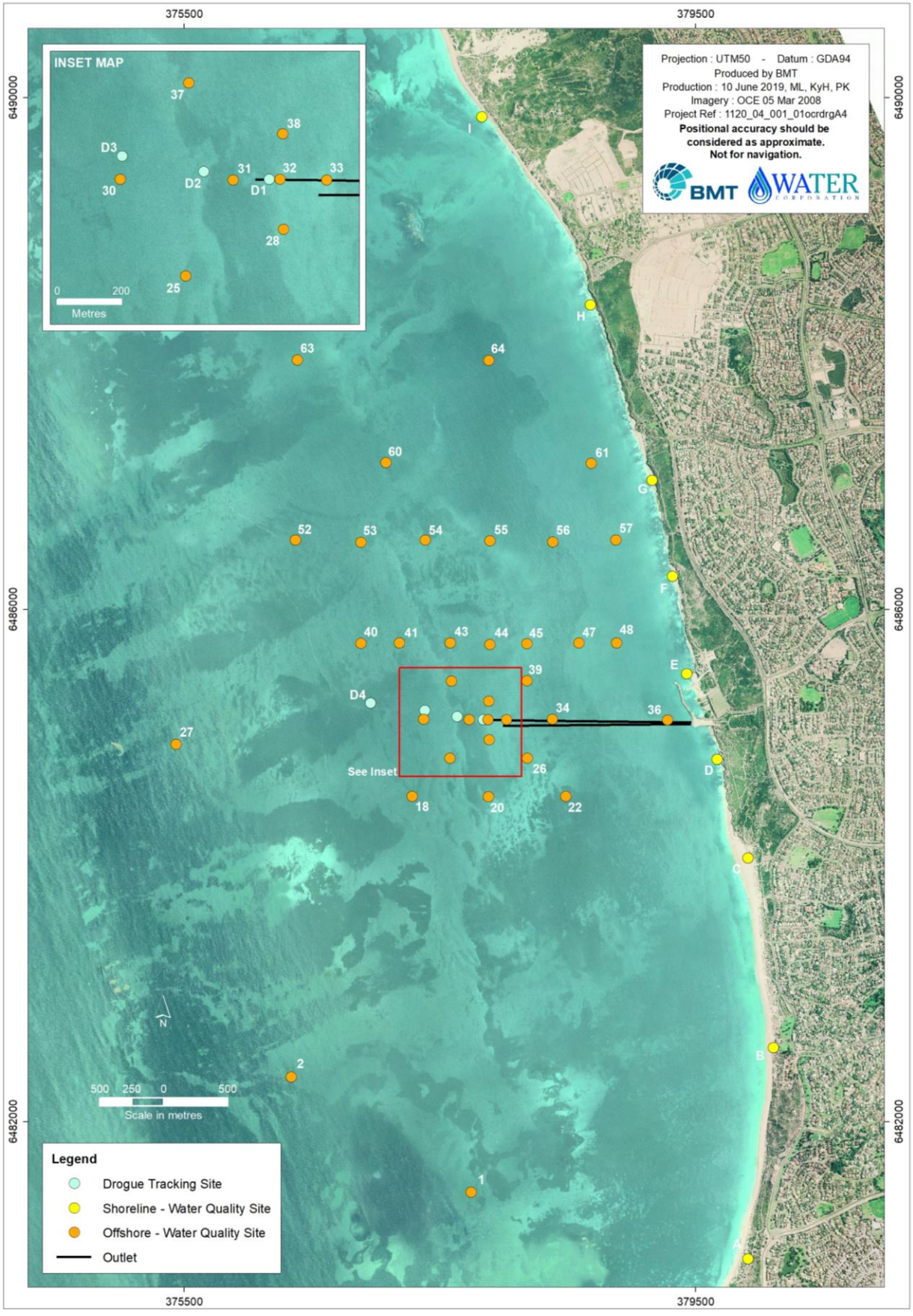


Figure 4 Ocean Reef drogue tracking locations, 5 February 2019

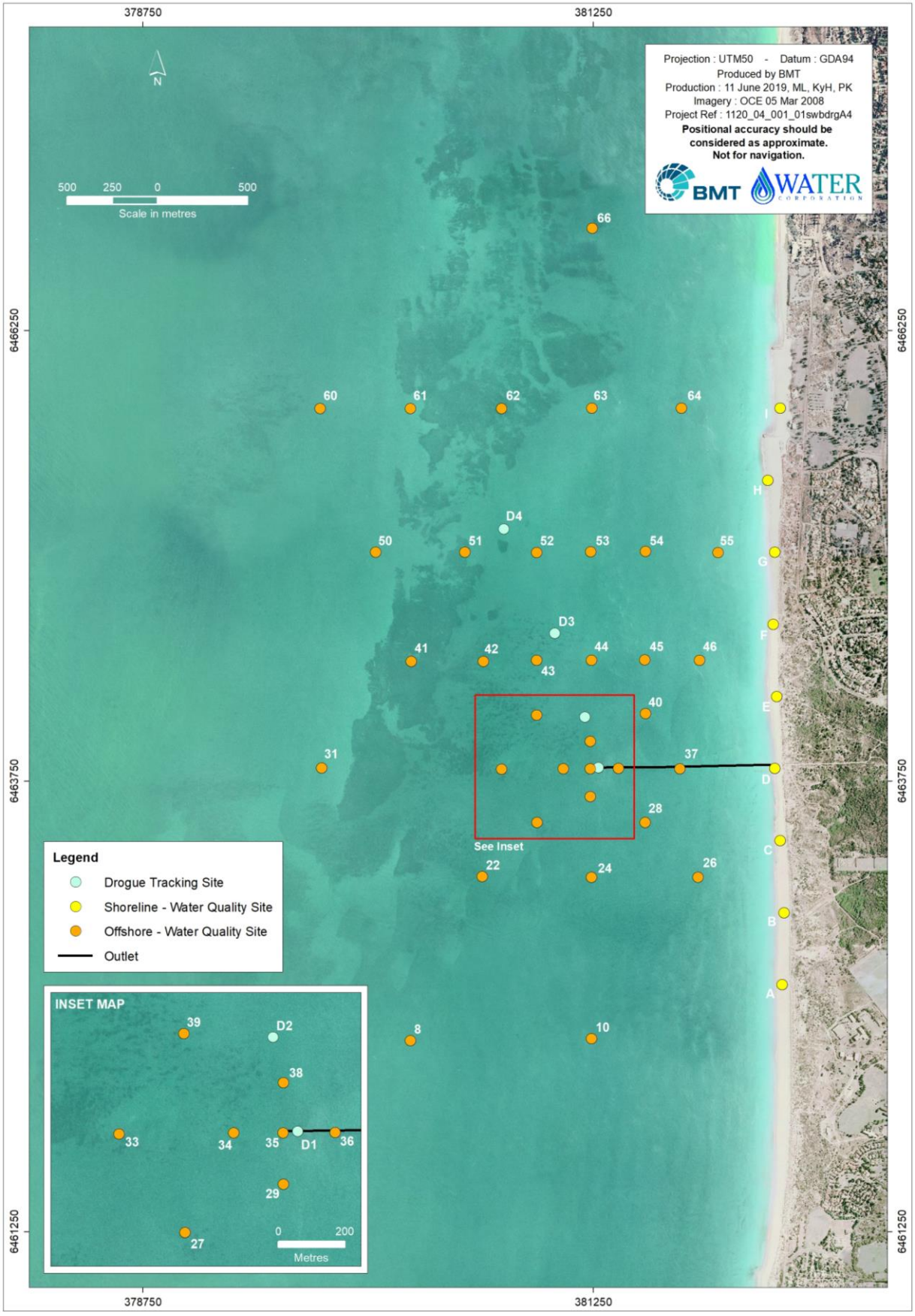


Figure 5 Swanbourne drogue tracking locations, 22 January 2019

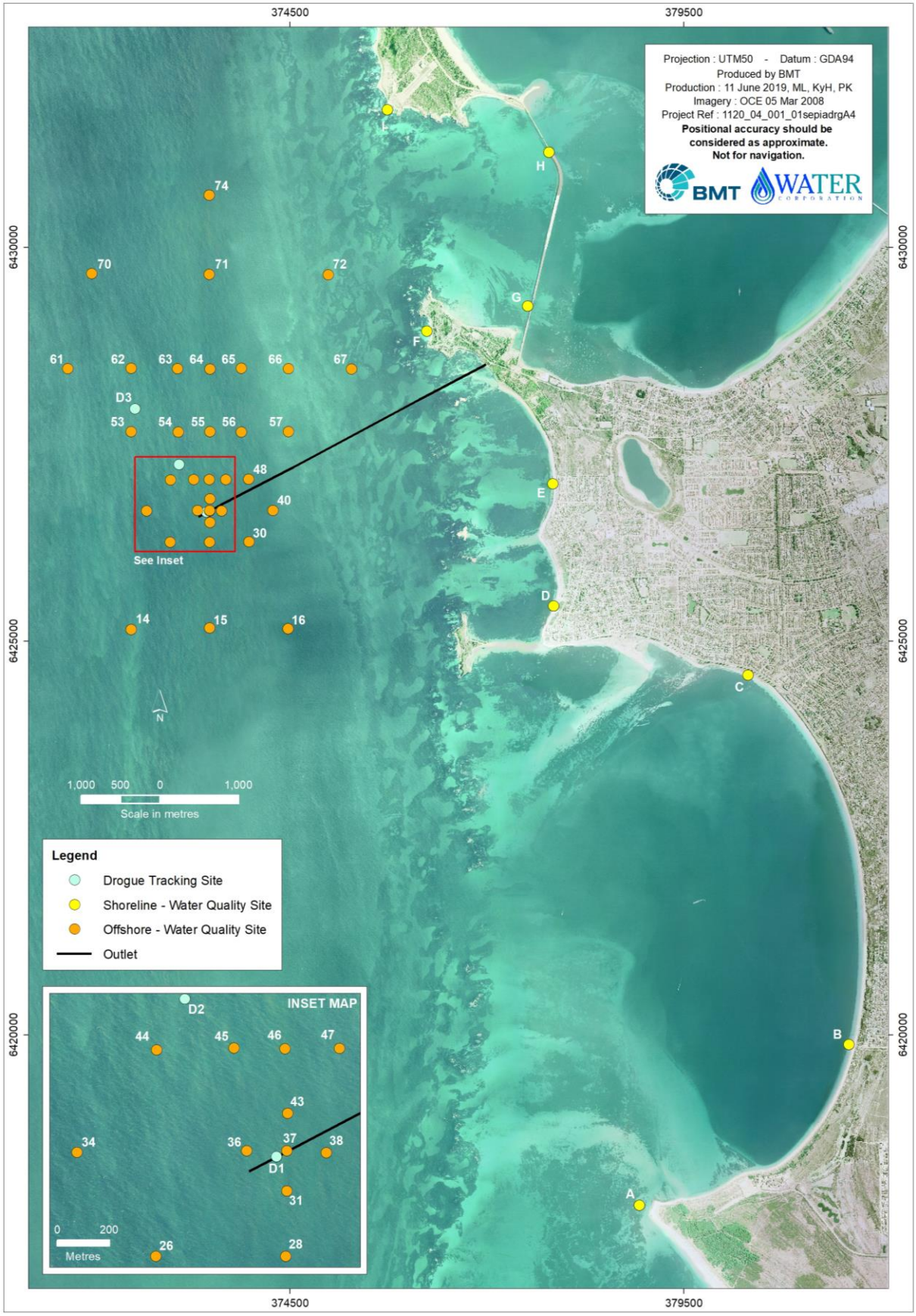


Figure 6 **Sepia Depression drogue tracking locations, 19 February 2019**

Dilution

Initial dilution occurs from where the plume first discharges into the surrounding waters and then, in the case of positively buoyant plumes, rises and mixes with the surrounding waters. Visual Plumes VPLUMES is an initial dilution model developed by the United States Environmental Protection Agency. These models capture simple features of the surrounding environment such as depth at point of discharge, net current and wind speed but do not take into account bathymetry and hydrodynamics and do not accurately predict the far-field behaviour (after the plume has reached the surface or is fully mixed in the water column).

The UM3 initial dilution model in (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 parameters were selected to represent the outlet diffuser, flows and ambient conditions at Ocean Reef, Swanbourne and Sepia Depression (Table 2). Vertical velocity profiles were derived from mean surface currents and assuming a linear decrease in current speeds of ~1.2% per metre at Ocean Reef/Swanbourne and ~3.8% per metre depth at Sepia Depression (Pattiaratchi et al. 1995). Initial dilution at the time of the surveys was 1:189 for Outlet A Ocean Reef, 1:168 for Outlet B Ocean Reef, 1:148 at Swanbourne and 1:583 at Sepia Depression (Table 2).

Table 2 Initial dilution model set-up parameters and output

Diffuser characteristics	Ocean Reef (Outlet A)	Ocean Reef (Outlet B)	Swanbourne	Sepia Depression
	5/02/2019	5/02/2019	22/01/2019	19/02/2019
Port diameter (m)	0.125	0.16	0.17	0.14
Port elevation (m)	0.76	0.84	1	0.75
Number of open ports	50	48	20	68
Port spacing (m)[1]	4.0	4.0	5.0	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				
Surface temp (°C)[2]	22.2		23.1	22.0
Bottom temp (°C)[2]	22.0		22.3	21.7
Surface salinity[2]	36.44		36.30	36.06
Bottom salinity[2]	36.45		36.13	36.10
Surface current (m/s)	0.11		0.15	
Bottom current	0.09		0.13	
Discharge characteristics				
Flow (ML/day)	57.2	57.2	55.8	136.5
Temperature (°C)	27.5	27.5	27.5	27.5
Salinity (psu)	0.55	0.55	0.70	0.68
Dilution Characteristics				
Dilution	189	168	148	583
Centre line dilution	75	65	54	270
Distance (m)	8	7	9	22

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.

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 outlet.

Salinity and density were slightly reduced at the surface immediately over the outlet at Ocean Reef but did not vary greatly with increasing distance downstream (Figure 7). At Swanbourne, a layer of low salinity and density overlies higher salinity/density water at 100 m from the outlet and extending to over at least 1900 m (Figure 8). At Sepia Depression, a layer of low salinity, low

density and elevated temperature overlies higher salinity/density water at and extending throughout the entire domain (Figure 9).

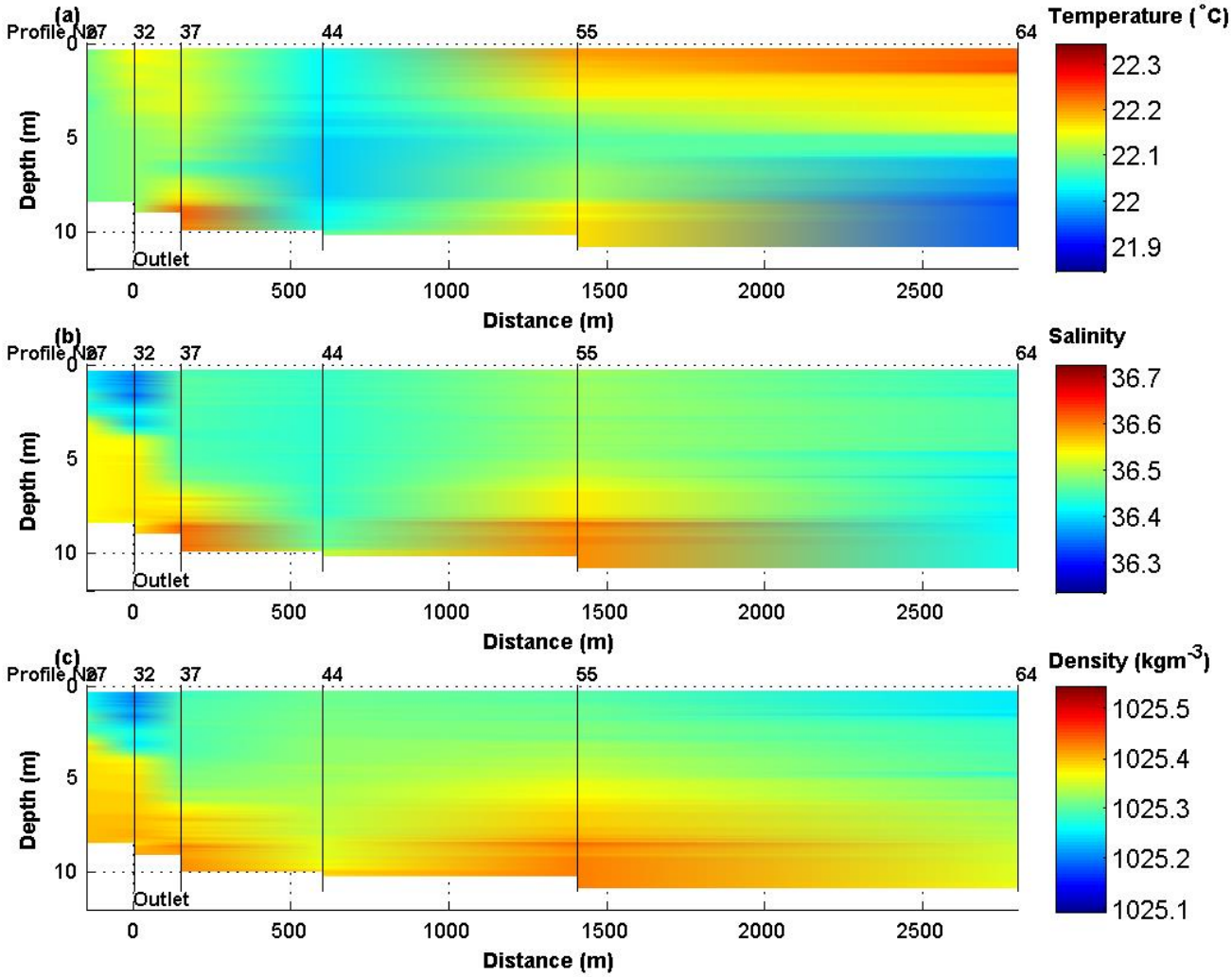


Figure 7 Temperature (a), salinity (b) and density (c) transect at Ocean Reef

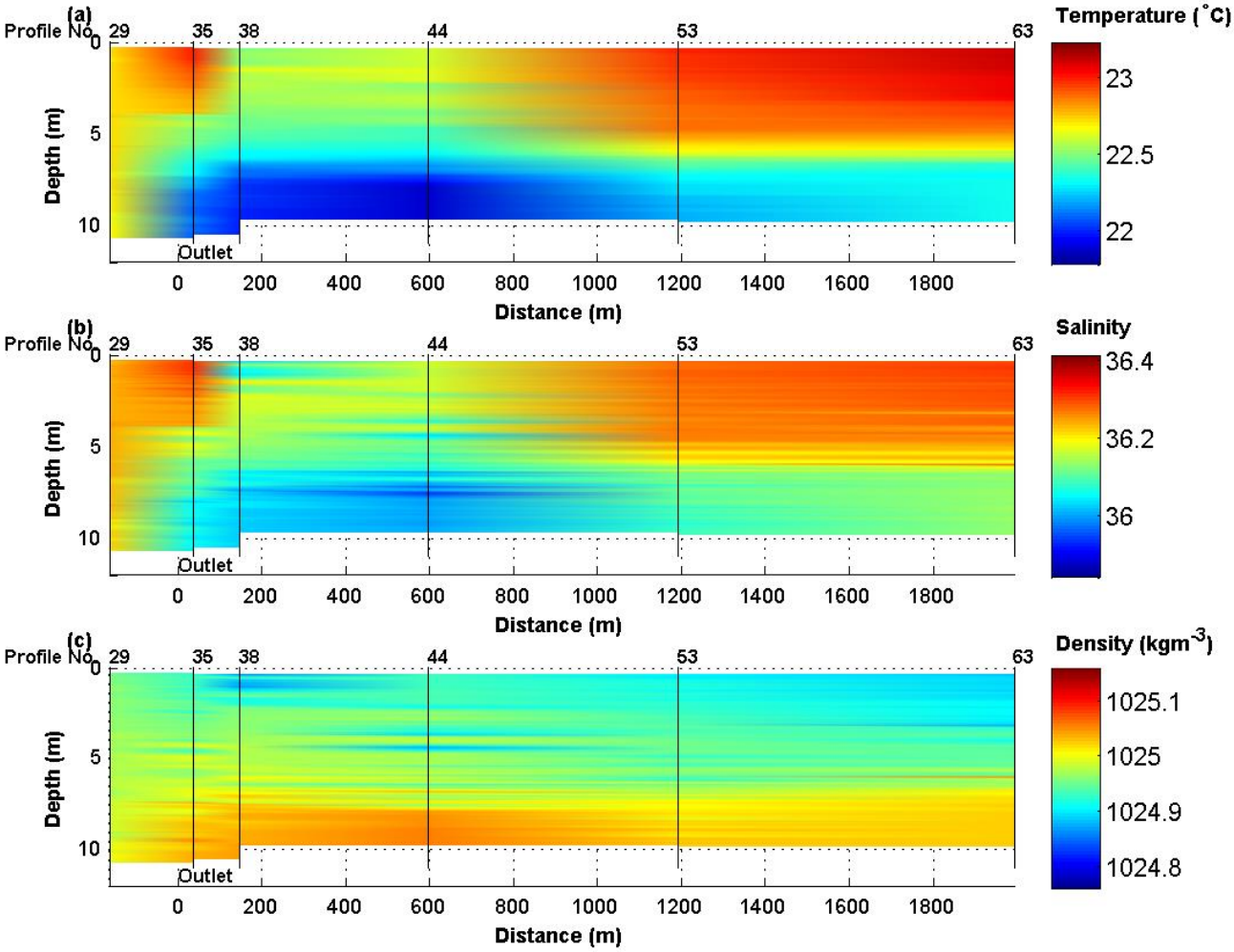


Figure 8 **Temperature (a), salinity (b) and density (c) transect at Swanbourne**

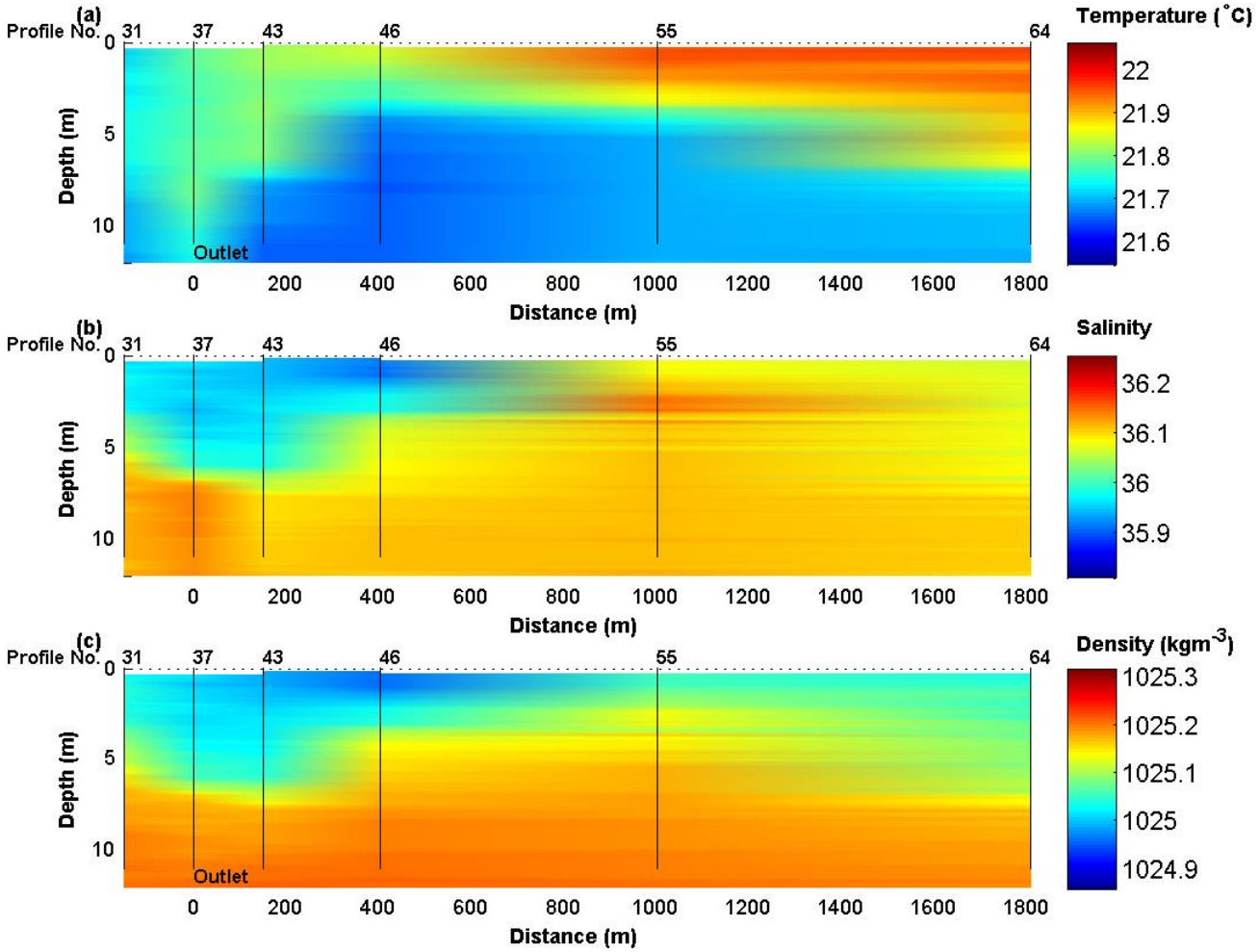


Figure 9 Temperature (a), salinity (b) and density (c) transect at Sepia Depression

Wastewater sampling

Flow-proportionate composite samples of treated wastewater were collected from each of the WRRFs 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 (TWW) prior to discharge determined (Table 3).

