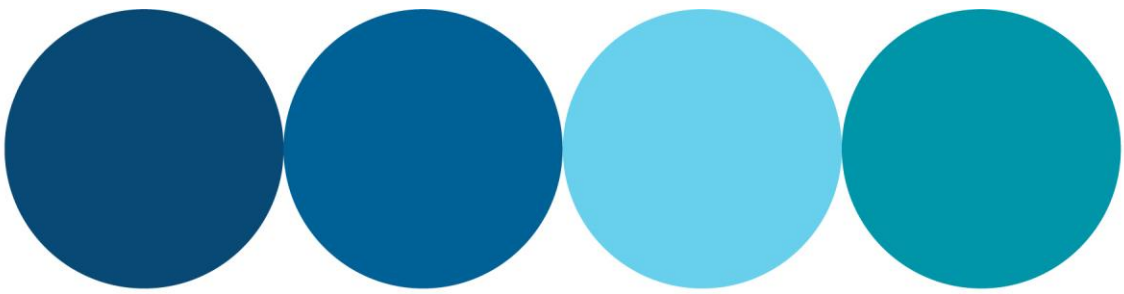
Bunbury Water Resource Recovery Facility Ocean Outlet Monitoring Program

Annual Report 2022/2023



WATER CORPORATION

Document Management

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BMT Commercial Australia Pty Ltd has prepared this report in accordance with our Integrated Management System, in compliance with ISO9001, ISO45001 and ISO14001.

Status

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Approved for final release:

Author
Date: 29/09/2023

Director (or delegate)
Date: 29/09/2023

Executive Summary

This report documents the results of 2023 marine environmental monitoring around the Bunbury ocean outlet. The monitoring has been carried out in accordance with the requirements of the Marine Impacts Monitoring and Management Plan (MIMMP; Water Corporation 2012). The monitoring program aims to determine the physical and chemical properties of the treated wastewater plume and establish its effect on the receiving marine environment. Results are reported in the context of the Environmental Quality Management Framework (EQMF) in accordance with the MIMMP (Water Corporation 2012) or EPA (2017). The results are summarised in Report Card format (Table ES 1). The report card contains colour-coded results, with the individual colours representing the extent to which the Environmental Quality Criteria (EQC) were met (Table ES 2 – Table ES 4).

Table ES 1 Summary report card legend

Management response	Colour code
Monitor: EQG met (continue monitoring)	
Investigate: EQG not met (investigate against the EQS)	
Action: EQS not met (management response required)	

Note: 1. The required response following an exceedance of either the Environmental Quality Guideline (EQG) or Environmental Quality Standard (EQS) is shown in parentheses.

Table ES 2 Summary report card for the Environmental Quality Objective 'Maintenance of Ecosystem Integrity'

Environmental quality indicator		EQC	Comments	Compliance
Toxicants in treated wastewater (TWW)	Bioaccumulating toxicants	EQG	Concentrations of cadmium and mercury in the undiluted TWW stream were below the analytical limit of reporting and ANZECC/ARMCANZ (2000) 80% species protection guideline	
	Non-bioaccumulating toxicants and initial dilution	EQG	Total ammonia, copper and zinc concentrations exceeded ANZECC/ARMCANZ (2000) guidelines in TWW prior to initial dilution. Initial dilution (of 1:568 expected at the LEPA boundary) was sufficient to reduce contaminant concentrations to below the associated ANZECC/ARMCANZ (2000) 99% species protection guidelines.	
	Total toxicity of the mixture (TTM)	EQG	The TTM for the additive effect of ammonia, copper and zinc after initial dilution was 0.38 and below the ANZECC/ARMCANZ (2000) guideline value of 1.0	
Nutrient enrichment	Chlorophyll-a	EQG	Median concentration of chlorophyll-a at compliance sites (0.3 µg/L)	

Environmental quality indicator		EQC	Comments	Compliance
indicators of increased nutrients and algal growth potential			exceeded the 80th percentile of reference site data (0.2 µg/L)	
	Phytoplankton biomass (measured as chlorophyll-a)	EQG	Chlorophyll-a concentration did not exceed 3 times the median of chlorophyll-a concentration of reference site data, on any occasion during summer monitoring	
	Light attenuation coefficient (LAC)	EQG	Median light attenuation measured over the summer period at compliance sites did not exceed the 80th percentile of historical reference site data.	
	Periphyton chlorophyll-a	EQG	Median concentration of periphyton biomass at compliance sites was above the 80th percentile of reference site data.	
	Seagrass health	EQS1	Median shoot density fell below the 20th percentile of reference sites, at site SG4, in two consecutive years (2022 and 2023).	
		EQS2	Median shoot density, at all sites in 2023, was greater than the 5th percentile of the pooled reference site data. The EQS overall is considered exceeded only if both EQS1 and EQS2 are exceeded. Because EQS2 was met the EQS was met overall.	
Physico-chemical stressor	Dissolved oxygen % saturation	EQG	Dissolved oxygen saturation in bottom waters remained above 90% saturation at all times.	
Microbial contaminants	Thermotolerant coliforms (TTC)	EQG	Median TTC concentrations (<10 CFU/100 mL) did not exceed 14 CFU/100 mL and less than 10% of samples exceeded 21 CFU/100 mL	
Algal biotoxins	Toxic phytoplankton species	EQG	No toxic phytoplankton species were recorded in numbers greater than WASQAP trigger values (DoF 2007)	

Notes:

1. Green (■) symbols indicate the Environmental Quality Criteria (EQC) were met; amber (■) and red (■) symbols represent an exceedance of the Environmental Quality Guideline or Environmental Quality Standard (EQS), respectively.

2. WASQAP = Western Australia Shellfish Quality Assurance Program (DoF 2007)

Contents

1 Introduction

1.1 Document purpose

Water Corporation is required to ensure that the discharge of treated wastewater (TWW) from the Bunbury Water Resource Recovery Facility (WRRF) to the marine environment is environmentally sustainable and managed appropriately for the protection of ecosystem and social values. To meet this outcome, Water Corporation undertake their operations in accordance with environmental commitments and Licence Conditions that are outlined in Ministerial Statement (MS) 572.

The Bunbury Operations Environmental Management program and the Marine Impacts Monitoring and Management Plan (MIMMP; Water Corporation 2012) for the Bunbury Ocean Outlet were designed according to Schedule 2 (Proponent's Environmental Management Commitments) of MS 572. The monitoring for the 2022-2023 reporting period was carried out in accordance with the methods and criteria in Water Corporation (2012).

This report describes the results and outcomes of the 2022-2023 Bunbury Ocean Outlet Monitoring (BOOM) program. The program aims to determine the chemical and physical properties of the TWW plume and to determine the effects of TWW discharge on the receiving marine environment.

1.2 Plant infrastructure

Ocean disposal of TWW from the Bunbury WRRF commenced in July 2002. The Bunbury WRRF primarily services the City of Bunbury. On the 20 January 2022, the flow rate into Bunbury WRRF was 10.85 ML. Prior to disposal, the wastewater is treated using microbial processes to reduce concentrations of nitrogen via an intermittently decanting extended aeration plant. These processes produce secondary TWW and biosolids.

The ocean outlet is located approximately 7 km south of the Bunbury Central Business District, south-west Western Australia (Figure 1.1). TWW is discharged via a sub-sea diffuser 1.7 km perpendicular to the shoreline (Water Corporation 2012). The freshwater TWW is less dense than seawater and forms a buoyant plume that rises through the water column and mixes as it ascends.

Figure 1.1 Location of the Bunbury Water Resource Recovery Facility and ocean outlet.

1.3 Conditions of operation

The Bunbury WRRF operates in accordance with Conditions outlined in MS 572. Conditions 6.1 and 6.2 of MS 572 include a requirement to ensure the ecological and social health objectives are met in their respective management areas.

1.4 Environmental Quality Management Framework

Monitoring was completed according to Western Australia's Environmental Quality Management Framework (EQMF; EPA 2016). The EQMF is based on:

- identifying Environmental Values (EVs) (Figure 1.2)
- establishing and spatially defining Environmental Quality Objectives (EQOs) that need to be maintained to ensure the associated EVs are protected (Figure 1.2)
- monitoring and managing to ensure the EQOs are achieved and/or maintained in the long-term in the areas they have been designated
- establishing Environmental Quality Criteria (EQC) which are quantitative benchmarks or 'trigger values' against which monitoring results can be compared.

There are two levels of EQC:

1. Environmental Quality Guidelines (EQGs) are quantitative, investigative triggers which, if met, indicate there is a high degree of certainty the associated EQO has been achieved. If the guideline is not met a more detailed assessment against the EQS is triggered.

2. Environmental Quality Standards (EQSs) are management triggers which, if exceeded, signify the EQO is at risk of not being met and that a management response may be required.

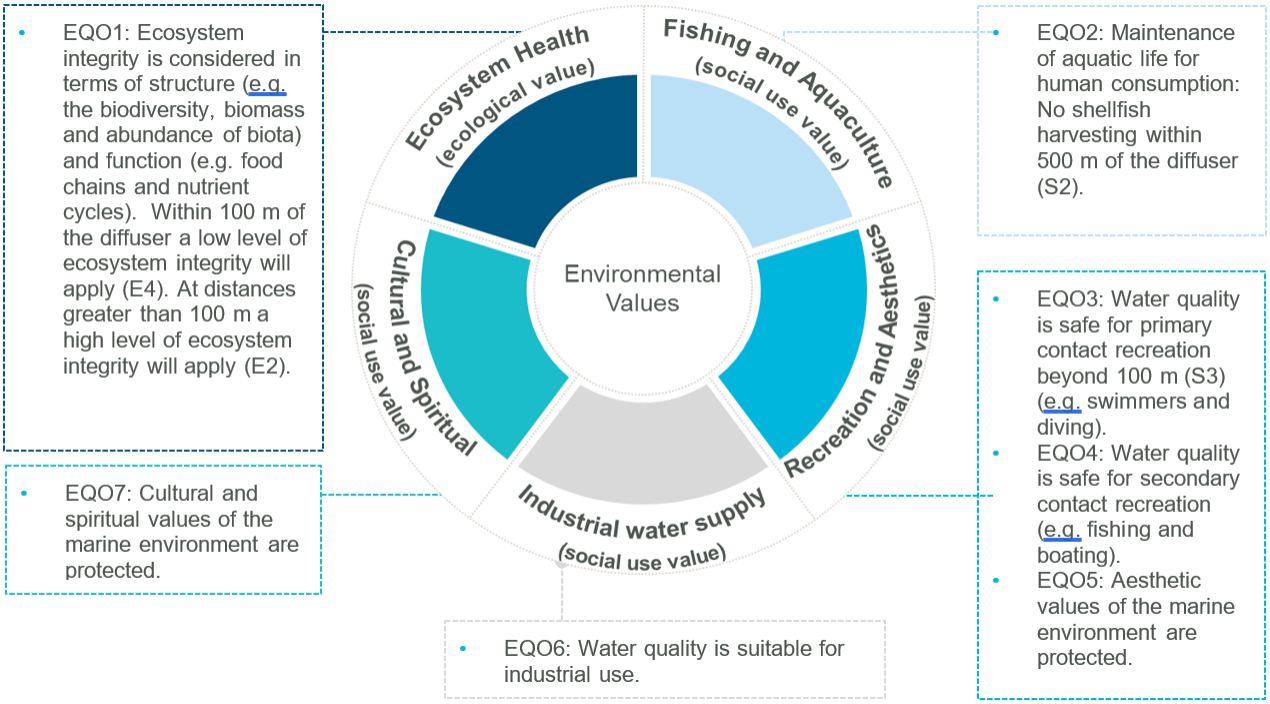


Figure 1.2 Establishing Values and Environmental Quality Objectives (EQO) for the marine waters of Western Australia

