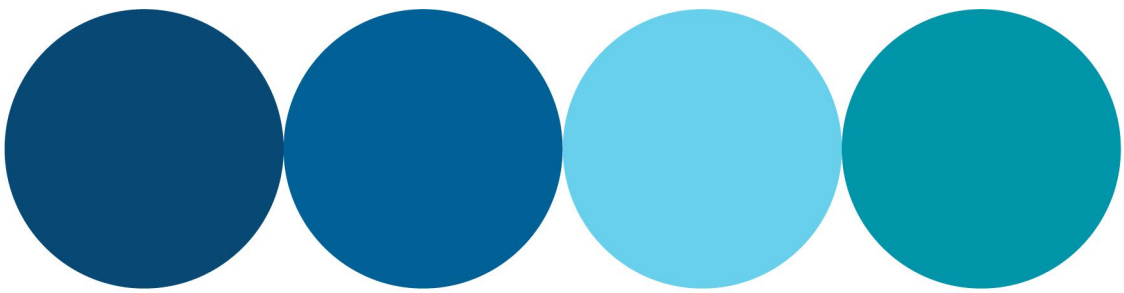
Perth Long Term Ocean Outlet Monitoring Program (PLOOM)

Beenyup Water Resource Recovery Facility

2023-2024 Annual Report



WATER CORPORATION

Document Management

This report has been prepared for Water Corporation by BMT, October 2024, Report Number 003034.

Document history

Distribution

Revision	*Author*	*Recipients*	*Organisation*	*No. copies & format*	*Date*
A	B Coelho	M Lourey	BMT	1 x docm	10/05/2024
B	M Lourey	M Nener	Water Corporation	1 x docm	14/06/2024
0	M Lourey	M Nener	Water Corporation	1 x docm	02/12/2024
1	M Lourey	M Nener	Water Corporation	1 x docm	19/12/2024

Review

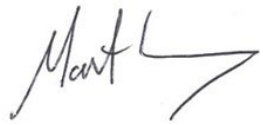
Revision	*Reviewer*	*Intent*	*Date*
A	M Lourey	Technical and editorial review	15/05/2024
B	M Nener	Client review	25/11/2024
0	M Nener	Client review	17/12/2024
1	M Lourey	Review	19/12/2024

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

Status

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

Approved for final release:



Author
Date: 19/12/2024

Contents

Acronyms

Acronym	Extension
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
CFU	Colony forming unit
CTWWC	Comprehensive Treated Wastewater Characterisation
DO	Dissolved oxygen
DoH	Western Australian Department of Health
DPIRD	Western Australia Department of Primary Industries and Regional Development
EPA	Environmental Protection Authority
EQC	Environmental Quality Criteria
EQG	Environmental Quality Guideline
EQMF	Environmental Quality Management Framework
EQO	Environmental Quality Objective
EQS	Environmental Quality Standard
EV	Environmental Value
HEPA	High ecological protection area
LAC	Light attenuation coefficient
LEPA	Low ecological protection area
LoR	Limit of reporting
EMMP	Environmental Monitoring and Management Plan
MPN	Most probable number
NATA	National Association of Testing Authorities
NOEC	No observed effect concentration
OZI	Observed Zone of Influence
PLOOM	Perth Long Term Ocean Outlet Monitoring
TCM	Trial Compliance Monitoring
TTC	Thermotolerant coliforms
TTM	Total toxicity of the mixture
TWW	Treated wastewater
WASQAP	Western Australian Shellfish Quality Assurance Program
WET	Whole of effluent toxicity
WRRF	Water Resource Recovery Facility
WWTP	Wastewater Treatment Plant

What do the results in this report mean for our community?

Ocean discharge is practiced worldwide and is a safe, sustainable and cost effective, way to dispose of wastewater. Treated wastewater from Perth's Water Resource Recovery Facilities (WRRF's) are discharged to the ocean via ocean outlets and is diluted through a number of physical and chemical processes. It is lighter and lower in density, so it rises and mixes with seawater, diluting the wastewater. Ocean outlet activities are regulated by the Department of Water and Environmental Regulation.

Water Corporation discharges treated wastewater from the Beenyup WRRF to the ocean via the Ocean Reef outlet. The Environmental Protection Authority (EPA; an independent authority appointed by the Governor on the recommendation of the Minister for Environment) has designated an area with a radius of 100 metres as a Low Ecological Protection Area (or LEPA). Within this area, the EPA allows for changes to marine water quality. Outside the LEPA, the EPA has designated the surrounding ocean to be a High Ecological Protection Area (HEPA) and expects there to be no detectable change in marine water quality.

Water Corporation undertakes investigations to test that water quality has returned to within the natural range expected in the HEPA and protect the environment and recreational users (swimmers, boaters and fishers). The Perth Long-term Ocean Outlet Monitoring (PLOOM) program comprises of these investigations. Water samples are collected within the LEPA, at the boundary of the LEPA and the HEPA, and at reference sites selected to be as similar as possible to the waters around the outlets. Results from the monitoring are compared against nationally agreed criteria. There are two levels of criteria - a simple, conservative early warning trigger (Environmental Quality Guideline or EQG) and a more detailed, complicated assessment of potential impacts (Environmental Quality Standard or EQS).

This annual report documents the findings of the 2023-2024 Ocean Reef ocean monitoring as part of the PLOOM program. The compliance results for 2023-2024 and for the previous five years (2018-2019, 2019-2020, 2020-2021, 2021-2022 and 2022-2023) are summarised in Report Card format 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.

Summary report card legend

Management response	Colour
Monitor: EQG & EQS 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.

Summary of key indicators

Ecosystem integrity

Ecosystem Integrity aims to protect the ecosystem from potential impacts from the discharge and maintain the variety and quantity of marine life at a high level. The top indicators we look at that give us an understanding of this are as follows:

Indicator	Indicator purpose	Result	Commentary
Toxicants in treated wastewater (TWW)			
Bioaccumulating toxicants	Cadmium and mercury are toxicants that can build up in the tissues of marine organisms and contaminate seafood. The concentration of these toxicants are measured in undiluted TWW against national guidelines that are designed to protect marine life.		Concentrations of cadmium and mercury were below the national guideline values.
Non-bioaccumulating toxicants	Some contaminants commonly discharged with domestic wastewater (e.g. detergents, metals and oils) may find their way into treated wastewater and monitoring ensures they are not directly toxic or likely to accumulate in marine life. Wastewater was screened for toxic substances and the concentrations were below the early warning EQG.		Concentrations of toxicants were below the national guideline values.
Total toxicity of the mixture (TTM)	TTM measures the potential for a combined, or cumulative, effect of ammonia, copper, and zinc in the TWW after it has been diluted into the ocean. It is used as an additional interpretative tool for estimating the potential toxicity of TWW.		The total toxicity of the mixture was below the national guideline value.
Whole of effluent toxicity (WET) testing	WET testing is another tool to test the potential toxicity of the TWW to marine life. WET testing is particularly useful for toxicants that occur in very low concentrations, or for which there are no national guidelines on safe levels. Direct tests on organisms determine the actual toxicity of the wastewater demonstrate that the discharge is not harmful to the ocean environment.		The TWW plume is sufficiently diluted to achieve the No Ecological Effects Concentration at the management boundary.
Nutrient enrichment and phytoplankton blooms			
Chlorophyll-*a*	Phytoplankton are a naturally occurring part of the marine environment, but treated wastewater contains nutrients (ammonia, nitrite, nitrate and orthophosphate) that can stimulate		Chlorophyll-*a* concentration outside the direct vicinity of the Ocean Reef outlet exceeded both the early warning EQG and the more rigorous EQS. This is likely due to naturally occurring

Indicator	Indicator purpose	Result	Commentary
	phytoplankton growth. Chlorophyll-*a* (the active constituent in phytoplankton) concentration is used as an indicator for phytoplankton abundance.		increases over time. See below for further information.
Light attenuation coefficient	Increased phytoplankton can also block (attenuate) light from reaching the bottom (impacting seagrass and macroalgae).		Light attenuation outside the direct vicinity of the Ocean Reef outlet exceeded the early warning EQG but the more rigorous EQS was met. Light transmission to the sea floor was not reduced over the long term at Ocean Reef.
Chlorophyll a The higher-than-normal chlorophyll-*a* (and associated light attenuation) were due to naturally occurring increases over time. Concentrations around the outlet were similar to the reference sites indicating that the gradual increase over time is regional and not a result of the ocean discharge. This increase in the baseline has caused chlorophyll-*a* concentrations and light attenuation to exceed their EQG and/or EQS criteria. The EQG should be updated to account for the high background to prevent confusion and focus on identifying actual impacts in the future. Water Corporation is in the process of investigating the apparent EQC exceedances with the aim of formulating and if necessary, implementing a formal response.			
Physical & chemical stressors			
Organic enrichment	Organic matter in treated wastewater is naturally decomposed by bacteria. Oxygen dissolved in water is used by the bacteria during the decomposition process. If the bacteria use more dissolved oxygen (DO) than they produce, the DO levels fall. Low DO levels can be harmful to marine life. We measure the dissolved oxygen concentration against the Environmental Protection Authority (EPA) guidelines		The amount of DO was high at all times and at all locations near the outlet. DO levels near the outlet were similar to those at the reference sites. There was a very low risk of DO levels falling below critical levels.
Salinity	Salinity refers to the 'saltiness' of water. Treated wastewater is fresh whereas the ocean is saline. When treated wastewater is discharged to the ocean, salinity will be reduced in an area around the outlet until the fresher water is fully mixed with the saline seawater. Low salinity water may cause stress to marine life.		Measurements of salinity near the outlet were similar to the salinity at appropriate reference sites. Stress to marine life from low salinity is unlikely.

Seafood safe for human consumption

Seafood safe for human consumption aims to ensure that caught or grown seafood remains safe for eating. The top indicators we look at that give us an understanding of this are as follows:

Indicator	Indicator purpose	Result	Commentary
Microbial contaminants			
Thermotolerant coliforms (TTC) near the outlets	The risk from bacteria to seafood safety is assessed using the indicator organism thermotolerant coliforms.		The relevant concentrations of thermotolerant coliforms near the outlet and adjacent the beaches were below the level where they can be detected by the laboratory. The risk to public health from bacteria via seafood in the vicinity of the outfalls was very low.
Shoreline TTC			
Algal biotoxins			
Toxic phytoplankton species	In some cases, phytoplankton can contain species than can taint seafood.		Densities of potentially toxic phytoplankton species were below levels that would pose a risk to seafood.

Primary and secondary contact recreation

Primary and secondary contact recreation aims to ensure that water quality is suitable for primary (e.g. swimming and diving) and secondary (e.g. fishing and boating) recreation contact activities. The top indicators we look at that give us an understanding of this are as follows:

Indicator	Indicator purpose	Result	Commentary
Faecal pathogens			
Enterococci spp. at the outlets	The risk from bacteria to recreation contact (swimming and boating) is assessed using the indicator organism *Enterococci* spp.		The relevant concentrations of *Enterococci* spp. near the outlets and adjacent beaches were below the level where they can be detected by the laboratory. The risk to public health from bacteria via recreation in the vicinity of the outfalls was very low.
Shoreline *Enterococci* spp.			
Algal biotoxins			
Phytoplankton cell concentration	In some cases, phytoplankton can reach concentrations that may harm swimmers (called blooms). The level that defines an algal bloom for recreational purposes is a		The chlorophyll-*a* based guidelines for phytoplankton are well below a level that would be visible as an algal bloom. The highest total phytoplankton cell

	phytoplankton cell count exceeding 10,000 cells/mL.		concentration in the HEPA was 1,727 cells/mL. There were no phytoplankton blooms during the monitoring period

Aesthetics

Aesthetics aims to ensure that aesthetic values of the marine environment are protected. The top indicators we look at that give us an understanding of this are as follows:

Indicators	Indicator purpose	Result	Commentary
Aesthetic factors	Perth's coastal waters are aesthetically pleasing, and that aesthetic value needs to be protected. Nuisance organisms (macrophytes, scums, algal mats, blue-green algae and fungus), dead organisms, dirty water, oily films, debris, or objectionable odours have the potential to reduce the aesthetic appeal.		Aesthetic values of Perth coastal waters were maintained and protected.

For further results please refer to the full report below.

Executive Summary

This report documents the findings of the 2023–2024 Ocean Reef monitoring program. The report outlines the findings of three environmental monitoring programs:

- Trial Compliance Monitoring (TCM)
- Whole of Effluent Toxicity (WET) testing
- Comprehensive Treated Wastewater Characterisation (CTWWC).

Results are reported in the context of the Environmental Quality Management Framework (EQMF) described in EPA (2017). Under the EQMF, Water Corporation should annually demonstrate achievement against Environmental Quality Objectives (EQOs):

- Maintenance of Ecosystem Integrity
- Maintenance of Seafood for Human Consumption
- Maintenance of Primary and Secondary Recreation
- Maintenance of Aesthetic Values.

The compliance results for 2023-2024 and for the previous five years (2018-2019, 2019-2020, 2020-2021, 2021-2022 and 2022-2023) are summarised in Report Card format 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 1 Summary report card legend

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

Note:

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

Environmental Quality Objective 'Maintenance of Ecosystem Integrity'

There are several EQC relevant to the 'EQO Maintenance of Ecosystem Integrity': the first is assessed based on the constituents of the treated wastewater (TWW) stream and their potential toxicity, while the remainder are based on monitoring of water column nutrients, phytoplankton abundance and physical-chemical stressors in the receiving environment.

Toxicants in treated wastewater

There are four Environmental Quality Guidelines (EQGs) for TWW toxicants:

- Concentrations of bioaccumulating toxicants (specifically, cadmium and mercury) must be below their respective ANZG (2018) 80% species protection guidelines prior to discharge and dilution with seawater. Concentrations of bioaccumulating toxicants were below their laboratory limits of reporting and the 80% species protection guidelines in all cases, thus meeting the EQG.

- Concentrations of non-bioaccumulating contaminants must not exceed the ANZG (2018) 99% species protection guideline at the notional Low Ecological Protection Area (hereafter LEPA) boundary (100 m radius from the diffuser). Initial dilution modelling for conditions on 23 January 2024 found that the Ocean Reef outlets were achieving a worst-case average initial dilution of 1:385 (at Outlet B; 1:409 at Outlet A). This was sufficient to dilute all contaminants to concentrations below their respective 99% species protection guidelines. EQG 2 for toxicants in TWW was therefore met.
- The total toxicity of the mixture (TTM) for the additive effect of ammonia, copper, and zinc in the diluted TWW plume must be less than 1.0 (ANZG 2018). The TTM following initial dilution was 0.59, which is lower than the guideline and EQG 3 was met.
- The highest concentration of TWW at which there is no statistically significant observed effect on fertilisation of sea urchin gametes exposed to different concentrations of TWW (NOEC) must be greater than 1.0% TWW concentration. The lowest NOEC from tests undertaken in October 2023, January 2024 and April 2024 was 50% and the EQG 4 was met.