Table 3 Treated wastewater characteristics from each plant/outlet coinciding with each survey

Parameter	Concentration		
	Beenyup	Subiaco	SDOOL
Total phosphorus	6.6 mg/L	4.9 mg/L	5.7 mg/L
Total nitrogen	9.6 mg/L	18 mg/L	33 mg/L
Total ammoniacal nitrogen	0.49 mg/L	9.2 mg/L	21 mg/L
Nitrate+nitrite	8.2 mg/L	5.1 mg/L	2.5 mg/L
Thermotolerant coliforms	27 000 CFU/100 mL	61 000 CFU/100 mL	2 000 000 CFU/100 mL
Enterococci spp.	1600 MPN/100 mL	3300 MPN/100 mL	24 000 MPN/100 mL
Total suspended solids	19 mg/L	5 mg/L	35 mg/L
Biological oxygen demand	26 mg/L	10 mg/L	22 mg/L
Total flow	114.4	55.8	136.5

Ocean sampling

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 as determined by the drogue (Figure 4, Figure 5 and Figure 6). Nine shoreline sites located along the coast adjacent to each ocean outlet were sampled at each outlet (Figure 4, Figure 5 and Figure 6).

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 flushed for ~30 s, the delivery hose prior to collecting the sample. Shoreline samples were collected in waist-deep water by directly filling the sample containers. All the samples were placed on ice and in the dark and returned to the laboratory for analysis (Table 4).

Table 4 Sample volumes, treatment and reporting limits

Parameter	Volume collected	Sample treatment	LoR
Total phosphorus	125 mL	Unfiltered	5 µg P/L
Total nitrogen analysis	125 mL	Unfiltered	50 µg N/L
Total ammoniacal nitrogen	10 mL	filtered	3 µg N/L
Nitrate+nitrite	10 mL	filtered	2 µg N/L
Ortho-phosphate	10 mL	filtered	2 µg P/L
chlorophyll-a (fluorometric)	10 mL	unfiltered	0.1 µg/L

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. 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).

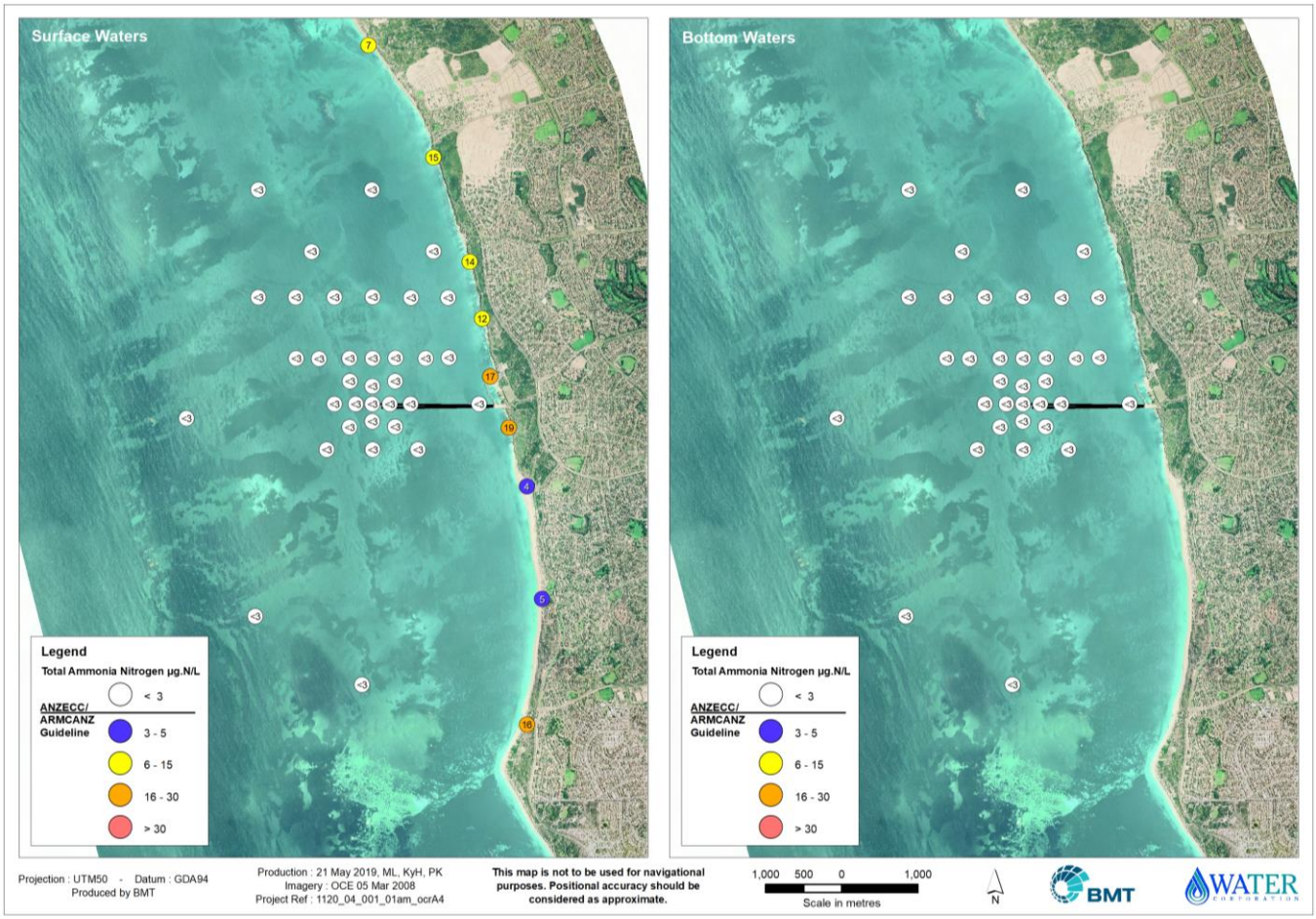
The summer surveys predate the Environmental Protection Authority's (EPA) Environmental Quality Management Framework (EQMF; EPA 2016) and while there are some similarities, the design of the program is not consistent with the framework and the results cannot be evaluated against the EQMF criteria. In cases where there are enough appropriate reference data available, ANZG (2019) recommends using locally derived guideline values for physical and chemical stressors based on the 80th and/or 20th percentile of natural background concentrations. Surface and bottom concentrations in the water column are measured at reference sampling sites located upstream of the outlet during each summer water quality survey from over the last 20 years (1999–2019), and have been used to derive guidelines (Table 5). These are low-risk guidelines and an exceedance should be regarded as an 'early warning' of a potential problem rather than evidence of a potential impact. The median concentration of samples collected within 250 m of and greater than 250 m from the diffuser were compared to the locally derived guidelines. This distance nominally represents the region encapsulating the initial stages of treated wastewater mixing, as indicated by historical initial dilution modelling.

Table 5 80th percentile of reference sites nutrient and chlorophyll a concentration

	Total ammoniacal 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	3	8	12	34	132	0.5
Ocean Reef – bottom Waters	3	8	11	32	130	0.5
Swanbourne – surface waters	3	6	3	32	137	0.5
Swanbourne – bottom waters	3	5	3	33	147	0.5
Sepia Depression – surface waters	5	6	4	31	130	0.5
Sepia Depression – bottom waters	3	5	3	30	145	0.7

Total ammoniacal nitrogen

Concentrations of total ammoniacal nitrogen in all (100%) surface and bottom samples from Ocean Reef (including those close to the outlet) were below the limit of reporting and the 80th percentile of the reference sites concentration (Figure 10; Table 5). In contrast, all (100%) of shoreline concentrations exceeded 80th percentile of the reference sites concentration (Figure 10; Table 5). The disconnect between low concentrations at the source (the outlet) and higher concentrations located a considerable distance away indicate that concentrations at the shoreline arise solely from terrestrial sources.



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 10 Total ammoniacal nitrogen at Ocean Reef

At the Swanbourne outlet, a total of 11 (31%) surface and three (9%) bottom samples exceeded the 80th percentile of the reference sites concentration for total ammoniacal nitrogen (Figure 11; Table 5). The highest individual total ammoniacal nitrogen concentration was 110 µg/L immediately north of the outlet (Figure 11). Elevated concentrations extended away from the outlet towards the northwest and from the shoreline. No shoreline sites exceeded the 80th percentile of the reference sites concentration (Figure 11; Table 5).

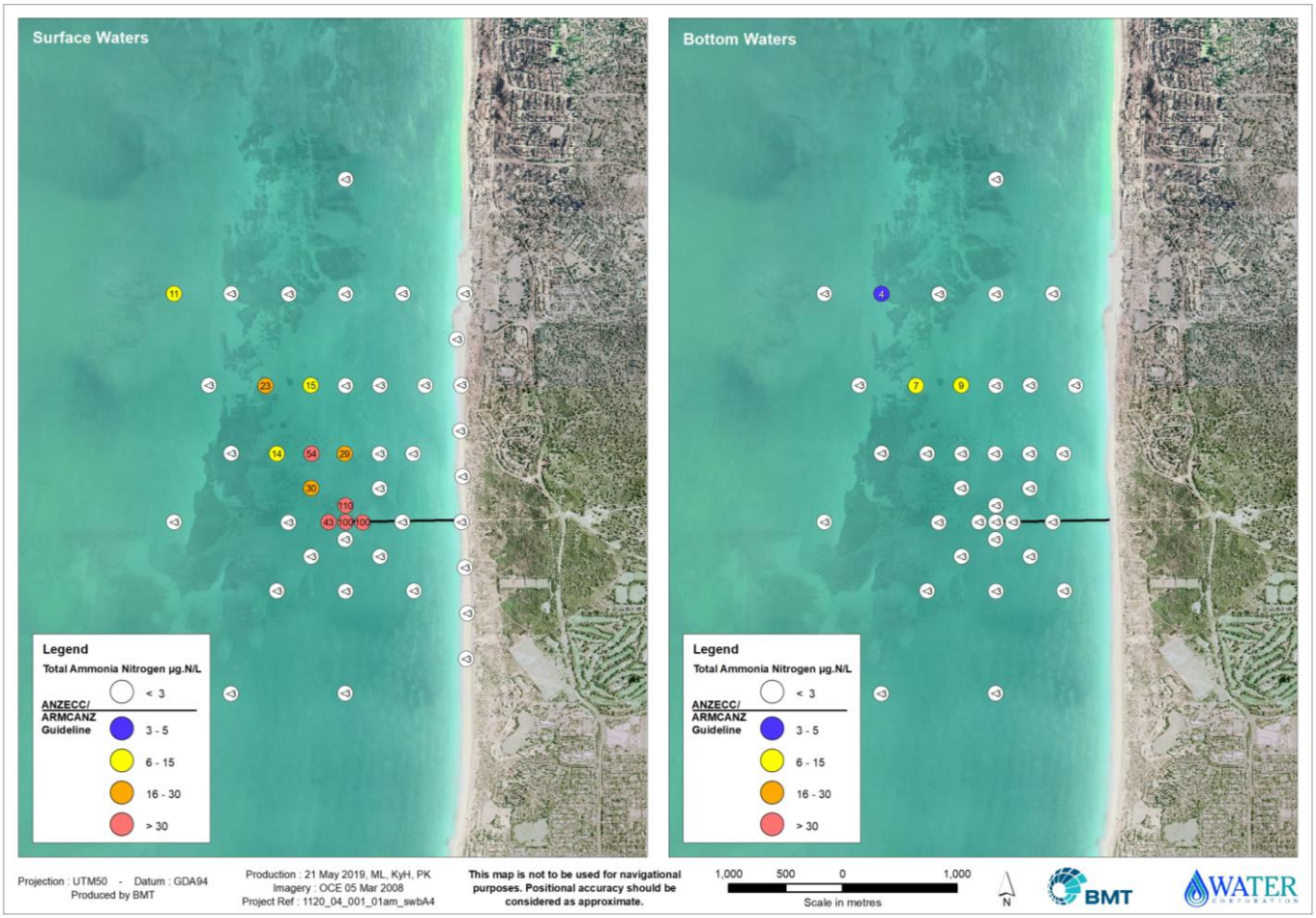


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Figure 11 Total ammoniacal nitrogen at Swanbourne

At Sepia Depression, 20 (59%) surface and four(12%) bottom exceeded the 80th percentile of the reference sites concentration for total ammoniacal nitrogen (Figure 12; Table 5). The highest overall concentration (200 µg/L) was north of the outlet (Figure 12). Elevated total ammoniacal nitrogen concentrations extended northwards away from the outlet and the coastline decreasing with increasing distance. Five out of nine (56%) shoreline sites exceeded the 80th percentile of the reference sites concentration (Figure 12; Table 5). Elevated concentrations at the outlet do not continuously extend to the shoreline and apparently arise solely from terrestrial sources rather than discharge.

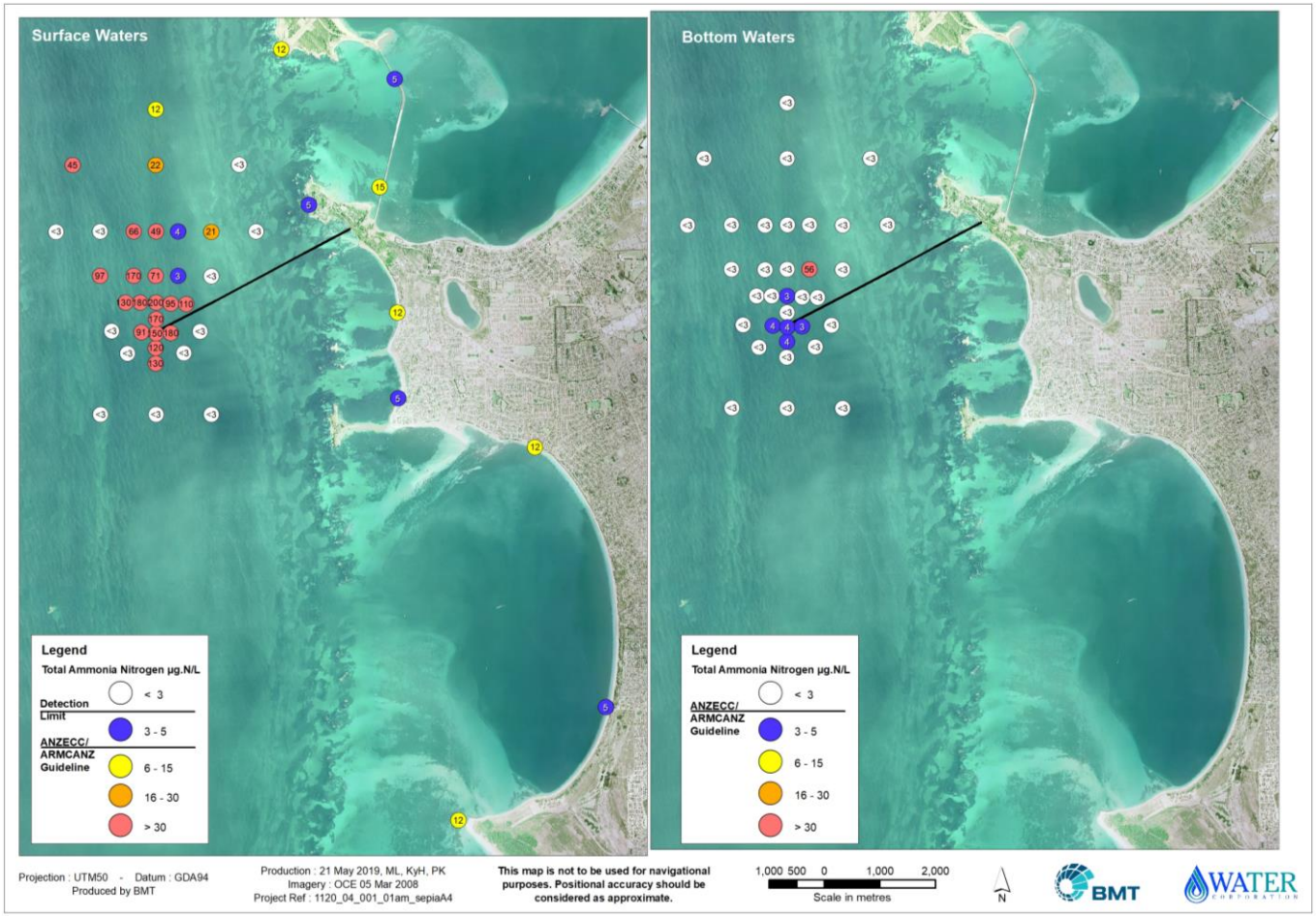

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Figure 12 Total ammoniacal nitrogen at Sepia Depression

Nitrate + nitrite

Nitrate + nitrite concentrations at Ocean Reef exceeded the 80th percentile of the reference sites concentration in 15 (43%) surface and six (17%) bottom samples (Figure 13; Table 5). All (100%) shoreline sites exceeded the 80th percentile of the reference sites concentration including one site where the concentration was 170 µg/L, three times the highest ocean concentration (Figure 13; Table 5). The elevated concentrations at the outlet extended in a north westerly direction and did not extend to the shoreline indicating elevated shoreline concentrations may be from terrestrial sources.

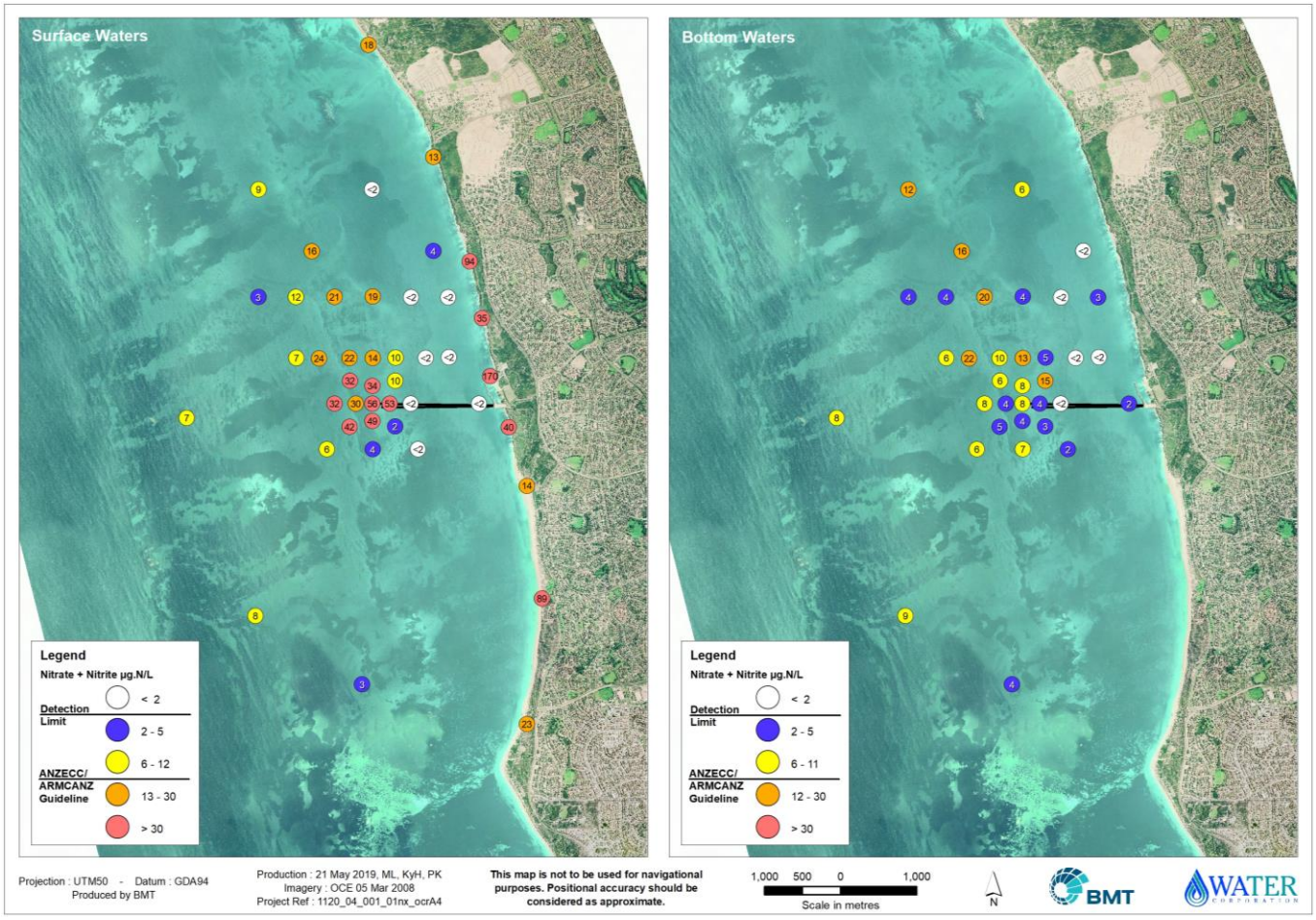

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Figure 13 Nitrate+nitrite at Ocean Reef

At Swanbourne, nine (26%) surface and three (9%) bottom samples exceeded the 80th percentile of the reference sites nitrate+nitrite concentration (Figure 14; Table 5). All nine (100%) shoreline samples exceeded the 80th percentile of the reference sites concentration (Figure 14; Table 5). The elevated concentrations at the outlet extend in a north westerly direction and do not extend to the shoreline suggesting elevated shoreline concentrations may be from terrestrial sources.