1.5 BOOM program framework

MS 572 requires that the EVs Ecosystem Health and Recreation and Aesthetics are maintained and the associated EQOs (EQO1, EQO3, EQO4 and EQO5; Figure 1.2) are met within 100 m of the Bunbury ocean outlet (Figure 1.3). MS 572 requires that the EV Fishing and Aquaculture is maintained and the associated EQOs (EQO2 Figure 1.2) are met within 500 m of the Bunbury ocean outlet (Figure 1.3).

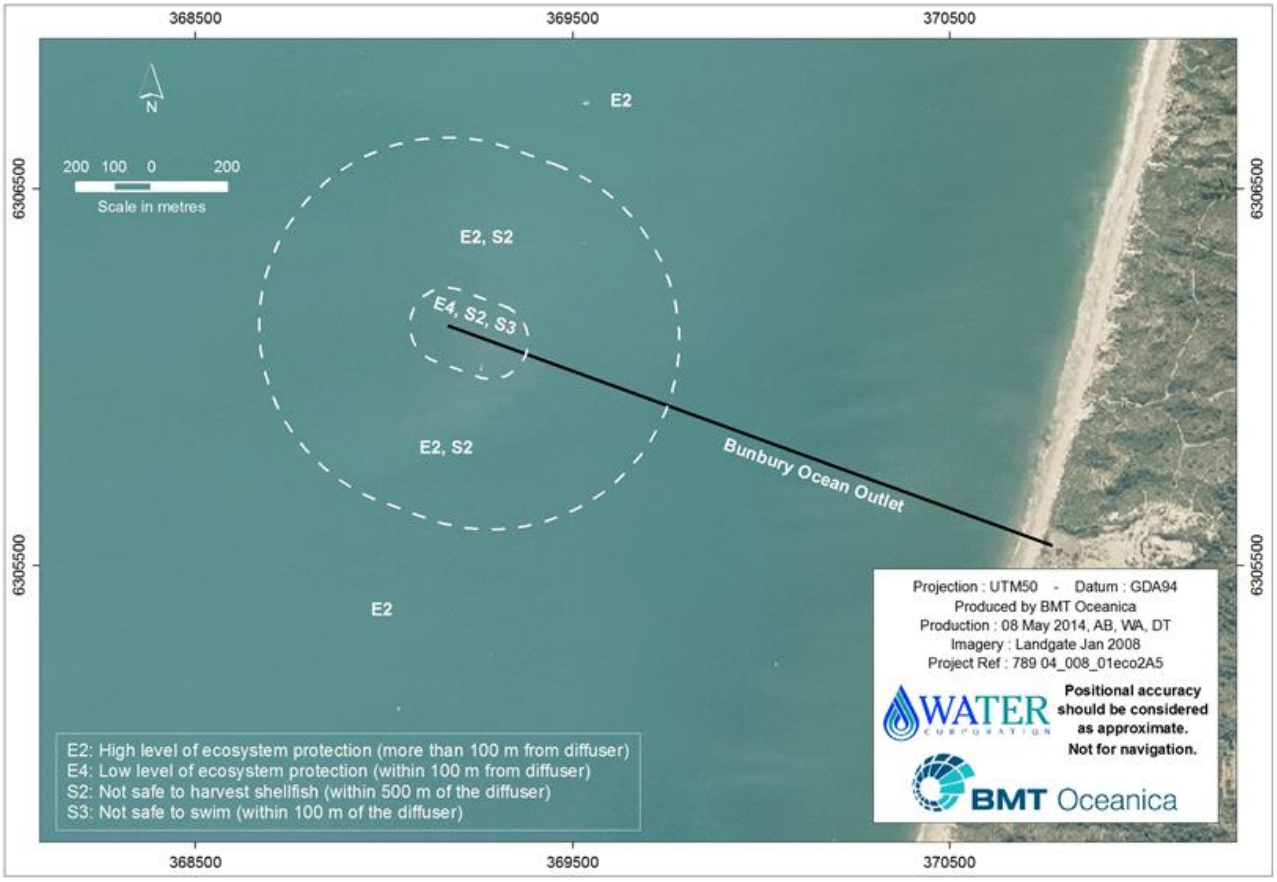


Figure 1.3 Environmental management areas as defined in Schedule 1 of Ministerial Statement 572

1.5.1 'Maintenance of ecosystem integrity' EQO

The intent of this EQO is to maintain a healthy and diverse ecosystem. The EQO applies a designated level of ecological protection: low, moderate, high, or maximum (Figure 1.4). A low level of ecological protection applies in the low ecological protection area (LEPA) occupying the area within a 100 m radius of the diffuser at the Bunbury outfall. Waters outside the LEPA are designated as a high ecological protection area (HEPA) and maintained to a high level of ecological protection.

The extent to which the EQO for the Maintenance of Ecosystem Integrity was met during the 2022–2023 reporting period is assessed against the EQC for waste stream characterisation (i.e. toxicants in TWW) and the EQC for receiving waters (i.e. water quality and seagrass health).

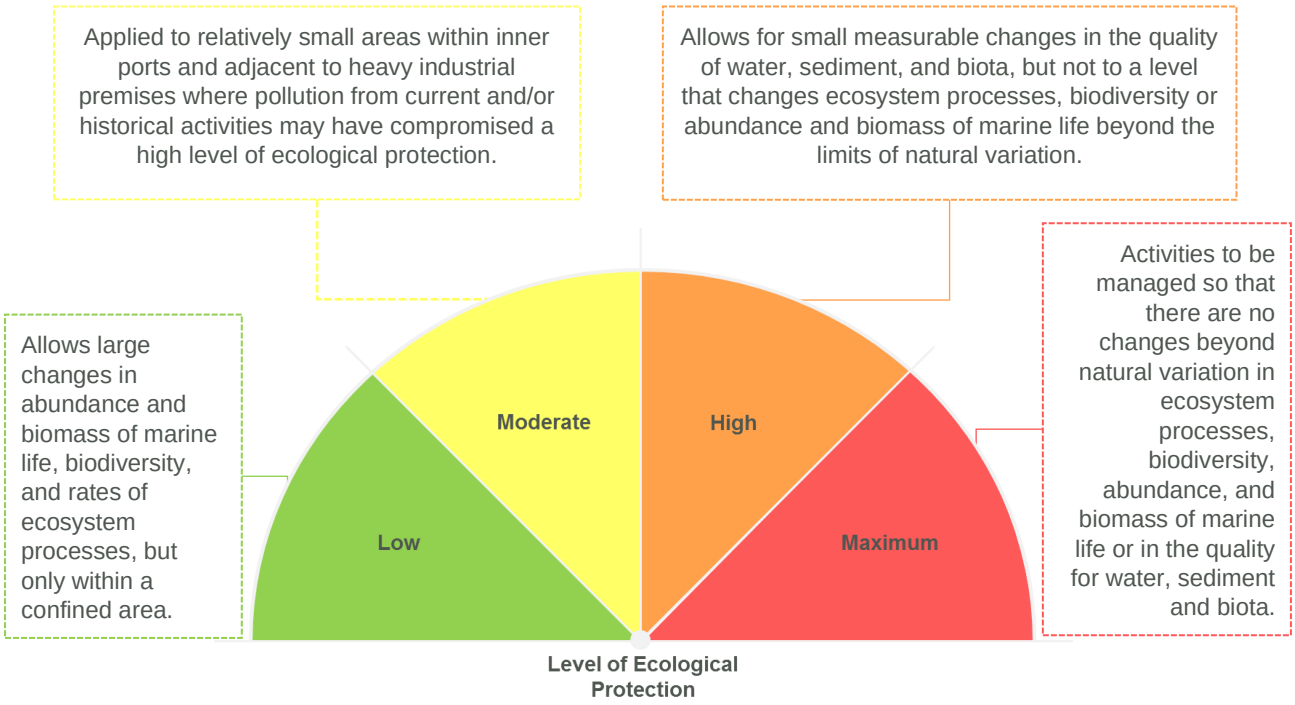


Figure 1.4 Level of ecological protection

1.5.2 'Maintenance of aquatic life for human consumption' EQO

The intent of this EQO is to maintain aquatic life safe for human consumption (a social value) except for a small area surrounding the ocean outlet within 500 m of the diffuser (S2; Figure 1.3), where shellfish may be unsafe to eat.

1.5.3 'Maintenance of primary and secondary contact recreation' EQO

Primary contact recreation will be maintained outside 100 m of the diffuser (S3; Figure 1.3). Secondary contact recreation is not to be affected by the presence of the Bunbury ocean outlet. As the EQO for maintenance of primary contact recreation uses a higher water quality standard than secondary contact recreation, it is assumed that if the primary contact criteria are met, then the secondary contact criteria are also met by default.

2 Waste Stream Monitoring

Monitoring of TWW prior to discharge consisted of:

- monthly TWW characterisation
- annual comprehensive TWW characterisation
- initial dilution monitoring.