Water quality monitoring – receiving environment

Ocean sampling was conducted fortnightly between December 2023 and March 2024 at fixed distance intervals down-current (determined using a drogue) of the outlets. There are six Environmental Quality Guidelines (EQGs) based on chlorophyll-*a* concentration (a measure of phytoplankton biomass), water temperature, salinity, dissolved oxygen and light attenuation coefficient:

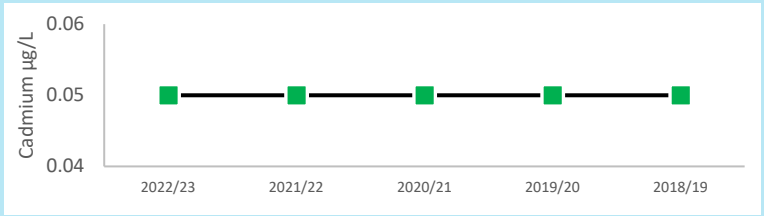
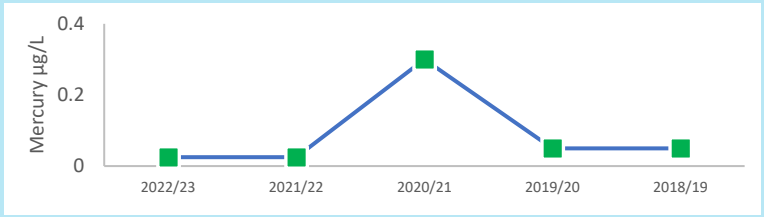
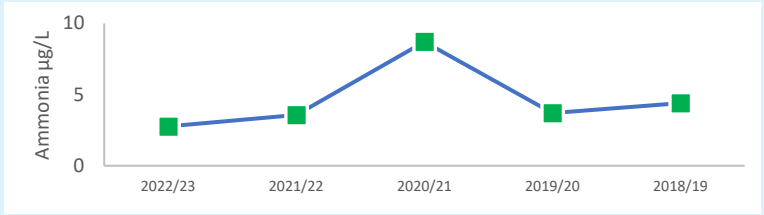
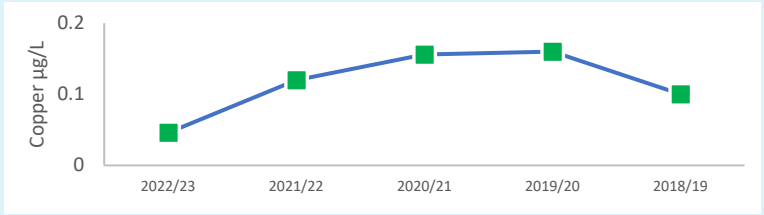
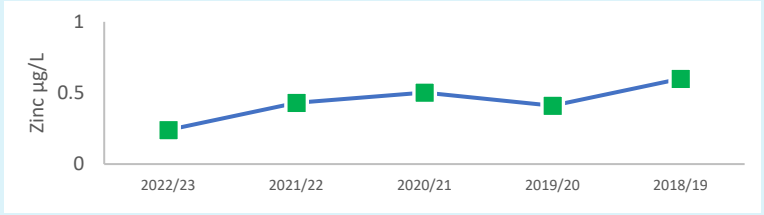
- The median chlorophyll-*a* concentration in the HEPA (i.e., 100 m and greater from the diffuser) during the non-river flow period must not exceed the 80th percentile of historical reference site data. Median chlorophyll-*a* concentration within the high ecological protection area (HEPA; 0.8 µg/L) was higher than the 80th percentile of historical reference site concentrations (0.4 µg/L) and the EQG was not met triggering assessment against the EQS.
  - The EQS requires that the EQG is not to be exceeded in two consecutive years. Median chlorophyll-*a* concentration in the Ocean Reef HEPA during 2022–23 (0.55 µg/L) was also above the 80th percentile of historical reference site data (0.4 µg/L), the EQG was exceeded in two consecutive years and the EQS was not met.
- The median light attenuation coefficient in the HEPA must not exceed the 80th percentile of historical reference site data. Median LAC within the HEPA (0.098 Log_{10}/m) was higher than the 80th percentile of historical reference sites (0.094 Log_{10}/m) and the EQG was not met triggering assessment against the EQS.
  - The EQS requires that the EQG is not to be exceeded in two consecutive years. Median LAC in the Ocean Reef HEPA during 2022-23 (0.0877 Log_{10}/m) was below the 80th percentile of historical reference site data (0.093 Log_{10}/m), the EQG was not exceeded for two consecutive years and the EQS was met.
- Median phytoplankton biomass, measured as chlorophyll-*a* must not exceed three times the median chlorophyll-*a* concentration of historical reference sites, on any occasion. Median chlorophyll-*a* concentrations exceeded three times the median of reference sites on five occasions (6 December 2023, 12 and 23 January, 08 and 19 March 2024) and the EQG was not met triggering assessment against the EQS.
  - EQGs are not to be exceeded in two consecutive years. Median phytoplankton biomass measured as chlorophyll-*a* exceeded three times median chlorophyll-*a* concentration of historical reference sites on three occasions in 2022–23, the EQG was exceeded in two consecutive years and the EQS was not met.
- Phytoplankton biomass measured as chlorophyll-*a* at any site must not exceed three times the median chlorophyll-*a* concentration of historical reference sites, on 25% or more occasions. Phytoplankton biomass, measured as chlorophyll-*a*, exceeded three times the median chlorophyll-*a* concentration of historical reference sites (0.6 µg/L) on more than 25% of occasions at all four HEPA sites and the EQG was not met triggering assessment against the EQS.
  - EQGs are not to be exceeded in two consecutive years. Phytoplankton biomass measured as chlorophyll-*a* exceeded three times the median chlorophyll-*a* concentration of historical reference sites on 37.5% of occasions at two HEPA sites (350 and 1500 m) during the 2022-2023 non-river flow period, the EQG was exceeded in two consecutive years and the EQS was not met.

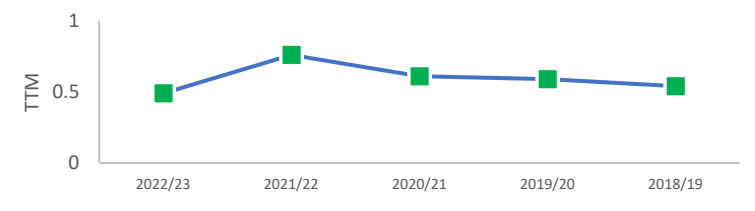
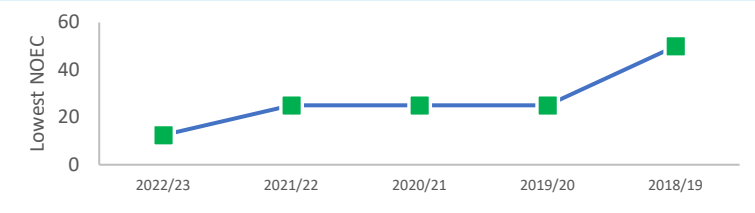
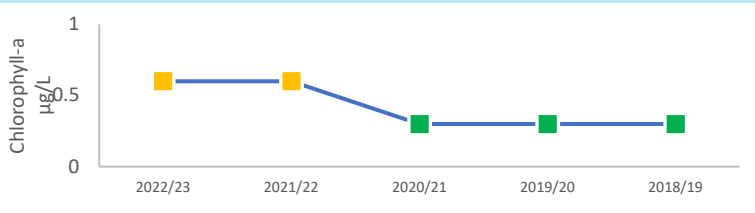
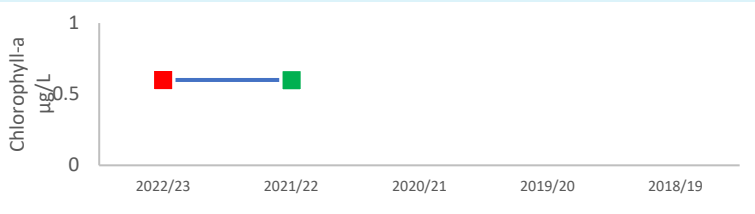
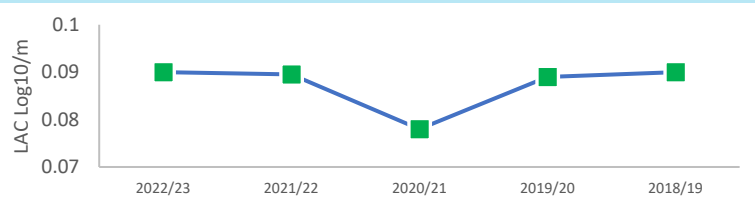
- Median dissolved oxygen in bottom waters (0–0.5 m above the sediment surface) in the HEPA must be greater than 90% saturation at any site for a defined period of not more than 6 weeks. Dissolved oxygen saturation within the HEPA was above 90% saturation at all times and the EQG was met.
- Median salinity (0.5 m below the water surface) at an individual site over any period is not to deviate beyond the 20th and 80th percentile of natural salinity range over the same period. Median salinity was between the 20th and 80th percentiles of the natural salinity range within the notional HEPA (at 100, 350, 1000, and 1500 m from the outlet) and the EQG was met.

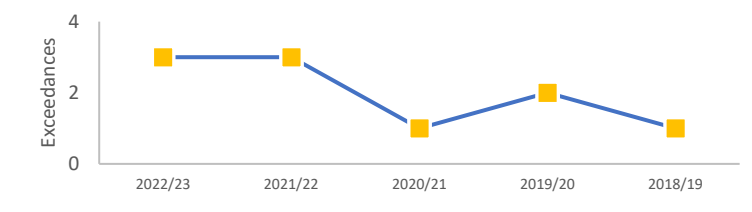
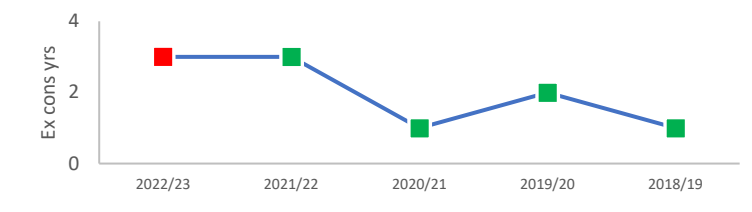
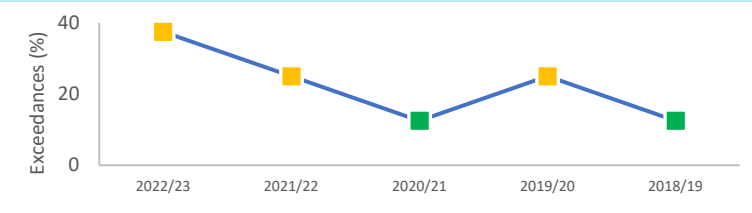
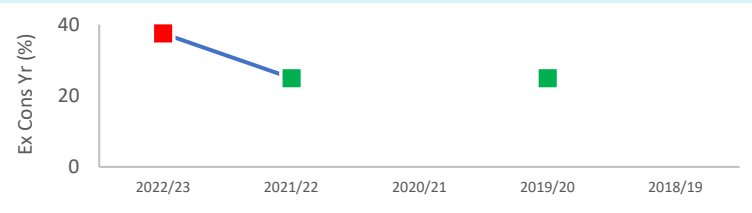
The exceedances of the EQG and EQS described above were due to a gradual increase in the background chlorophyll-*a* concentration (and associated increase in light attenuation). The EQC were met if assessed against the criteria based on the corresponding sampling period. With the formal approval of the Beenyup Ocean Outlets Monitoring and Management Plan (Water Corporation 2023) and likelihood on ongoing exceedances BMT recommends a formal investigation into the changing background chlorophyll-*a* concentration with the intent of developing a more robust protocol for determining variability at the reference sites.

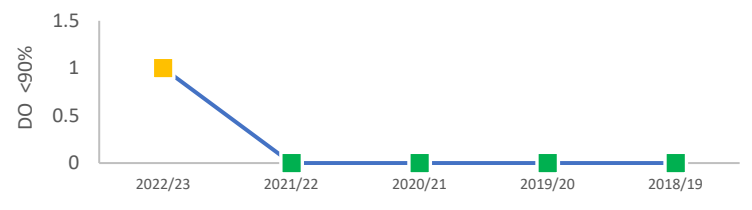
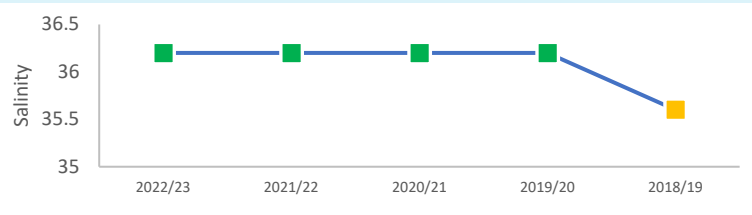
Water Corporation is in the process of investigating the apparent EQC exceedances with the aim of formulating and if necessary, implementing a formal response.

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

Environmental quality indicator		EQC	Comments	Compliance	Last 5 years (2018-2019 to 2022-2023)
Toxicants in treated wastewater (TWW)	Bioaccumulating toxicants	EQG 1	Concentrations of cadmium and mercury in the undiluted TWW stream were below their limit of reporting and the ANZG (2018) 80% species protection guidelines (36 and 1.4 µg/L, respectively).		 
	Non-bioaccumulating toxicants and initial dilution	EQG 2	Initial dilution on 23/01/2024 (1:385 at Ocean Outlet B) was sufficient to reduce non-bioaccumulating contaminant concentrations to below their ANZG (2018) 99% species protection guidelines.		  

Environmental quality indicator		EQC	Comments	Compliance	Last 5 years (2018-2019 to 2022-2023)
	Total toxicity of the mixture (TTM)	EQG 3	The TTM for the additive effect of ammonia, copper, and zinc after initial dilution (0.59) was below the ANZG (2018) guideline of 1.0.		
	Whole of effluent toxicity testing	EQG 4	The lowest NOEC during the reporting period was 50%. Only two dilutions with background seawater are required to achieve this NOEC, which is lower than the worst-case dilutions achieved at the LEPA boundary during the monitoring period (1:385).		
Nutrient enrichment	Chlorophyll-*a*	EQG 1	Median chlorophyll-*a* concentration within the high ecological protection area (HEPA; 0.8 µg/L) was higher than the 80th percentile of historical reference site concentrations (0.4 µg/L).		
	Chlorophyll-*a*	EQS 1	Median chlorophyll-*a* concentration within the high ecological protection area (HEPA) was higher than the 80th percentile of historical reference sites in two consecutive years.		
	Light attenuation coefficient (LAC)	EQG 2	Median LAC within the HEPA (0.098 Log_{10}/m) was higher than the 80th percentile of historical reference sites (0.094 Log_{10}/m).		

Environmental quality indicator		EQC	Comments	Compliance	Last 5 years (2018-2019 to 2022-2023)
		EQS 2	Median LAC within the HEPA was not higher than the 80th percentile of historical reference sites in two consecutive years.		Not assessed in previous 5 years
Phytoplankton blooms	Phytoplankton biomass (measured as chlorophyll-*a*)	EQG 1	Median chlorophyll-*a* concentrations exceeded three times the median of reference sites on five occasions (6 December 2023, 12 and 23 January, 08 and 19 March 2024).		
		EQS 1	Median chlorophyll-*a* concentration exceeded three times the median of reference sites on five occasions in the 2023-2024 non-river flow period and three times in the 2022-2023 non-river flow period.		
		EQG 2	Phytoplankton biomass, measured as chlorophyll-*a*, exceeded three times the median chlorophyll-*a* concentration of historical reference sites (0.6 µg/L) on more than 25% of occasions at all four HEPA sites.		
		EQS 2	The EQG was exceeded in two consecutive years (phytoplankton biomass measured as chlorophyll-*a* also exceeded three times the median chlorophyll-*a* concentration of historical reference sites on 37.5% of occasions at two HEPA sites during the 2022-2023 non-river flow period).		

Environmental quality indicator		EQC	Comments	Compliance	Last 5 years (2018-2019 to 2022-2023)
Physical chemical stressors	Organic enrichment	EQG 1	Dissolved oxygen saturation within the HEPA was above 90% saturation at all times.	■	
	Salinity	EQG 2	Median salinity was between the 20th and 80th percentiles of the natural salinity range within the notional HEPA (at 100, 350, 1000, and 1500 m from the outlet).	■	

Notes:

1. Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) and red (■) symbols represent an exceedance of the EQG or Environmental Quality Standard (EQS), respectively.
2. LEPA = low ecological protection area.
3. HEPA = high ecological protection area.
4. LAC = light attenuation coefficient.
5. NOEC = no observed effect concentration; the highest concentration of TWW at which there is no statistically significant observed effect on gamete fertilisation.