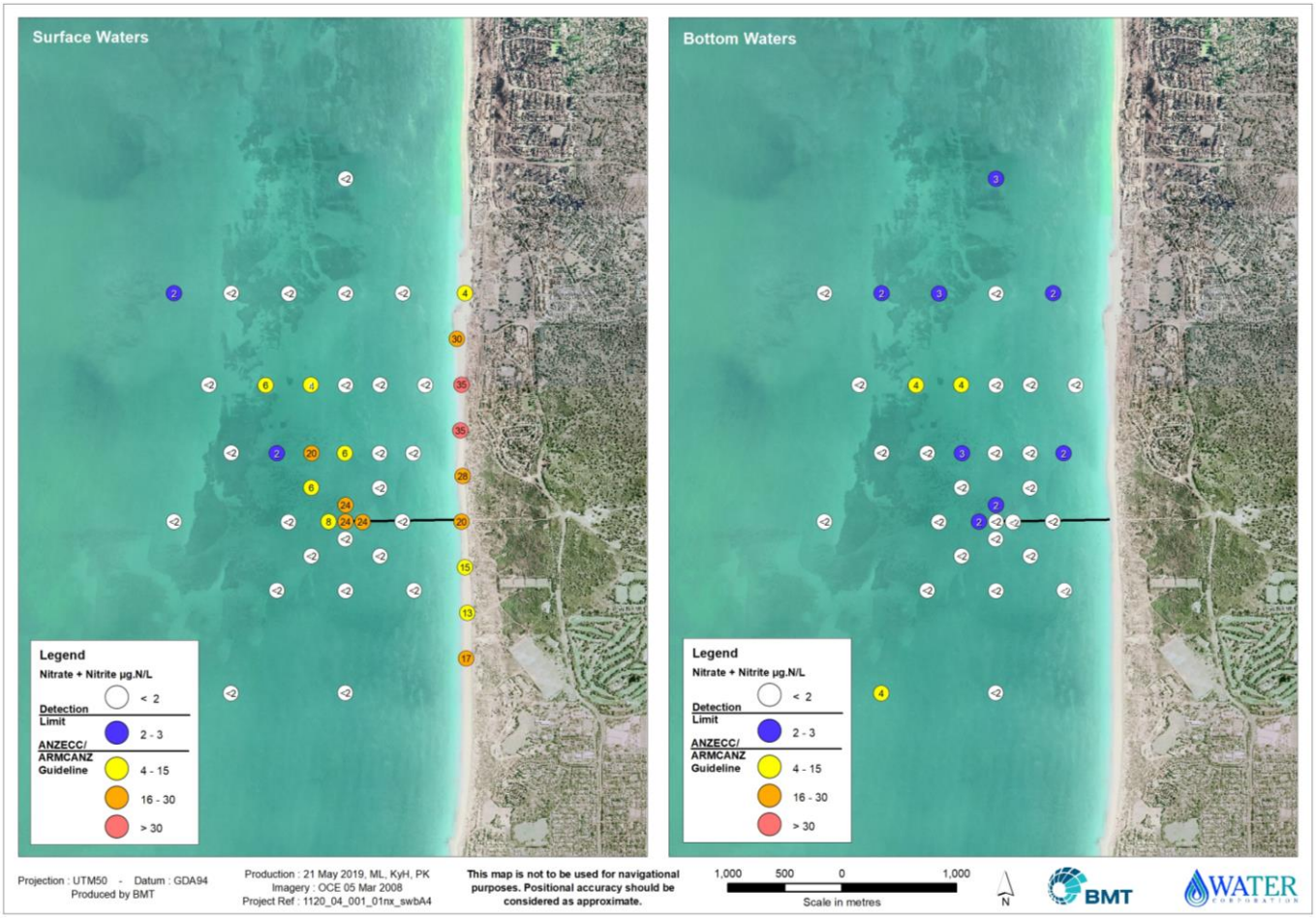

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Figure 14 Nitrate+nitrite at Swanbourne

Fifteen (44%) surface samples and one (3%) bottom sample exceeded the 80th percentile of the reference sites nitrate+nitrite concentration at Sepia Depression (Figure 15; Table 5). Three of the nine (33%) shoreline sites exceeded the 80th percentile of the reference sites concentration (Figure 15; Table 5). Elevated concentrations at the outlet extended north, away from the shoreline.

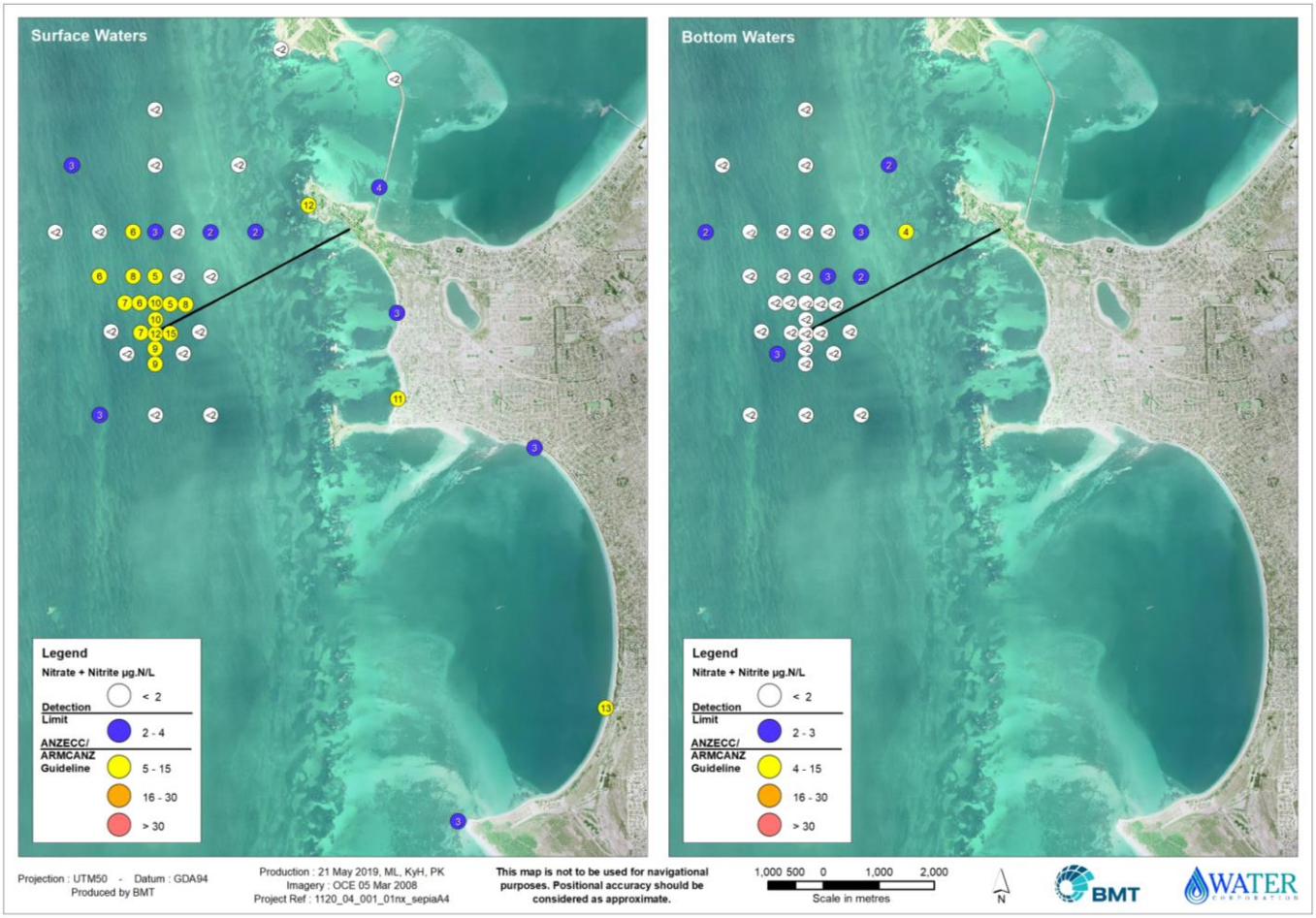

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Figure 15 Nitrate+nitrite at Sepia Depression

Total nitrogen

At Ocean Reef, eight (23%) surface and two (6%) bottom samples exceeded the 80th percentile of the reference sites concentration (Figure 16; Table 5). All nine (100%) shoreline sites exceeded the 80th percentile of reference sites concentration (Figure 16; Table 5). Concentrations are far in excess of those in the immediate vicinity of the outlet and are indicative of an alternative (terrestrial) source.

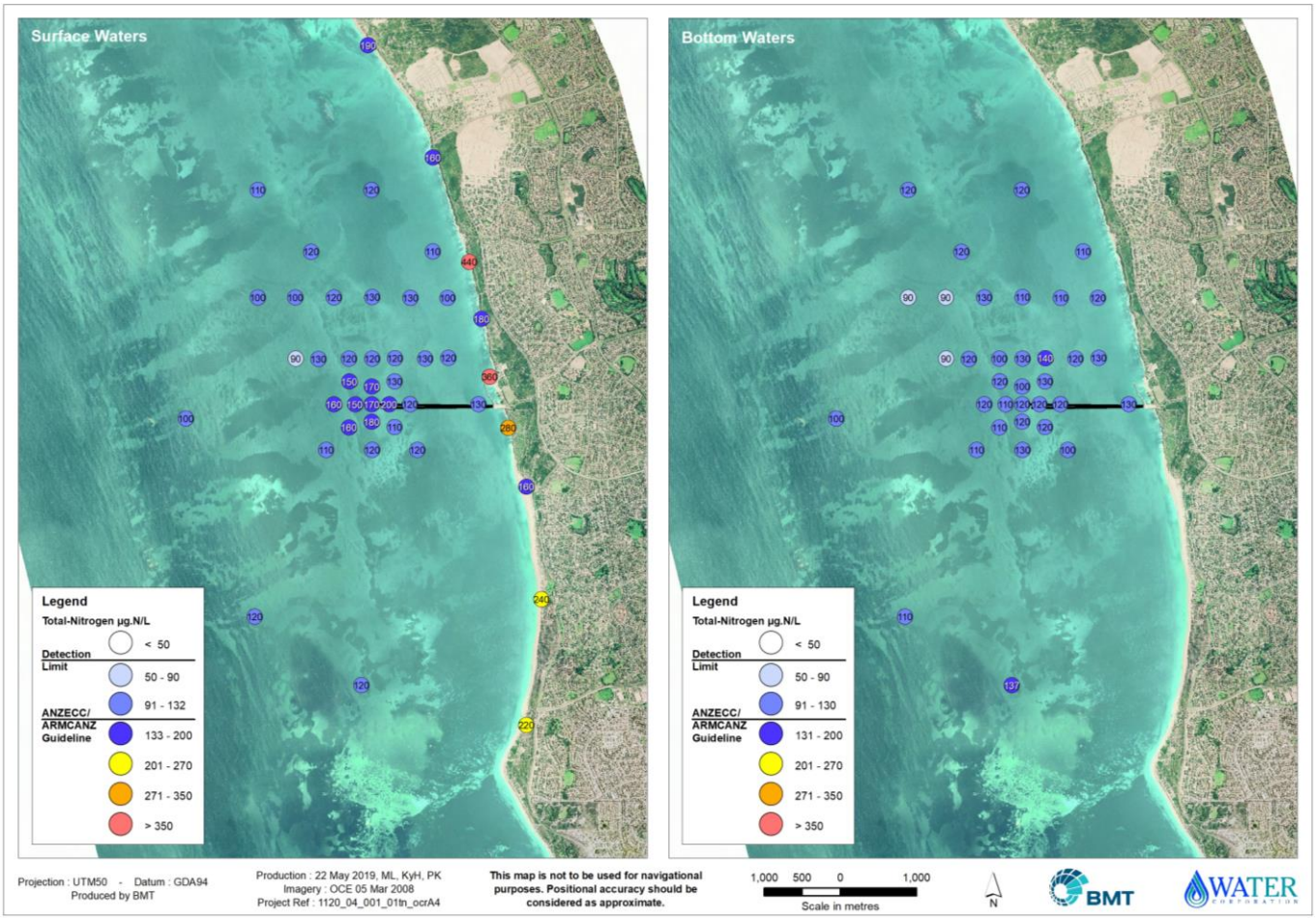

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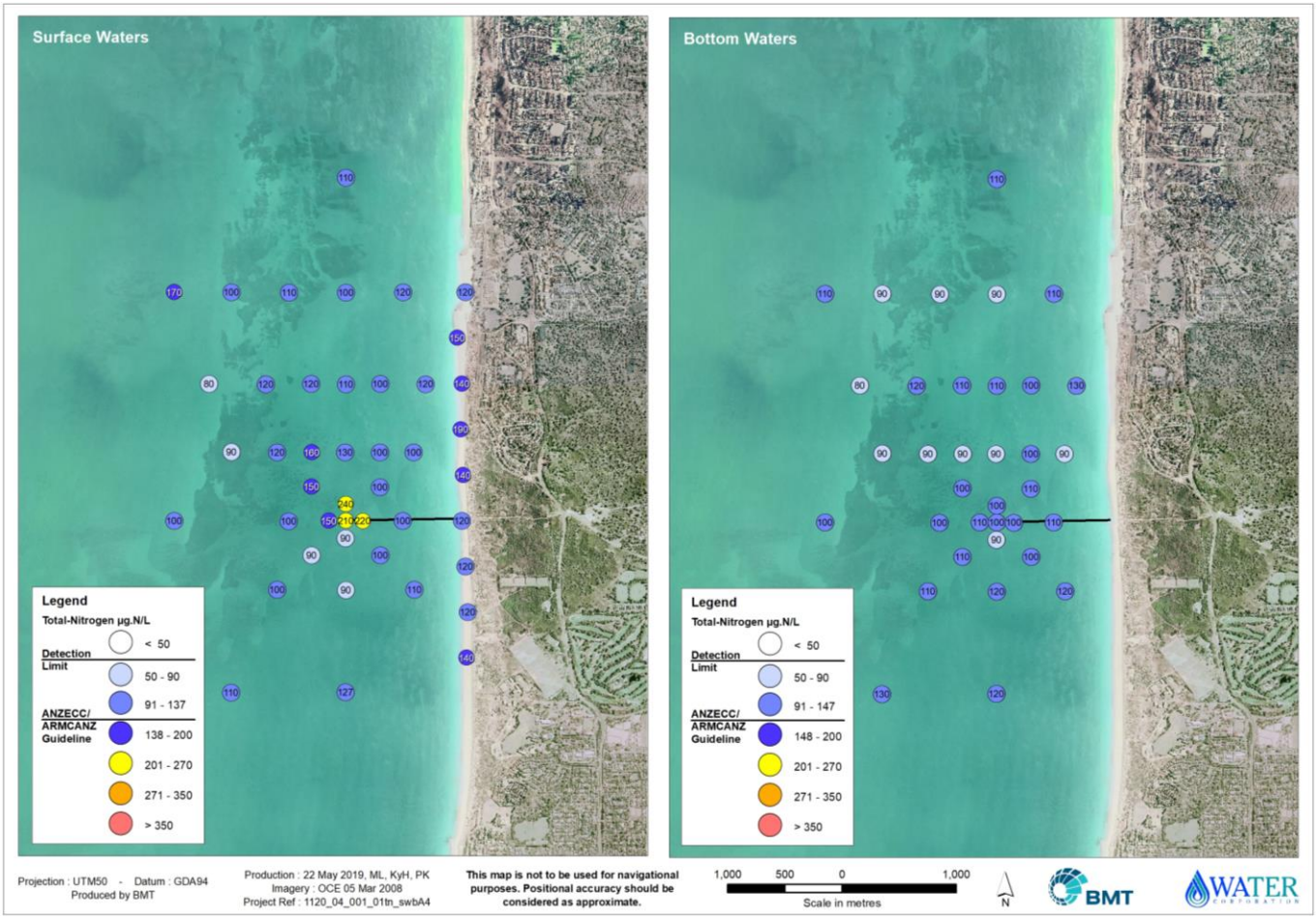
Figure 16 Total nitrogen at Ocean Reef

At Swanbourne, seven (20%) surface samples and no bottom samples exceeded the 80th percentile of the reference sites total nitrogen concentration (Figure 17; Table 5). The highest concentrations occurred within a short distance of the outlet and decreased with increasing distance from the outlet. Five (56%) of the shoreline sites exceeded the 80th percentile of the reference sites concentration (Figure 17; Table 5).



Notes:

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Figure 17 Total nitrogen at Swanbourne

Eighteen (53%) surface and one (3%) bottom sample exceeded the 80th percentile of the total nitrogen concentration at the reference sites (Figure 18; Table 5). Eight (88%) of the nine shoreline samples exceeded the 80th percentile of the total nitrogen concentration at the reference sites (Figure 18; Table 5). The elevated concentrations at the outlet extend in a northerly direction and do not extend to the shoreline suggesting elevated shoreline concentrations may be from terrestrial sources.

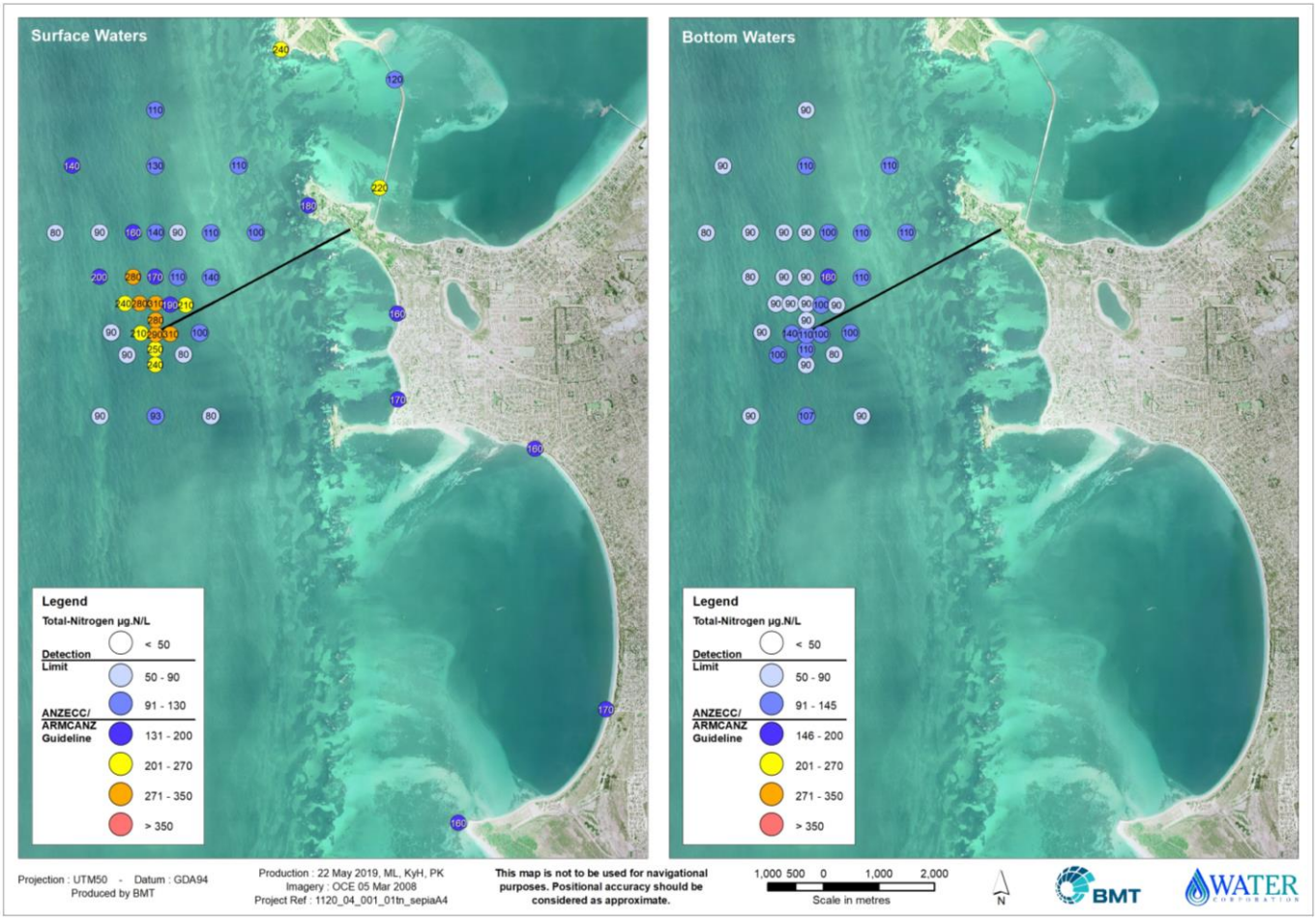

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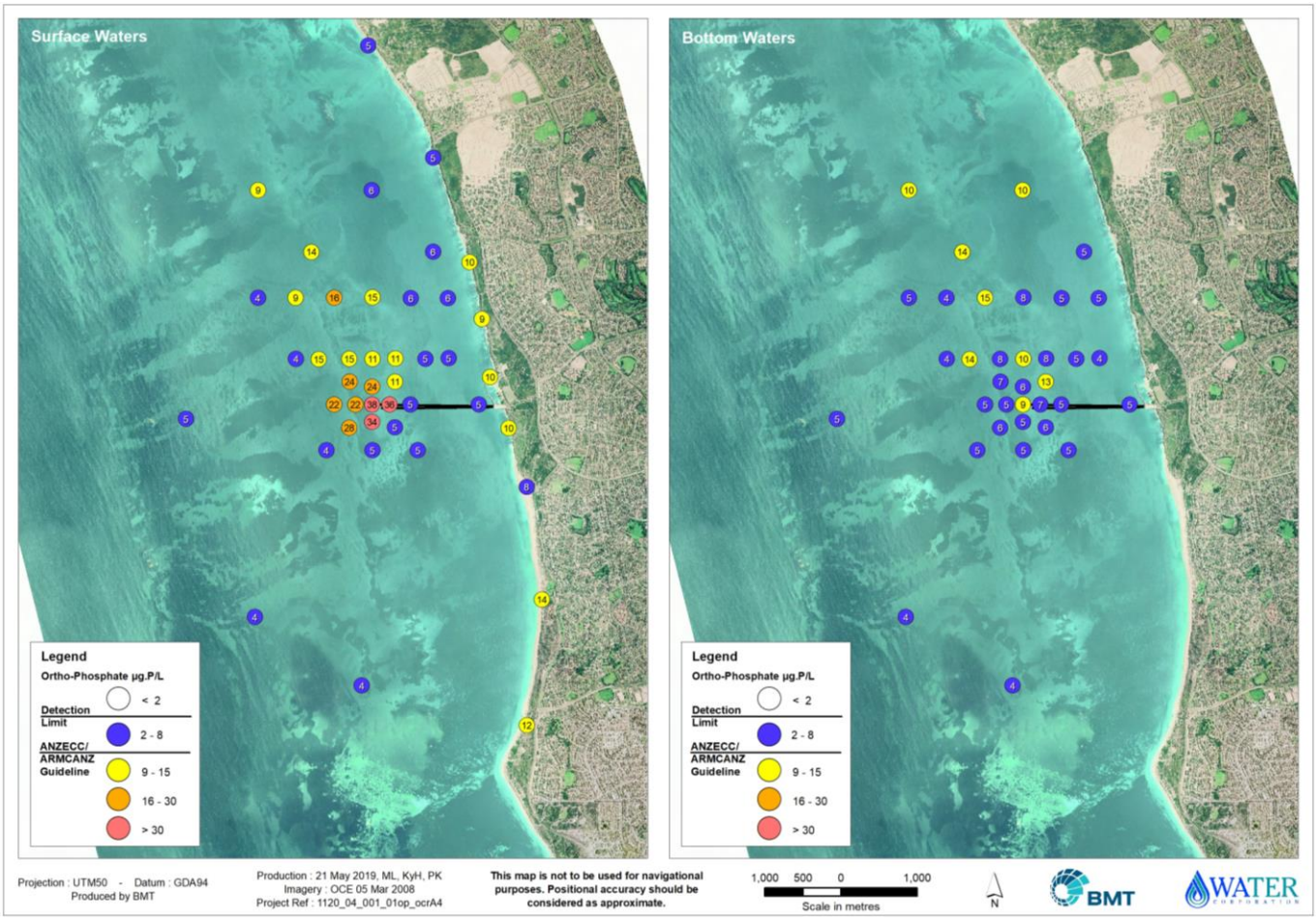
Figure 18 Total nitrogen at Sepia Depression

Orthophosphate

At Ocean Reef, 18 (51%) surface and eight (23%) bottom samples exceeded the 80th percentile of the orthophosphate concentration at the reference sites (Figure 19; Table 5). The highest concentrations were directly over the outlet. Elevated concentrations extended to the northwest of the outlet decreasing with distance away from the diffuser. Six of the nine (67%) shoreline samples exceeded the 80th percentile of the the reference sites orthophosphate concentration (Table 5) but these elevated concentrations were removed from those offshore and are indicative of an independent (terrestrial) source (Figure 19).