2.1 Monthly Treated Wastewater Characterisation

TWW from Pond 2 Discharge Weir was sampled on the second Tuesday of each month by Water Corporation and analysed for:

- total ammonium
- filtered biochemical oxygen demand (BOD)
- conductivity at 25 oC
- total nitrogen (TN)
- total phosphorus (TP)
- nitrate and nitrite (NOx)
- *Escherichia coli* (*E. coli*).

This regulatory monthly sampling is carried out in accordance with Bunbury No. 2 WRRF operating licence L5972/1922/14. The operating licence limit for total phosphorus of 10 mg/L was met during the July 2022–June 2023 reporting period (Table 2.1). All other discharge limits in the Schedule 1 Table of MS 572 (suspended solids, biochemical oxygen demand, total nitrogen and total nitrogen load) are reported separately.

Table 2.1 Regulatory monthly parameter results from Pond 2 Discharge Weir

Month	Total ammonium	Filtered BOD	Conductivity Laboratory at 25 °C	*E. coli*	NOx	TN	TP
Unit	mg/L	mg/L	mg/L	Cells/100mL	mg/L	mg/L	cells/100mL
LoR							
Jul 22	2.4	<5	101	>24000	3	8	4.1
Aug 22	2.2	<5	95	>24000	3.6	8.6	2.5
Sep 22	3.9	<5	96	>24000	3.1	11	5.3
Oct 22	3.3	<5	97	>24000	3.7	9.3	3
Nov 22	2.6	<5	96	14000	4.5	9.9	2.5
Dec 22	2.9	<5	99	11000	4.6	9.5	3.4
Jan 23	2.6	<5	101	8200	5.2	10	3.3
Feb 23	2.2	<5	101	20000	3.6	8	3
Mar 23	2.9	<5	100	20000	2.2	7.1	3.3
Apr 23	2.9	<5	96	>24000	1.2	6.1	2.5
May 23	3.3	<5	96	20000	1.5	6.3	2.7
Mean	2.7	<5	98.1	14702.9	2.9	8.1	3.1

Note: 1.LoR = Limit of reporting, BOD = biological oxygen demand, TN = total nitrogen, TP = total phosphorus, NOx = nitrate+nitrite, *E. coli* = *Escherichia coli*, NA = not applicable.

2.2 Comprehensive treated wastewater characterisation

TWW (final effluent) from the Bunbury WRRF was analysed for a suite of potential contaminants of concern:

- ammonium as nitrogen
- NOx as nitrogen
- TP
- TSS
- BOD (5–day)
- salinity
- metals (Ag, As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, Zn)
- pesticides
- herbicides

2.2.1 Initial dilution monitoring

The MIMMP requires the initial dilution of TWW to be estimated using two different methods (i) using an internationally recognised mixing model (in this case VPLUMES) simulation of the conditions at the time of sampling and (ii) using the concentrations of nutrients within TWW compared to the in-water estimates at the times of sampling (Water Corporation 2012). The most conservative (lowest) estimate of the two is used in further calculations and comparisons (Water Corporation 2012).

2.2.2 Initial dilution using model simulation

Initial dilution modelling (using plume dispersion model VPLUMES) was used to predict the near field dilution of the wastewater plume around the Bunbury ocean outlet. Initial dilution is the dilution between the point of discharge and the point of maximum rise or fall of the plume (in this case when the buoyant plume reaches the surface).

On 10 January 2022 (concurrent to the first summer water quality survey), ambient temperature and flow were collected for input into the plume dispersion model. To determine the current velocity and direction at the time of sampling, a surface drogue was released above the outlet diffuser and the location of the drogue recorded at intervals over time using an on-board Global Positioning System. Surface current velocities were used to synthesise a vertical velocity profile based on the gradient determined by current meters deployed at 2 m and 7.5 m above the seabed ~900 m offshore from the diffuser at the Bunbury ocean outlet (WNI 2000).

Modelling using VPLUMES indicated an average initial dilution of 1:568 and a centreline dilution of 1:248 on 10 January 2023 (Figure 2.1). The full model output is included in Appendix 1.

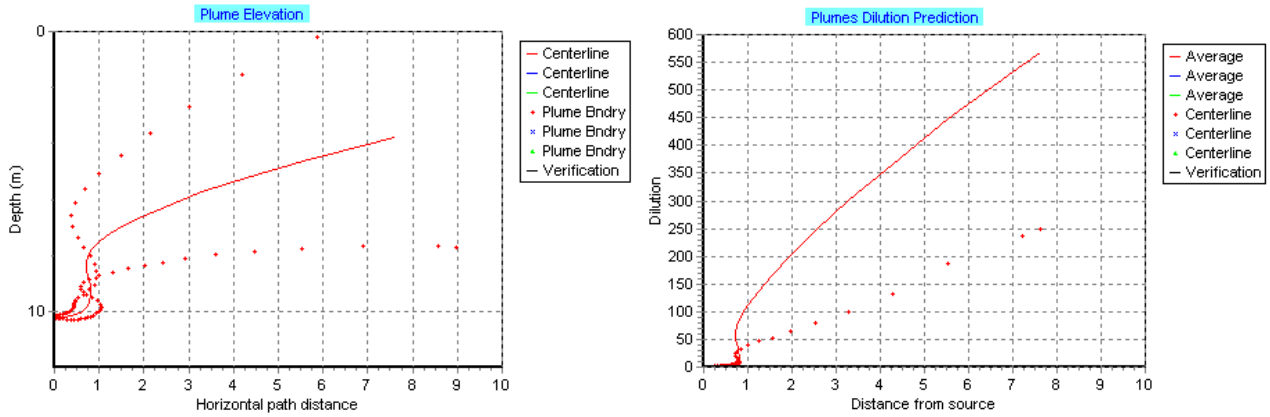


Figure 2.1 Initial dilution modelling output showing predicted plume elevation trajectory (left) and predicted average and centreline dilutions (right)

2.2.3 Initial dilution using the nutrient concentrations

The lowest dilution expected to occur at the Bunbury outlet based on measurement of in-water nutrient concentrations was 1:64 for total phosphorus (Table 2.2). The most conservative estimate of initial dilution was the average initial dilution modelled via VPLUMES, which was 1:568 and it will be used in calculations below.

Table 2.2 Minimum initial dilution achieved for total ammonia, nitrate+nitrite and total phosphorus

Parameter	Undiluted TWW concentration (µg/L)	Surface maximum[1] (µg/L)	Surface background[2] (µg/L)	Minimal initial dilution achieved[3]
Total ammonia	4300	27	1.5	169
Nitrate+nitrite	3600	57	1	64
Total phosphorus	8000	58	2.8	145

Notes:

1. Highest surface concentration recorded at the nutrient dilution sites.
2. Average surface concentration of five reference sites (WQR1-WQR5); where this value was <LoR, the LoR was used to calculate the average surface concentration.
3. Minimum initial dilution = treated wastewater (TWW) concentration/surface maximum – surface background.
4. N/A = not applicable because surface maximum concentration equals surface background concentration.

2.2.4 Bioaccumulating toxicants

The EQG for bioaccumulating toxicants (cadmium and mercury) in the TWW is outlined in Table 2.3.

Table 2.3 Environmental Quality Guideline (EQG) for bioaccumulating toxicants

EQG	Concentrations of contaminants will not exceed the ANZECC/ARMCANZ (2000) 80% species protection guideline trigger levels for bioaccumulating toxicants in wastewater stream before dilution

Source: Water Corporation (2012)

Concentrations of cadmium and mercury (i.e. bioaccumulating toxicants) in the TWW sample before dilution were both below their analytical limit of reporting (and the ANZECC/ARMCANZ (2000) 80% species protection guideline trigger levels) and the EQG for bioaccumulating toxicants was met (Table 2.4).

2.2.5 Non-bioaccumulating toxicants

With the exception of ammonia, copper and zinc, non-bioaccumulating toxicant concentrations were below the analytical limit of reporting and the ANZECC/ARMCANZ 99% species protection guidelines prior to discharge and initial dilution with seawater (Table 2.4). After an initial dilution of 1:568 (a conservative estimate of the dilution expected at the LEPA boundary;~~,~~), contaminant concentrations of ammonia, copper and zinc were below ANZECC/ARMCANZ (2000) 99% species protection guidelines (Table 2.4) and the EQG for non-bioaccumulating toxicants was met.

Table 2.4 Toxicants in the Bunbury TWW compared with relevant guideline trigger levels after initial dilution

Toxicant	Bunbury TWW concentration (µg/L)	Concentration after initial dilution (µg/L)[1]	Trigger (µg/L)[2]
Ammonia-N	**4300**	9.07	500
Nitrate+Nitrite	3600	-	ID
Total phosphorus	8000	-	n/a
Total suspended solids	8000		<10[3]
Arsenic	<20	-	n/a
Cadmium	<0.6	-	36
Chromium	<1	-	0.14 (Cr VI)
Copper	**3**	0.09	0.3
Lead	<10	-	2.2
Mercury	<0.1	-	1.4
Nickel	<7	-	7
Selenium	<20	-	n/1
Silver	<10	-	0.8
Zinc	**53**	0.24	7
Molybdenum	<4	-	ID
Salinity (psu)	0.5	-	n/a
BOD (mg/L)	6	-	n/a
Chloropyrifos	<0.1	-	0.0005
Endrin	<0.01	-	0.004
Endosulfan sulfate	<0.01	-	0.005

Notes:

1. Concentration after initial dilution and natural surface background. Initial dilution = 1:568. Natural surface background ammonia 1.5 µg/L; copper 0.08 µg/L and zinc 0.15 µg/L (Table 2.6). Contaminant dilution calculations were not performed (–) on any toxicants where concentrations were below the analytical limit of reporting or where the 99% species protection guideline value was not the trigger (i.e. cadmium, mercury and total suspended solids).
2. Assessment against ANZECC/ARMCANZ (2000) 99% species protection guidelines for non-bioaccumulating toxicants; guideline values for marine waters.
3. Guideline value for the protection of aquaculture species in saltwater production (ANZECC/ARMCANZ (2000))
4. The bioaccumulating toxicants cadmium and mercury must meet the 80% species protection guidelines at the diffuser (i.e. prior to initial dilution), and therefore a diluted concentration was not calculated.
5. ID = insufficient data to derive a reliable national trigger value.
6. Bold text represents an exceedance of guideline values prior to initial dilution.

2.2.6 Total toxicity of the mixture

The potential for additive toxic effects of TWW on marine organisms at the edge of the initial mixing zone (i.e. after initial dilution of the TWW with seawater) was assessed as per the ANZECC/ARMCANZ (2000) calculation for the total toxicity of the mixture (TTM). TTM is a relative score and does not have a unit of measurement. The EQG for the TTM is outlined in Table 2.5.