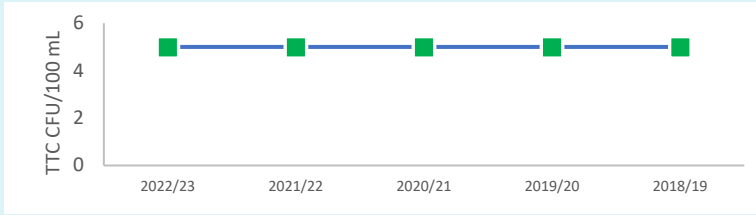
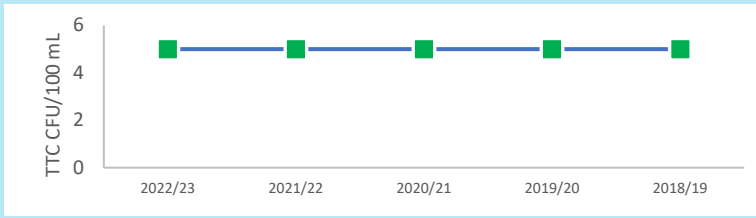
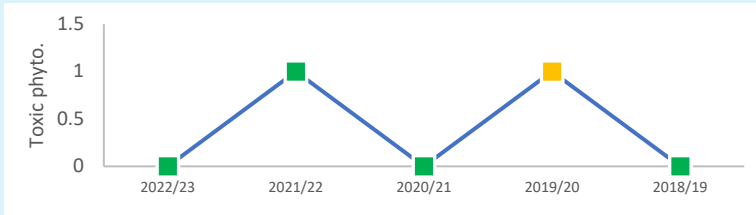
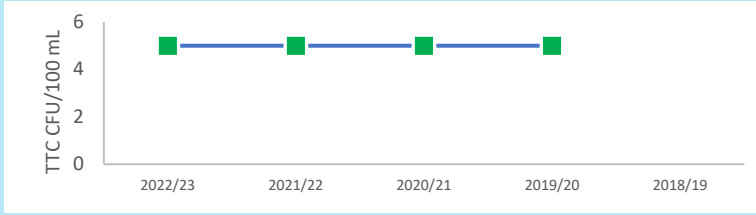
Environmental Quality Objective 'Maintenance of Seafood Safe for Human Consumption'

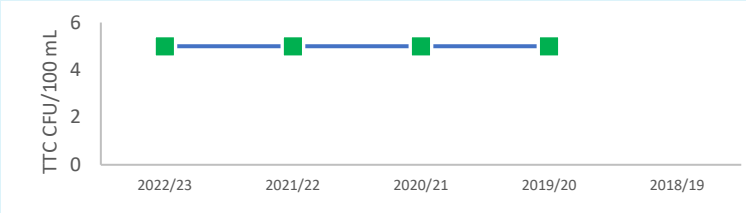
There are two EQC for the EQO 'Maintenance of the Seafood Safe for Human Consumption': the first is based on in-water concentrations of thermotolerant coliforms (TTC), and the second is based on in-water concentrations of toxic phytoplankton species (to monitor for algal biotoxins):

- To meet the EQG for TCC, median TTC concentrations at sites at the boundary of the Observed Zone of Influence (OZI) are not to exceed 14 CFU/100 mL and the 90th percentile of TTC concentrations must not exceed 21 CFU/100 mL. Median TTC concentration from three sampling seasons (2021-22, 2022-23 and 2023-24)[1] was at the limit of reporting (<10 CFU/100 mL) and below the 14 CFU/100 mL guideline. The 90th percentile TTC concentration was equal to the limit of reporting (<10 CFU/100 mL) and less than the 21 CFU/100 mL criteria. The EQG for TTC was met (Table ES 3).
- To meet the EQG for biotoxins, concentrations of potentially toxic algae at sites at the boundary of the OZI must not exceed the Western Australian Shellfish Quality Assurance Program (WASQAP; DoH, DPIRD and Industries 2020) concentrations. Densities of toxic phytoplankton were below relevant WASQP guidelines meeting the EQG for toxic phytoplankton species (Table ES 3).

[1] *NHMRC (2008) guidelines and EPA (2005) suggest that a minimum of 100 samples over the non-river flow period (pooled from multiple years if required) are needed for accurate assessment of microbial water quality EQC.*

Table ES 3 Summary report card for the Environmental Quality Objective 'Maintenance of Seafood Safe for Human Consumpt

Environmental quality indicator		EQC	Comments	Compliance	
Microbiological contaminants	Thermotolerant coliforms (TTC)	EQG: Median TCC concentrations at sites at the boundary of the OZI are not to exceed 14 CFU/100 mL and the 90th percentile of TCC concentrations must not exceed 21 CFU/100 mL.	Median TTC concentrations derived from 120 samples collected over the 2021-22, 2022-23 and 2023-24 sampling seasons was at the limit of reporting (<10 CFU/100 mL) and below the 14 CFU/100 mL criteria.		
			The 90th percentile was equal to the limit of reporting (<10 CFU/100 mL), and less than the 21 CFU/100 mL criteria.		
Algal biotoxins	Toxic phytoplankton species	EQG: Cell counts of potentially toxic algae species at sites at the boundary of the OZI are not to exceed the WASQP[5] guideline concentrations.	During the 2023-2024 monitoring period, there were no recorded instances of toxic phytoplankton species exceeding the Western Australian Shellfish Quality Guidelines.		
Microbiological contaminants at the shoreline sites[6]	Thermotolerant coliforms (TTC)	EQG: Median TTC concentrations at sites along the shoreline are not to exceed 14 CFU/100 mL and the 90th percentile of TCC concentrations must not exceed 21 CFU/100 mL	Median TTC concentrations derived from 128 samples collected over the 2022-2023 and 2023-2024 sampling seasons was at the limit of reporting (<10 CFU/100 mL) and below the 14 CFU/100 mL criteria.		

Environmental quality indicator		EQC	Comments	Compliance	
			The 90th percentile was equal to the limit of reporting (<10 CFU/100 mL), and less than the 21 CFU/100 mL criteria.		

Notes:

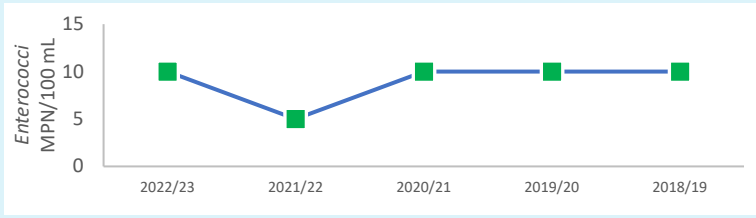
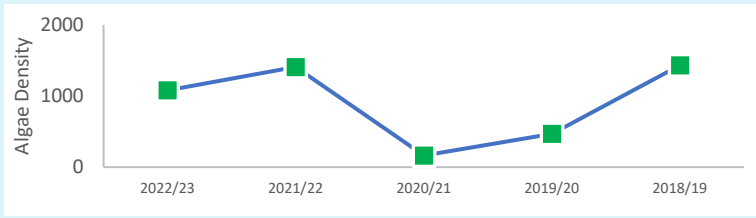
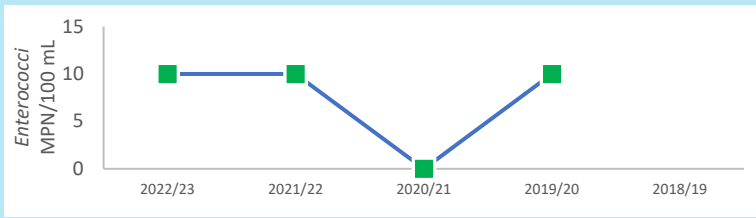
1. Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) symbol represents an exceedance of EQG.
2. TTC results below the analytical limit of reporting (<10 CFU/mL) were halved (=5 CFU/mL) to calculate median value (ANZG 2018).
3. TTC = Thermotolerant coliforms, CFU = colony forming units.
4. OZI = Observed zone of influence.
5. Marine Biotoxin Monitoring and Management Plan 2020 version 2: Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH, DPIRD and Industry, 2020).
6. Shoreline monitoring commenced in 2020-21 sampling season. Shoreline sites are not formally assessed against the EQC.

Environmental Quality Objective 'Maintenance of Primary and Secondary Recreation'

There are two EQC for the EQO 'Maintenance of Primary and Secondary Recreation': the first is based on in-water concentrations of faecal pathogens (*Enterococci* spp.), and the second is based on in-water measures of total phytoplankton cell densities.

- To meet the *Enterococci* spp. EQGs, the 95th percentile value of faecal pathogens (*Enterococci* spp.) outside the Observed Zone of Influence (OZI) boundary must not exceed 200 MPN/100 mL and 2000 MPN/100 mL for primary and secondary contact recreation, respectively. The 95th percentile of *Enterococci* spp. concentrations based on pooled data from three sampling seasons (2021–2022, 2022–2023 and 2023–2024) was <10 MPN/100 mL meeting the EQGs for both primary (EQG 1) and secondary (EQG 2) contact recreation (Table ES 4).
- To meet the algal biotoxin EQG, total phytoplankton cell concentration at any site must not exceed 10,000 cells/mL. The highest total phytoplankton cell concentration was 1,727 cells/mL and the EQG was met (Table ES 4).

Table ES 4 Summary report card for the Environmental Quality Objective 'Maintenance of Primary and Secondary Contact Re

Environmental Quality Indicator		EQC	Comments	Compliance	
Faecal pathogens	*Enterococci* spp.	EQG 1 (primary contact; 200 MPN/100 mL)	The 95th percentile of *Enterococci* spp. concentrations (<10 MPN/100 mL) was lower than the 200 MPN/100 mL.	■	
		EQG 2 (secondary contact; 2000 MPN/100 mL)		■	
Algal biotoxins	Phytoplankton (cell concentration)	EQG (15 000 cells/mL)	Estimated total phytoplankton cell count at individual sites were <10,000 cells/mL at each site and sampling occasion during 2023-2024 monitoring.	■	
Faecal pathogens along the shoreline[2]	*Enterococci* spp.	EQG 1 (primary contact; 200 MPN/100 mL)	The 95th percentile of *Enterococci* spp. concentrations (<10 MPN/100 mL) was lower than the 200 MPN/100 mL.	■	
		EQG 2 (secondary contact; 2000 MPN/100 mL)		■	

Note:

1. Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met.
2. Shoreline monitoring commenced in 2020-2021 sampling season. Shoreline sites are not formally assessed against the EQC.

Environmental Quality Objective 'Maintenance of Aesthetic Values'

The EQO 'Maintenance of Aesthetic Values' is to ensure that Perth's coastal waters are aesthetically pleasing and that the aesthetic value is protected. There are a series of EQGs that ensure this EQO is being met:

- Macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae, and sewage fungus should not be present in excessive amounts. Nuisance organisms were not present in excessive amounts and the EQG was met (Table ES 5).
- There should be no reported incidents of large-scale deaths of marine organisms relating from unnatural causes. There were no instances of dead marine organism observed and the EQG was met (Table ES 5).
- The natural visual clarity of the water should not be reduced by more than 20%. Measurements of light attenuation determined that the natural visual clarity of the water was reduced by ~6% (i.e. <20%) and the EQG was met (Table ES 5).
- The natural hue of the water should not be changed by more than ten points on the Munsell scale. There was a noticeable colour variation (green tones) on six (75%) sampling occasions and the EQG was not met (Table ES 5).
  - The EQS requires no overall decrease in the aesthetic water quality values of the marine receiving environment using direct measures of the community's perception of aesthetic value. Water Corporation received complaints for the 2023-2024 non-river flow period, but these were due to *Trichodesmium* blooms at Mullaloo Beach and unrelated to the operation of the Ocean Outlets and the EQS was met (Table ES 5).
- Oil and petrochemicals should not be noticeable as a visible film on the water or detectable by odour. No surface films or oil were recorded on any sampling event and the EQG was met (Table ES 5).
- Water surfaces should be free of floating debris, dust and other objectionable matter, including substances that cause foaming. No floating debris or matter was visible on the surface on any sampling occasion and the EQG was met (Table ES 5).
- There should be no objectionable odour. No noticeable odour was detected on any sampling occasion and the EQG was met (Table ES 5).

Table ES 5 Summary report card for the Environmental Quality Objective 'Maintenance of Aesthetic Values'

Environmental Quality Indicator	EQC	Comments	Compliance[1]	Previous year (2022-2023)[2]
Nuisance organisms	EQG	Nuisance organisms were not present in excessive amounts.	■	■
Faunal deaths	EQG	There were no instances of dead marine organism observed.	■	■
Water clarity	EQG	Measurements of light attenuation determined that the natural visual clarity of the water was reduced by ~6% (i.e. <20%).	■	■
Colour	EQG	There was a noticeable colour variation (green tones) on six (75%) sampling occasions.	■	■
Surface films	EQG	No surface films or oil were recorded on any sampling event.	■	■
Surface debris	EQG	No floating debris or matter was visible on the surface on any sampling occasion.	■	■
Odour	EQG	No noticeable odour was detected on any sampling occasion.	■	■
Overall aesthetic water quality values of the marine receiving environment using direct measures of the community-s perception of aesthetic value	EQS	Water Corporation received complaints for the 2023-2024 non-river flow period, but these were due to Trichodesmium blooms at Mullaloo Beach and unrelated to the operation of the Ocean Outlets.	■	Not assessed

Note:

1. Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) and red (■) symbols represent an exceedance of the EQG or Environmental Quality Standard (EQS), respectively.
2. Aesthetics measurements for the Ocean Reef ocean outlets commenced in 2022-2023

1 Introduction

1.1 Document purpose

This annual report documents the findings of the 2023–2024 Ocean Reef ocean monitoring program, completed as part of the Perth Long-term Ocean Outlet Monitoring (PLOOM) Program. Monitoring was completed according to Western Australia's Environmental Quality Management Framework (EQMF; EPA 2016).

1.2 Water Resource Recovery Facility (WRRF) infrastructure and discharge

Water Corporation operates the Beenyup Water Resource Recovery Facility (WRRF) in metropolitan Perth, which treats approximately 116 ML wastewater per day to produce advanced secondary treated wastewater (TWW). The TWW is traditionally discharged to the sea through two ocean outlets at Ocean Reef (Figure 1). The outlets are 1.65 km (Outlet A) and 1.85 km (Outlet B) in length and located in ~10 m of water (Figure 1). Discharge commenced from Outlet A in 1978 and Outlet B in 1992.

Stage 1 of Water Corporation's Perth Groundwater Replenishment Scheme (GWRS) consists of a 14 GL/year capacity plant. Secondary TWW from the Beenyup WRRF is diverted into the Advanced Water Recycling Plant (AWRP) and further treated via ultrafiltration (UF), reverse osmosis (RO) and ultraviolet (UV) disinfection processes to drinking water standard for recharge of the confined aquifers.

The AWRP reduces the environmental impact of potable water extraction from the aquifer but with a corresponding reduction in the volume and change to the composition of the TWW being discharged to the marine environment through the ocean outlets. Expansion (Stage 2 of the GWRS) will increase the capacity of the AWRP to 28 GL/year, treat a larger proportion of the secondary TWW from the Beenyup WRRF for groundwater recharge and further reduce/alter the discharge to the ocean (Figure 1).