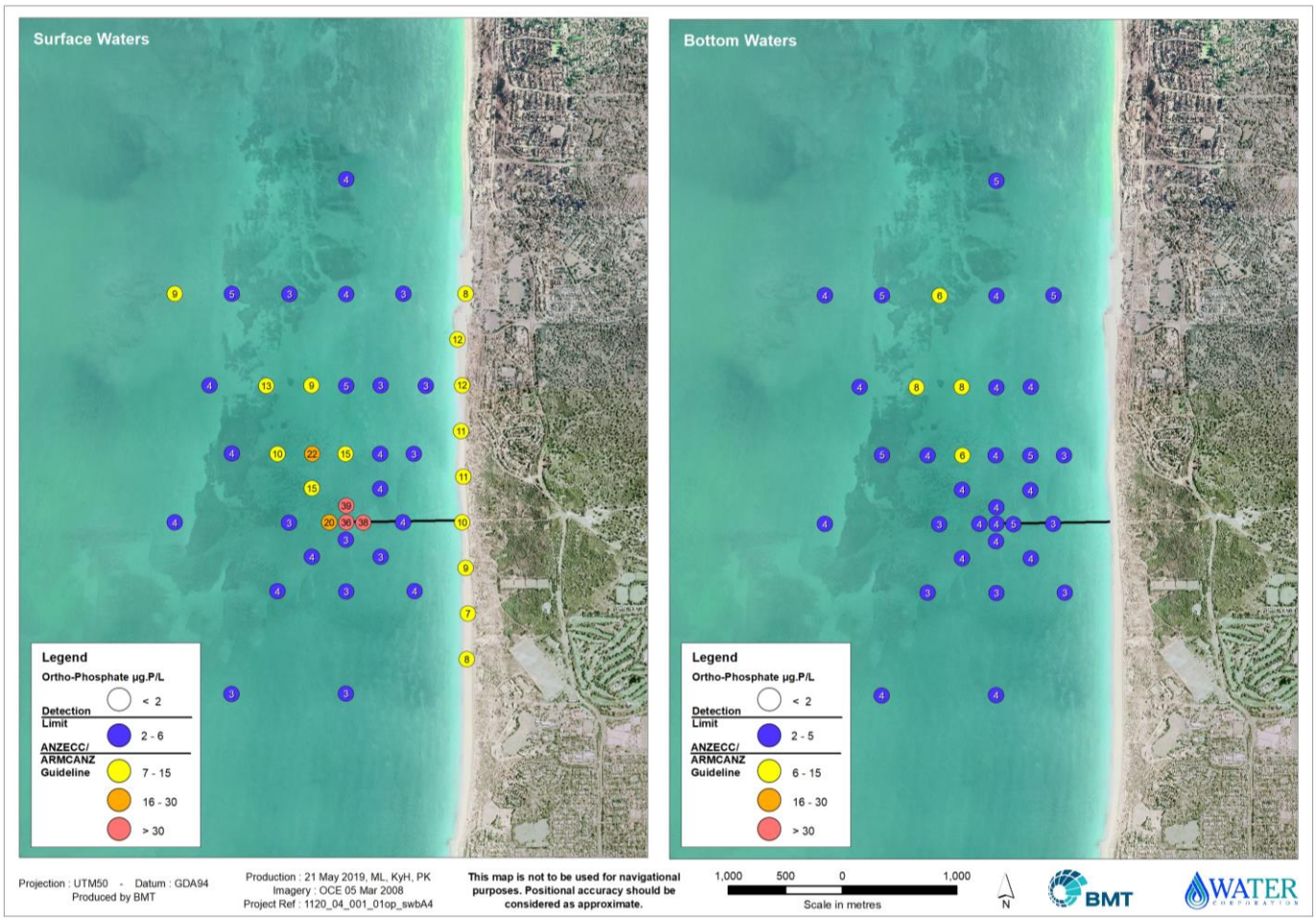


Notes:

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 19 Orthophosphate at Ocean Reef

At the Swanbourne outlet, the highest orthophosphate concentrations were directly over the outlet, extending to the northwest. Concentrations decreased with increasing distance away from the outlet. At Swanbourne, 11 (31%) surface and four (11%) bottom samples exceeded the 80th percentile of the reference sites orthophosphate concentration (Figure 20; Table 5). All nine (100%) shoreline samples exceeded the 80th percentile of the reference sites orthophosphate concentration at (Figure 20; Table 5). Elevated shoreline concentrations are isolated from those further offshore and may arise from a different and terrestrial source.

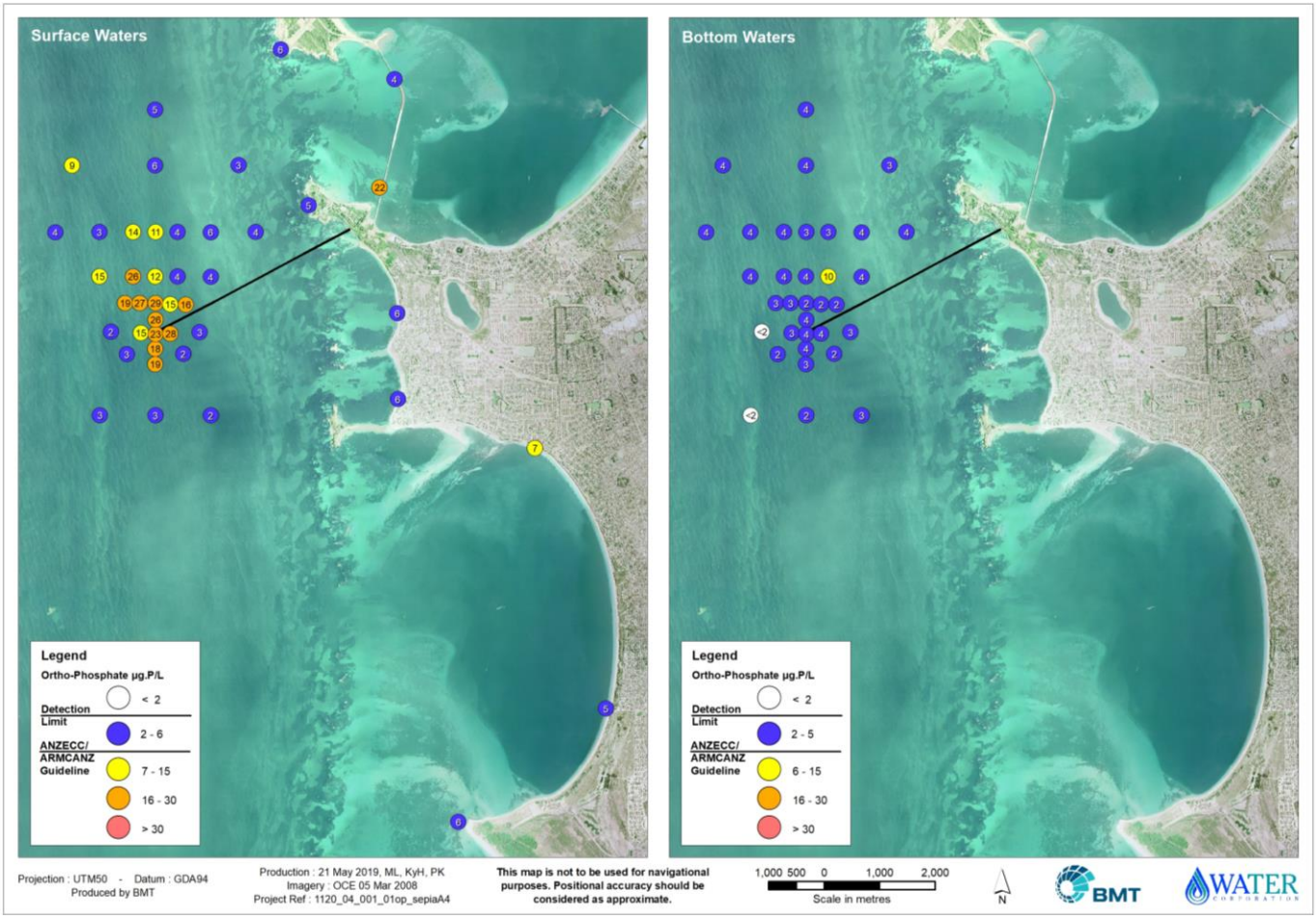


Notes:

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 20 Orthophosphate at Swanbourne

At Sepia Depression, 17 (50%) surface and one (3%) bottom sample exceeded the 80th percentile of the at reference sites orthophosphate concentration (Figure 21;Table 5). Two of the nine (22%) shoreline samples exceeded the guideline (Figure 21;Table 5). The elevated concentrations at the outlet extend in a northerly offshore direction. The discharge plume does not intersect with the shoreline suggesting that the localised exceedances at the shoreline may be from terrestrial sources.



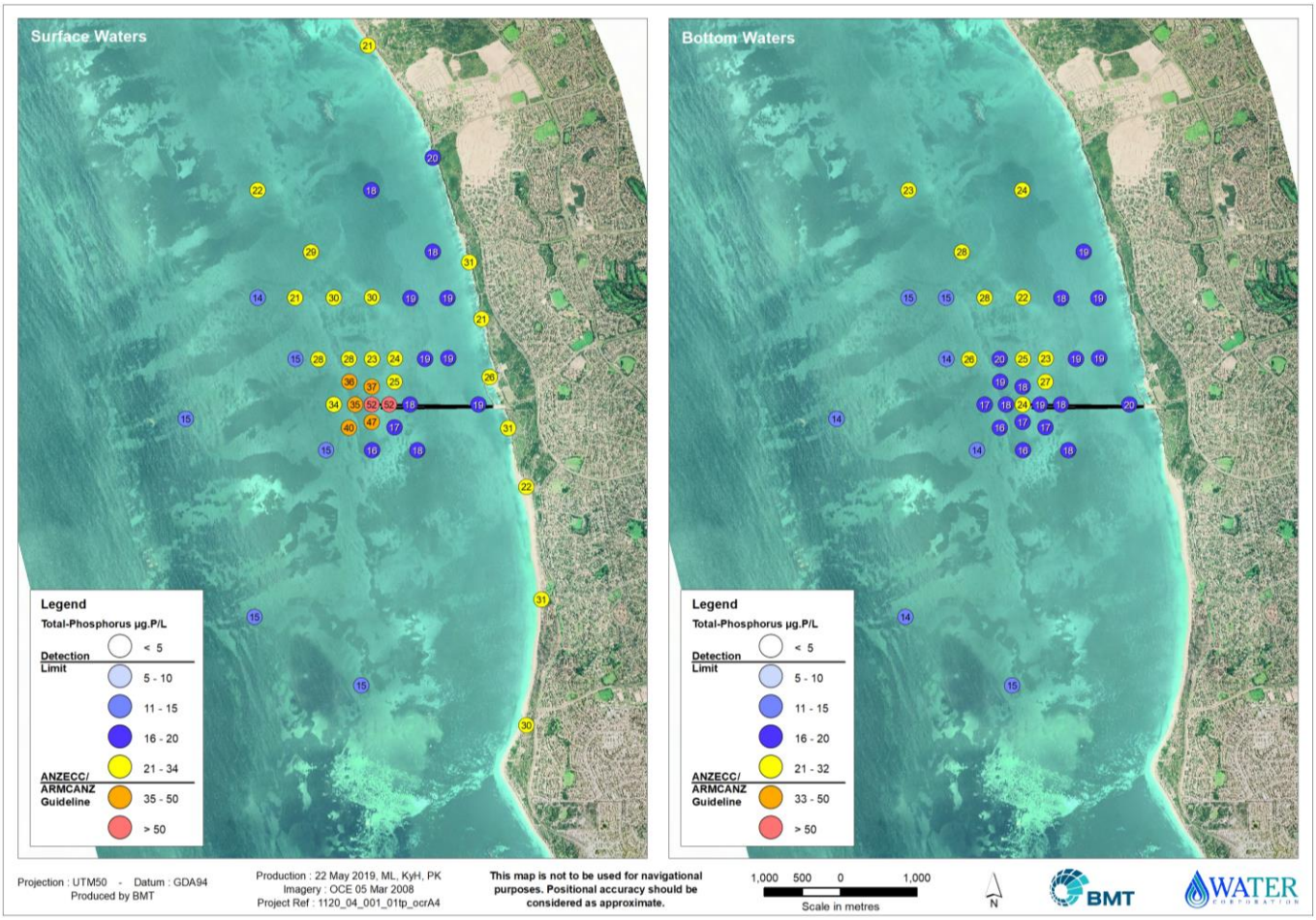
Notes:

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 21 Orthophosphate at Sepia Depression

Total phosphorus

At Ocean Reef eight (23%) surface and no bottom samples exceeded the 80th percentile of the total phosphorus concentration at reference sites (Figure 22; Table 5). The plume extended offshore in a north westerly direction and no shoreline samples exceeded the guideline (Figure 22; Table 5).

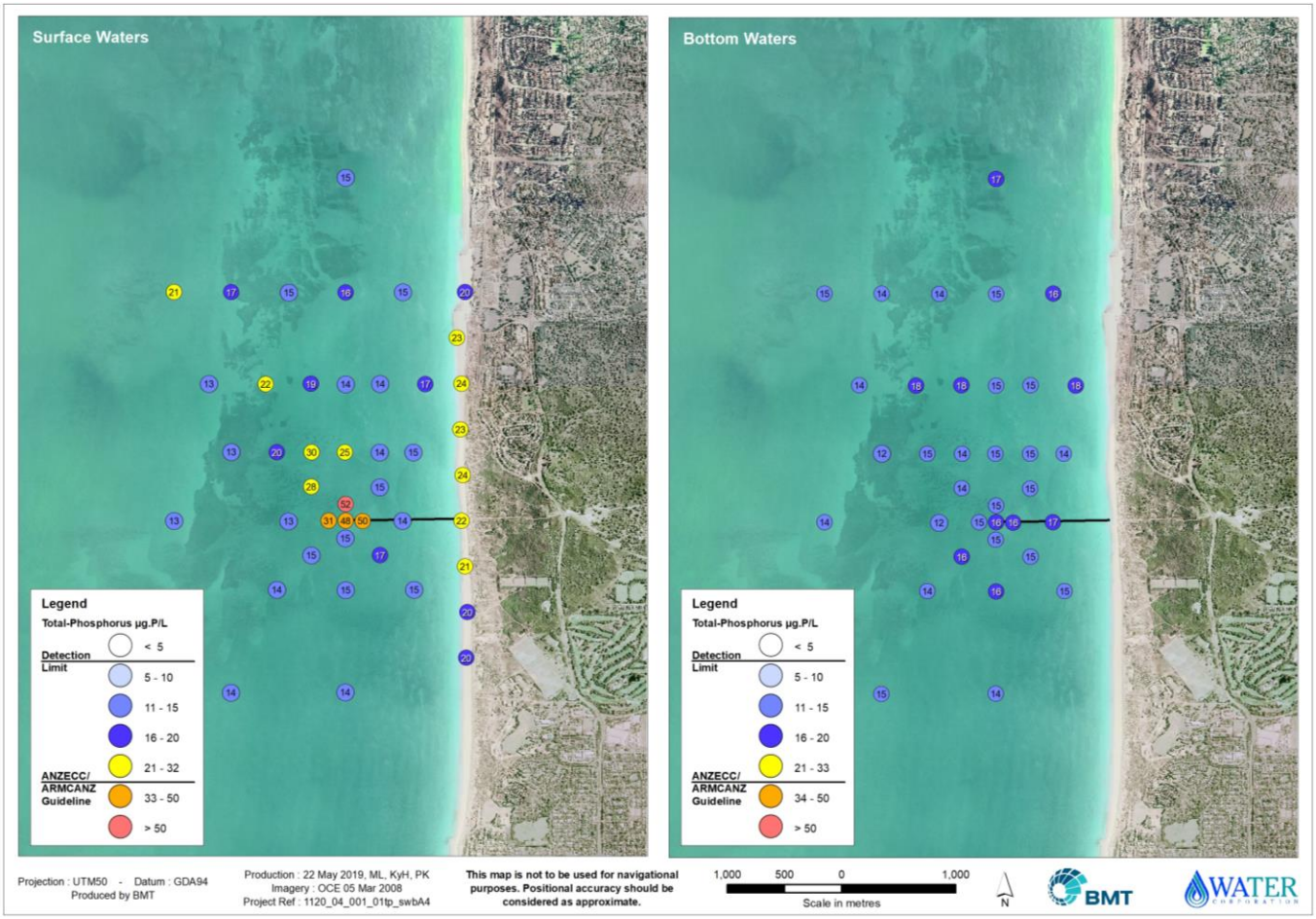


Notes:

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 22 Total phosphorus at Ocean Reef

At Swanbourne, only three (9%) surface samples exceeded the 80th percentile of the reference sites total phosphorus concentration (Figure 23; Table 5). The plume extended offshore in a north westerly direction No bottom or shoreline samples (0%) exceed the guideline (Figure 23; Table 5).

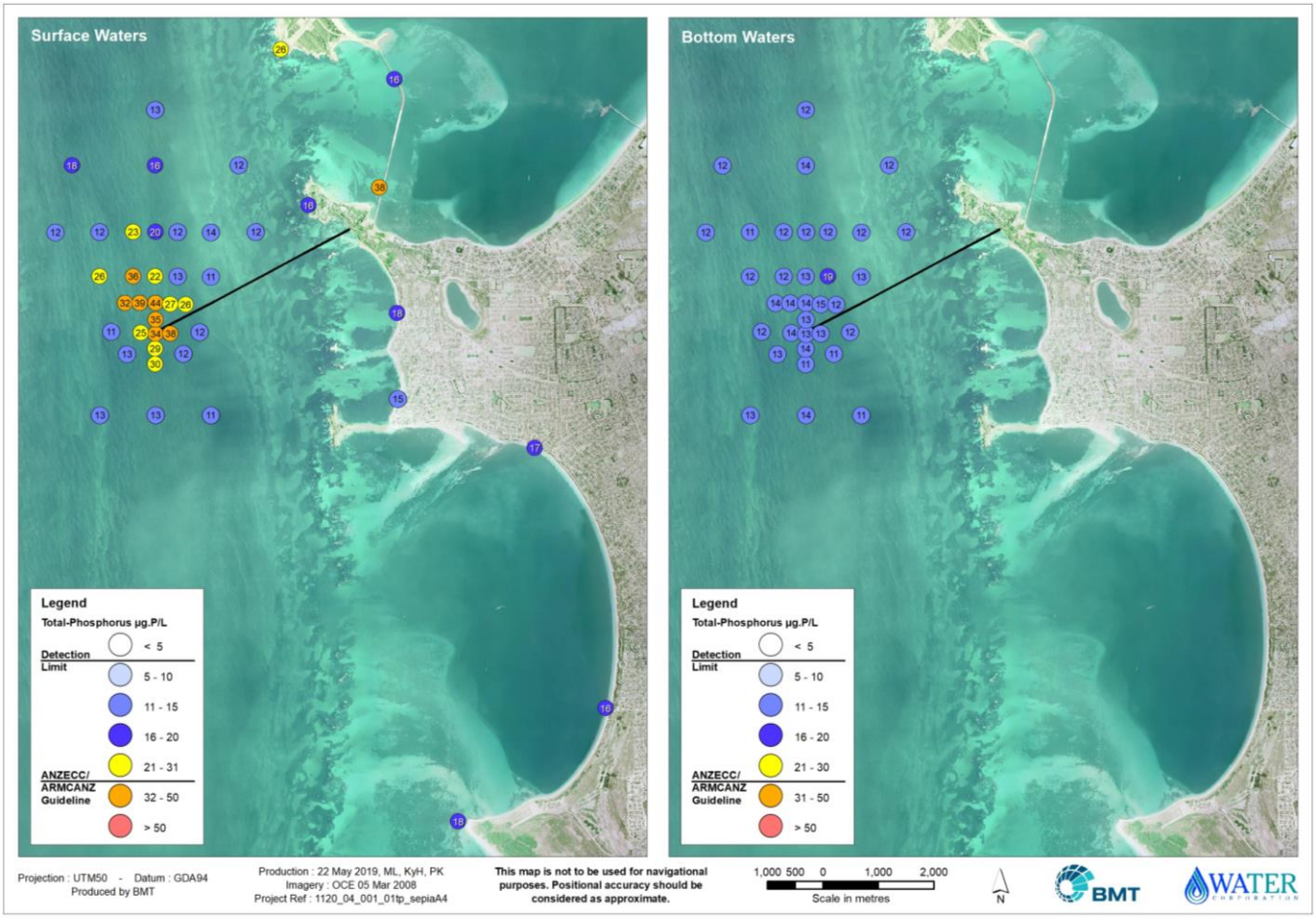


Notes:

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 23 Total phosphorus at Swanbourne

At Sepia Depression, seven (21%) surface samples exceeded the 80th percentile of the reference sites total phosphorus concentration (Figure 24; Table 5). No bottom samples (0%) exceeded the 80th percentile of the reference sites total phosphorus concentration (Figure 24; Table 5). Only one (11%) shoreline sample exceeded the guideline (Figure 24). That site was outside the influence of the plume which was transported offshore in a north westerly direction away from the coastline.