Table 2.5 Environmental Quality Guideline for the Total Toxicity of the Mixture (TTM)

EQG	Where there are mixtures of toxicants, the TTM at a single site or for a defined area, should not exceed 1, using the TTM formula.

Notes:
1. EQG = Environmental quality guideline; TTM = total toxicity of the mixture
2. TTM = Σ (Ci/EQGi) where Ci is the concentration of the 'i'th component in the mixture and the EQGi is the guideline for that component.

The TTM following minimum initial dilution of 1:568 was 0.38 (Table 2.6) and was below the ANZECC/ARMCANZ (2000) guideline, meeting the EQG. As such, it is not expected that the combined additive effect of these contaminants will have an adverse effect on marine flora and fauna on the area surrounding the Bunbury ocean outlet.

Table 2.6 Total toxicity of treated wastewater (TWW) at the edge of the initial mixing zone associated with the Bunbury ocean outlet

Natural conentrations in Perth`s coastal waters			Initial dilution of TWW with seawater	Total toxicity of the mixture (TTM)
Ammonia (µg/L)	Cooper (µg/L)	Zinc (µg/L)		
1.5	0.08	0.15	1:568	0.38

Notes:
1. Background concentrations for copper and zinc from McAlpine et al. (2005); Perth marine waters (99. 19; Table 12). Surface background concentration for ammonia calculated as the average surface concentration of the five reference sites (WQR1-WQR5); where this value was less than the limit of reporting (LoR), half the LoR was used in calculations.
2. TTM = [ammonia]/guideline + [copper]/guideline + [zinc]/guideline.

3 Water Quality Monitoring – Receiving Environment

Water Corporation (2012) requires the assessment of indicators of nutrient enrichment and physico-chemical stress in receiving waters. Indicators for nutrient enrichment that were measured in receiving waters to assess marine water quality are:

- surface chlorophyll-*a*
- phytoplankton biomass
- light attenuation coefficient (LAC)
- periphyton
- seagrass shoot density

Dissolved oxygen (DO) was also measured and is the indicator for physico-chemical stress due to increased organic matter load.

Sampling procedures were followed at compliance monitoring, plume tracking, periphyton monitoring and seagrass health sites over the summer monitoring period (Appendix 2). Nutrients, phytoplankton biomass, light attenuation and the physico-chemical stressor DO were monitored during three separate surveys on 10 January, 08 February and 16 March 2023, along a down-current gradient away from the diffuser (Appendix 2). Periphyton was monitored using collector plates deployed from 11 January 2023 to 09 February 2023 (Appendix 2). Seagrass health was monitored through measuring shoot density on 10 and 11 January and 08 and 09 February 2023.

Nutrient concentrations (ammonia, ortho-phosphate, nitrate+nitrite) in receiving waters were measured down current from the outlet (to test for nutrient gradients), for contextual purposes only (see Appendix 3 for results).

3.1 Nutrient enrichment

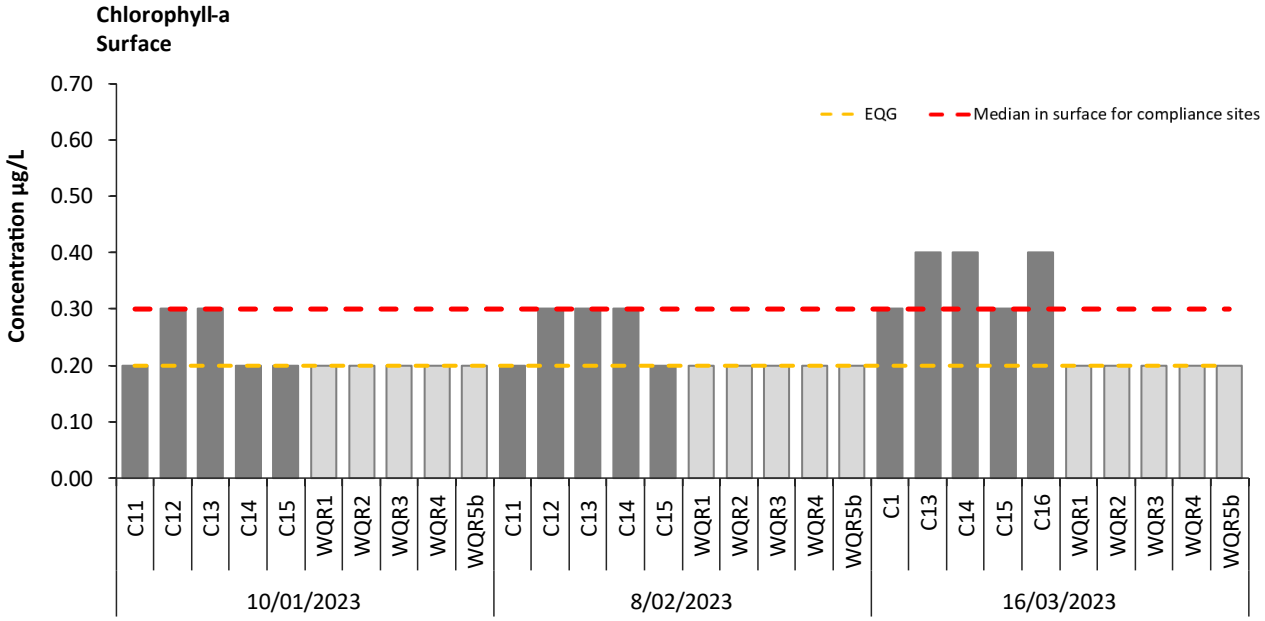
3.1.1 Surface water chlorophyll-a

The EQG for surface water chlorophyll-a is outlined in Table 3.1.

Table 3.1 Environmental Quality Guideline for surface water chlorophyll-a

EQG	The median surface chlorophyll-a concentration at the boundary of the LEPA is not to exceed the 80th percentile of historical reference site data.

Chlorophyll-*a* in surface waters ranged from 0.2 µg/L to 0.4 µg/L across all sites (Figure 3.1). The median chlorophyll-*a* concentration in surface waters for compliance monitoring sites was 0.3 µg/L. This was above the 80th percentile of historical reference site data (0.2 µg/L from 2003–2022: yellow dashed line in Figure 3.1), exceeding the EQG for surface water chlorophyll-*a*.



Notes:

1. Water quality monitoring occurred at compliance sites C11–C15 on 10 January, C11–C15 on 8 February and C13–C16, C1 on 16 March 2023, as a result of prevailing currents at the time of sampling.
2. Dark grey bars indicate sites relevant to the Environmental Quality Guideline (EQG) for chlorophyll-a.
3. Yellow dashed line represents the 80th percentile of historical reference site data which is the Environmental Quality Guideline (0.2 µg/L) for surface chlorophyll-a.

Figure 3.1 Surface chlorophyll-*a* concentrations at compliance and reference sites in 2023 around Bunbury ocean outlet

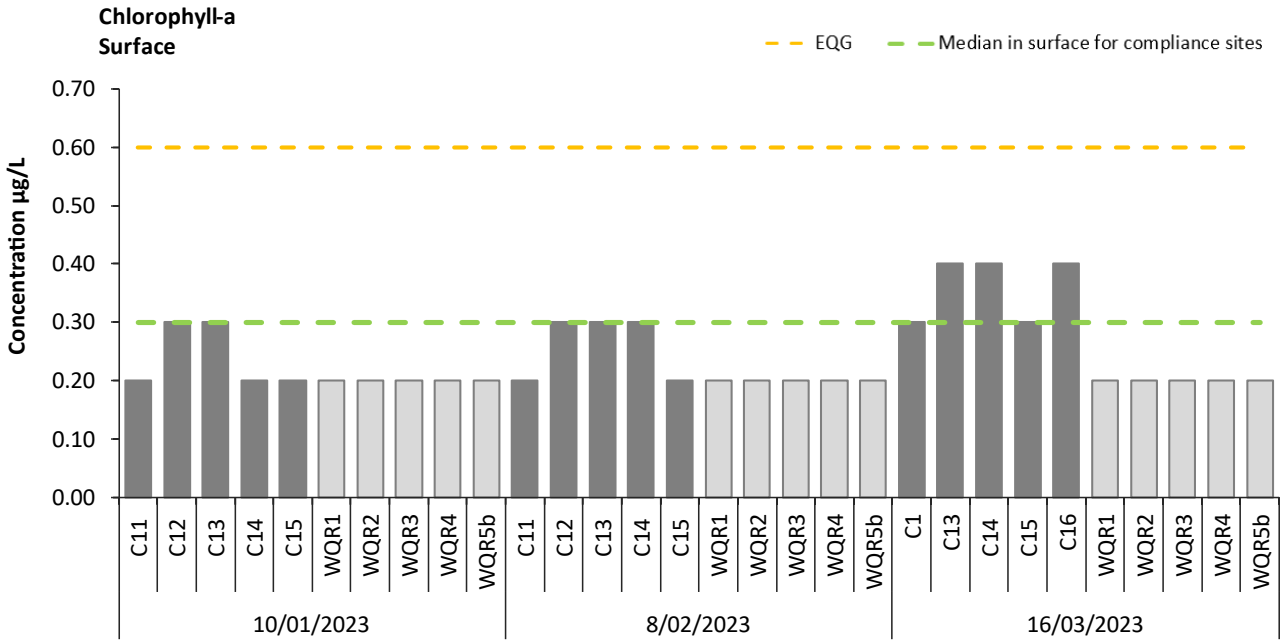
3.1.2 Phytoplankton biomass

The EQG for phytoplankton biomass (also measured as concentration of chlorophyll-a) is outlined in Table 3.2.

Table 3.2 Environmental Quality Guideline for phytoplankton biomass

EQG	Phytoplankton biomass (measured as chlorophyll-a concentration) does not exceed three times the median of chlorophyll-a concentrations of historical reference site data, on any occasion, during the non-river flow period.

Phytoplankton biomass (measured as chlorophyll-*a*) ranged from 0.2 to 0.4 µg/L in surface waters across all compliance sites. Phytoplankton biomass did not exceed three times the median of historical reference site data (0.6 µg/L from 2003-2022: yellow dashed line in Figure 3.2) on any occasion during the non-river flow period, meeting the EQG.