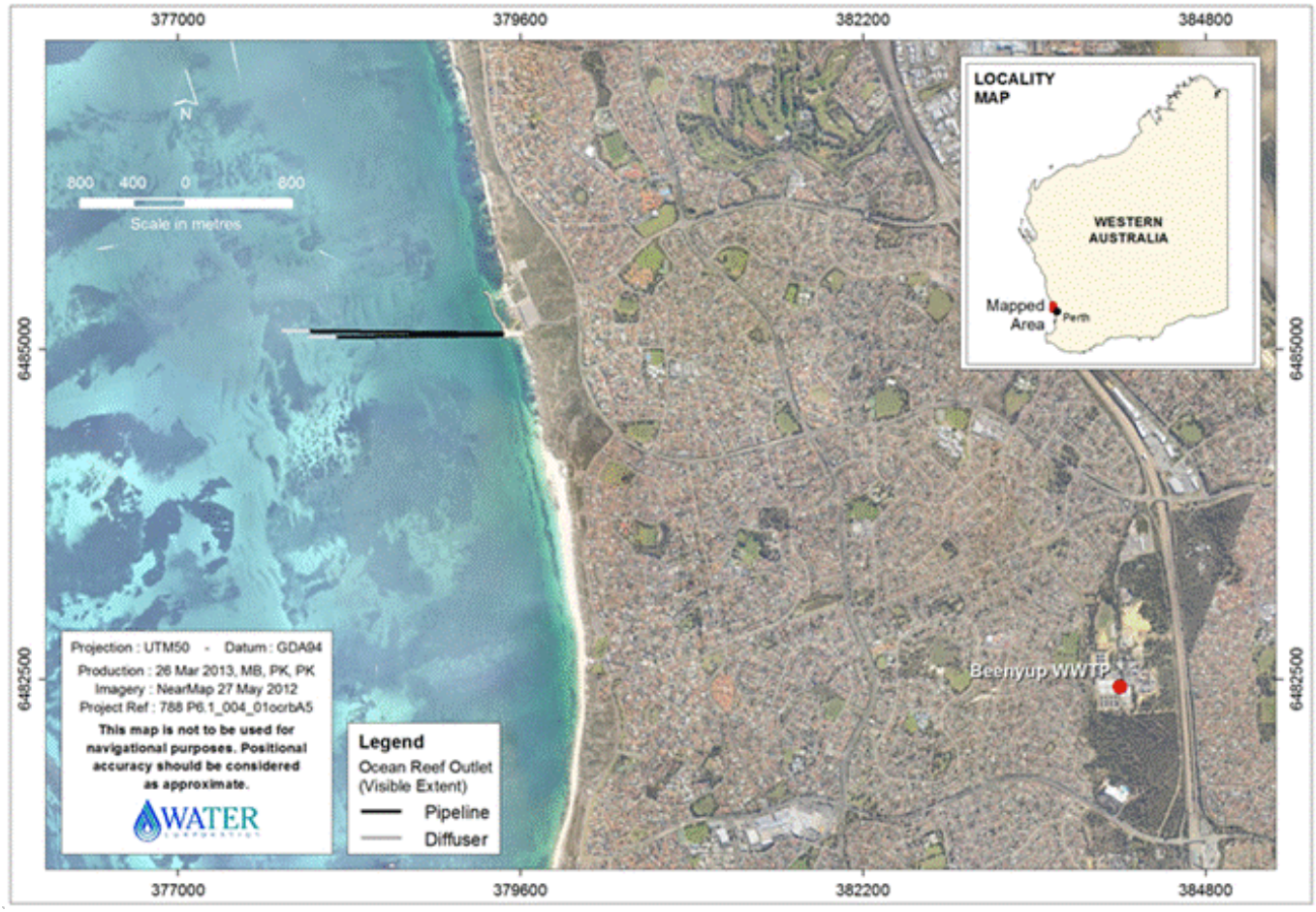
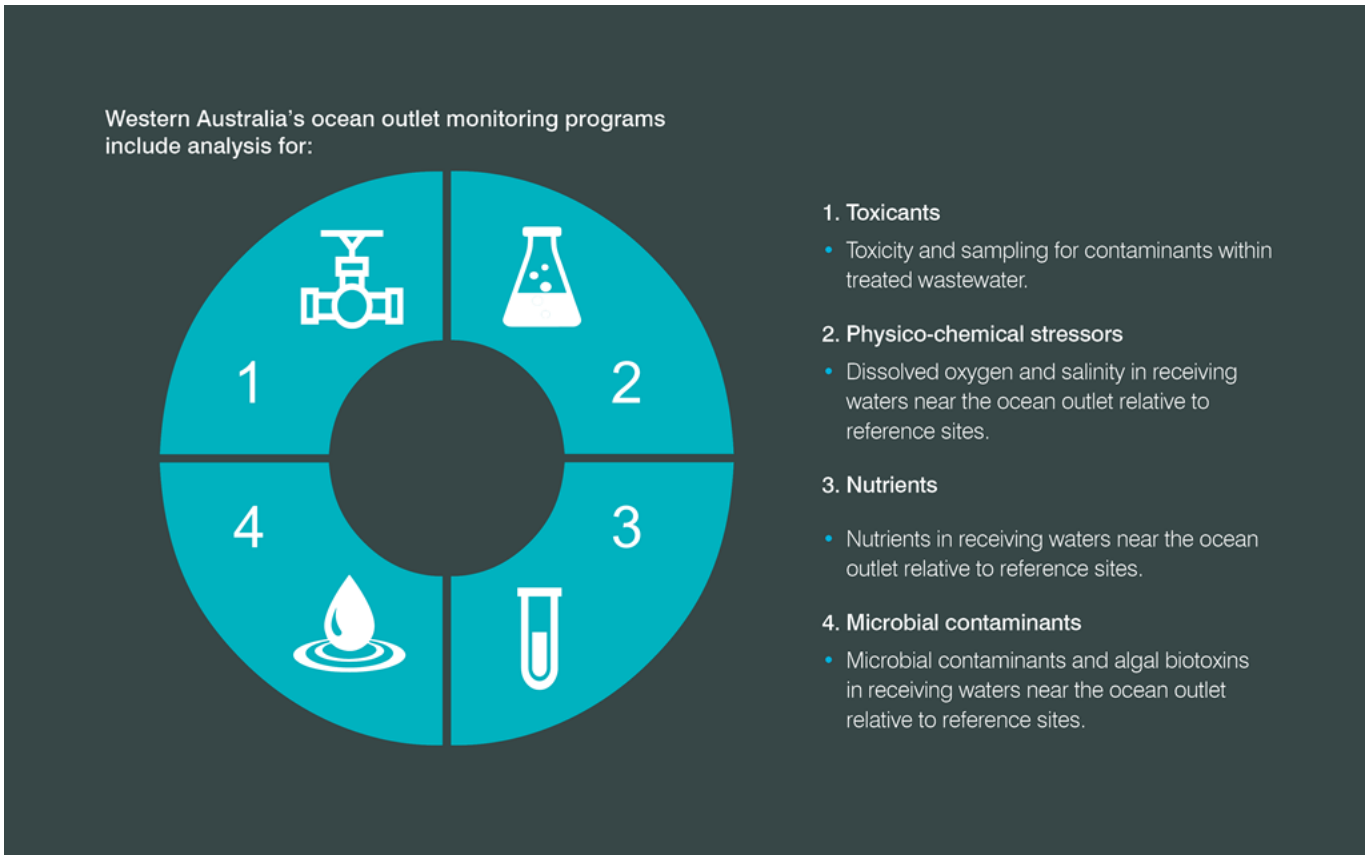


Figure 1 **Location of the Beenyup Water Resource Recovery Facility (includes the Advanced Water Recycling Plant) and Ocean Reef ocean outlets**

1.3 Potential stressors in treated wastewater



1.3.1 Toxicants

Metals and persistent organic compounds may be directly toxic to marine biota and/or may accumulate in marine biota at concentrations sufficient to pose a risk to humans if consumed. Under the PLOOM program, TWW is screened for bioaccumulating and non-bioaccumulating toxicants, and the concentrations are compared to relevant EPA guidelines. To account for the synergistic effects of multiple toxicants and toxicants without guidelines, the overall toxicity of the TWW is determined using whole effluent toxicity (WET) testing.

1.3.2 Physico-chemical stressors

TWW contains organic matter, the decomposition of which by microorganisms uses oxygen. If more dissolved oxygen (DO) is consumed than is produced, DO levels decline. Measurements of DO saturation in receiving waters near the outlet, relative to measurements at reference sites, provide an indication of the risk posed by deoxygenation.

Reduced salinity near the outlet, resulting from freshwater in the TWW plume, may cause osmotic stress in marine biota. Measurements of salinity in receiving waters near the outlet are compared to the salinity at appropriate reference sites. The comparison allows evaluation of whether salinity near the outlet is within the range of natural variation.

1.3.3 Nutrients

TWW contains elevated concentrations of biologically available nutrients such as ammonia, nitrite, nitrate and orthophosphate. At times, the addition of nutrients may stimulate phytoplankton growth beyond natural levels, which can lead to shading of photosynthetic organisms such as seagrasses and/or macroalgae. The potential for shading is measured using in-water measures of chlorophyll-*a* (a proxy for phytoplankton biomass) and light attenuation (a measure for water clarity).

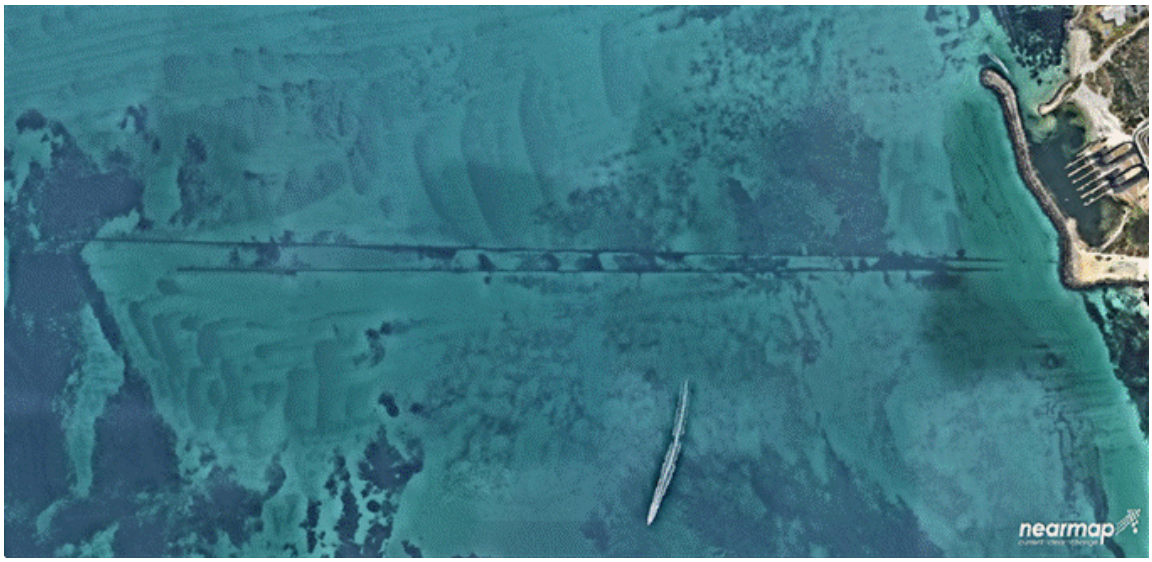
Although most algal blooms are harmless, some contain species that produce toxins that may be harmful to swimmers (via ingestion or skin contact) or contaminate seafood. Phytoplankton species composition and cell concentrations are monitored to ensure concentrations are within acceptable limits.

1.3.4 Microbial contaminants

Disease-causing organisms in the TWW pose a risk to humans if exposed during primary and/or secondary contact activities (i.e. swimming and boating). The same organisms, if ingested by marine fauna, may reduce their suitability for human consumption. To assess the risk, concentrations of indicator organisms are routinely compared to the Environmental Protection Authority's (EPA's) criteria for primary and secondary contact, and the criteria for seafood safe for human consumption.

1.4 Environmental management approach

Water Corporation's formal environmental commitments pertaining to this report are outlined in Ministerial Statements 382 and 569. To maintain consistency with the other metropolitan ocean outlet programs, the Ocean Reef outlets (Figure 2) were monitored as part of the Perth Long-Term Ocean Outlet Monitoring (PLOOM) program. The ocean monitoring program is consistent with the approach advocated under the State Government's EQMF, which is applied to Western Australia's coastal waters (EPA 2016).



Source: Nearmap Pty Ltd

Figure 2 Aerial image of the Ocean Reef ocean outlets

After the completion of the 2023-2024 monitoring program, Ministerial Statements 382 and 569 were replaced by Ministerial Statement 1219. Ministerial Statement 1219 implements the Beenyup Ocean Outlets Monitoring and Management Plan (Water Corporation 2023) which brings the management framework into line with contemporary Department of Water and Environmental Regulation policy (EPA 2017) and establishes formal management areas around the outlets.

1.5 Environmental Quality Management Framework (EQMF)

The EQMF is based on:

- Identifying Environmental Values (EVs) (Figure 3).
- Establishing and spatially defining Environmental Quality Objectives (EQOs) that need to be maintained to ensure the associated EVs are protected (Figure 3).
- 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 'guidelines' against which monitoring results can be compared.

There are two levels of EQC:

1. **Environmental Quality Guidelines** (EQGs) are quantitative investigative guidelines which, if met, indicate there is a high degree of certainty that 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 guidelines which, if exceeded, signify that the EQO is at risk of not being met and that a management response may be required.

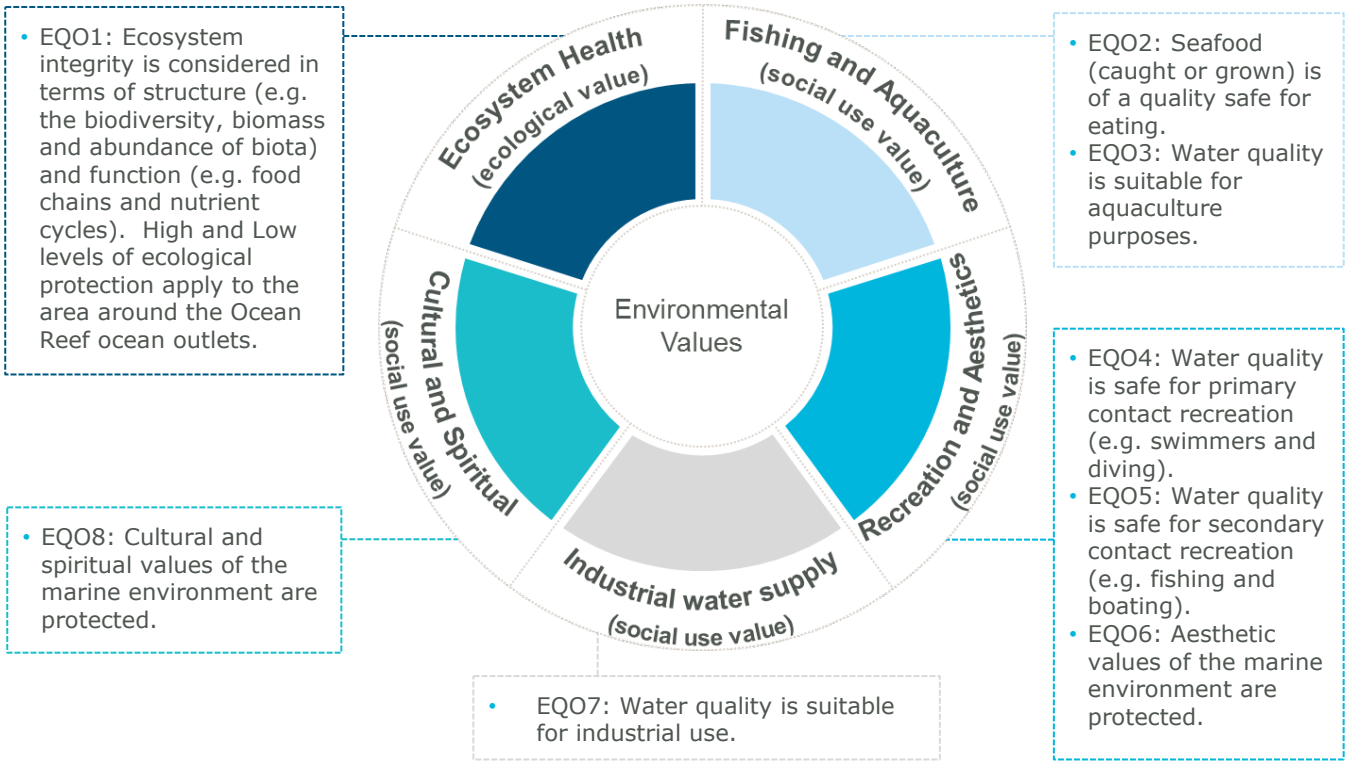


Figure 3 **Environmental Values and Environmental Quality Objectives (EQO) for the marine waters of Western Australia**

The compliance results for 2023-2024 are summarised in Report Card format (Table 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 1 Report card legend

Management response	Colour
Monitor: EQG & EQS 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.

1.5.1 'Maintenance of Ecosystem Integrity' EQO

The intent of this EQO is to maintain a healthy and diverse ecosystem. There are four levels of ecological protection, with each applied depending on the designated level required: low, moderate, high or maximum (Figure 4).

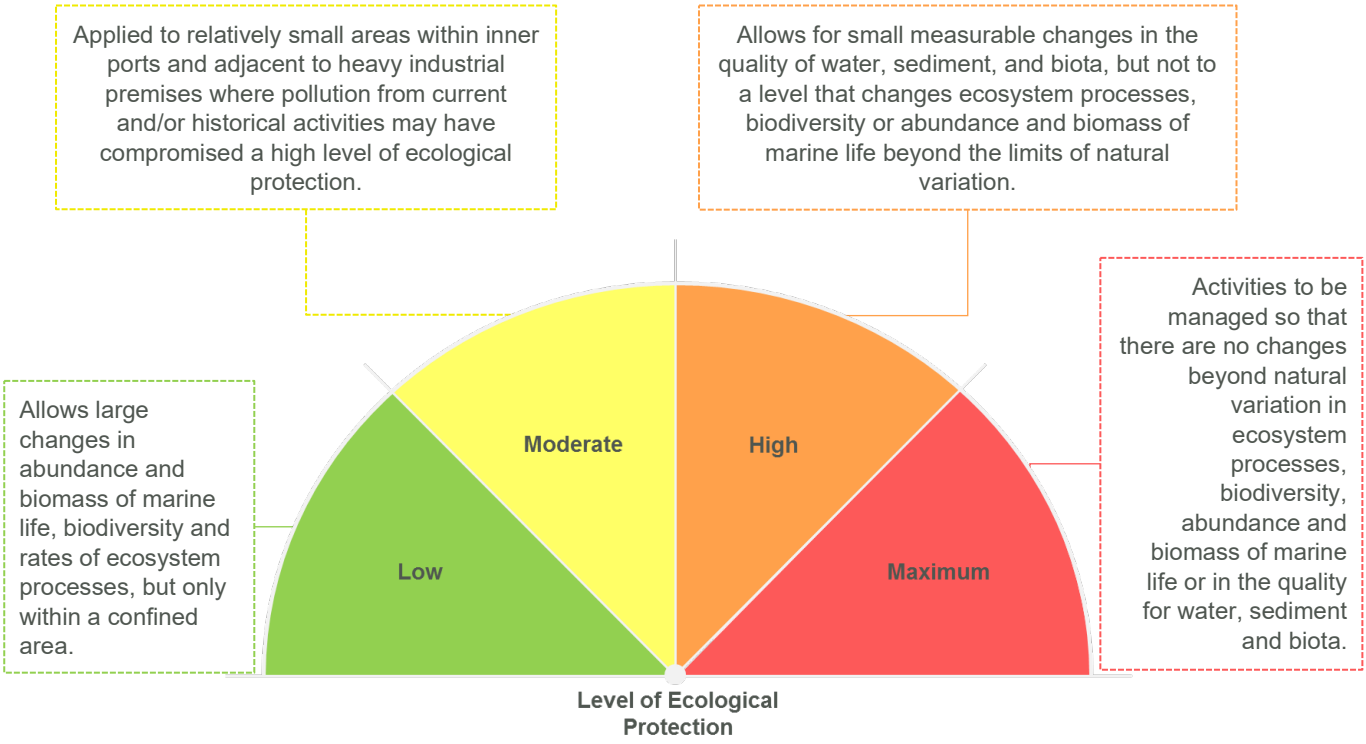


Figure 4 Level of Ecological Protection

A notional Low Ecological Protection Area (LEPA) has been established around the Ocean Reef outlets and occupies the area within a 100 m radius of the diffusers (Figure 5). A formal LEPA now applies following publication of Ministerial Statement 1219 in April 2024. Waters outside the notional LEPA are maintained to a high level of ecological protection (HEPA; Figure 5).