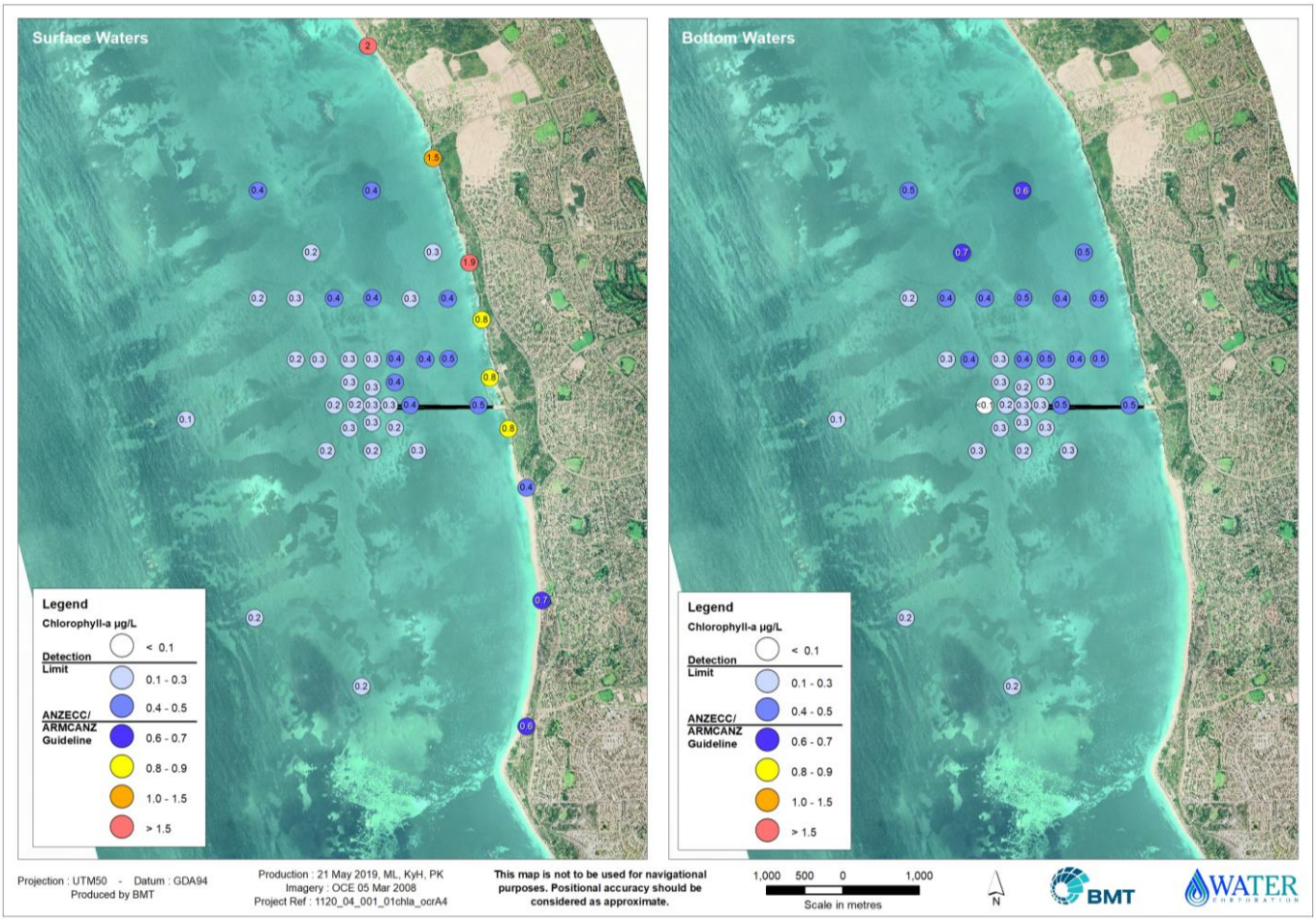
Notes:

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 24 Total phosphorus at Sepia Depression

Chlorophyll a

There were no exceedances of the 80th percentile of the reference sites chlorophyll a concentration at the surface, but five (14%) of the bottom samples exceeded at Ocean Reef (Figure 25; Table 5). Chlorophyll a concentration was higher at the shoreline and eight of nine (89%) shoreline samples exceed the guideline (Figure 25; Table 5). Elevated shoreline concentrations are completely uncorrelated with nearby offshore samples in the immediate vicinity of the outlet suggesting a different origin.

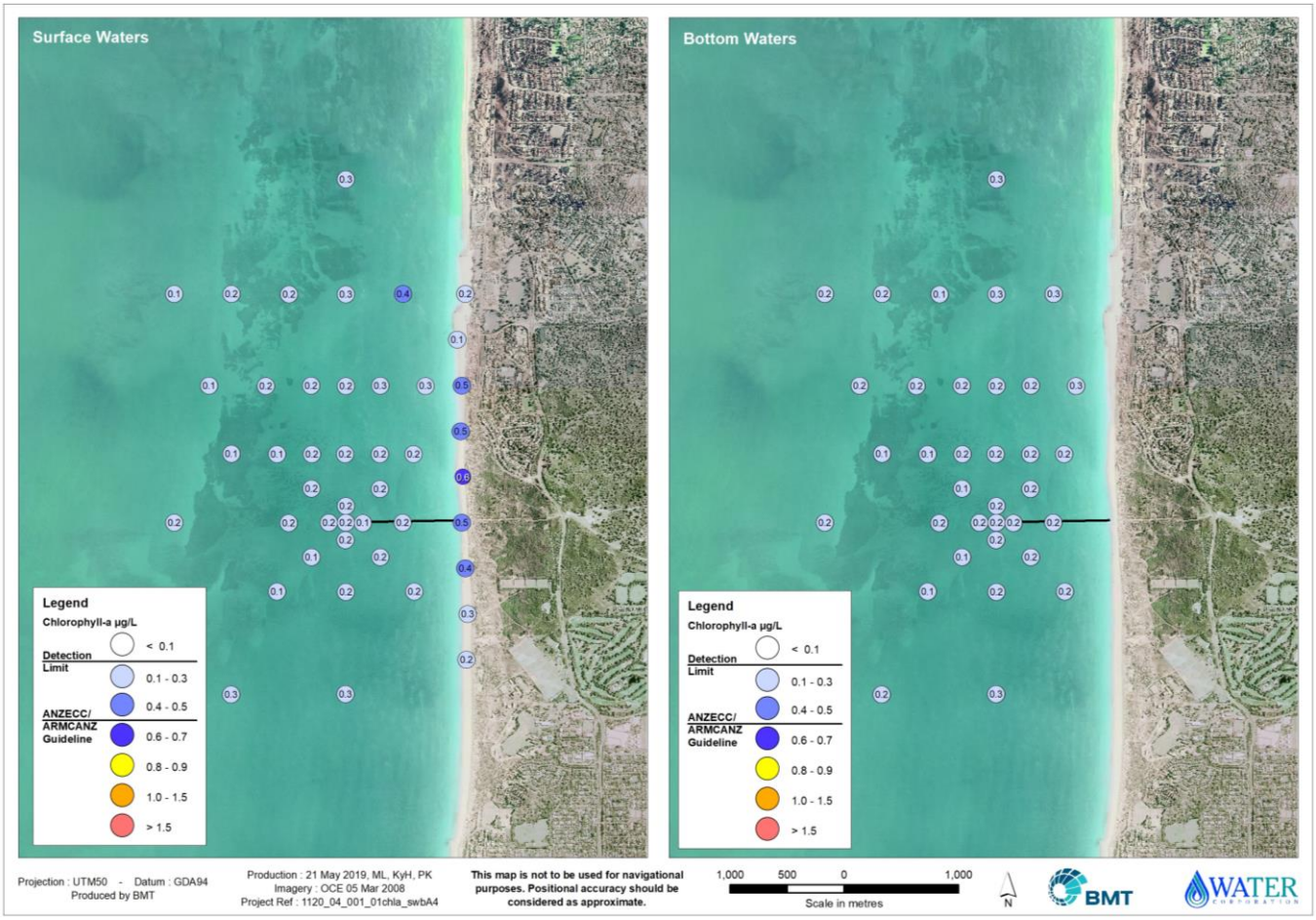


Notes:

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 25 Chlorophyll-a at Ocean Reef

Chlorophyll a concentrations at Swanbourne were low and there was little variation among offshore samples. No surface or bottom samples exceeded the 80th percentile of reference sites chlorophyll a concentration (Figure 26; Table 5). One shoreline sample (11%) exceeded the 80th percentile of the reference sites concentration.

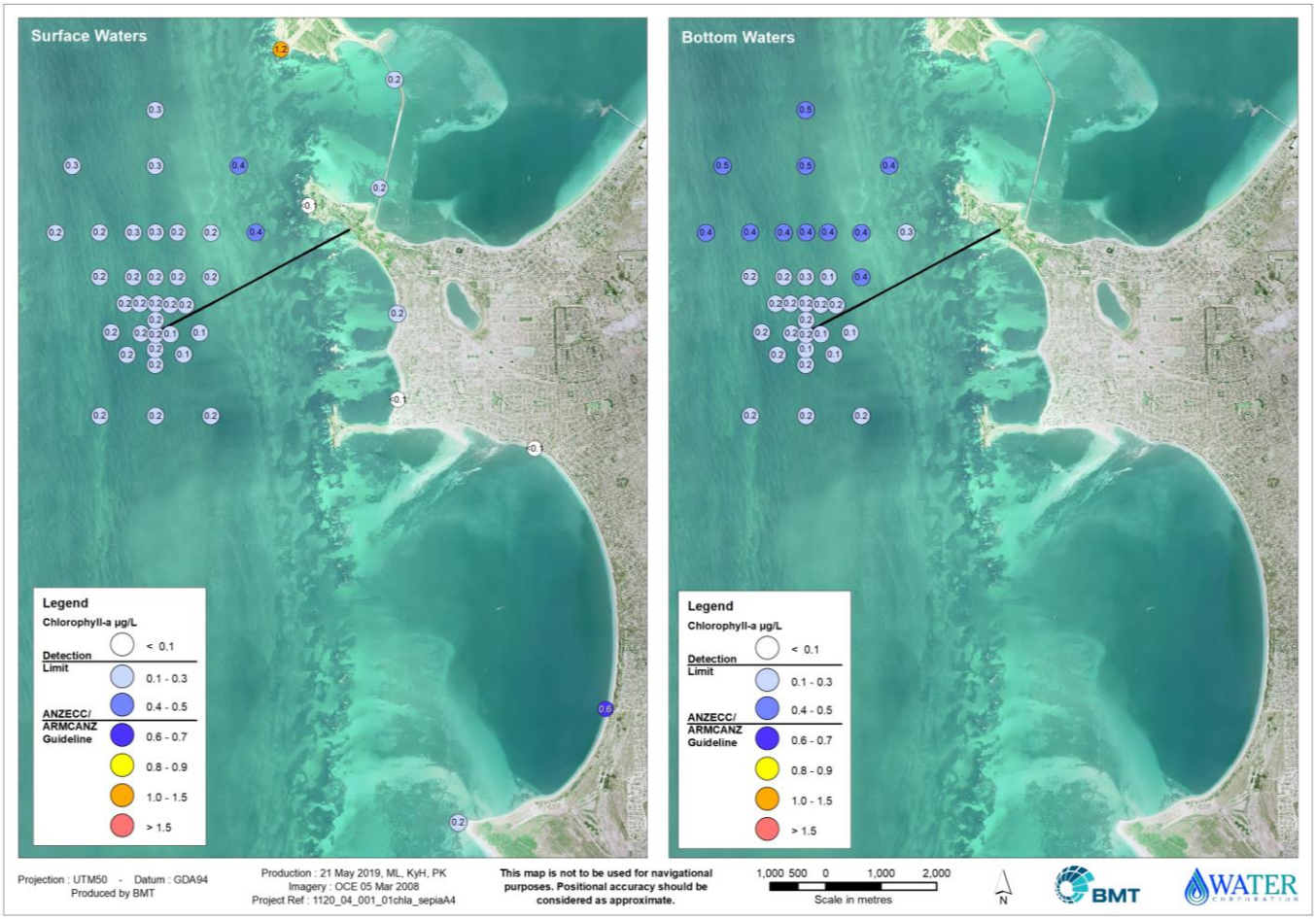


Notes:

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 26 Chlorophyll a at Swanbourne

Offshore chlorophyll a concentrations at Sepia Depression were low and there was little variation among samples. None of the surface or bottom samples exceeded the 80th percentile of the reference sites chlorophyll a concentration (Figure 27; Table 5). Two of nine (22%) shoreline samples exceeded the 80th percentile of the reference sites chlorophyll a concentration, one in the north of the domain and one in the south (Figure 27; Table 5). These isolated pockets of chlorophyll a are outside the influence of the TWW plume.



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 27 Chlorophyll a at Sepia Depression

Recreational contact

The guidelines for primary and secondary contact recreation in marine waters are exceeded if the median of the impact monitoring sites exceeds the guideline (Table 6). 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 area referred to as the post-upgrade boundary.

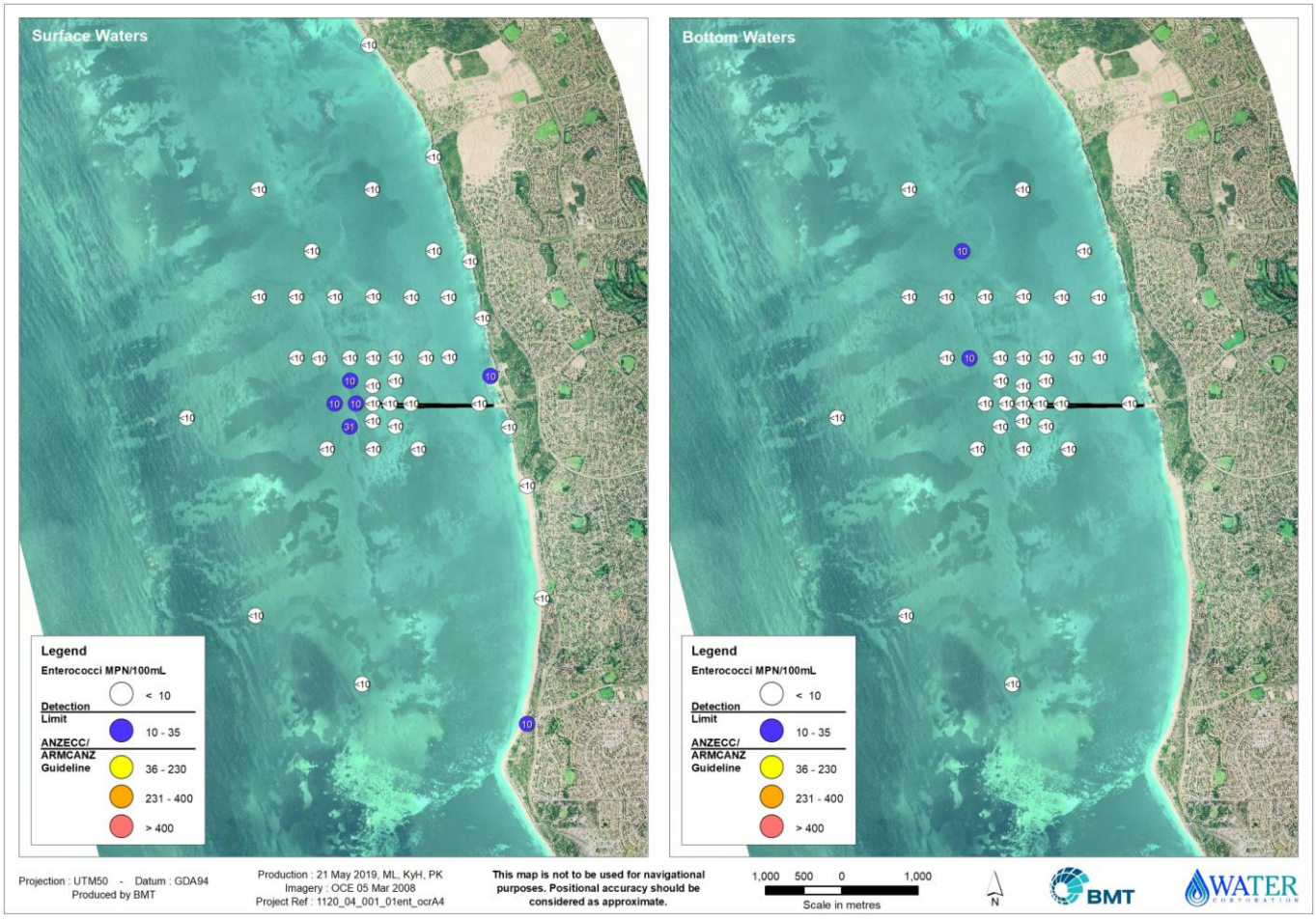
Table 6 Guidelines for primary and secondary contact recreation in marine waters

Type of recreation contact	*Enterococci* spp. guidelines
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

At Ocean Reef, the highest *Enterococci* spp. concentration was 10 MPN/100 mL (Figure 28). None of the surface, bottom or shoreline samples exceeded the primary contact recreation guideline (Figure 28).

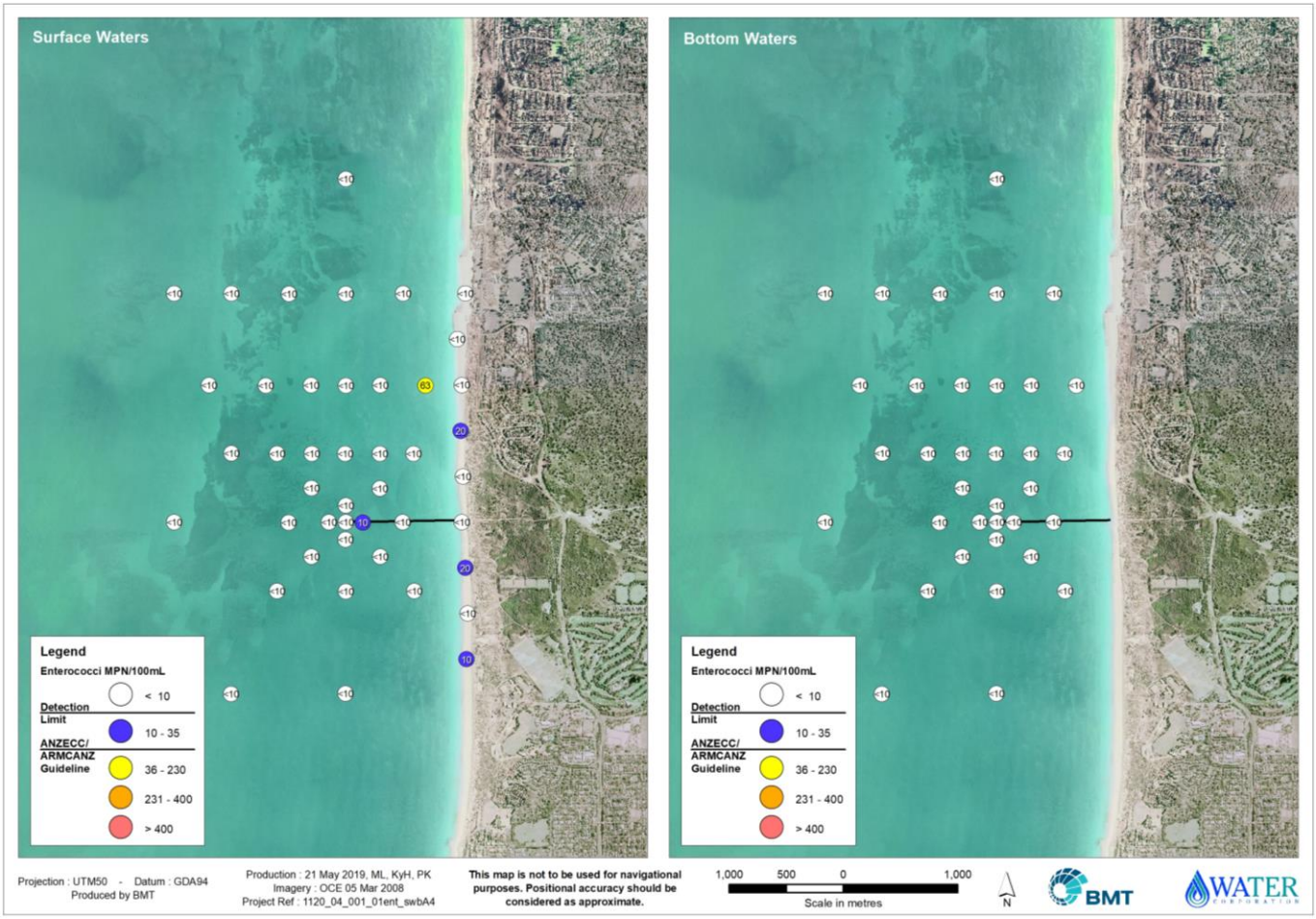


Notes:

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 28 *Enterococci* spp. at Ocean Reef

At Swanbourne, a single anomalous sample (63 MPN/100 mL) exceeded the primary recreation contact guideline (Figure 29). This elevated surface sample was the only sample (3%) that exceeded the primary recreation contact guideline and beyond the influence of the TWW plume (Figure 29). None of the bottom or shoreline samples exceeded the relevant guideline (Figure 29).