Notes:

1. Water quality monitoring occurred at compliance sites C11–C15 on 10 January, C11–C15 on 8 February and C13–C16, C1 on 16 March 2023, as a result of prevailing currents at the time of sampling.
2. Dark grey bars indicate sites relevant to the Environmental Quality Guideline (EQG) for phytoplankton biomass.
3. Yellow dashed line represents 3 times the median chlorophyll-a concentration of historical reference site data which is the Environmental Quality Guideline (0.6 µg/L) for phytoplankton biomass.

Figure 3.2 Phytoplankton biomass at compliance and reference sites in 2023 around Bunbury ocean outlet

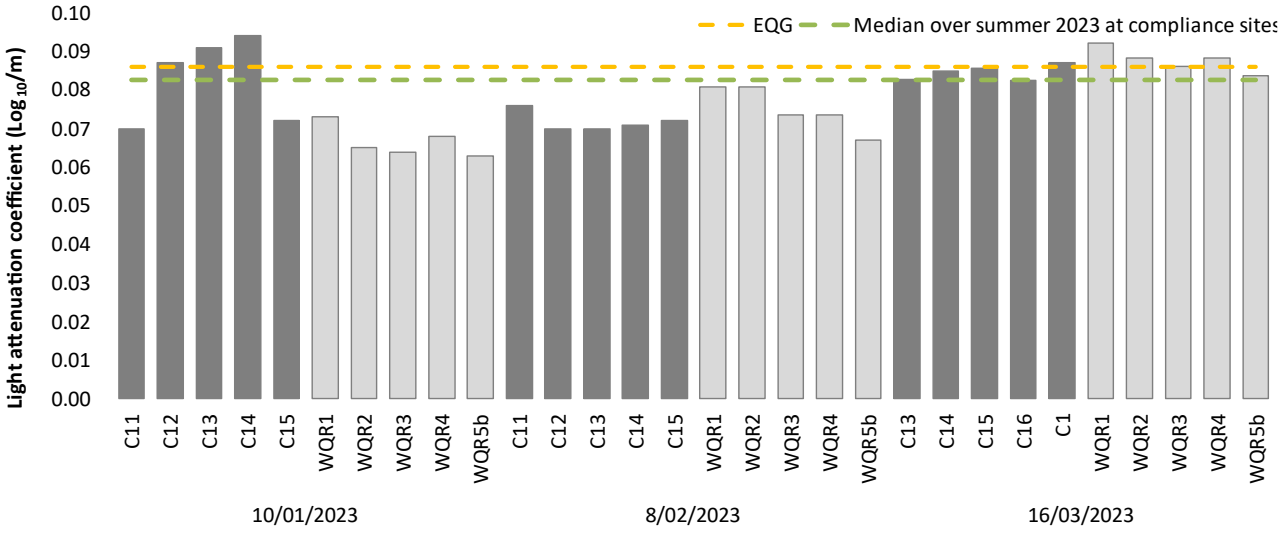
3.1.3 Light attenuation coefficient

The EQG relevant to the LAC is outlined in Table 3.3.

Table 3.3 Environmental Quality Guideline for light attenuation

EQG	The median LAC, during the summer period, is not to exceed 80th percentile of historical reference site data.

Median LAC measured over summer 2023 at compliance sites (0.0825 Log10/m) did not exceed the 80th percentile of historical reference site data (0.0859 Log10/m from 2013-2023 yellow dashed line in Figure 3.3), meeting the EQG for this indicator (Figure 3.3).



Notes:

1. Water quality monitoring occurred at compliance sites C11–C15 on 10 January, C11–C15 on 08 February and C13–C16, C1 on 16 March 2023, as a result of prevailing currents at the time of sampling.
2. Dark grey bars indicate sites relevant to the Environmental Quality Guideline (EQG) for light attenuation, median of which is 0.0825 Log10/m.
3. Yellow dashed line is 80th percentile of historical reference site data which is the Environmental Quality Guideline (0.0859 Log10/m).

Figure 3.3 Light attenuation coefficient measured at compliance and reference sites in 2023

3.1.4 Periphyton biomass

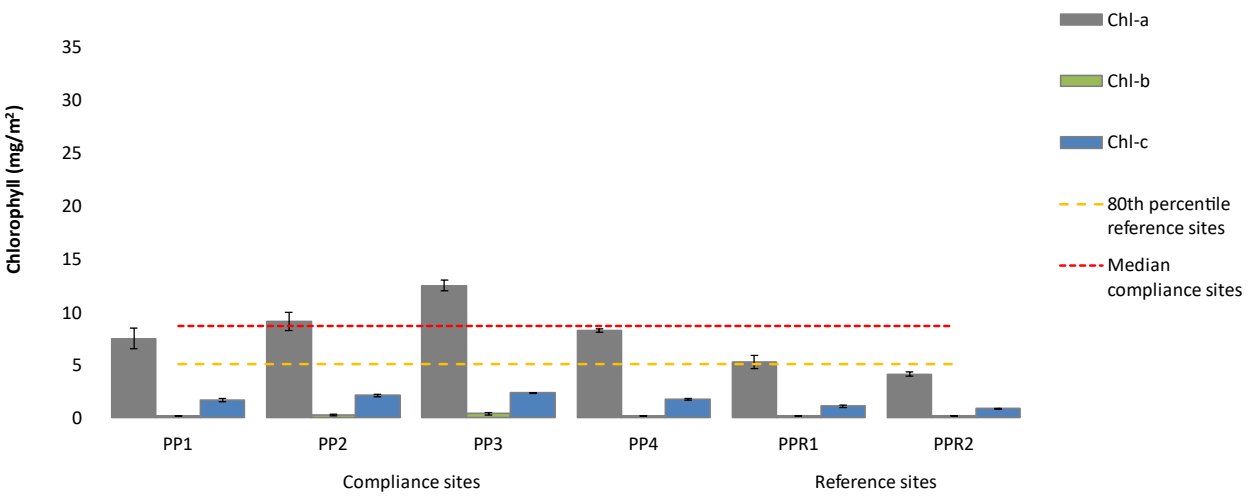
Periphyton collectors provide a time-integrated measure of attached algal growth (epiphytes). Increased periphyton biomass on artificial substrata (measured as chlorophyll-a, -b and -c) in response to nutrient enrichment has been confirmed as an indicator of enhanced productivity resulting from wastewater discharge in Perth's coastal waters (Cosgrove et al. 2004). The EQG for periphyton biomass is in Table 3.4.

Table 3.4 Environmental Quality Guideline for periphyton biomass

EQG	Median periphyton biomass (measured as chlorophyll a) from compliance sites is not to exceed the 80th percentile of reference site data from the same sampling period at 8 m depth.

The median chlorophyll-*a* concentration from the 8 m depth was 8.7 mg/m^2 and was above the 80th percentile of reference site data from the same 2023 sampling period at the 8 m depth (5.0 mg/m^2) (Figure 3.4). Therefore, the EQG was not met and further assessment against the EQS (seagrass health) was triggered.

Of the three chlorophyll types (chlorophyll-*a*, -*b* and -*c*) measured on periphyton collector plates, chlorophyll-*a* was present in the highest biomass, followed by chlorophyll-*c* and then chlorophyll-*b* (Figure 3.4). The dominant chlorophyll-*a* content is indictive of a periphyton assemblage dominated by diatoms and/or brown algae (SKM 1999).



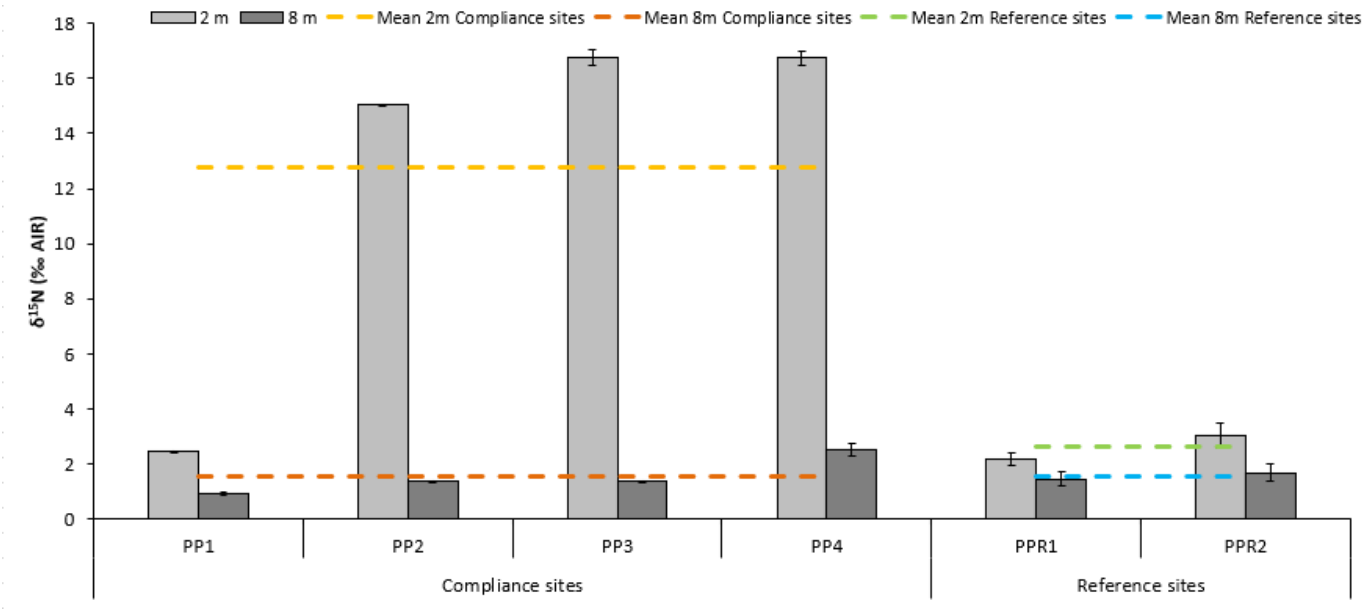
Notes:

1. Bars=mean (± standard error) chlorophyll-a, -b and -c concentration at compliance sites (PP1-PP4) and reference sites (PPR1 and PPR2).
2. Green dashed line = median of chlorophyll-a concentration across compliance sites (8.7 mg/m2 where n=8).
3. Yellow dashed line = 80th percentile of chlorophyll-a concentration at reference sites (28.3 mg/m2 where n=4).

Figure 3.4 Periphyton chlorophyll-*a*, -*b*, and -*c* content at compliance and reference sites at 8m depth.