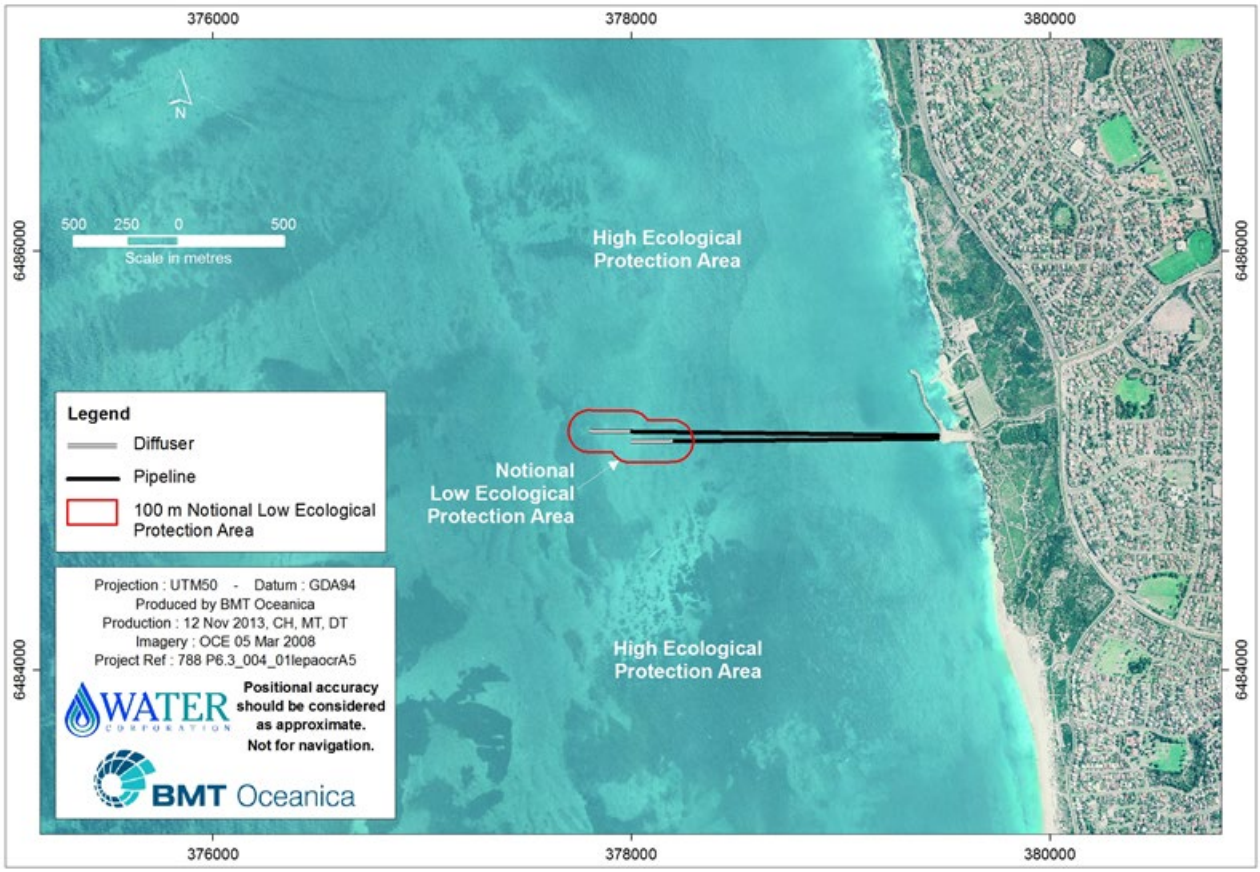


Figure 5 Ocean Reef ocean outlets notional ecological protection areas

1.5.2 'Maintenance of Seafood Safe for Human Consumption' EQO

The intent of this EQO is to maintain seafood safe for human consumption (a social value) outside a small area surrounding the ocean outlets where EQO 2 may not be achieved, and seafood may be unsafe to eat. An informal zone has been developed for the Ocean Reef outlets encompassing the management area for seafood safe for human consumption based on microbiological observations from historical ocean monitoring data (Figure 6). The zone represents the area where microbiological organism concentrations are most likely to exceed the EPA's criteria for seafood safe for human consumption under worst-case conditions.

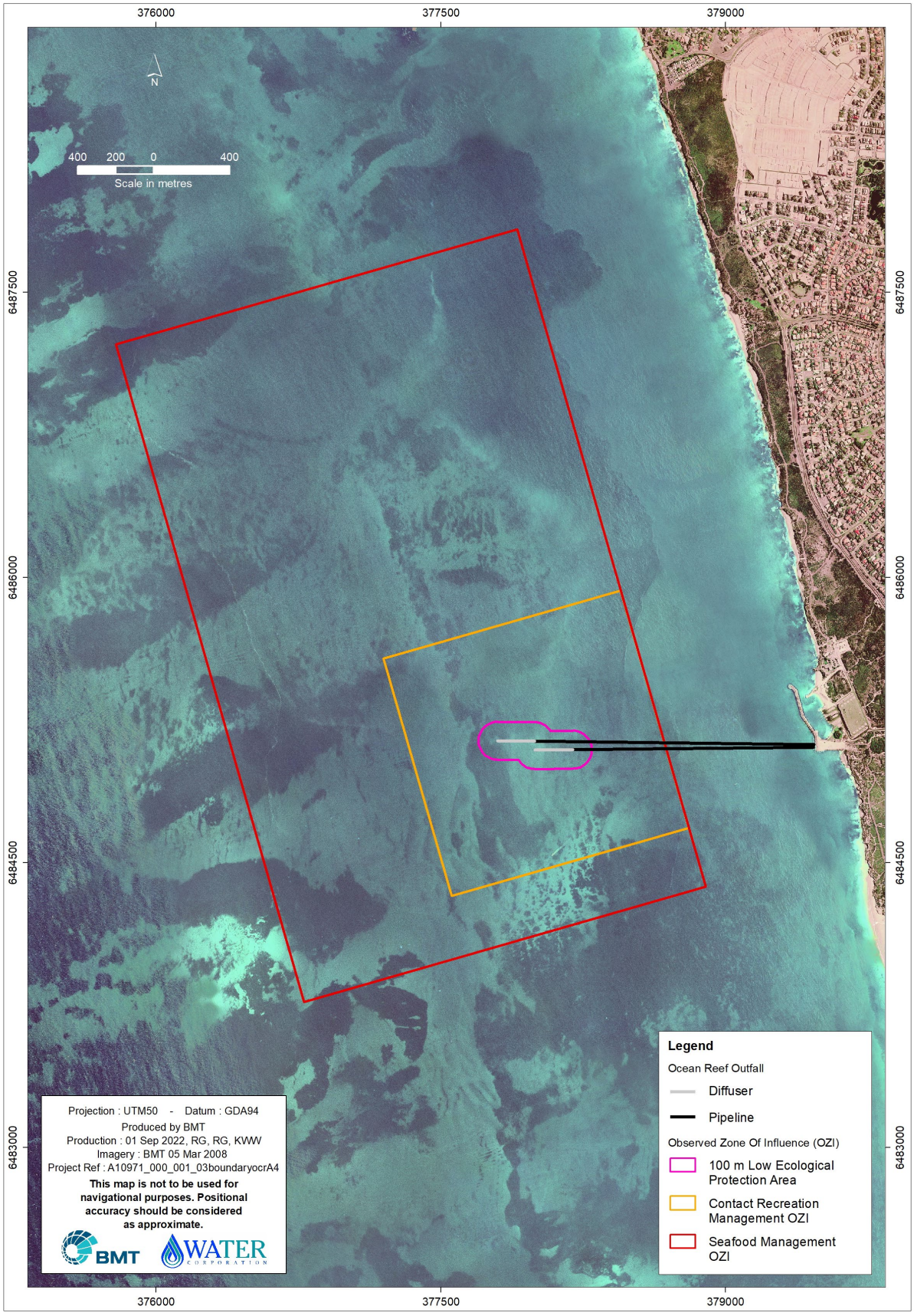


Figure 6 **Ocean Reef ocean outlet protection area and management zones.**

1.5.3 'Maintenance of Primary and Secondary Contact Recreation' EQOs

The primary and secondary contact EQOs support swimming and boating activities, respectively. The EQOs apply throughout Perth's coastal waters except for areas immediately surrounding the ocean outlets, where water quality may not be suitable for swimming. An informal zone has been developed for the Ocean Reef outlets encompassing the management area for primary and secondary contact recreation (Figure 6).

1.5.4 'Maintenance of Aesthetic Value' EQO

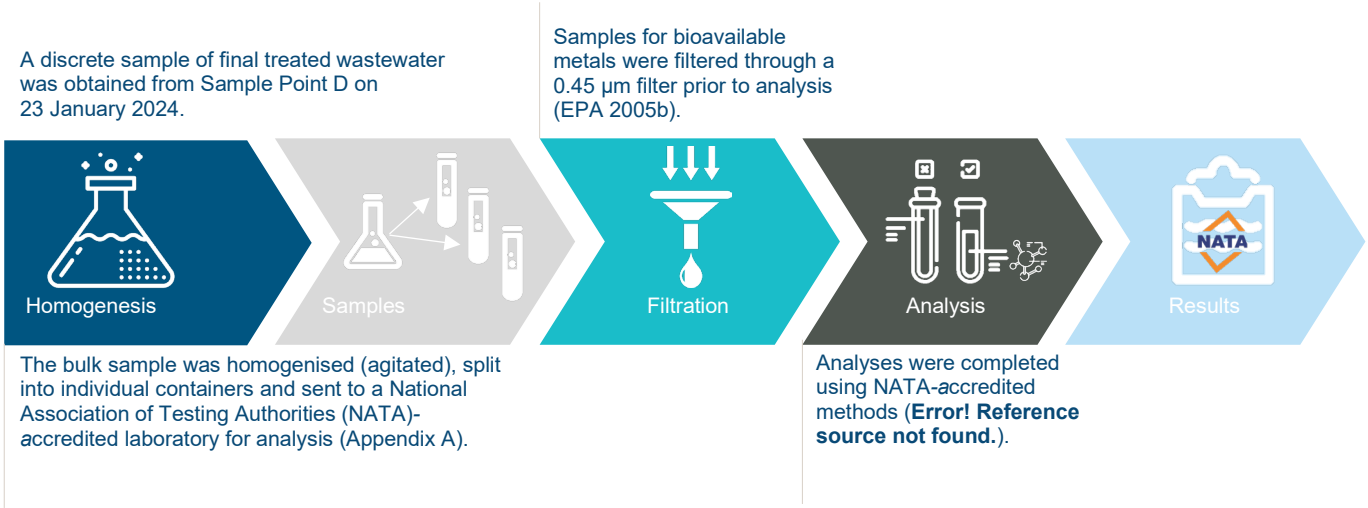
The objective of this EQO is to ensure that the aesthetic value of Perth's coastal waters is protected. To ensure this EQO is being met, monitoring routinely assesses the quality of the surface water appearance.

2 Toxicants in treated wastewater

2.1 Comprehensive treated wastewater characterisation (CTWWC)

Treated wastewater (TWW; final effluent) from both outlet A and outlet B were analysed for a suit of parameters comprising the major contaminants of concern for the Ocean Reef ocean outlet:

- nutrients (total nitrogen, ammonia, nitrate+nitrite [NOx], total phosphorus, orthophosphate)
- microbiological contaminants (thermotolerant coliforms and *Enterococci* spp.)
- bioavailable metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc)
- pesticides and herbicides (organophosphate pesticides, organochlorine pesticides, triazine herbicides)
- polyaromatic hydrocarbons
- phthalates
- polychlorinated biphenyls
- benzene, toluene, ethylbenzene, and xylenes
- petroleum hydrocarbons
- surfactants
- dissolved organic carbon.



2.1.1 Bioaccumulating toxicants

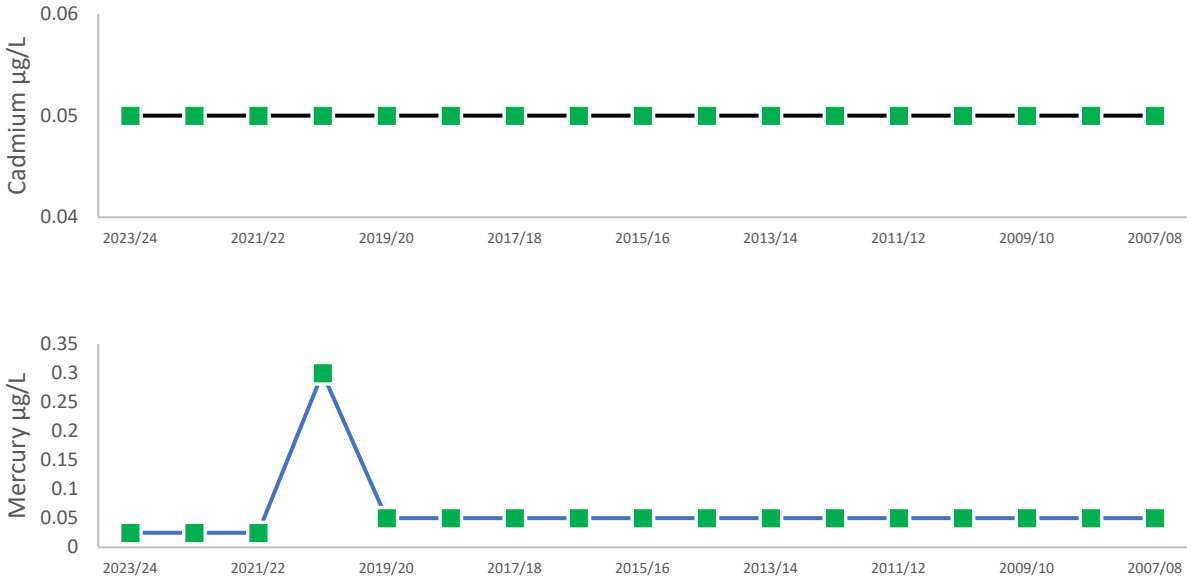
Concentrations of both cadmium and mercury (i.e. bioaccumulating toxicants) in the TWW sample were below their analytical limit of reporting (LoR; 0.1 µg/L) and the EQG concentrations for cadmium and mercury as bioaccumulating toxicants (36 and 1.4 µg/L, respectively) were met (Table 2). Concentrations of bioaccumulating toxicants in the discharge have been consistent over time and generally reflect the Limit of Reporting (Figure 7). There were elevated concentrations of mercury in the 2020/21 sample but the EQG was still met (Figure 7).

Table 2 Environmental Quality Guideline for bioaccumulating toxicants

EQG	Concentrations of bioaccumulating contaminants in the wastewater stream will not exceed the ANZG (2018) 80% species protection guidelines.

Note:

1. EQG = Environmental Quality Guideline.
2. ANZG 2018



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

Figure 7 Historical compliance of concentrations of bioaccumulating toxicants, cadmium and mercury

2.1.2 Non-bioaccumulating toxicants

Modelling predicted an average initial dilution of 1:409 at Ocean Outlet A and 1:385 at Outlet B (Appendix C). The worst-case initial dilution of 1:385 was used as a conservative estimate of the dilution expected at the notional LEPA boundary. Contaminant concentrations after the initial dilution of 1:385 were below the ANZG (2018) 99% species protection guidelines (Table 4), and the EQG for non-bioaccumulating toxicants (Table 3) was met. Over time, initial dilution (Figure 8) has been sufficient to reduce the concentration of non-bioaccumulating toxicants to below their EQG concentrations (Figure 9).

Table 3 Environmental Quality Guideline for non-bioaccumulating toxicants

EQG	Wastewater contaminant concentration corrected for minimum dilution at the Low Ecological Protection Area (LEPA) boundary will ensure the ANZG (2018) 99% species protection guidelines for toxicants are being achieved at the boundary of the LEPA (i.e. a high level of protection is met beyond a 100 m radius of the diffuser).