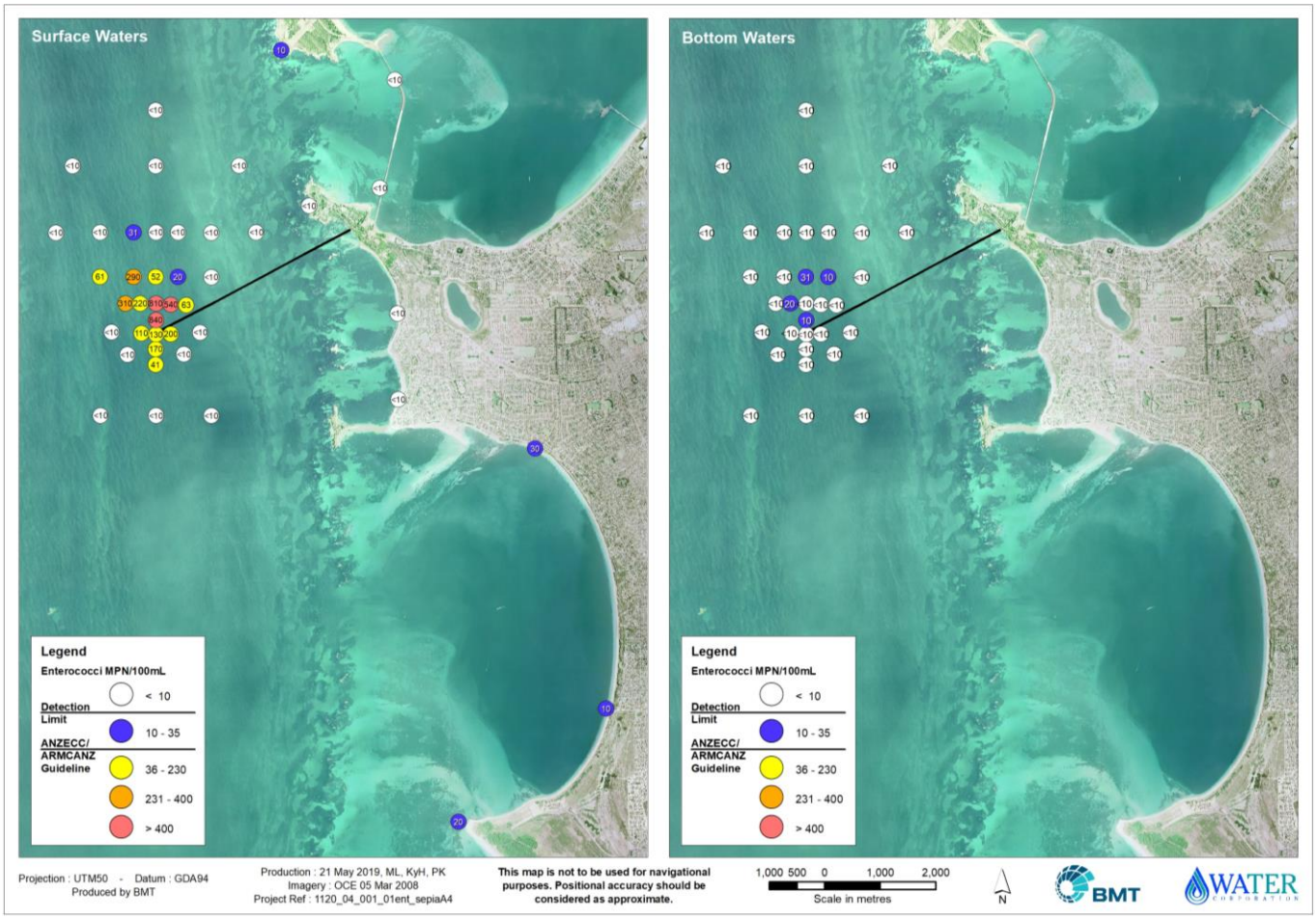


Notes:

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 29 *Enterococci* spp. at Swanbourne

Enterococci spp. concentrations at Sepia Depression were elevated in the immediate vicinity of the outlet. The highest concentration (840 MPN/100 mL) was in surface waters at the site immediately north of the outlet (Figure 30). Fourteen (42%) of the surface samples (0 bottom samples) exceeded the primary recreation contact guideline (Figure 30). The elevated *Enterococci* spp. concentrations extend away from the outlet in a north westerly direction and no shoreline samples exceeded the primary recreation contact guideline (Figure 30).



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 30 *Enterococci* spp. at Sepia Depression

Seafood for human consumption

The Department of Health (DoH) discourages the public from taking wild shellfish, recommending only shellfish harvested commercially under strict monitoring programs are consumed. Regardless, the EPA (2017) has published Environmental Quality Criteria (Table 7) that serve as a measure of the potential risk to human health for consumption of 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).

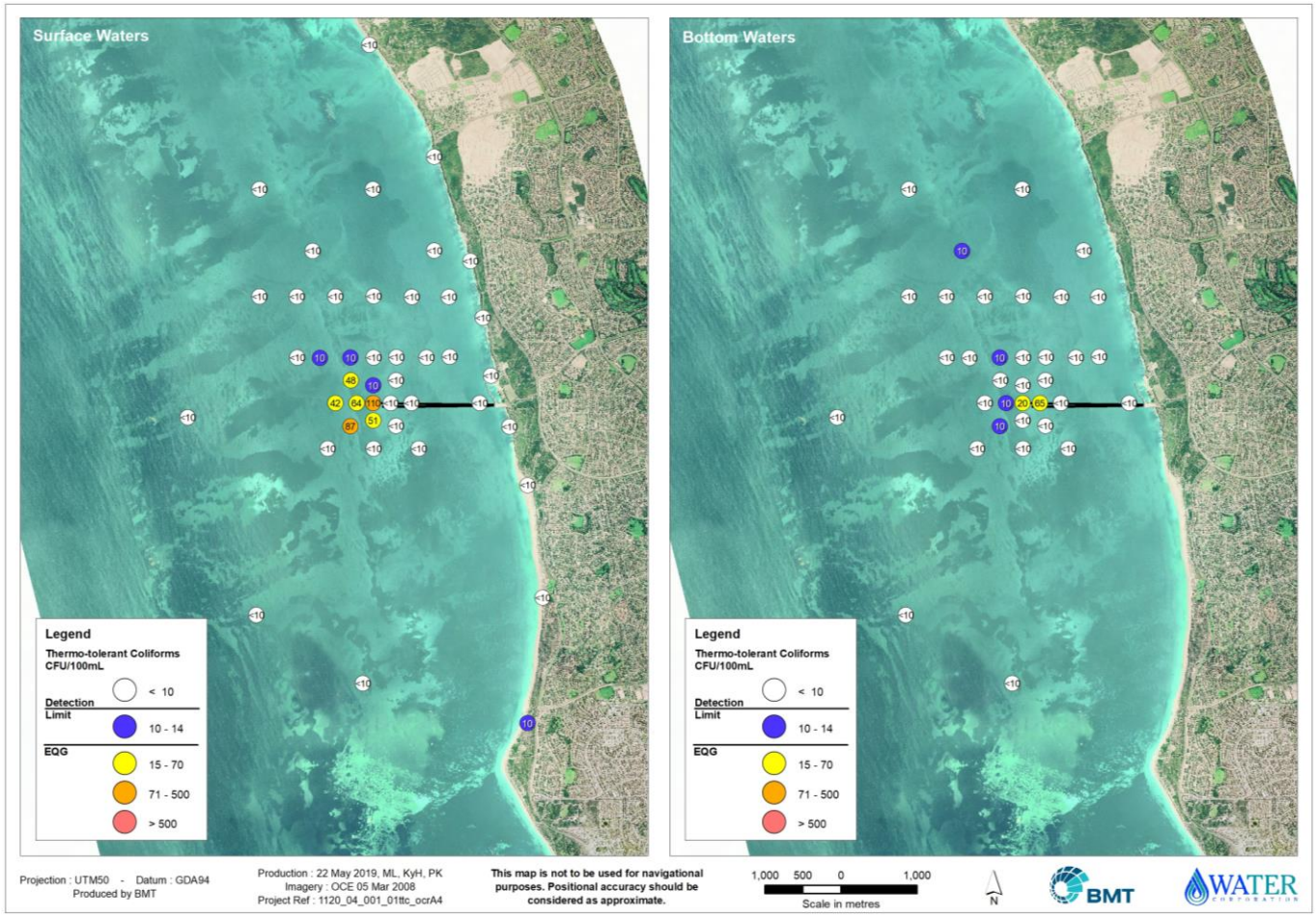
Table 7 Environmental Quality Criteria for the maintenance of seafood safe for human consumption

Thermotolerant coliforms	Environmental Quality Criteria
Environmental Quality Guideline (EQG)	14 CFU/100 mL
Environmental Quality Guideline (EQS)	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

Ocean Reef thermotolerant coliform concentrations exceeded the seafood consumption Environmental Quality Guideline (EQG) in six (17%) surface and two (6%) bottom samples (Figure 31). The highest concentration (110 CFU/100 mL) was at the surface immediately over the outlet (Figure 31). The elevated concentrations extend away from the outlet in a north westerly direction. The discharge does not impact on the shoreline and none of the shoreline samples exceeded the seafood consumption EQG (Figure 31).

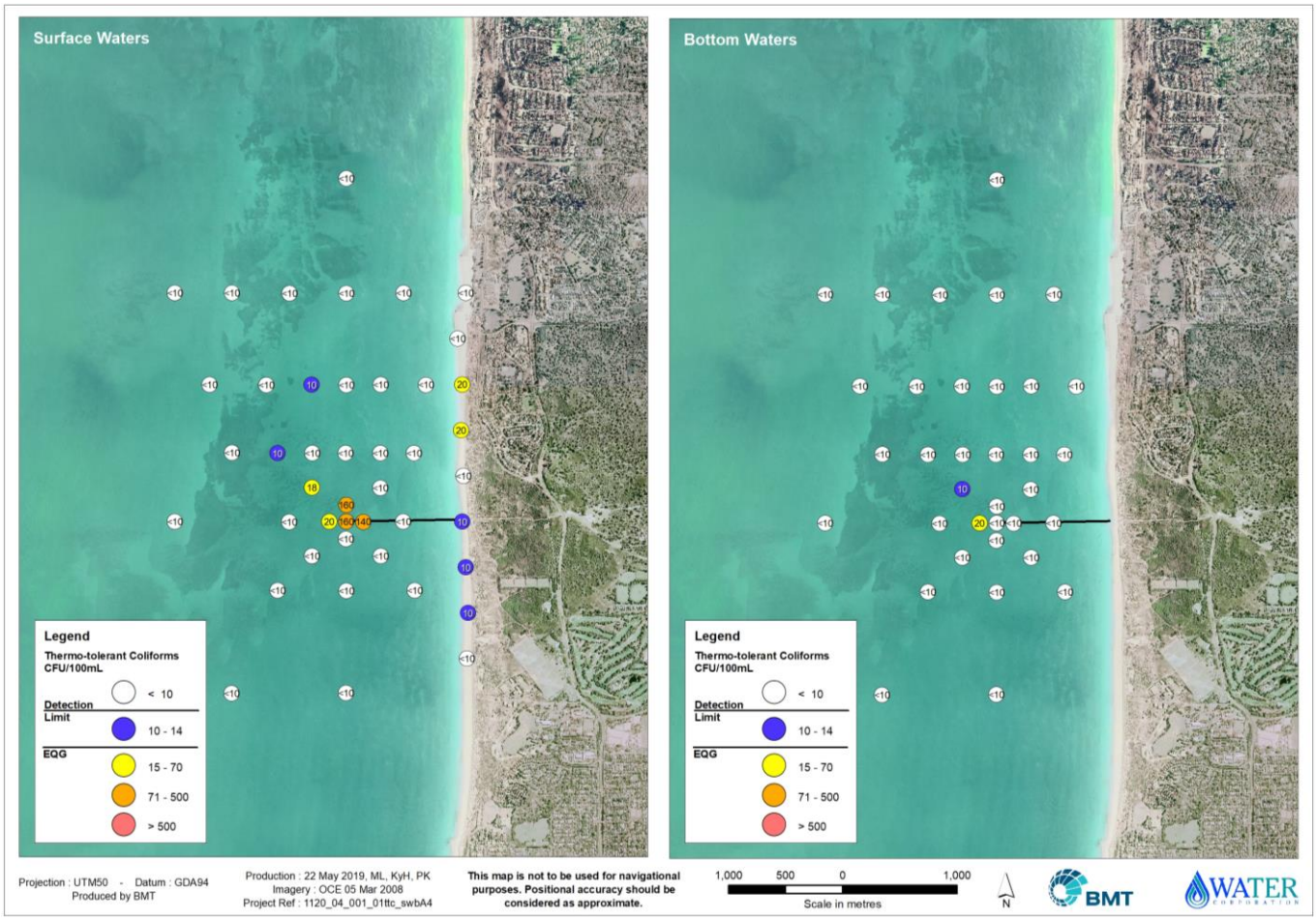


Notes:

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 EPA (2017) guideline.

Figure 31 Thermotolerant coliforms at Ocean Reef

At Swanbourne, five (14) surface and one (3%) bottom sample exceeded the seafood consumption EQG (Figure 32). The highest concentrations were near the outlet, and concentrations decreased with increasing distance from the outlet in a north westerly direction (Figure 32). Two surface samples (22%) at the shoreline exceeded the seafood consumption EQG (Figure 32).

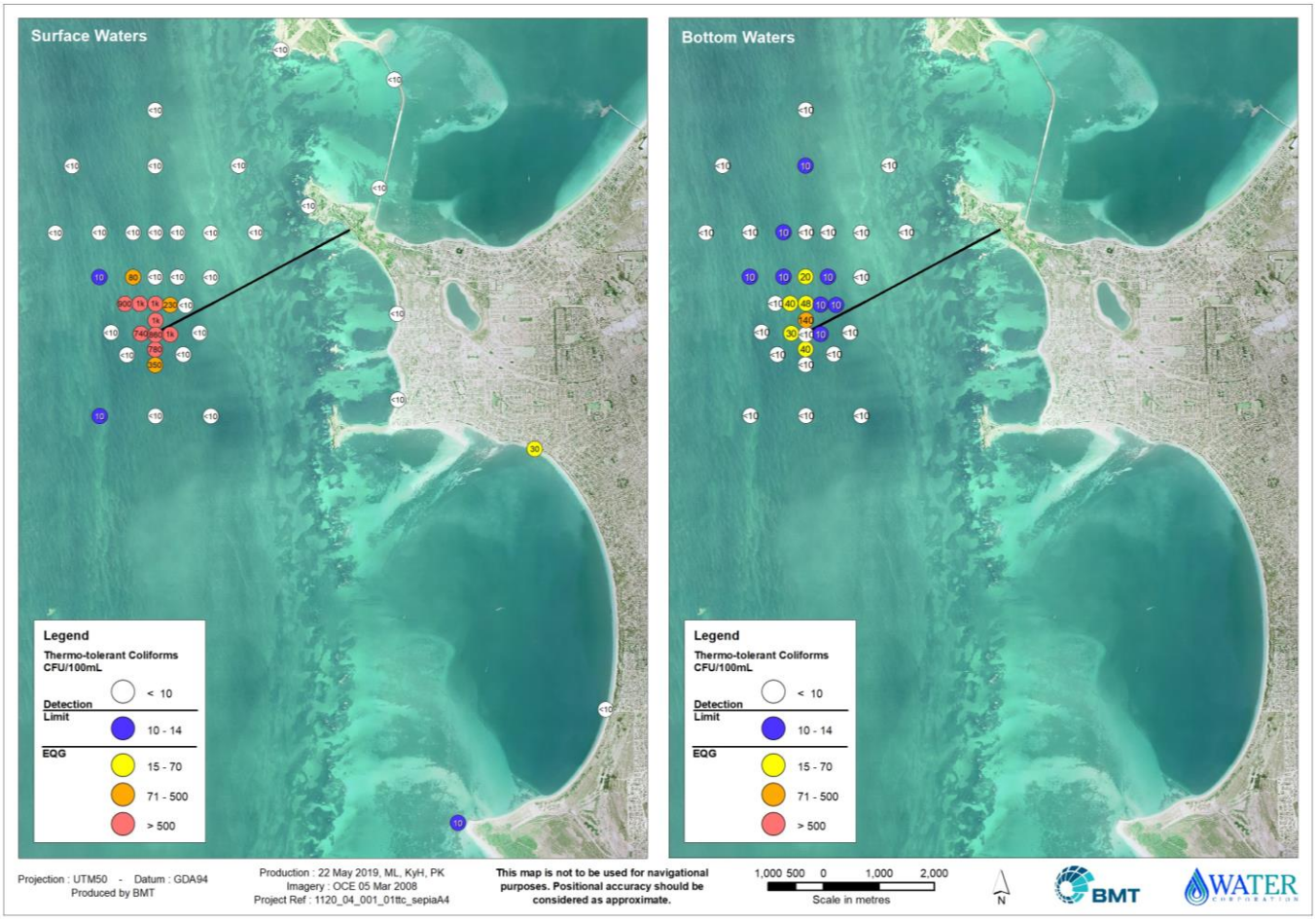


Notes:

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 32 Thermotolerant coliforms at Swanbourne

Thermotolerant coliform concentrations at Sepia Depression exceeded the seafood consumption EQG in 11 (32%) surface and six (18%) bottom samples (Figure 33). One shoreline sample (11%) exceeded the seafood consumption EQG (Figure 33). The elevated shoreline concentrations occurred in the opposite direction to the prevailing current and does not arise from the TWW discharge.



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 33 Thermotolerant coliforms at Sepia Depression

Summary

The summer water quality surveys were not specifically designed for comparison to the 80th percentile of the reference sites concentration but comparisons were made for sites located outside the 250 m mixing zone as an indicator rather than a means of assessing 'compliance'. Despite elevated concentrations at some individual sites nearest to the outlets, the guidelines for demonstrating ecosystem protection and public health criteria outside the mixing zone were met (Table 8). There was no indication that the TWW nutrients were stimulating detectable increases in phytoplankton (chlorophyll a) within or outside the 250 m area around the diffuser (Table 8).

During the surveys, the TWW 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). At each outlet, the plume dispersed in a north westerly direction away from the shoreline. In general, shoreline monitoring found elevated nutrient concentrations at some sites may be arising from terrestrial sources unrelated to the outlet (Table 8).

Median concentrations of microbial indicators (*Enterococci* spp. and thermotolerant coliforms) outside the 250 m mixing zone were below the limit of reporting and the respective guidelines for recreation contact and seafood quality (Table 8). Median concentrations at the shoreline were at or below the limit of reporting and also below the respective guidelines for recreation contact and seafood quality (Table 8).

These surveys demonstrate that ecosystem integrity, primary and secondary recreation contact and seafood quality are maintained outside the 250 m mixing zone around the outlets. On the day of each survey, the discharge plume dispersed offshore and did not interact with the shoreline or beach users.

Table 8 Assessment of potential contaminants against the relevant criteria

Potential contaminants	Median concentration outside the mixing zone (sites >250 m from outlets)	
	Surface	Bottom
Ocean Reef		
Total ammoniacal nitrogen	<3	<3
Ortho-phosphate	6	5
Nitrate+nitrite	7	5.5
Total phosphorus	6	5
Total nitrogen	120	120
Chlorophyll-a	0.3	0.4
Thermotolerant coliforms	<10	<10
Enterococci spp.	<10	<10
Swanbourne		
Total ammoniacal nitrogen	<3	<3
Ortho-phosphate	4	4
Nitrate+nitrite	<2	<2
Total phosphorus	15	15
Total nitrogen	105	105
Chlorophyll-a	0.2	0.2
Thermotolerant coliforms	<10	<10
Enterococci spp.	<10	<10
Sepia Depression		
Total ammoniacal nitrogen	12	<3
Ortho-phosphate	5	3
Nitrate+nitrite	2	<1
Total phosphorus	13	12
Total nitrogen	110	90
Chlorophyll-a	0.2	0.2
Thermotolerant coliforms	<10	<10
Enterococci spp.	<10	<10

Notes:
1. Numbers are medians
2. Green numbers = median < criteria, red numbers = median > criteria
3. Total ammoniacal nitrogen, ortho-phosphate, nitrate+nitrite, total phosphorus, total nitrogen and chlorophyll-a criteria is the 80th percentile of the reference sites concentration (Table 5)
4. Thermotolerant coliforms criteria 14 CFU/100mL (Table 7)
5. Enterococci spp. criteria = 35 MPN/100 mL (Table 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

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EPA (2017) Environmental Quality Criteria Reference Document for Cockburn Sound – A Supporting Document to the State Environmental (Cockburn Sound) Policy 2015. Environmental Protection Authority, Perth, Western Australia, April 2017

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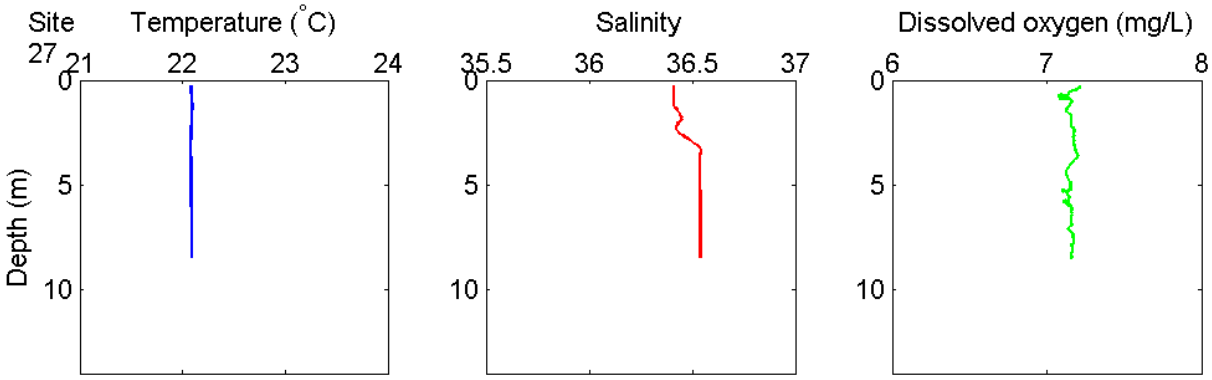
Pattiaratchi C, Imberger J, Zaker N, Svenson T (1995) Perth Coastal Waters Study – Physical Measurements. Prepared for Water Authority of Western Australia, Perth, Western Australia, January 1995