Periphyton samples were analysed for nitrogen isotopic composition, to determine if the periphyton growth patterns can be attributed to nutrient-rich wastewater around the Bunbury ocean outlet.

Mean δ15N was higher in surface samples at all compliance sites (PP1–PP4), than surface samples from the two reference sites (PPR1 and PPR2) (Figure 3.5). At each site, mean δ15N of periphyton was higher in the surface samples than for the bottom samples (Figure 3.5). In bottom compliance site samples, mean δ15N was very low compared to surface samples and to reference site samples (Figure 3.5). The high mean periphyton δ15N at the surface but not in bottom samples (Figure 3.5) suggests that the influence of the buoyant TWW plume is restricted to the surface.



Notes:

1. PP1-PP4 = periphyton compliance sites; PPR1 and PPR2 = periphyton reference sites.
2. At each site and each depth there was sufficient epiphyte growth on the collector plates for 2 replicates.
3. Error bars represent ± standard error.

Figure 3.5 Mean δ15N content in periphyton collected at compliance and reference sites

3.1.5 Seagrass health

The EQG for periphyton biomass was exceeded during the 2023 monitoring and assessment against the EQS (seagrass health) was required. The EQS for seagrass health are outlined in Table 3.5.

Table 3.5 Environmental Quality Standards for seagrass health

EQS1	Median seagrass meadow shoot density measured during January and in two consecutive years is greater than the 20th percentile of shoot density measured at an appropriate reference site. And
EQS2	Median seagrass meadow shoot density in any one year is greater than the 5th percentile of meadow shoot density measured at an appropriate reference site.

Notes:

1. The EPA derived these EQS for seagrass shoot density specifically relevant for assessing the health of species of Posidonia (EPA 2005).

EQS1 is exceeded if median shoot density at the same site over two consecutive years falls below the 20th percentile of reference sites (red dashed line; Figure 3.6). Median shoot density, at site SG4, was below the 20th percentile of reference sites (red dashed line; Figure 3.6) in 2022 and in 2023, leading to an exceedance of EQS1. At no other site was median shoot density below the 20th percentile of reference sites in two consecutive years. In 2022, median shoot density at site SG4 (368 shoots/m^2) was only below the EQS1 (384 shoots/m^2) by 16 shoots/m^2, while the standard error was 83 shoots/m^2. This suggests that seagrass health is not compromised but rather that sample size could be the limiting factor.

In 2023, at all sites, the median shoot density was greater than the 5th percentile of the pooled reference site data (red solid line; Figure 3.6), meeting EQS2. The EQS overall is considered exceeded only if both EQS1 and EQS2 are exceeded. Because EQS2 was met the EQS was met overall.

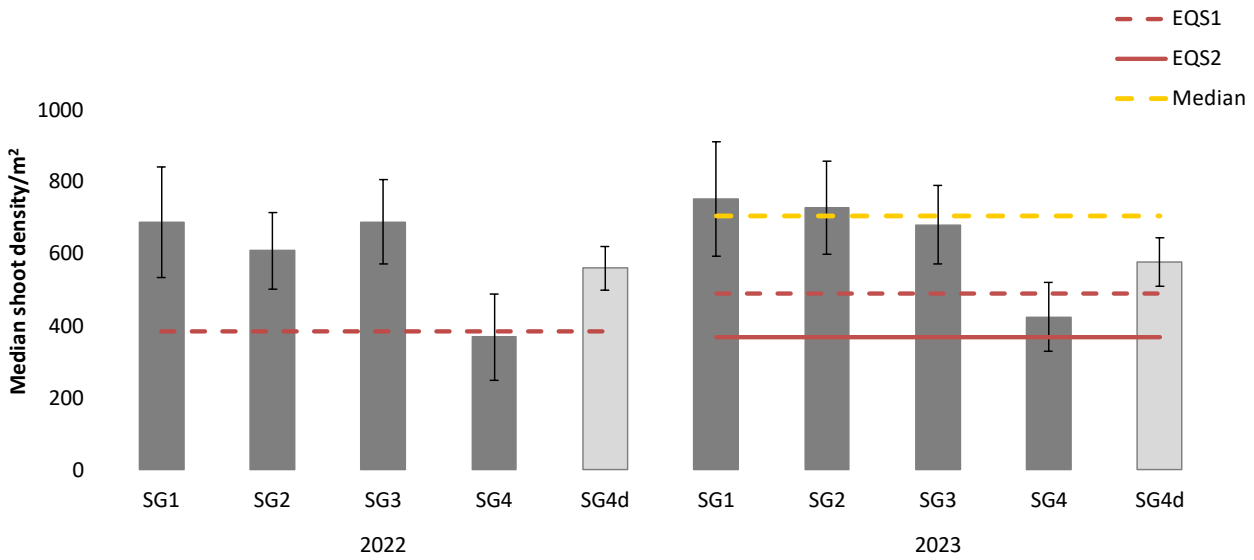


Figure 3.6 Median seagrass shoot density at seagrass health monitoring sites

3.2 Physico-chemical stressor

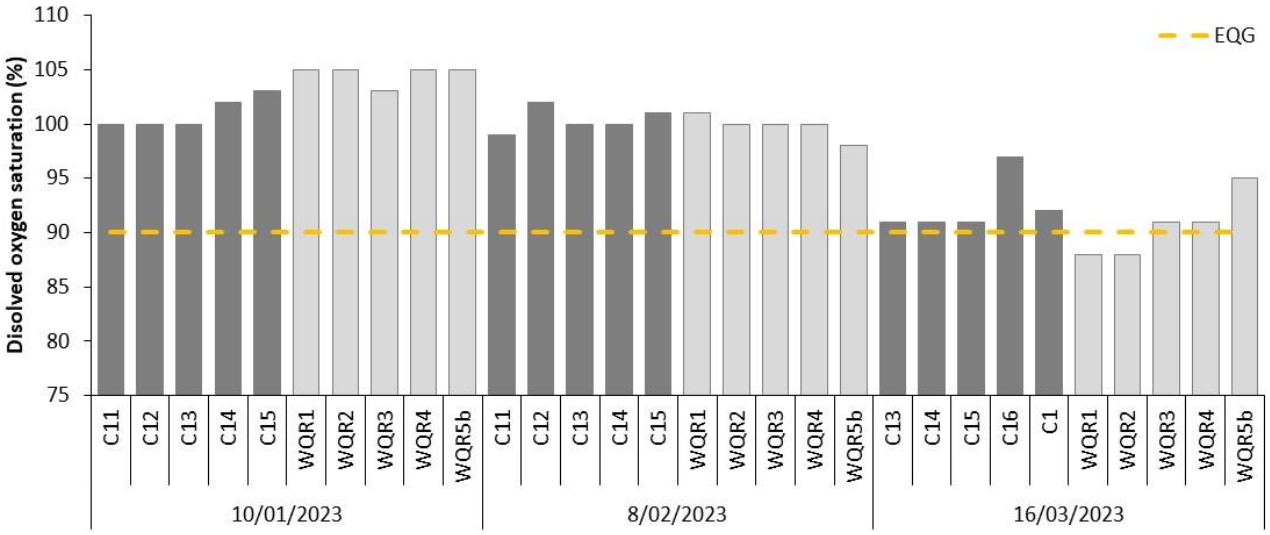
3.2.1 Dissolved oxygen

The EQG for dissolved oxygen (DO) is outlined in Table 3.6.

Table 3.6 Environmental Quality Guideline for dissolved oxygen

EQG	Ambient dissolved oxygen in bottom waters (0-0.5 m above the sediment surface) is greater than 90% saturation at any site for a defined period of not more than six weeks.

The EQG for dissolved oxygen (DO) in the bottom remained above 90% saturation at all compliance monitoring sites, at all times, meeting the EQG (Figure 3.7). Two reference sites (WQR1 and WQR2) had DO below 90% saturation during the March 2023 sampling event which was unrelated to the discharge from the ocean outlet (Figure 3.7)



Notes: 1. Water quality monitoring occurred at compliance sites C11–C15 on 10 January, C11–C15 on 8 February and at C1, C13–C16 on 16 March 2023, as a result of prevailing currents at the time of sampling.

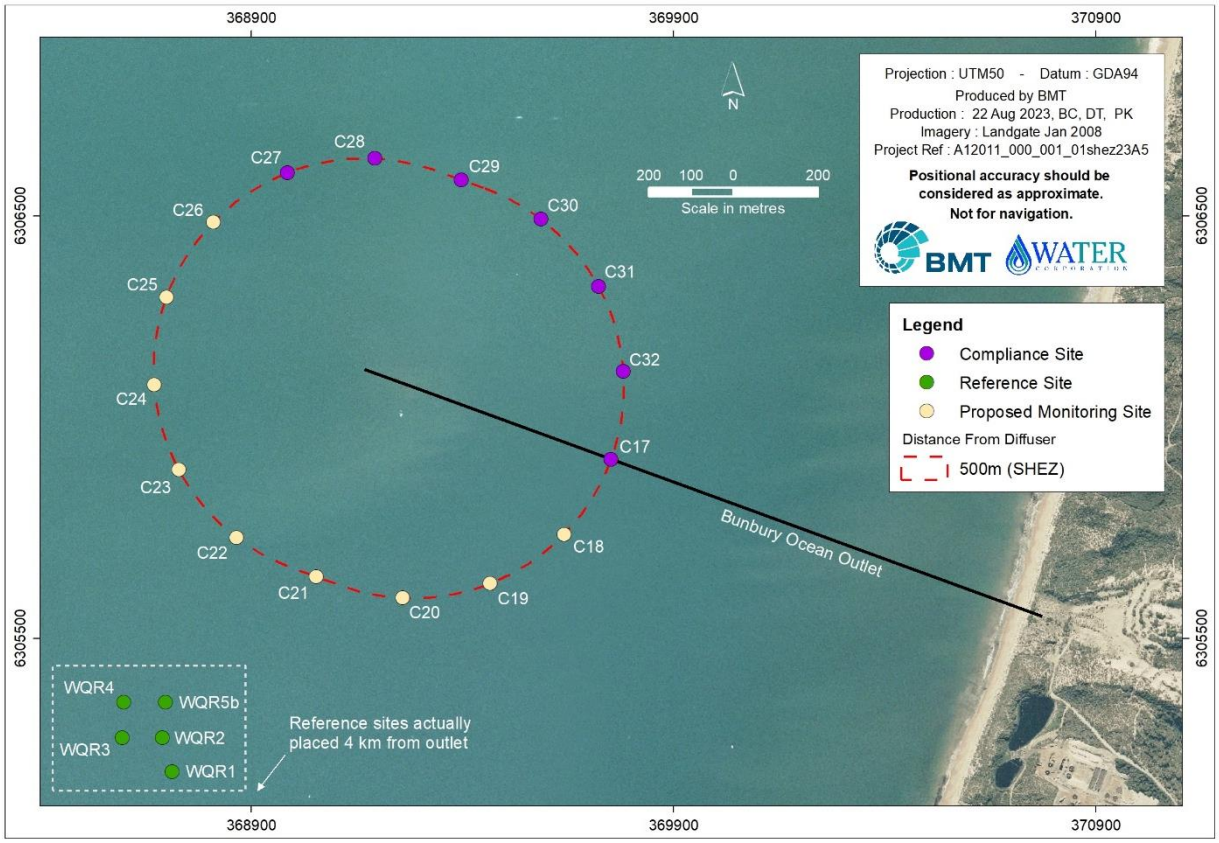
1. Dark grey bars indicate sites relevant to the Environmental Quality Guideline for dissolved oxygen (DO).
2. Yellow dashed lines is the EQG for DO (90% saturation).
3. DO was measured from the seabed to 0.5 m above seabed.