Note:
1. EQG = Environmental Quality Guideline

Table 4 Non-bioaccumulating toxicant concentrations in the Beenyup TWW stream compared with relevant guideline levels after initial dilution

Toxicant	Beenyup TWW concentration (µg/L)	Concentration after initial dilution (µg/L)	Trigger level (µg/L)
Ammonia-N	2,400	7.7	500
Cadmium*	<0.1	-	36
Chromium*	1.4	0.004	0.14 (Cr VI) 7.7 (Cr III)
Copper*	27	0.15	0.3
Lead*	<1	-	2.2
Mercury*	<0.05	-	1.4
Nickel*	4.8	0.013	7
Silver*	<0.8	-	0.8
Zinc*	100	0.41	7
Chloropyrifos	<0.1	-	0.0005
Endrin	<0.001	-	0.004
Endosulfan sulfate	<0.001	-	0.005
Benzene	<1	-	500
Naphthalene	<0.01	-	50
Benzo(g,h,i)perylene	<0.01	-	50

Notes

1. Assessment against ANZG (2018) 99% species protection guidelines was undertaken only for those toxicants where guideline levels were available.
2. TWW = treated wastewater
3. Initial dilution = 1:385 (predicted average value at Ocean Reef Outlet B). Contaminant dilution calculations were not performed (–) on any toxicants where concentrations were below the analytical limit of reporting.
4. The guidelines for marine waters are from ANZG (2018). The EPA has provided advice that in WA waters where a high level of protection applies, the 99% species protection levels should be used.
5. 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.
6. Analytical limits for chloropyrifos were not low enough to confirm exceedance of, or compliance with, the ANZG (2018) guidelines. Until reporting limits required for direct comparison can be attained by commercial laboratories, WET Testing will provide a test of the toxicity of the wastewater stream.
7. Trigger values are for endosulfan, not endosulfan sulfate; ANZG (2018).
8. * = dissolved metals 0.45 µm filtered.

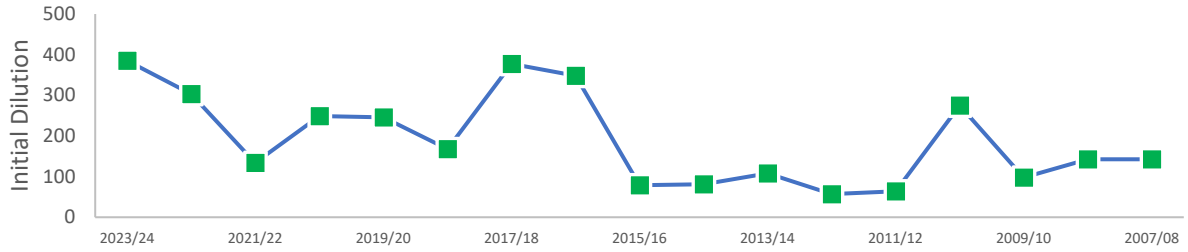


Figure 8 Historical initial dilution

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

Figure 9 Historical compliance of concentrations of the highest risk (concentration relative to guidelines) non-bioaccumulating toxicants

2.1.3 Total toxicity of the mixture

The total toxicity of the mixture (TTM) is an indicator of the potential for cumulative toxic effects on marine organisms (Table 5). For the combined effect of ammonia, copper and zinc (historically the contaminants with the highest

concentrations relative to their guidelines) following dilution, the TTM (0.59, Table 6) was less than the ANZG (2018) guideline of 1.0 and the EQG (Table 5) was met. Total toxicity of the mixture has exceeded the EQG criteria on one occasion (2012-2013) but has generally been consistent over time (Figure 10).

Table 5 Environmental Quality Guideline for the total toxicity of the mixture

EQG	The total toxicity of the mixture (TTM) for the additive effect of ammonia, copper and zinc, calculated as per ANZG (2018), will not exceed the guideline of 1.0.

Notes:

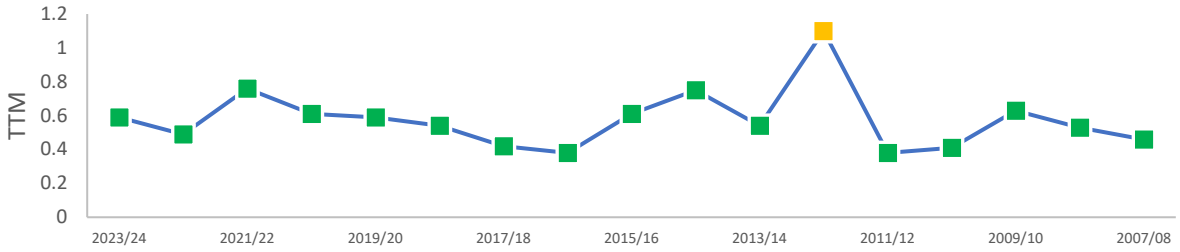
1. EQG = environmental quality guideline; TTM = total toxicity of the mixture
2. TTM = Σ(Ci/EQGi) where Ci is the concentration of the 'i'th component in the mixture and the EQGi is the guideline for that component.

Table 6 Total toxicity of treated wastewater at the edge of the initial mixing zone associated with the Ocean Reef ocean outlets

Toxicant	TWW concentration (µg/L)	Background concentration (µg/L)[1]	Dilution	Concentration after dilution (µg/L)	Contaminant concentration/ guideline	TTM[2]
Ammonia	2,400	1.5	1:385	7.7	0.02	0.59
Copper	27	0.08		0.15	0.51	
Zinc	100	0.15		0.41	0.06	

Notes:

1. Background concentrations for copper and zinc from McAlpine *et al*. (2005); Perth marine waters (pp.19). Surface background concentrations for ammonia calculated as median of reference site data from 2003–2023 (BMT Oceanica, unpublished data).
2. Guideline values are from Table 4
3. TTM = total toxicity of the mixture = [ammonia]/guideline + [copper]/guideline + [zinc]/guideline, TWW = treated wastewater.



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

Figure 10 Historical total toxicity of the mixture

2.2 Whole of effluent toxicity (WET) testing

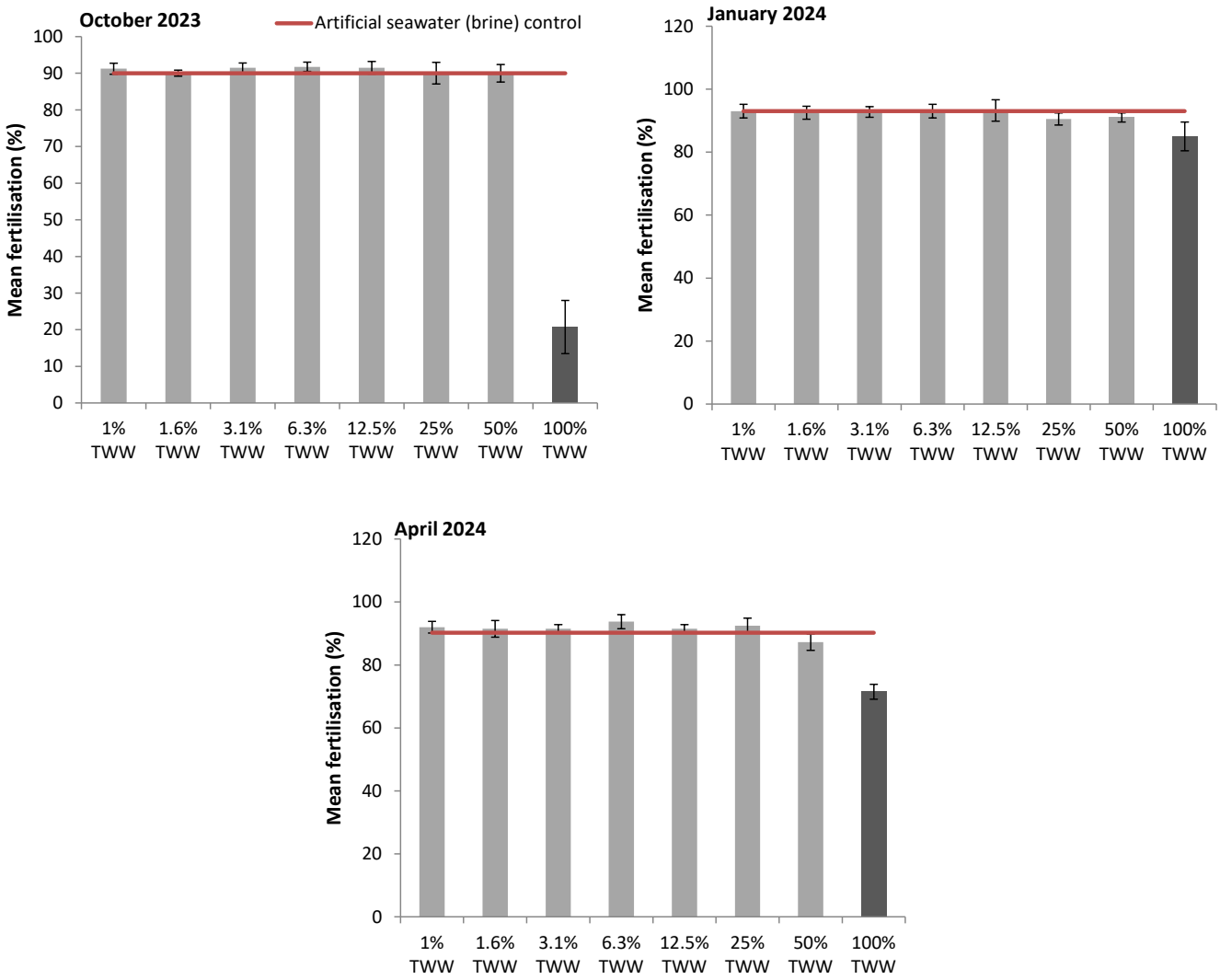
WET testing is useful for assessing the toxicity of potential contaminants without guidelines, or where the effects may be cumulative. Fertilisation success in sea urchins (*Heliocidaris tuberculata*) exposed to salt-adjusted dilutions (1.0, 1.6, 3.1, 6.3, 12.5, 25, 50 and 100%) of TWW was used to calculate a No Observed Effect Concentration (NOEC; the highest concentration where no significant effect is observed; Appendix D).

In October 2023, January 2024 and March 2024, sea urchin fertilisation in samples exposed to 100% TWW was significantly lower than the artificial seawater control. Fertilisation in all other dilutions were not significantly different to the control (Figure 11). For all three sampling dates, the NOEC was greater than 1% TWW (Table 8) and the EQG for WET testing (Table 7) was met. The lowest annual NOEC (and highest apparent toxicity) has been variable over time without an identifiable trend (Figure 12). The lowest has been 12.5% TWW requiring just 4 dilutions to reduce toxicity to background (equal to seawater) conditions (Figure 12).

Table 7 Environmental Quality Guideline for whole of effluent toxicity testing

EQG	The EQG will be exceeded if following the 1-hour sea urchin test: $\frac{TDA}{DRNOEC} \leq 1.0$ where TDA = Typical Dilutions Achieved (constant based on 200-fold dilution) DRNOEC = number of dilutions required to achieve the no observed effects concentration (NOEC). Breaching the above triggers an investigation against the EQS, which would comprise the full suite of WET tests (minimum of five species from four trophic groups).

Source: BMT Oceanica 2014



Notes:

1. Error bars represent ±1 standard deviation; n = 4.
2. TWW = treated wastewater.
3. Light grey bars represent concentrations of TWW at which there is no observed significant effect on fertilisation. Dark grey bars represent concentrations of TWW that acted to significantly reduce the success of sea urchin fertilisation.

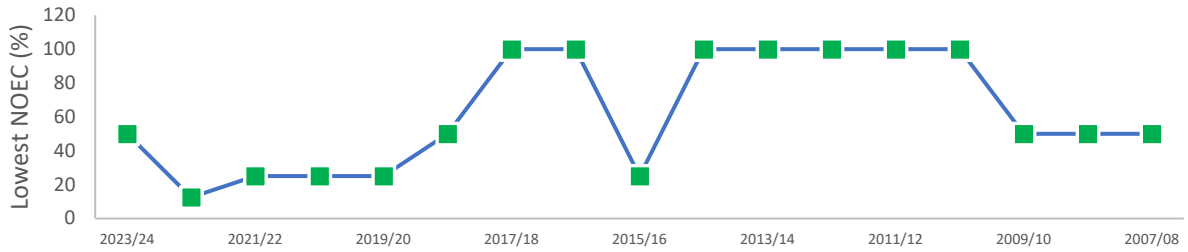
Figure 11 Comparison of whole effluent toxicity TWW dilution results to artificial seawater control

Table 8 Calculated parameters from whole of effluent toxicity tests

Indicator	October 2023	January 2024	April 2024
NOEC (%)	50%	50%	50%
Dilutions required to meet the NOEC	2	2	2
Dilutions required/dilution achieved	0.01	0.01	0.01
≤1	Yes	Yes	Yes

Notes:

1. NOEC = no observed effect concentration.
2. Calculation based on 310 dilutions achieved, which is expected at the notional LEPA boundary.



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

Figure 12 Historical No Observed Effect Concentration over time

3 Water quality monitoring – receiving environment

Nutrients, phytoplankton biomass and physical and chemical stressors were monitored approximately fortnightly from the beginning of December 2023 to the end of March 2024 (coinciding with the summer non-river flow period) along a down-current gradient away from the diffuser (Table 9; Appendix E).

Table 9 Water quality monitoring dates near the Ocean Reef ocean outlets between December 2023 and March 2024

Sample day	Date
1	06/12/2023
2	19/12/2023
3	12/01/2024
4	23/01/2024
5	08/02/2024
6	28/02/2024
7	08/03/2024
8	19/03/2024

Wind direction, strength, current grid direction and cloud cover were recorded on the day of sampling (Table 10).

Table 10 Weather and current grid during water quality monitoring near the Ocean Reef ocean outlets

Date	Wind direction	Wind strength (knots)	Cloud cover (%)	Current grid
06/12/2023	SSE-S-SSW	3 to 16	0	N
19/12/2023	E-ESE	10 to 18	20-40	W
12/01/2024	SE-ESE	5 to 10	5	NNW
23/01/2024	S-SSE-SSW	5 to 16	5-10	N
05/02/2024	SE	5 to 8	5	NW
16/02/2024	W-WSW-WNW	2 to 7	100	SE
08/03/2024	Calm - N	0 to 2	80-90-rain	SW
19/03/2024	SE	16 to 20	0	NW

Notes:

1. N = north, S = south, W = west, E = east, SW = south-west, SE = south-east, NW = north-west, NE = north-east, ENE = east north-east, ESE = east south-east, SSE = south south-east, NNE = north north-east, SSW = south south-west, WNW = west, north-west, WSW = west south-west, NNW = north north-west.
2. Winds are designated by the direction they come from while currents are designated by the direction they flow to.
3. Wind direction and strength are obtained from field observations.

3.1 Nutrient enrichment

The median chlorophyll-*a* concentration in the Ocean Reef HEPA (100, 350, 1000 and 1500 m) in 2023-24 was 0.8 µg/L and was greater than the 80th percentile of historical reference site data (0.4 µg/L; Figure 13), which exceeded the EQG (Table 11). The EQS for chlorophyll-*a* states that the EQG must not be exceeded in two consecutive years. Median chlorophyll-*a* concentration in the Ocean Reef HEPA (100 m and greater from the diffuser) during 2022–23 (0.55 µg/L) was also above the 80th percentile of historical reference site data (0.4 µg/L), meaning the EQG was exceeded in a second consecutive year. Therefore, the EQS (Table 11) was not met.

The exceedance of the EQG in 2023-24 was due to a gradual increase in the background chlorophyll-*a*. The median chlorophyll-*a* concentration in the Ocean Reef HEPA (0.8 µg/L) in 2023-2024 was lower than the 80th percentile of concentrations at reference sites over the same December to March period (1.08 µg/L), which suggests the elevated chlorophyll-*a* concentrations were not restricted to within the vicinity of the ocean outlets.