Appendix A Physical Profiles

Ocean Reef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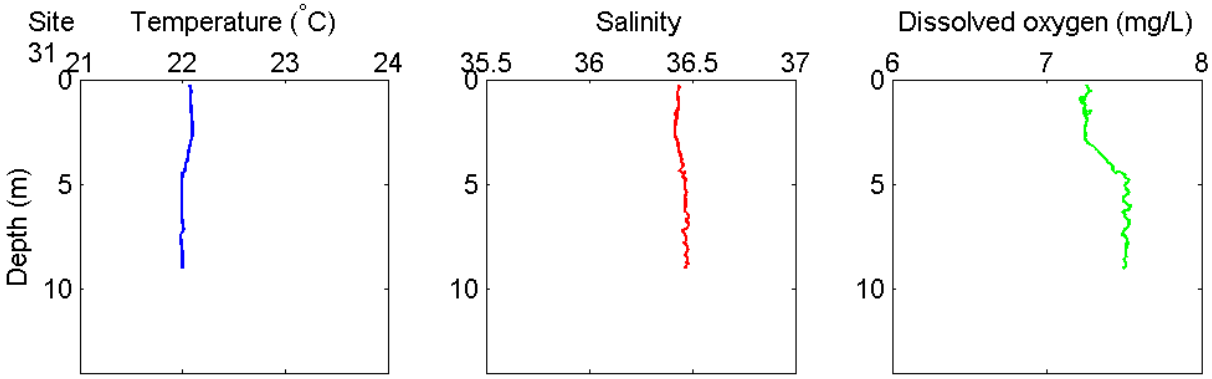
21
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10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Temperature (°C)
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22
23
24
Salinity
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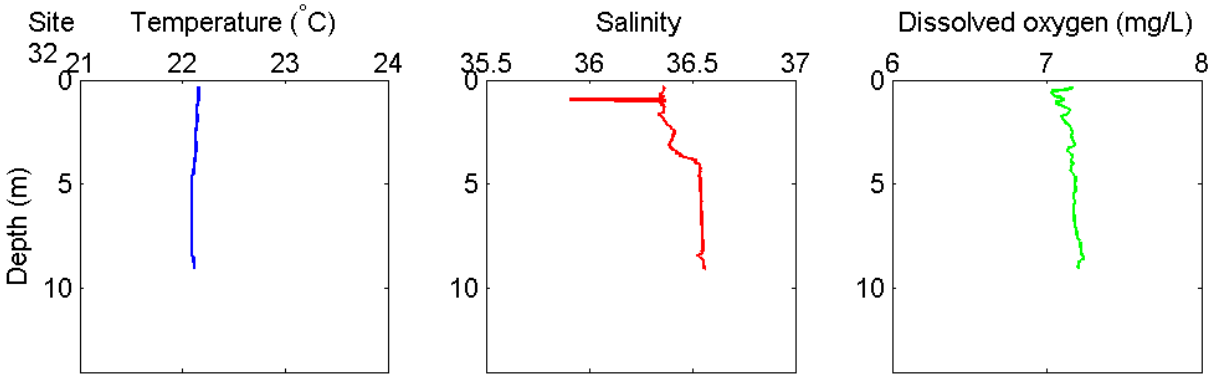
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10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Temperature (°C)
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22
23
24
Salinity
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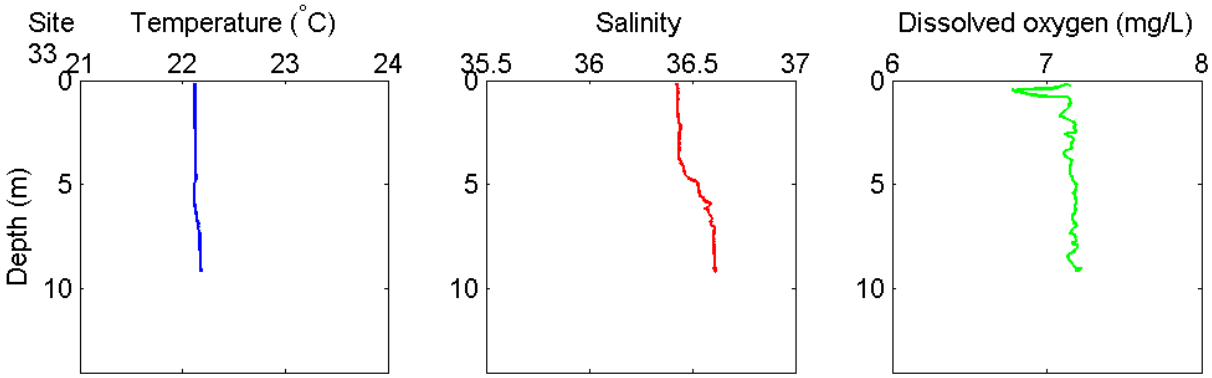
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10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Temperature (°C)
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24
Salinity
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36
36.5
37
Dissolved oxygen (mg/L)
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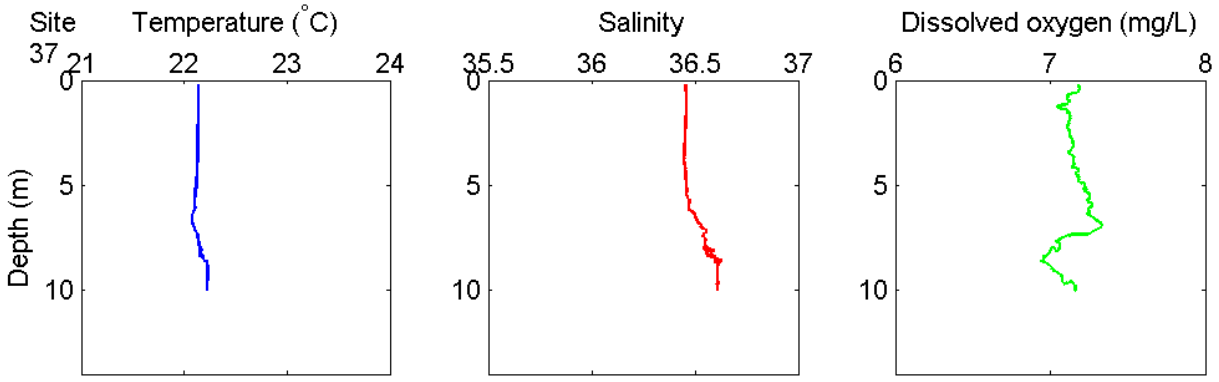
7
8
Depth (m)
0
5
10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22
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Salinity
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36.5
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Dissolved oxygen (mg/L)
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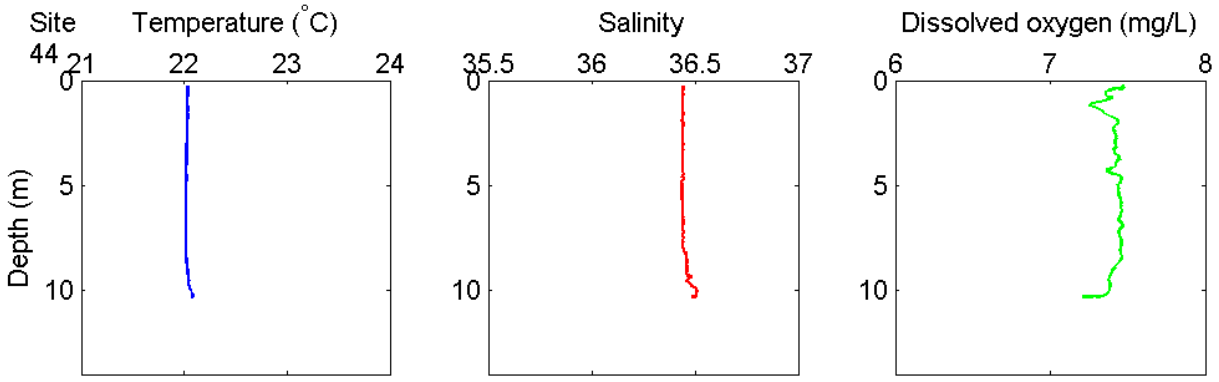
7
8
Depth (m)
0
5
10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22
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Salinity
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37
Dissolved oxygen (mg/L)
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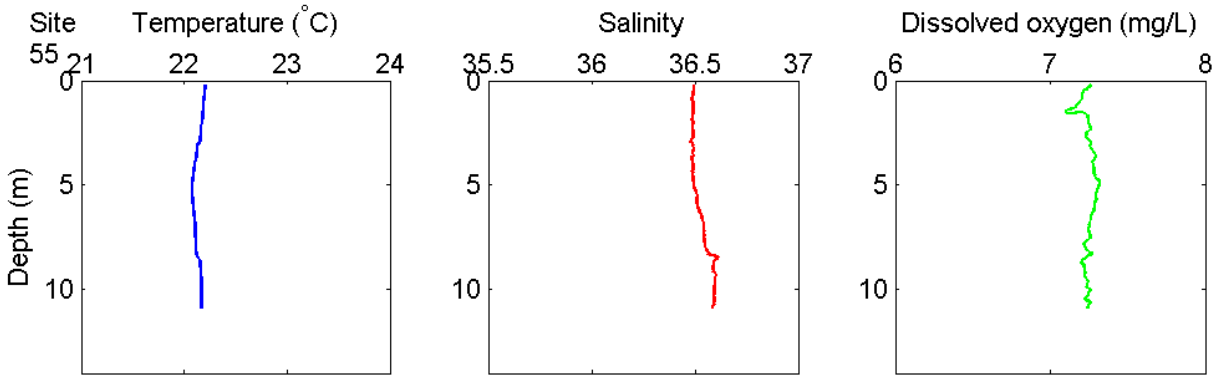
7
8
Depth (m)
0
5
10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37
Dissolved oxygen (mg/L)
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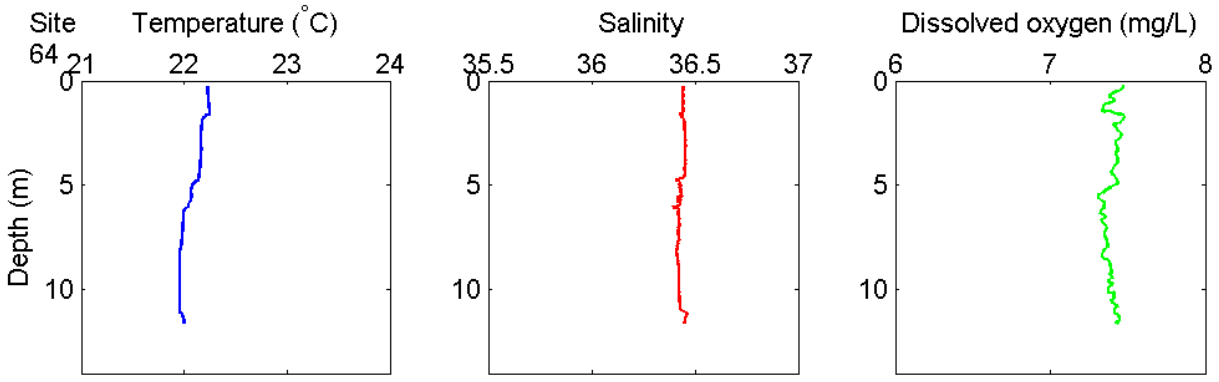
7
8
Depth (m)
0
5
10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21
22
23
24
Salinity
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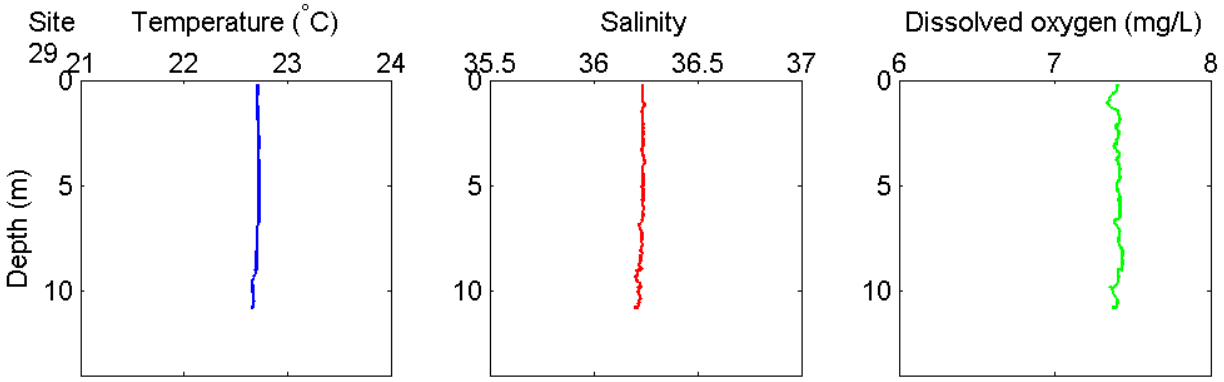
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10

Swanbourne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Temperature (°C)
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22
23
24
Salinity
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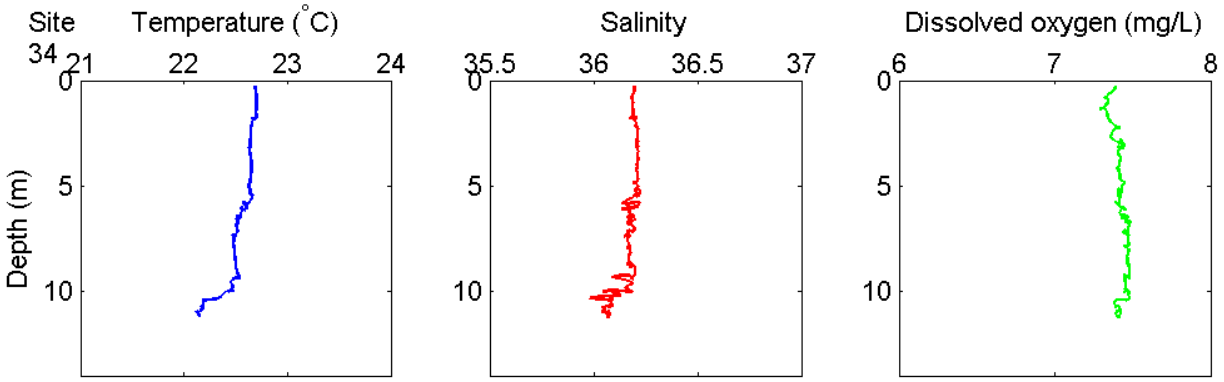
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10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Temperature (°C)
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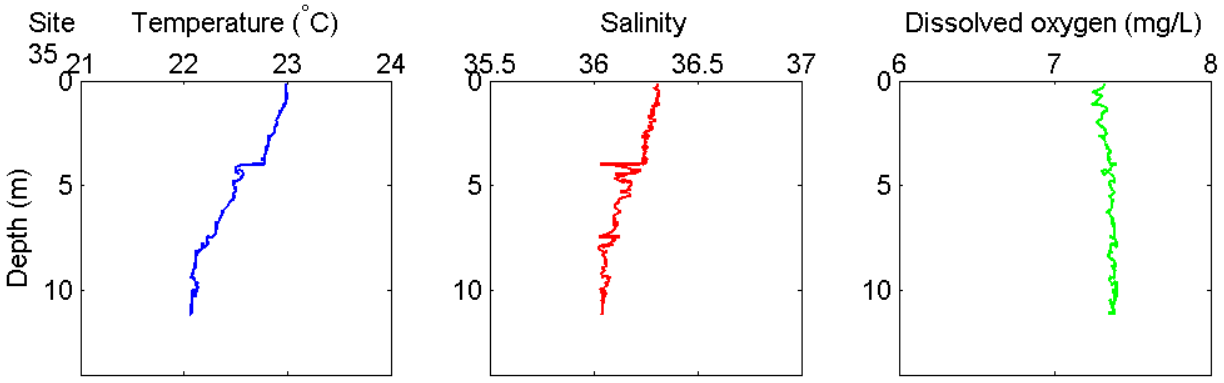
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10


Site 35
Temperature (°C)
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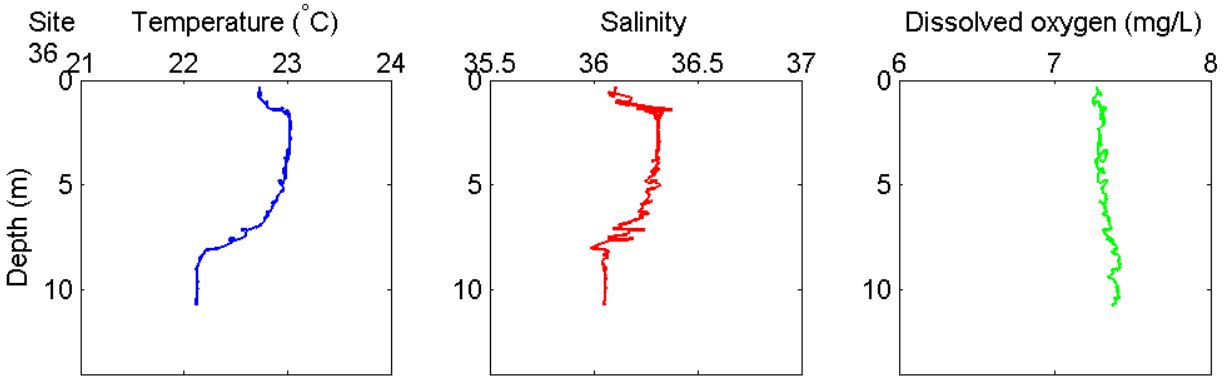
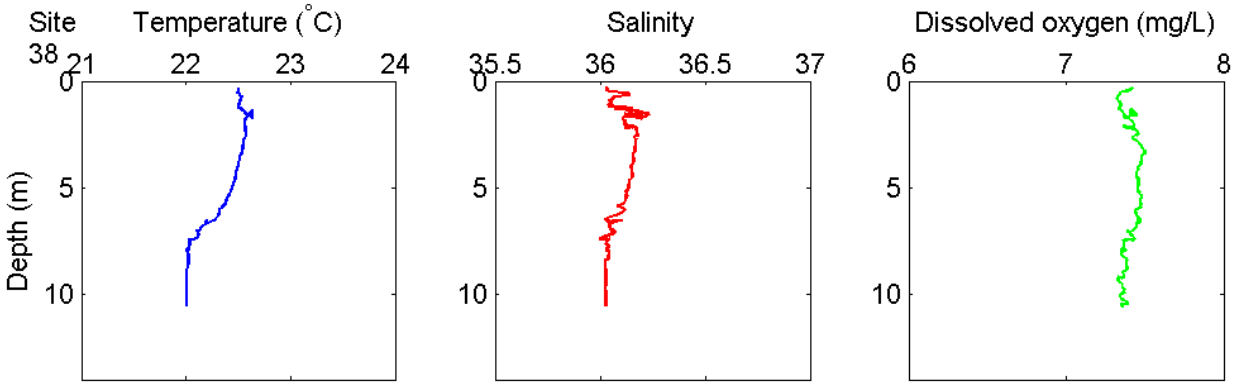
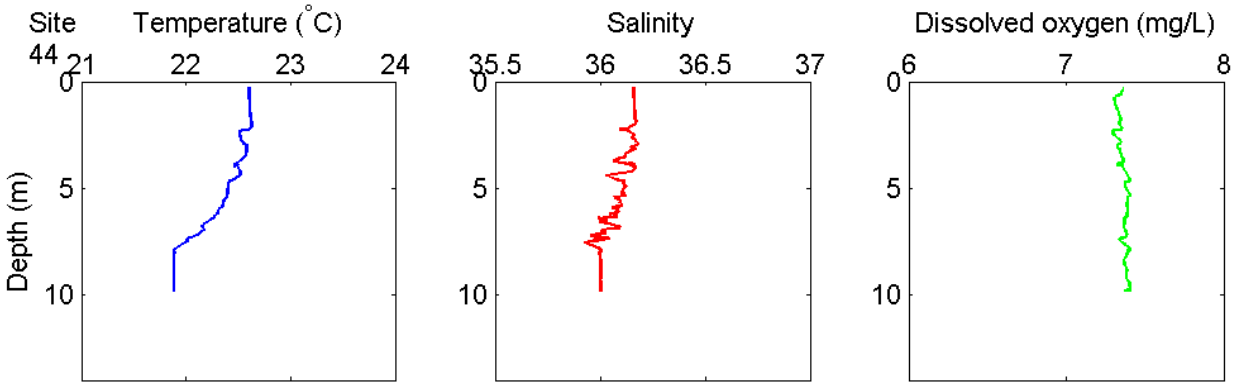
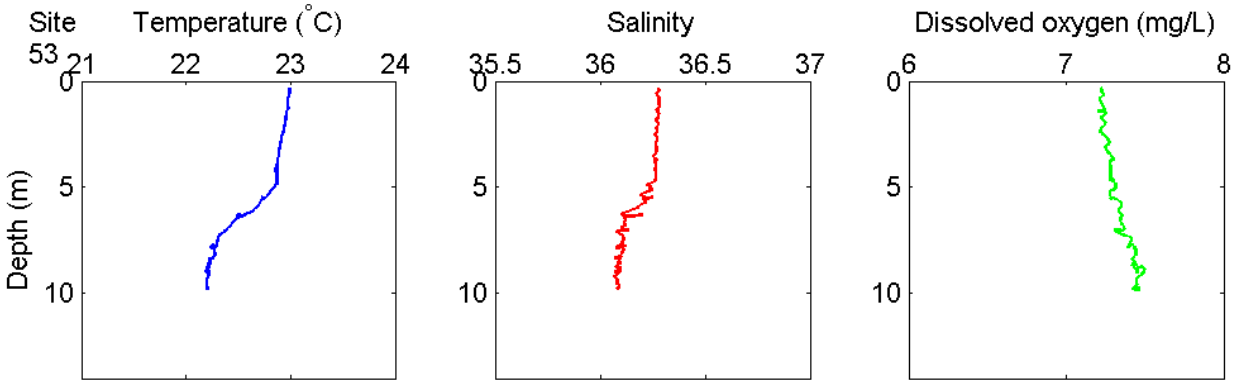
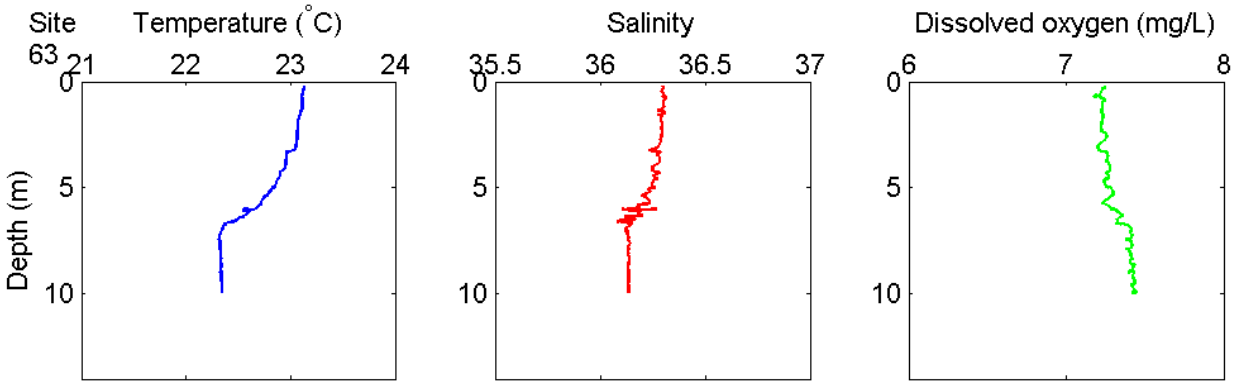
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10


Site 36
Temperature (°C)
21
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10

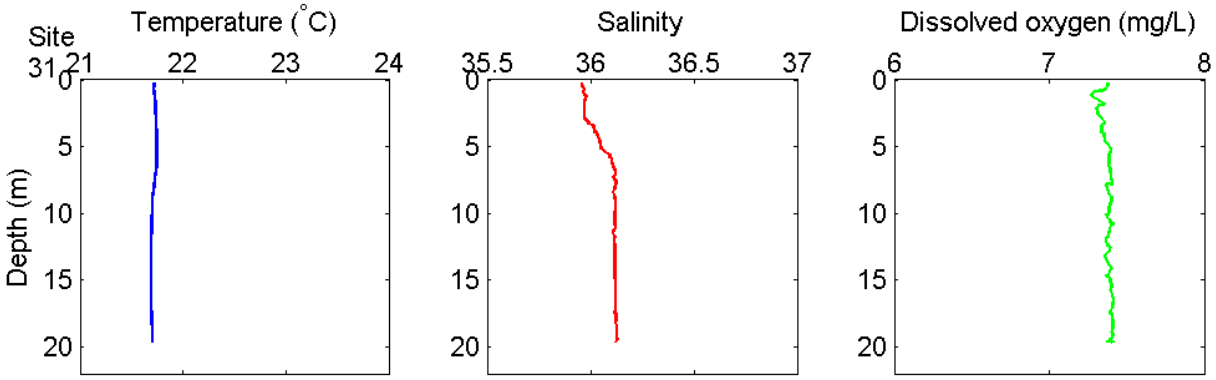

Site 38
Temperature (°C)
21
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10

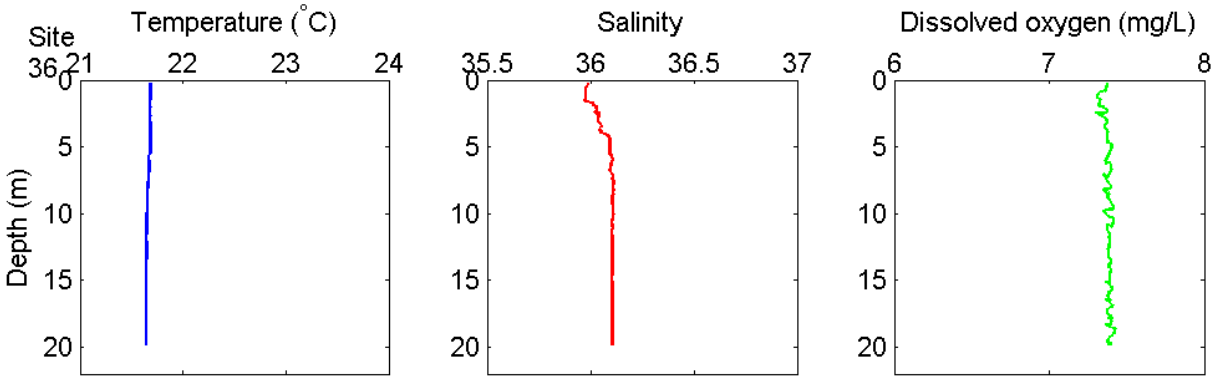

Site 44
Temperature (°C)
21
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10