Figure 3.7 Dissolved oxygen in bottom waters at compliance and reference site

4 Seafood Safe for Human Consumption

4.1 Sampling approach and site locations

The EQO for the EV 'Fishing and Aquaculture' is aimed at ensuring that seafood is safe for human consumption. To ensure the EQO is met, thermotolerant coliforms (TTC) and algal biotoxins are monitored. The social health EQO of 'Seafood Safe for Human Consumption' must be met at the boundary of the Shellfish Harvesting Exclusion Zone (SHEZ, or S2 area), represented by a concentric ring 500 m from the diffuser (Figure 4.1). Shellfish compliance monitoring sites (C17–C32) are positioned at the boundary of the SHEZ, but only the five compliance sites directly down-current of the outlet are sampled during each monitoring period (January, February and March).



Notes: 1. Water quality monitoring occurred at compliance sites C27–C31 on 10 January, C27–C31 on 8 February and at C17, C28–C32 on 16 March 2023, as a result of prevailing currents at the time of sampling.

Figure 4.1 Aquatic life for human consumption compliance (C17-C32) and reference (WQR1-WQR5b) monitoring sites

The EQO, Maintenance of Seafood Safe for Human Consumption, is primarily concerned with the harvesting and consumption of raw shellfish (meaning filter-feeding bivalve molluscs including oysters, mussels, pipis, scallops, cockles and razor clams), and not other forms of seafood. The Department of Health (DoH) discourages the public from taking wild shellfish recommending that instead shellfish are only consumed if grown commercially under strict monitoring programs. There is no aquaculture within 250 m of the diffuser, and there are no licensed

shellfish growing areas located in the Bunbury region (DoH 2015). The DoH has further indicated that "it is impossible to guarantee the safety of eating wild shellfish without having a comprehensive monitoring program that tests the waterway concerned for harmful microorganisms and toxins" (EPA 2005) and has formally advised the Department of Environment Regulation (DER) that, in the absence of a full monitoring program, the application of the TTC criteria (EPA 2005) is insufficient to protect those who wish to collect and eat wild shellfish.

4.2 Thermotolerant coliforms sampling

Many disease-causing organisms are transferred from human and animal faeces to water via TWW and can then be ingested by marine fauna, adversely affecting the suitability of such fauna for human consumption. Thermotolerant coliforms (TTCs) are bacteria that primarily originate in the intestines of warm-blooded animals. By testing for TTC, it can be determined whether the ocean water around the Bunbury ocean outlet has been exposed to faecal contamination.

Water samples were taken from the surface and bottom of the water column for TTC analyses at compliance monitoring sites, shoreline monitoring sites, plume tracking sites and reference sites over the three sampling dates 10 January, 8 February and 16 March 2023. Samples were collected in pre-sterilised bottles before being chilled to 4oC and placed in the dark. On completion of sampling, the samples were transferred to the PathWest Laboratory and analysed to NATA-accredited methods.

4.3 Thermotolerant coliforms results

The EQG for microbial contaminants for the protection of aquatic life for human consumption is outlined in Table 4.1.

Table 4.1 Environmental Quality Guideline for thermotolerant coliforms

EQG	Median TTC concentrations across compliance sites are not to exceed 14 CFU/100 mL and that no more than 10% of samples are to exceed 21 CFU/100 mL

All concentrations of TTC in both surface and bottom waters and at all compliance monitoring sites were below the analytical limit of detection (<10 CFU/100 mL; Table 4.2). Median concentrations of TTC were below 14 CFU/100 mL and less than 10% of samples exceeded 21 CFU/100 mL (Table 4.2), meeting the EQG (Table 4.1).

Table 4.2 Confirmed thermotolerant coliform concentrations downstream of the Bunbury treated wastewater ocean outlet

Date	Compliance site	TTC in surface water (CFU/100 mL)	TTC in bottom waters (CFU/100 mL)
10 January 2023	C27	<10	<10
	C28	<10	<10
	C29	<10	<10
	C30	<10	<10
	C31	<10	<10
08 February 2023	C27	<10	<10
	C28	<10	<10
	C29	<10	<10
	C30	<10	<10
	C31	<10	<10
16 March 2023	C17	<10	<10
	C29	<10	<10
	C30	<10	<10
	C31	<10	<10
	C32	<10	<10

Notes:

1. Water quality samples for microbiological contaminants were sampled ~1 m below the surface of the water and 2 m above the seabed (Water Corporation 2012).

2. TTC = thermotolerant coliforms.

4.4 Algal biotoxins sampling

Nutrient enrichment (as a result of the TWW discharge) can induce shifts in the naturally occurring planktonic algae community to more harmful species. Water Corporation (2012) includes a requirement to monitor for potentially toxic phytoplankton species (as per DoF 2007) in the area surrounding Bunbury ocean outlet. Although most algal blooms are non-toxic, some may contain species that produce toxins and/or have a potentially harmful effect on the surrounding marine environment. For example, algae species *Heterosigma akashiwo* and *Prymnesium parvum* (Prymnesiophyta) cause large and recurrent fish mortalities. In terms of trophic consequences of algal biotoxins (i.e. flow-on effects up the food chain), there are ~2000 species that can induce poisonings in humans (DoF 2013).

Water samples were taken from the surface and bottom of the water column at compliance monitoring sites and reference sites (outlined in Figure 4.1), at the SHEZ – 500 m, boundary from the diffuser, and analysed for toxic species of phytoplankton (defined by Western Australian Shellfish Quality Assurance Program (WASQAP) guidelines; DoF 2007). Phytoplankton samples were preserved in Lugol's iodine solution and identified to the lowest taxonomic level possible. The phytoplankton results are presented in Appendix 4.

4.5 Algal biotoxins results

The EQG for toxic phytoplankton species (Table 4.3) states that concentrations of potentially toxic algae are not to exceed the WASQAP trigger concentrations in any samples (DoF 2007). Table 4.4 lists the phytoplankton species known to produce toxins that may be concentrated in shellfish and their WASQAP (DoF 2007) guideline trigger concentrations.

Table 4.3 Environmental Quality Guideline for toxic phytoplankton species

	Phytoplankton specie	Concentration of potentially toxic algae at the boundary of the SHEZ are not exceed the WASQAP[1] trigger concentrations in any sample
EQG	*Alexandrium* spp.	100 cells/L
	Gymnodinium catenatum	1,000 cells/L
	Karenia spp.	1,000 cells/L
	Dinophysis spp.	500 cells/L
	Dinophysis acuminata	3,000 cells/L
	Prorocentrum lima	500 cells/L
	Pseudo-nitzschia spp.	250,000 cells/L
	Gonyaulax cf. spinifera	100 cells/L
	Protoceratium reticulatum	50,000 cells/L

Notes: 1. Western Australian Shellfish Assurance Program (WASQAP; DoF 2007) as stipulated by Water Corporation 2012.

There were no instances where toxic phytoplankton species were present at densities greater that the WASQAP (DoF 2007) guideline values (Table 4.4).

Table 4.4 Estimated cell density of phytoplankton species known to produce toxins that may be concentrated in shellfish downstream of the Bunbury treated wastewater ocean outlet

Date	Site	Depth	Species	Estimated cell density (cells/L)	WASQAP[1] (cells/L)	Compliance
10 January 2023	C27	Surface	*Pseudo-nitzschia* spp.	80	250,000	■
			Prorocentrum lima	80	500	
	C28	Surface	No toxic species detected	NA	NA	■
	C29	Surface	*Pseudo-nitzschia* spp.	80	250,000	■
	C30	Surface	No toxic species detected	NA	NA	■
	C31	Surface	*Pseudo-nitzschia* spp.	80	250,000	■
	C27	Bottom	*Gonyaulax spinifera*	80	100	■
	C28	Bottom	*Gonyaulax spinifera*	80	100	■
	C29	Bottom	*Gonyaulax spinifera*	80	100	■
	C30	Bottom	No toxic species detected	NA	NA	■
	C31	Bottom	No toxic species detected	NA	NA	■
8 February 2023	C27	Surface	No toxic species detected	NA	NA	■
	C28	Surface	*Pseudo-nitzschia* spp.	80	250,000	■
	C29	Surface	No toxic species detected	NA	NA	■
	C30	Surface	No toxic species detected	NA	NA	■
	C31	Surface	*Prorocentrum lima*	80	500	■
	C27	Bottom	*Pseudo-nitzschia* spp.	80	250,000	■
	C28	Bottom	*Pseudo-nitzschia* spp.	80	250,000	■
	C29	Bottom	*Prorocentrum lima*	80	500	■
	C30	Bottom	No toxic species detected	NA	NA	■
	C31	Bottom	No toxic species detected	NA	NA	■

Date	Site	Depth	Species	Estimated cell density (cells/L)	WASQAP[1] (cells/L)	Compliance
16 March 2023	C17	Surface	*Pseudo-nitzschia* spp.	240	250,000	■
			Dinophysis spp.	80	500	
	C29	Surface	*Pseudo-nitzschia* spp.	480	250,000	■
			Dinophysis spp.	80	500	
	C30	Surface	*Pseudo-nitzschia* spp.	80	250,000	■
	C31	Surface	*Pseudo-nitzschia* spp.	320	250,000	■
	C32	Surface	*Pseudo-nitzschia* spp.	160	250,000	■
	C17	Bottom	*Pseudo-nitzschia* spp.	160	250,000	■
	C29	Bottom	*Pseudo-nitzschia* spp.	80	250,000	■
	C30	Bottom	*Dinophysis* spp.	80	500	■
	C31	Bottom	No toxic species detected	NA	NA	■
	C32	Bottom	*Pseudo-nitzschia* spp.	320	250,000	■
			Dinophysis spp.	80	500	