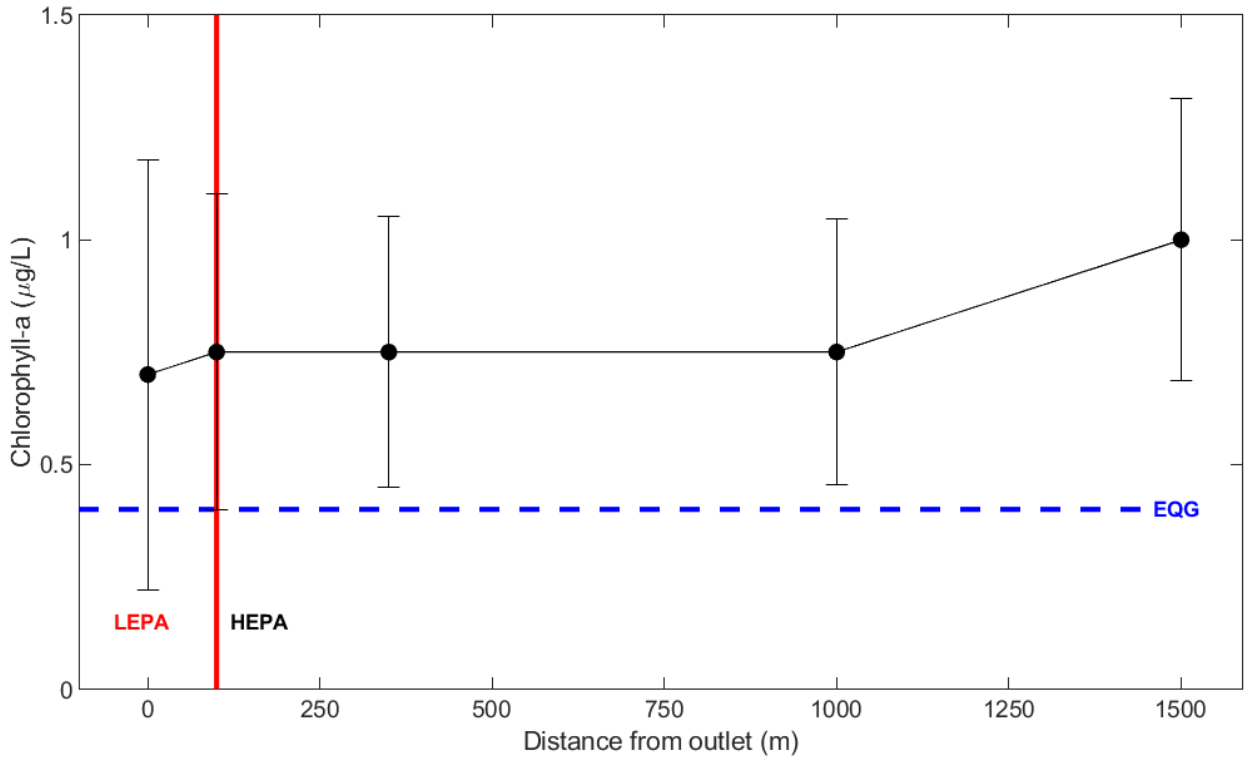
Median chlorophyll-*a* was higher in the 2023-2024 monitoring period than in any proceeding year (Figure 14). The EQG was exceeded in 7 years, including the last 3 (Figure 14). The present EQS was not applied historically, but the EQS was exceeded in the last 2 years (Figure 15).

Table 11 Environmental Quality Guidelines for nutrients

EQG	The median chlorophyll-*a* concentration in the HEPA (100 m and greater from the diffuser) during the non-river flow period is not to exceed the 80th percentile of historical reference site data.
	The median light attenuation coefficient in the HEPA during the non-river flow period is not to exceed the 80th percentile of historical reference site data.
EQS	EQGs are not to be exceeded in a second consecutive year.

Note:

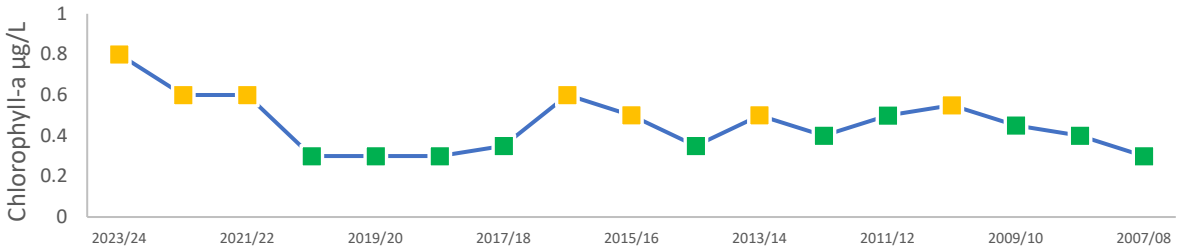
1. EQG = Environmental Quality Guideline; EQS = Environmental Quality Standard



Notes:

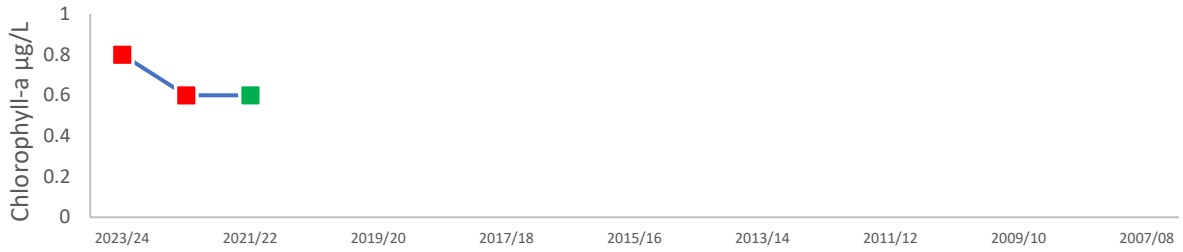
1. Error bars represent ±95% confidence intervals; n = 8.
2. Dark blue dashed line = Environmental Quality Guideline (EQG) is the 80th percentile of historical reference site data (0.4 µg/L chlorophyll-*a*).
3. LEPA = low ecological protection area (notional); HEPA = high ecological protection area.
4. Data at each distance were pooled across eight sampling days from December 2023 to March 2024.

Figure 13 Median chlorophyll-*a* concentrations down-current of the Ocean Reef outlets during the summer monitoring period



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) represent an exceedance of the EQG.

Figure 14 Median chlorophyll-*a* concentration over time (assessment against the EQG)

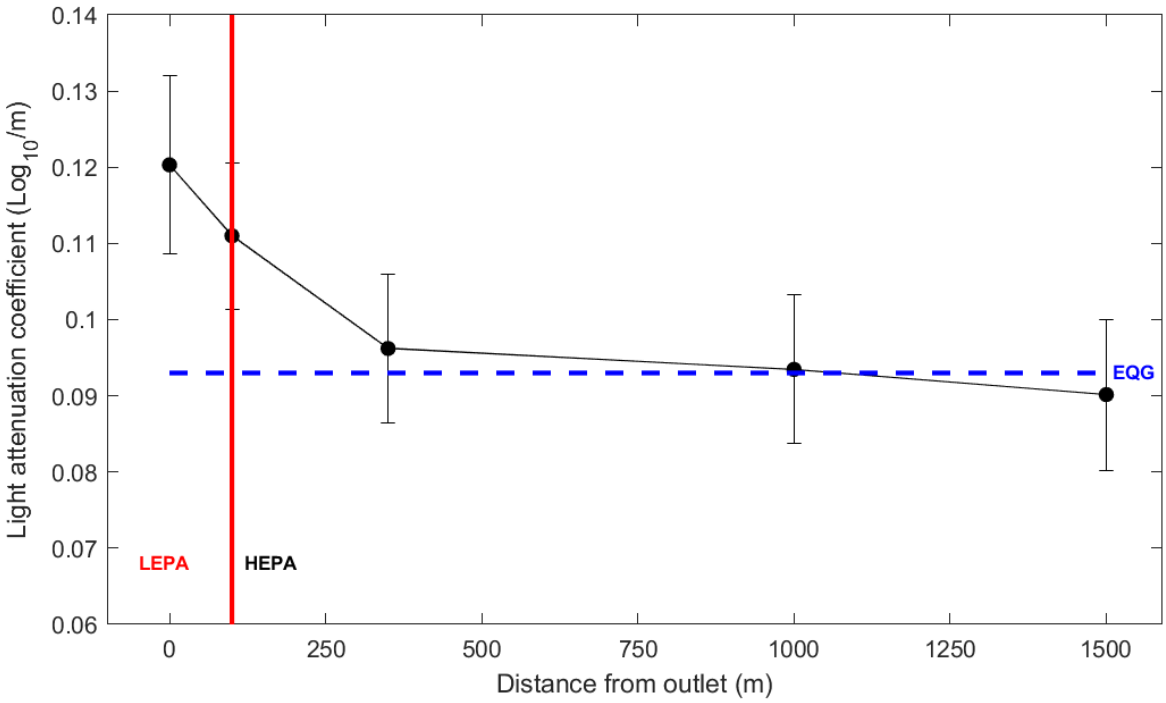


1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Standard (EQG) was met and red (■) symbols represent an exceedance of the EQS.

Figure 15 Median chlorophyll-*a* concentration over time (assessment against the EQS)

The median light attenuation coefficient (LAC) in the Ocean Reef HEPA (100, 350, 1000 and 1500 m) was 0.098 Log_{10}/m, exceeded the 80th percentile of historical reference site data (0.094 Log_{10}/m; Figure 16) and the EQG was not met (Table 11). The EQS for light attenuation states that the EQG must not be exceeded in two consecutive years. Median LAC in the Ocean Reef HEPA (100 m and greater from the diffuser) during 2022-23 (0.0877 Log_{10}/m) was below the 80th percentile of historical reference site data (0.093 Log_{10}/m). The EQG was not exceeded for two consecutive years and the EQS (Table 11) was met. The exceedance of the EQG in 2023-24 was due to a gradual increase in the background light attenuation. The median LAC in the Ocean Reef HEPA (0.098 Log_{10}/m) was lower than the 80th percentile of reference site data for the corresponding period (0.11 Log_{10}/m). Historically, median light attenuation exceeded the EQG in 6 years, including the 2023-2024 sampling season (Figure 17). The present EQS was not applied historically but was met for the 2023-2024 (Figure 18).

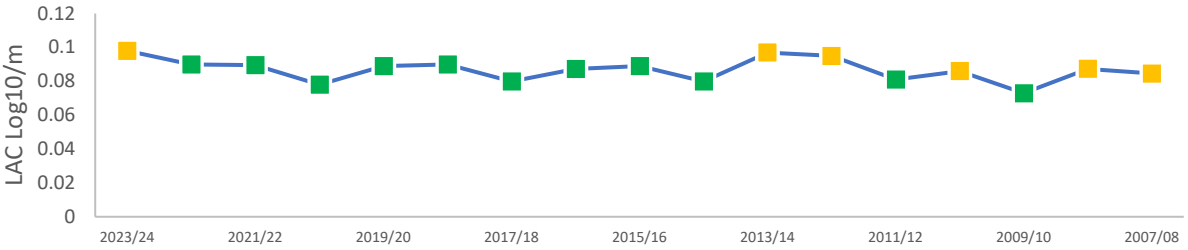
With the formal approval of Ministerial Statement 1219, implementation of Beenyup Ocean Outlets Monitoring and Management Plan (Water Corporation 2023) and likelihood on ongoing exceedances BMT recommends a formal investigation into the changing background chlorophyll-*a* concentrations with the intent of developing a more robust protocol for determining variability at the reference sites.



Notes:

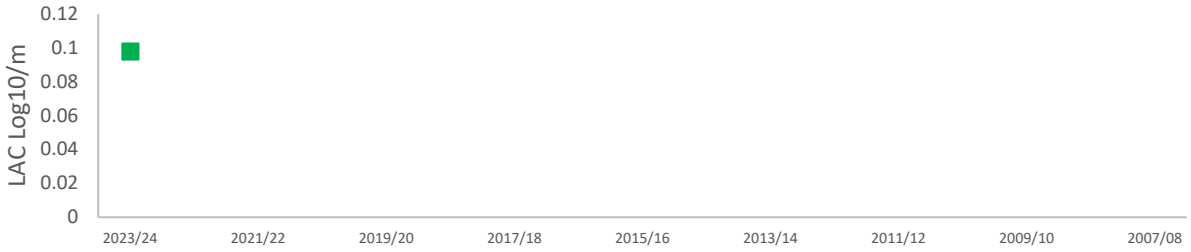
1. Error bars represent ±95% confidence intervals; n = 8.
2. Dark blue dashed line = Environmental Quality Guideline (EQG) is the 80th percentile of historical reference site data (0.093 Log_{10}/m).
3. LEPA = low ecological protection area (notional); HEPA = high ecological protection area.
4. Data at each distance were pooled across eight sampling days from December 2023 to March 2024.

Figure 16 Median light attenuation coefficient down current of the Ocean Reef outlets during the summer monitoring period



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) symbols represent an exceedance of the EQG.

Figure 17 Median light attenuation coefficient over time (assessment against the EQG)



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Standard (EQS) was met; and red (■) symbols represent an exceedance of the EQS.

Figure 18 Median light attenuation coefficient over time (assessment against the EQS)

3.2 Phytoplankton biomass

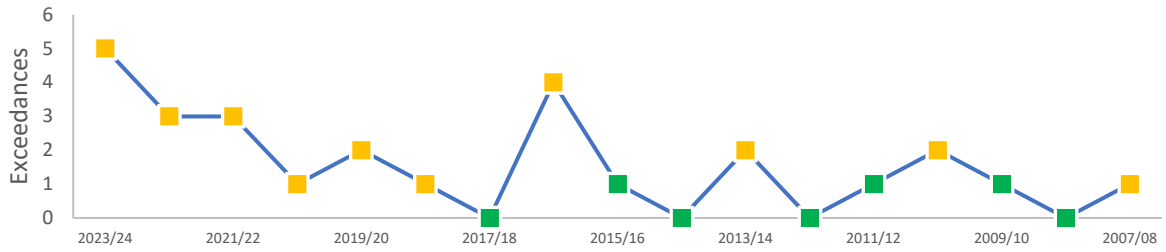
Median phytoplankton biomass measured as chlorophyll-*a* exceeded three times the median historical chlorophyll-*a* concentration at reference sites (0.6 µg/L; Figure 23) on five occasions (0.85 µg/L on 06 December 2023, 0.75 µg/L on 12 January 2024, 1.2 µg/L on 23 January 2024, 1.45 µg/L on 8 March 2024, and 1.25 µg/L on 18 March 2023) exceeding EQG1 (Table 12) and triggering assessment against EQS1. Median phytoplankton biomass measured as chlorophyll-*a* exceeded three times median chlorophyll-*a* concentration of historical reference sites on more than one occasion in two consecutive years (exceeding three times in 2022–23) and EQS 1 was not met. The exceedance of the EQG in 2023-24 was due to a gradual increase in the background chlorophyll-*a*. On no occasion did the median chlorophyll-*a* concentration in the Ocean Reef HEPA exceed three times the median at the reference site for the corresponding 2023-2024 December to March period (1.65 µg/L). Historically, median phytoplankton biomass, measured as chlorophyll-*a* has routinely exceeded three times the median chlorophyll-*a* concentration of historical reference sites, on an occasion during the non-river flow period (Figure 19). The EQS has only been exceeded across the last two seasons (Figure 20).

Table 12 Environmental Quality Criteria for phytoplankton in receiving waters

EQG1	Median phytoplankton biomass, measured as chlorophyll-*a* does not exceed three times the median chlorophyll-*a* concentration of historical reference sites, on any occasion during the non-river flow period.
EQG2	Phytoplankton biomass measured as chlorophyll-*a* at any site does not exceed three times the median chlorophyll-*a* concentration of historical reference sites, on 25% or more occasions during the non-river flow period.
EQS1	Median phytoplankton biomass measured as chlorophyll-*a* does not exceed three times median chlorophyll-*a* concentration of historical reference sites, on more than one occasion during non-river flow period and in two consecutive years.
EQS2	Phytoplankton biomass measured as chlorophyll-*a* at any site does not exceed three times the median chlorophyll-*a* concentration of historical reference sites, on 25% or more occasions during the non river-flow period and in two consecutive years.

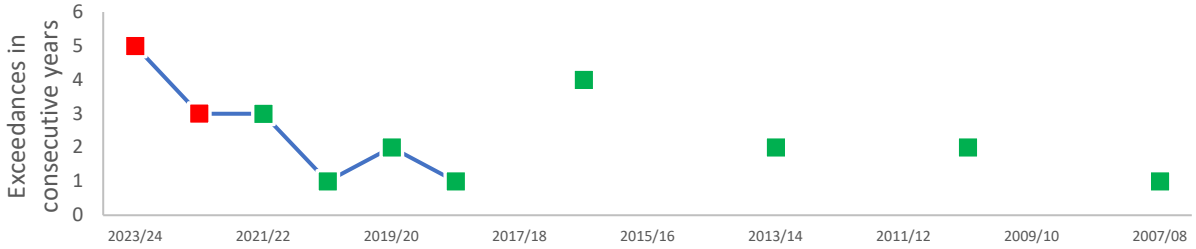
Notes:

1. EQG = Environmental Quality Guideline; EQS = Environmental Quality Standard



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) symbols represent an exceedance of the EQG.