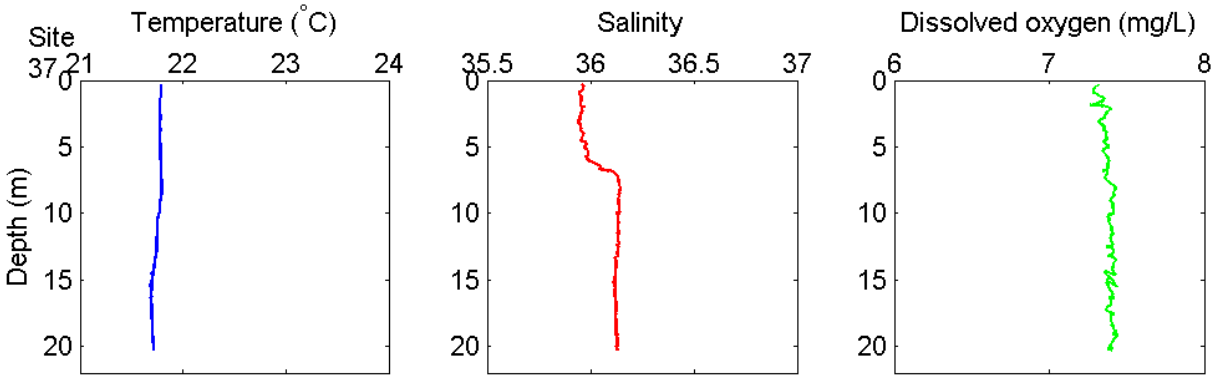

Site 53
Temperature (°C)
21
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10

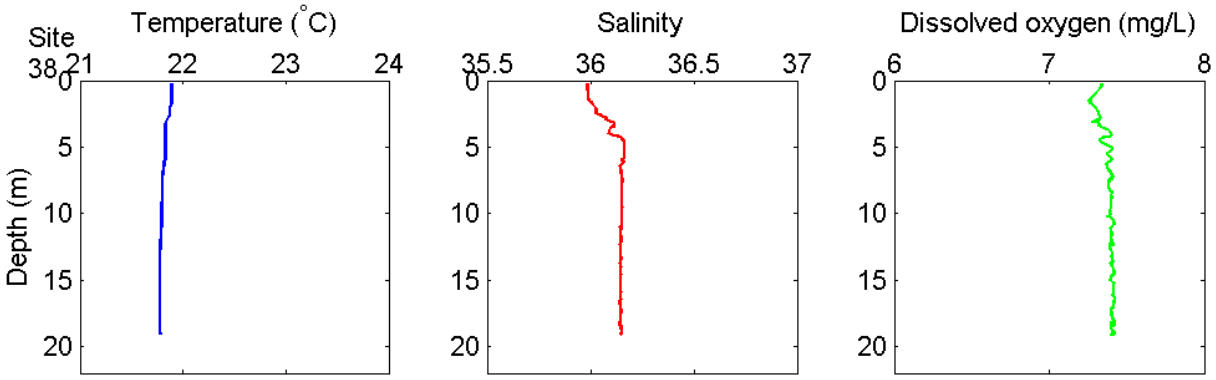

Site 63
Temperature (°C)
21
22
23
24
Salinity
35.5
36
36.5
37
Dissolved oxygen (mg/L)
6
7
8
Depth (m)
0
5
10

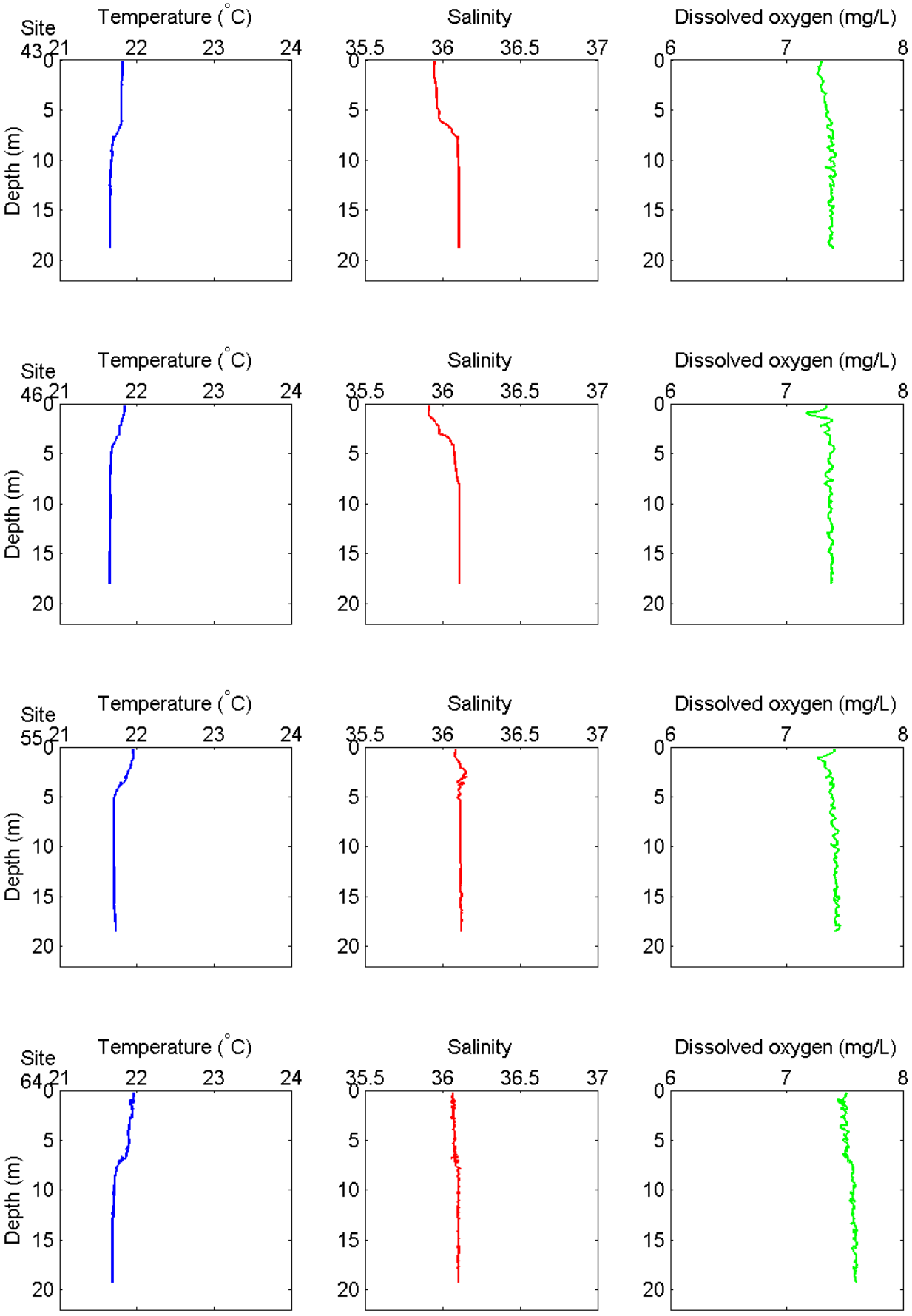
Sepia Depression







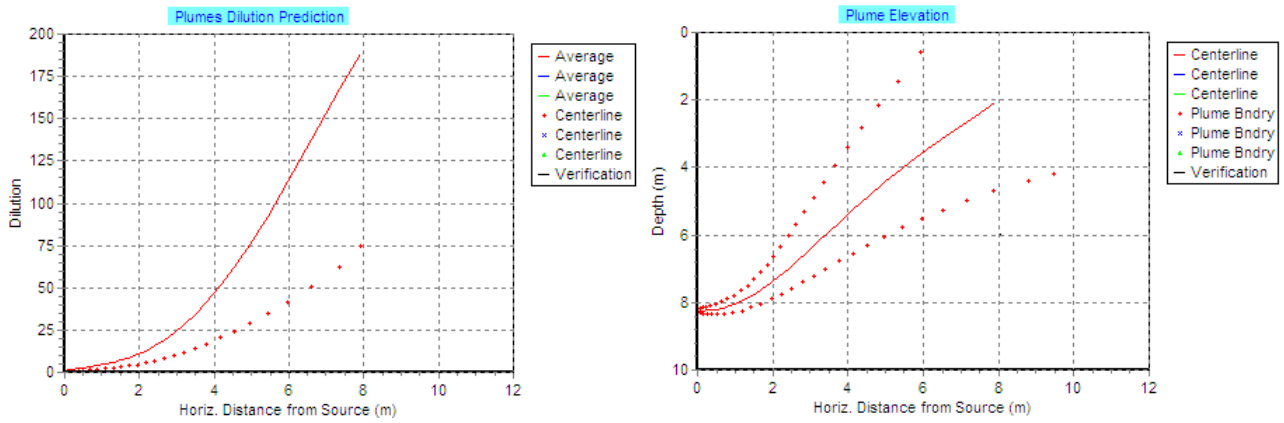



Site 43
Temperature (°C)
Salinity
Dissolved oxygen (mg/L)
Depth (m)
Site 46
Site 55
Site 64

Appendix B UM3 Initial Dilution Model Output

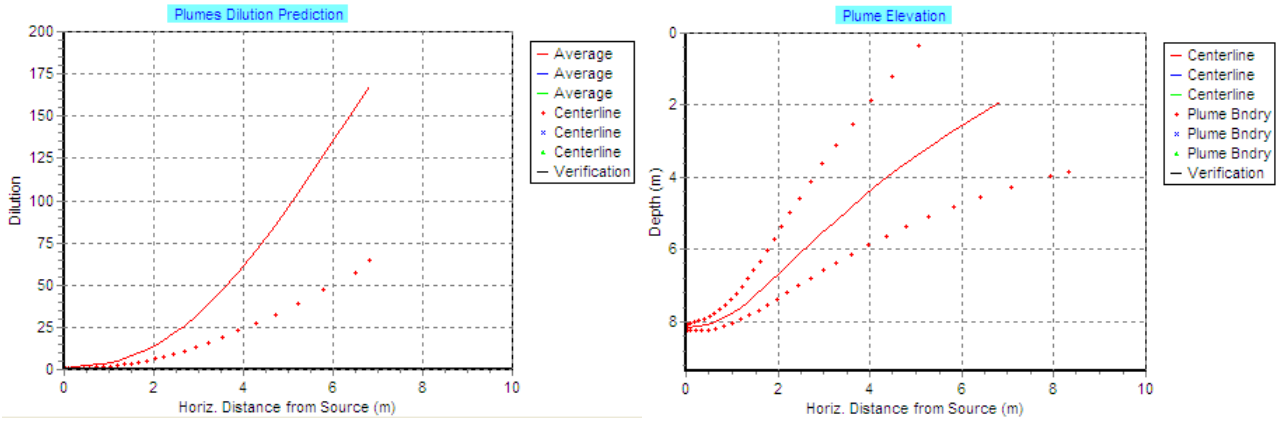
Ocean Reef

A



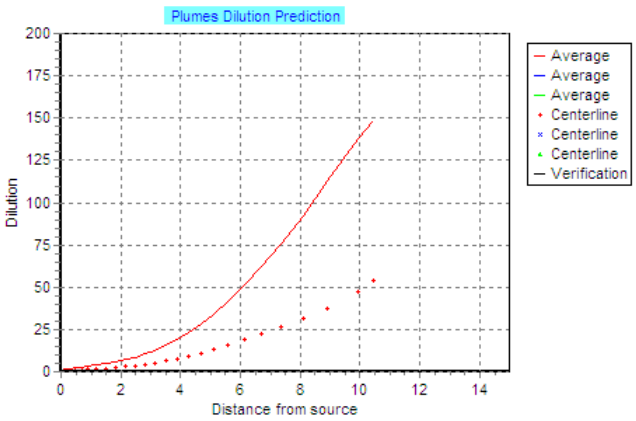

```
/ UM3. 6/12/2019 2:33:06 PM
Case 1; ambient file c:\plumes\VP plume 74.001.db; Diffuser table record 1: ---------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol     Decay   Far-spd   Far-dir   Disprsn   Density
         m       m/s       deg       psu         C     kg/kg       s-1       m/s       deg  m0.67/s2   sigma-T
       0.0     0.107    -188.0     36.44      22.2       0.0     0.001         -         -     0.001     25.28
       9.0     0.095    -188.0     36.45      22.0       0.0     0.001         -         -     0.001     25.34

Diffuser table:
   P-dia  P-elev V-angle H-angle   Ports Spacing AcuteMZ ChrncMZ P-depth Ttl-flo Eff-con    Temp Polutnt
     (m)     (m)   (deg) (N-deg)      ()     (m)     (m)     (m)     (m)   (MLD)(mmho/cm)     (C) (kg/kg)
   0.125    0.76     0.0   278.0    50.0     4.0   100.0   150.0    8.24    57.2   1.119   27.52    0.01

Simulation:
Froude number:      5.769; effleunt density (sigma-T)    -3.109; effleunt velocity     1.079(m/s);
        Depth  Amb-cur    P-dia  Polutnt   Dilutn  CL-diln   x-posn   y-posn
Step      (m)   (cm/s)      (m)  (kg/kg)       ()       ()      (m)      (m)
   0     8.24    9.599    0.125     0.01      1.0      1.0      0.0      0.0;
 100    7.766    9.659    0.651  0.00137    7.071    3.139   -1.499    0.211;
 200    5.238    9.984    2.281 0.000186    51.06    20.75    -4.11    0.578;
 248    3.182    10.25    4.021 7.054E-5    132.0    48.44   -6.394    0.899; merging;
 249    3.131    10.26    4.069 6.912E-5    134.7    49.48   -6.458    0.908; matched energy radial vel = 0.0444m/s;
 250    3.077    10.26     4.12 6.772E-5    137.4    50.58   -6.525    0.917; stream limit reached;
 266    2.072    10.39    5.247 4.872E-5    188.6    74.53   -7.842    1.102; surface, matched energy radial vel = 0.0832m/s;
 ;
2:33:06 PM. amb fills: 2
```

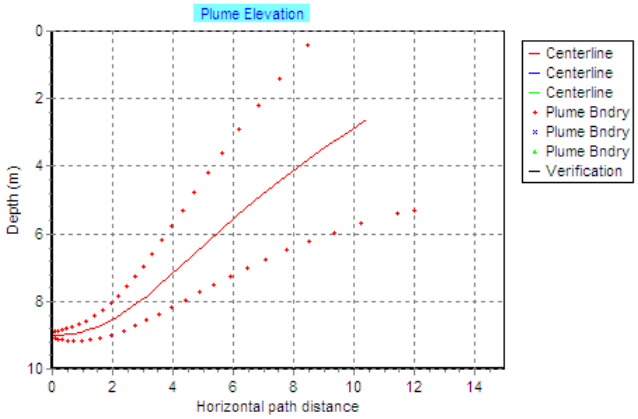
B




```
/ UM3. 6/12/2019 2:47:25 PM
Case 1; ambient file c:\plumes\VP plume 74.001.db; Diffuser table record 1: ----------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol     Decay   Far-spd   Far-dir   Disprsn   Density
         m       m/s       deg       psu         C     kg/kg       s-1       m/s       deg  m0.67/s2   sigma-T
       0.0     0.107    -188.0     36.44      22.2       0.0     0.001         -         -     0.001     25.28
       9.0     0.095    -188.0     36.45      22.0       0.0     0.001         -         -     0.001     25.34

Diffuser table:
   P-dia  P-elev V-angle H-angle   Ports Spacing AcuteMZ ChrncMZ P-depth Ttl-flo Eff-con    Temp Polutnt
     (m)     (m)   (deg) (N-deg)      ()     (m)     (m)     (m)     (m)   (MLD)(mmho/cm)     (C) (kg/kg)
    0.16    0.84     0.0   278.0    48.0     4.0   100.0   150.0    8.16    57.2   1.119   27.52    0.01

Simulation:
Froude number:      3.242; effleunt density (sigma-T)    -3.109; effleunt velocity     0.686(m/s);
        Depth  Amb-cur    P-dia  Polutnt   Dilutn  CL-diln   x-posn   y-posn
Step      (m)   (cm/s)      (m)  (kg/kg)       ()       ()      (m)      (m)
   0     8.16    9.609     0.16     0.01      1.0      1.0      0.0      0.0;
 100    7.458    9.698    0.659  0.00148     6.55    2.958   -1.329    0.187;
 200    4.885    10.03    2.241 0.000201    47.28    19.47   -3.499    0.492;
 250    2.738    10.31    4.032 7.325E-5    127.2    46.94   -5.722    0.804; merging;
 251    2.686    10.31     4.08 7.177E-5    129.8    47.95   -5.784    0.813; matched energy radial vel = 0.0519m/s;
 254    2.522    10.33    4.242 6.750E-5    137.7    51.24   -5.982    0.841; stream limit reached;
 264    1.903    10.41    4.926 5.497E-5    167.9    65.07   -6.756    0.949; surface, matched energy radial vel = 0.0858m/s;
 ;
2:47:25 PM. amb fills: 2
```

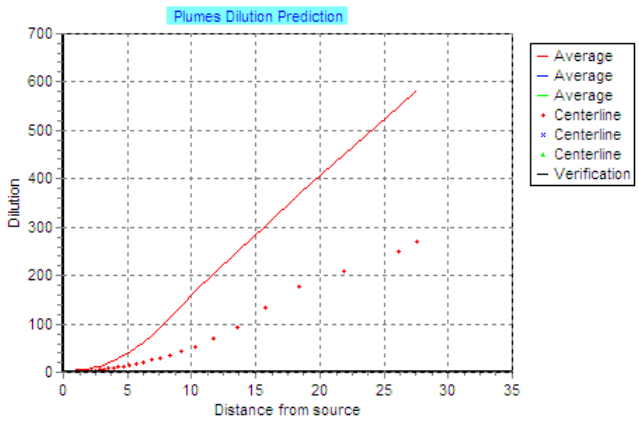
Swanbourne

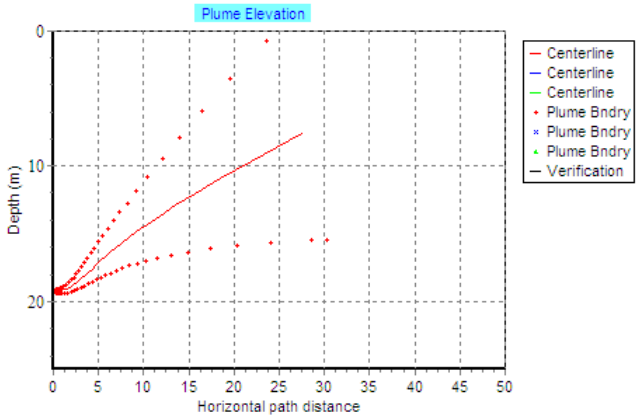





```
/ UM3. 6/12/2019 2:11:49 PM
Case 1; ambient file c:\plumes\VP plume 74.001.db; Diffuser table record 1: ----------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol     Decay   Far-spd   Far-dir   Disprsn   Density
         m       m/s       deg       psu         C     kg/kg       s-1       m/s       deg  m0.67/s2   sigma-T
       0.0     0.153    -248.0      36.3      23.1       0.0     0.001         -         -     0.001     24.91
       9.0     0.134    -248.0     36.13      22.3       0.0     0.001         -         -     0.001     25.01

Diffuser table:
   P-dia  P-elev V-angle H-angle   Ports Spacing AcuteMZ ChrncMZ P-depth Ttl-flo Eff-con    Temp Polutnt
     (m)     (m)   (deg) (N-deg)      ()     (m)     (m)     (m)     (m)   (MLD)(mmho/cm)     (C) (kg/kg)
    0.17     1.0     0.0   338.0    20.0     5.0   100.0   150.0     9.0    55.8   1.406   27.52    0.01

Simulation:
Froude number:      6.574; effleunt density (sigma-T)    -2.991; effleunt velocity     1.423(m/s);
        Depth  Amb-cur    P-dia  Polutnt   Dilutn  CL-diln   x-posn   y-posn
Step      (m)   (cm/s)      (m)  (kg/kg)       ()       ()      (m)      (m)
   0      9.0    13.4     0.17     0.01      1.0      1.0      0.0      0.0;
 100    8.465   13.51    0.904  0.00137    7.074    3.046   -0.805    1.993;
 200    5.478   14.12    3.197 0.000186    51.08    19.18   -2.295     5.68;
 239    3.601    14.5    5.017 8.443E-5    110.5    37.72   -3.305    8.181; merging;
 254    2.621    14.7    6.198 6.206E-5    148.8    53.62   -3.911     9.68; surface;
 ;
2:11:49 PM. amb fills: 2
```

Sepia Depression






```
/ UM3. 6/12/2019 1:40:18 PM
Case 1; ambient file c:\plumes\VP plume 74.001.db; Diffuser table record 1: ----------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol     Decay   Far-spd   Far-dir   Disprsn   Density
         m       m/s       deg       psu         C     kg/kg       s-1       m/s       deg  m0.67/s2   sigma-T
       0.0     0.194    -234.0     36.06      22.0       0.0     0.001         -         -     0.001     25.05
     19.25     0.147    -234.0      36.1      21.7       0.0     0.001         -         -     0.001     25.16

Diffuser table:
   P-dia  P-elev V-angle H-angle   Ports Spacing AcuteMZ ChrncMZ P-depth Ttl-flo Eff-con    Temp Polutnt
     (m)     (m)   (deg) (N-deg)      ()     (m)     (m)     (m)     (m)   (MLD)(mmho/cm)     (C) (kg/kg)
   0.135    0.75     0.0   324.0    68.0    4.65   100.0   150.0   19.25   136.5   1.366   27.52    0.01

Simulation:
Froude number:      8.393; effleunt density (sigma-T)    -3.008; effleunt velocity     1.623(m/s);
        Depth  Amb-cur    P-dia  Polutnt   Dilutn  CL-diln   x-posn   y-posn
Step      (m)   (cm/s)      (m)  (kg/kg)       ()       ()      (m)      (m)
   0     19.25    14.7    0.135     0.01      1.0      1.0      0.0      0.0;
 100     18.94   14.77    0.745  0.00138    7.073    2.984   -1.077    1.482;
 200     16.75    15.3    2.689 0.000187    51.07    18.09   -3.337    4.593;
 249     14.89   15.75     4.67 6.930E-5    134.7    42.58   -5.357    7.373; merging;
 271     13.61   16.06    6.405 4.406E-5    208.3    73.74   -6.997    9.631; stream limit reached;
 300      10.9   16.71    10.71 2.383E-5    369.8    176.9   -10.83    14.91;
 323     7.561   17.51    16.57 1.429E-5    583.2    270.0   -16.21    22.31; surface;
 ;
1:40:18 PM. amb fills: 2
```