Notes:

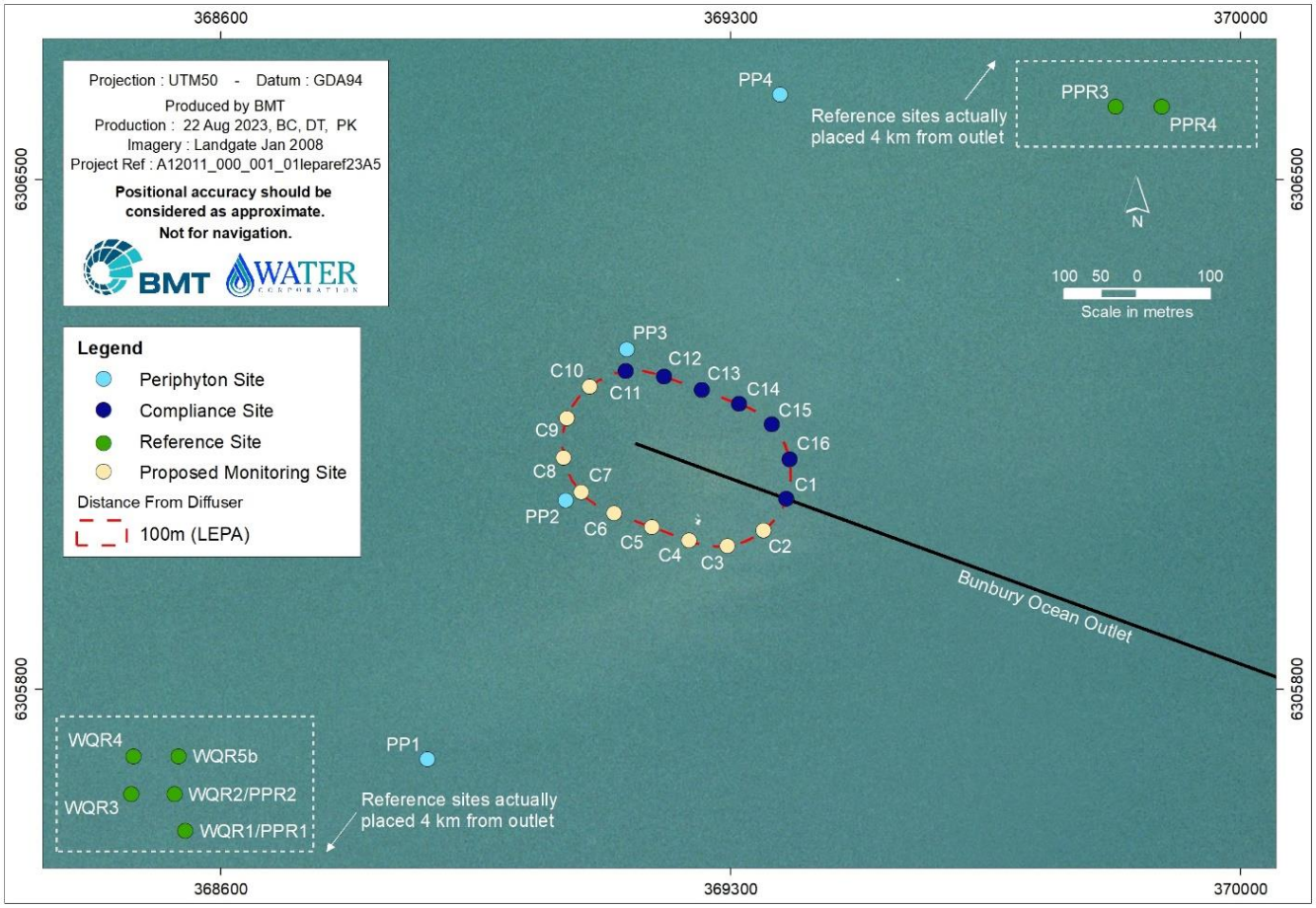
1. WASQAP = Western Australian Quality Assurance Program (DoF 2007, as per Water Corporation 2012).
2. NA = not applicable.
3. Green symbols indicate the estimated cell density was below the WASQAP toxic algae trigger concentration.

5 Primary and secondary contact recreation

5.1 Sampling approach and site locations

The EQO for the EV 'Recreation' [and 'Aesthetics'] is aimed at ensuring coastal waters are safe for primary and secondary contact recreation activities such as swimming and boating, respectively. To meet the EQO, water quality around the Bunbury ocean outlet is to be maintained so that primary and secondary contact recreation is safe in all waters except those areas designated otherwise.

Water quality monitoring sites (C1–C16) are positioned along the boundary of the LEPA, but on each sampling occasion (January, February and March), only the five sites directly down current of the diffuser are sampled (Figure 5.1).



Notes: 1. Water quality monitoring occurred at compliance sites C11–C15 on 10 January, C11–C15 on 8 February and at C1, C13–C16 on 16 March 2023, as a result of prevailing currents at the time of sampling.

Figure 5.1 Primary and secondary recreational contact compliance (C1-C16) sites and reference monitoring sites (WRQ1-WQR5b)

5.2 Faecal pathogens sampling

Disease-causing microorganisms (pathogens) associated with bathing areas include salmonellae, *Shigellae, enteropathogenic*, *Escheria coli*, cysts of *Entamoeba histolytica*, parasite ova and infectious hepatitis (Hart 1974, McNeil 1985; cited in ANZECC/ARMCANZ 2000). The most common types of diseases associated with water borne pathogens are eye, ear, nose and throat infections, skin diseases and gastrointestinal disorders (ANZECC/ARMCANZ 2000). Detecting faecal pathogens within water samples is difficult, therefore 'indicator' micro-organisms are used to assess the health risks associated with pathogens in recreational waters (Elliot & Colwell 1985; cited in ANZECC/ARMCANZ 2000).

To test for presence of pathogens, water samples were taken from the surface and bottom of the water column at compliance monitoring sites, shoreline monitoring sites, plume tracking sites and reference sites on 10 January, 08 February and 16 March 2023 and analysed for *Enterococci* spp. Samples were collected in pre-sterilised bottles before being chilled and placed in the dark. On completion of sampling, the samples were transferred to the PathWest Laboratory and analysed according to NATA-accredited methods (Appendix 5).

5.3 Faecal pathogen results

The EQG for faecal pathogens is outlined in Table 5.1.

Table 5.1 *Enterococci* spp. concentrations downstream of the Bunbury ocean outlet

EQG	The 95th percentile of pooled *Enterococci* spp. concentrations in surface waters is not to exceed 40 MPN/100 mL outside the LEPA boundary

Source: Water Corporation (2012)

Notes: 1. MPN = most probable number; LEPA = low ecological protection area.

The 95th percentile of pooled *Enterococci* spp. concentrations in surface waters was 135 MPN/100 mL (Table 5.2). Therefore, the EQG was not met and further assessment against the EQS is required. The EQS states that 95th percentile of the pooled *Enterococci* organism data from shoreline sites, when compared against the upper National Health and Medical Research Council (NHMRC 2008) Category A value, should not exceed 40 MPN/100 mL.

Table 5.2 *Enterococci* spp. concentrations downstream of the Bunbury ocean outlet

Date	Compliance site	*Enterococci* spp. in surface waters (MPN/100 mL)	*Enterococci* spp. in bottom waters (MPN/100 mL)
10 January 2023	C11	63	<10
	C12	73	<10
	C13	41	<10
	C14	280	<10
	C15	10	<10
08 February 2023	C11	<10	<10
	C12	<10	<10
	C13	<10	<10
	C14	<10	<10
	C15	<10	<10
16 March 2023	C1	<10	<10
	C13	<10	<10

Date	Compliance site	*Enterococci* spp. in surface waters (MPN/100 mL)	*Enterococci* spp. in bottom waters (MPN/100 mL)
	C14	<10	<10
	C15	<10	<10
	C16	<10	<10
95th percentile of compliance sites		**135**	**<10**

The 95th percentile of the pooled *Enterococci* organism data from shoreline sites was 10 MPN/100 mL (Table 5.3); therefore, the EQS was met.

Table 5.3 *Enterococci* spp. concentrations at the shoreline sites.

Date	Shoreline site	*Enterococci* spp. (MPN/100 mL)
10 January 2023	A	<10
	B	<10
	C	<10
	D	<10
	E	<10
	F	<10
	G	<10
	H	10
	I	<10
08 February 2023	A	10
	B	<10
	C	<10
	D	<10
	E	<10
	F	<10
	G	<10
	H	<10
	I	<10
16 March 2023	A	<10
	B	<10
	C	<10
	D	<10
	E	<10
	F	<10
	G	<10
	H	10
	I	10
95th percentile of shoreline sites		**10**

5.4 Algal biotoxins sampling

Algal biotoxins resulting from increased nutrient loads can be harmful to human/animal health if encountered via ingestion or skin contact. Although most algal blooms are considered harmless, some may contain species that produce toxins that are harmful to humans. For this reason, phytoplankton cell counts were monitored on three sampling occasions during summer (10 January, 8 February and 16 March 2023) to ensure concentrations are occurring within acceptable guideline limits (NHMRC 2008).

5.5 Algal biotoxins results

The EQG for algal biotoxins is outlined in Table 5.4.

Table 5.4 Environmental Quality Guideline for algal biotoxins

EQG	Median total phytoplankton cell count (either from one sampling occasion or from a single site over an agreed period of time) should not exceed 10 cells/mL *Karenia brevis* and/or have *Lyngbya majuscula* and/or *Pfiesteria* sp. present in high numbers outside the LEPA

Source: Water Corporation (2012)

Notes: 1. LEPA = low ecological protection area

Toxic algae species *Karenia brevis*, *Lyngbya majuscula* and *Pfiesteria* spp. were not recorded at compliance monitoring sites at the boundary of the LEPA during the 2023 summer monitoring and the EQG relevant to algal biotoxins (for the EQO, Maintenance of Primary and Secondary Contact Recreation) was met.

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