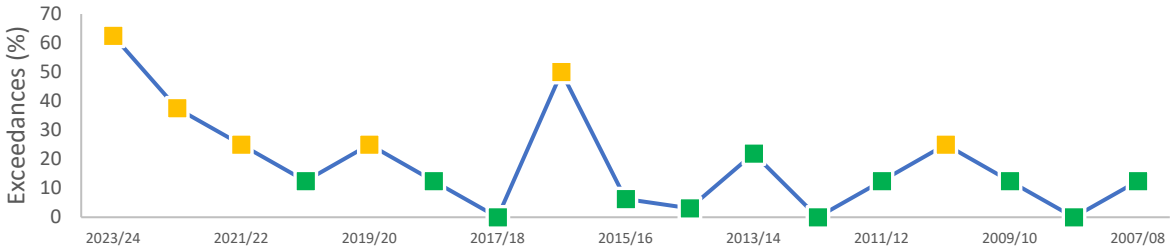
Figure 19 Exceedance of three times the median chlorophyll-*a* concentration of reference sites on any occasion



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Standard (EQS) was met and red (■) symbols represent an exceedance of the EQS.

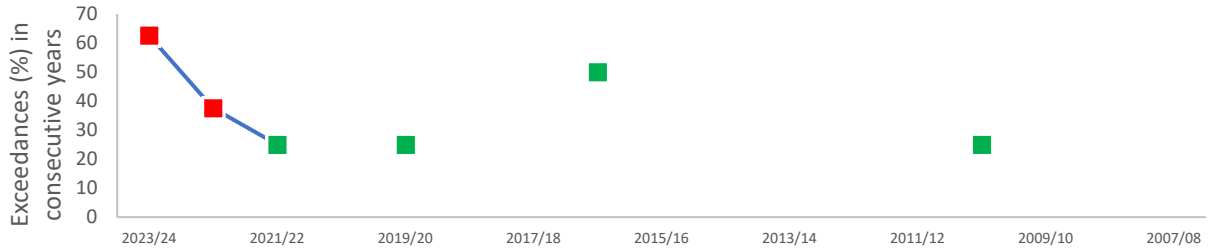
Figure 20 Exceedance of three times the median chlorophyll-*a* concentration of reference on more than one occasion and in two consecutive years

Phytoplankton biomass, measured as chlorophyll-*a*, exceeded three times the median chlorophyll-*a* concentration of historical reference sites (0.6 µg/L) on more than 25% of occasions at all four HEPA sites (50% of occasions at 350 m from the outlets and 62.5% of the time at 100,1000 and 1500 m from the outlets) during the non-river flow period (Figure 23) exceeding EQG2 (Table 12) and triggering assessment against EQS2. Median phytoplankton biomass measured as chlorophyll-*a* exceeded three times the median chlorophyll-*a* concentration of historical reference sites on more than 25% of occasions at two HEPA sites (37.5% of occasions at 350 and 1500 m from the outlets) during the 2022-2023 non-river flow period (Figure 23). As the EQG was exceeded in two consecutive years, EQS2 was not met. The exceedance of the EQG in 2023-24 was due to a gradual increase in the background chlorophyll-*a*. Historically, the EQG has routinely been exceeded (Figure 21). The last two seasons were the first with corresponding exceedances of the EQS (Figure 22).



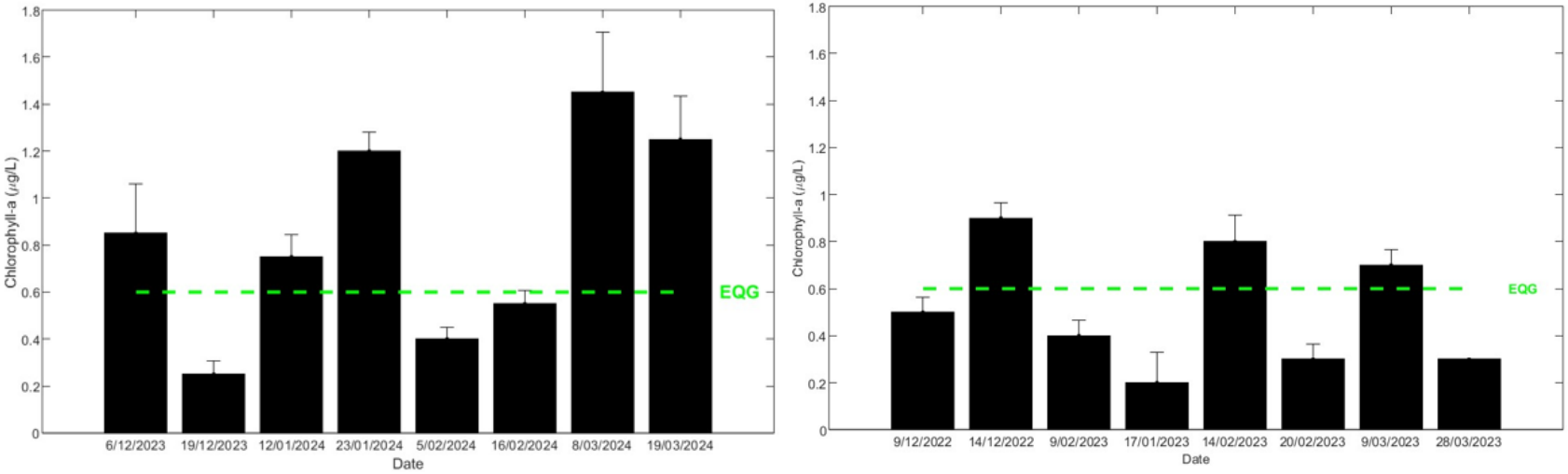
1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) symbols represent an exceedance of the EQG.

Figure 21 Percentage of occasions chlorophyll-*a* concentration exceeded 3 times reference site concentrations at any site (assessment against the EQG)



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Standard (EQS) was met; and red (■) symbols represent an exceedance of the EQS.

Figure 22 Percentage of occasions chlorophyll-*a* concentration exceeded 3 times reference site concentrations at any site and in two consecutive years (assessment against the EQG)



Notes:

1. Error bars represent ±95% confidence intervals; n = 9.
2. Green dashed line = Environmental Quality Guideline (EQO) is 3-times the median chlorophyll-*a* concentration of reference site data.
3. Data pooled from fixed sites ≥100 m down-current of the outlets. Concentrations at 0 m are not included in the figure or EQC assessment, as the 0 m site is situated directly above the outlets within the notional low ecological protection area (LEPA).

Figure 23 Median phytoplankton biomass during the summer monitoring period from the 2023–2024 (left) and 2022–2023 (right) monitoring period

3.3 Physical-chemical stressors

3.3.1 Dissolved oxygen (DO)

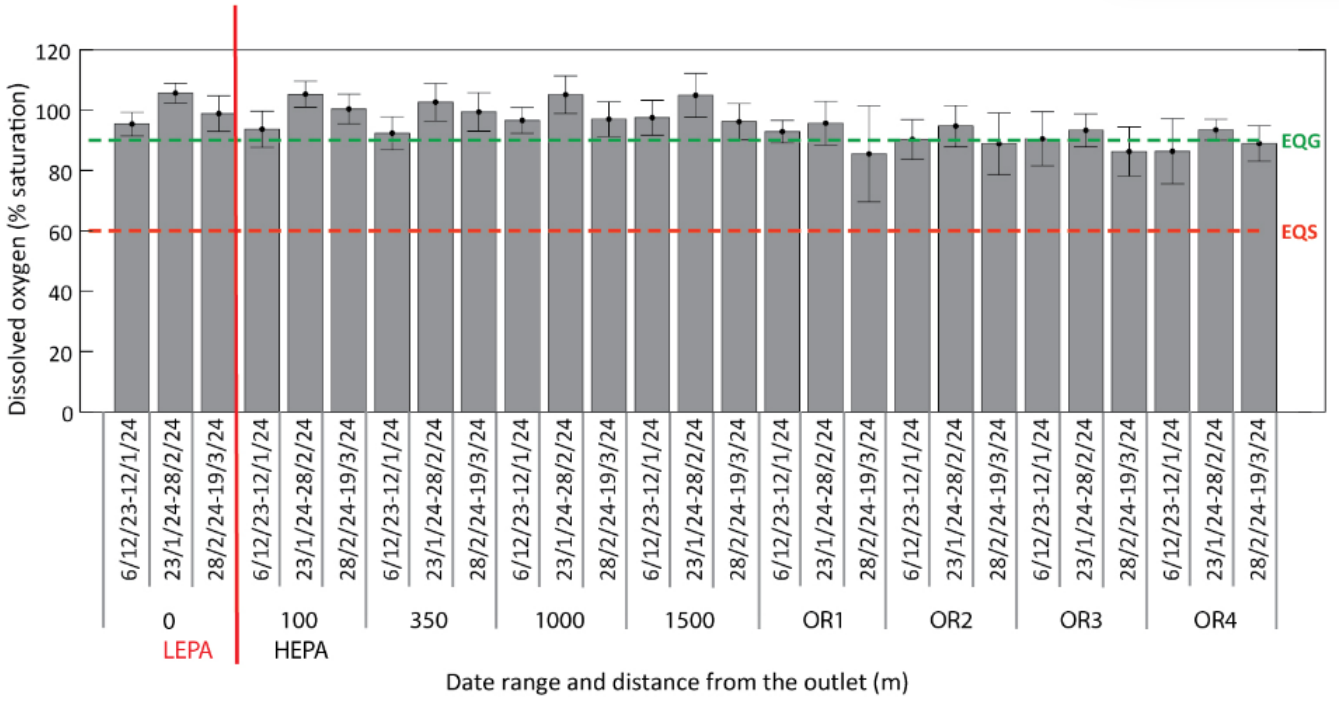
Bottom (0–0.5 m) dissolved oxygen saturation at HEPA sites (100, 350, 1000 and 1500 m) was >90% at all sites and times throughout the summer survey period (Figure 24), and the EQG for organic enrichment (Table 13) was met. Historically, DO has fallen below 90% in at least one 6-week period on two occasions (Figure 25). DO has not fallen below 60% for any 6-week period at any time (Figure 26).

Table 13 Environmental Quality Guideline for dissolved oxygen

EQG	Median dissolved oxygen in bottom waters (0–0.5 m above the sediment surface) in the HEPA must be greater than 90% saturation at any site for a defined period of not more than 6 weeks during the non-river flow period.
EQS	Median dissolved oxygen in bottom waters (0–0.5 m above the sediment surface) in the HEPA must be greater than 60% saturation at any site for a defined period of not more than 6 weeks during the non-river flow period.

Note:

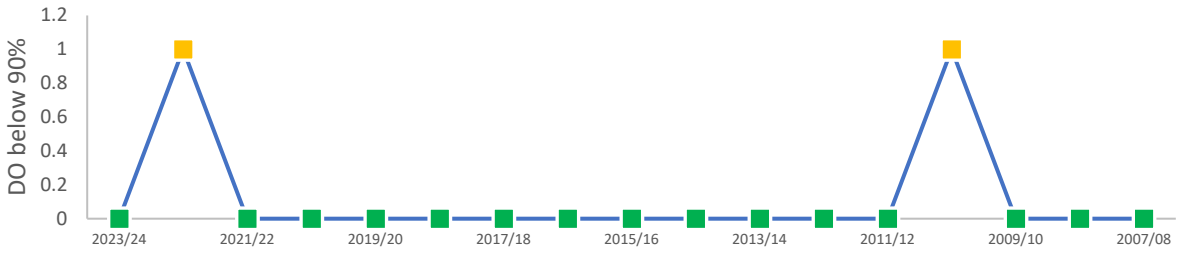
1. EQG = Environmental Quality Guideline; EQS = Environmental Quality Standard



Notes:

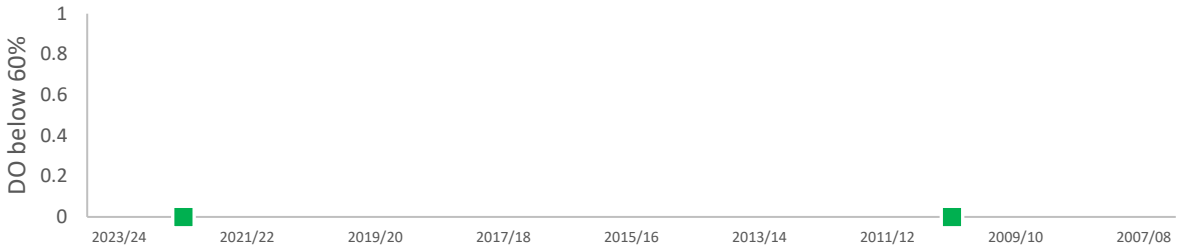
1. Error bars ±95% confidence intervals (n=3)
2. Dissolved oxygen (DO) measured 0–0.5 m above the seabed
3. Green dashed line = Environmental Quality Guideline (EQG) = 90% DO saturation.
4. Red dashed line = Environmental Quality Standard (EQS) = 60% DO saturation.
5. LEPA = low ecological protection area (notional); HEPA = high ecological protection area.
6. Reference site data (ORR1–ORR4) are compared against EQG for contextual purposes only.

Figure 24 Median dissolved oxygen for defined periods of ≤6 weeks during the summer monitoring period



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) symbols represent an exceedance of the EQG.

Figure 25 Number of periods where DO was below 90% (EQG) over time



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Standard (EQS) was met; and red (■) symbols represent an exceedance of the EQS.

Figure 26 Number of periods where DO was below 60% (EQS) over time

3.3.2 Salinity

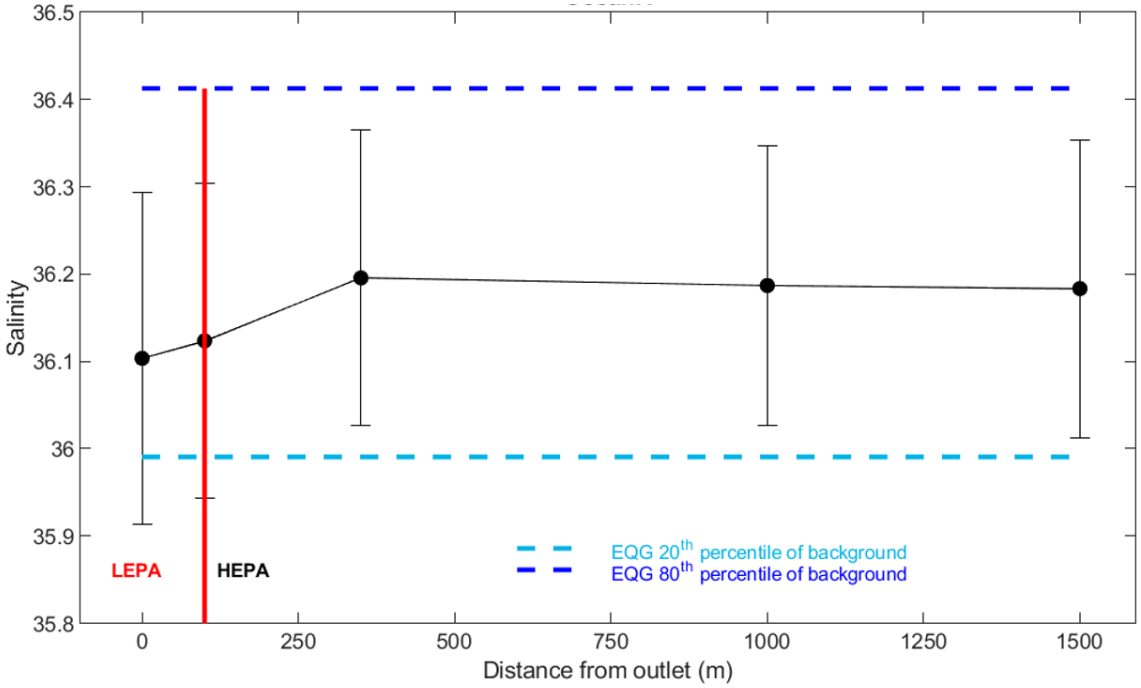
Median salinity was between the 20th and 80th percentile of the natural salinity range within the notional HEPA (at 100, 350, 1000 and 1500 m from the outlets), meeting the EQG (Table 14 and Figure 27). In the past, median salinity has fallen below the 20th percentile of the natural salinity range for the same period and the EQG has been exceeded on two occasions (Figure 28). The EQS was not exceeded on either of those occasions (Figure 29).

Table 14 Environmental Quality Guideline for salinity

EQG	Median salinity (0.5 m below the water surface) at an individual site over any period is not to deviate beyond the 20th and 80th percentile of natural salinity range over the same period.
EQS	No deaths of marine organisms (identified during surveys of via complaints) resulting from anthropogenically sourced salinity stress.

Note:

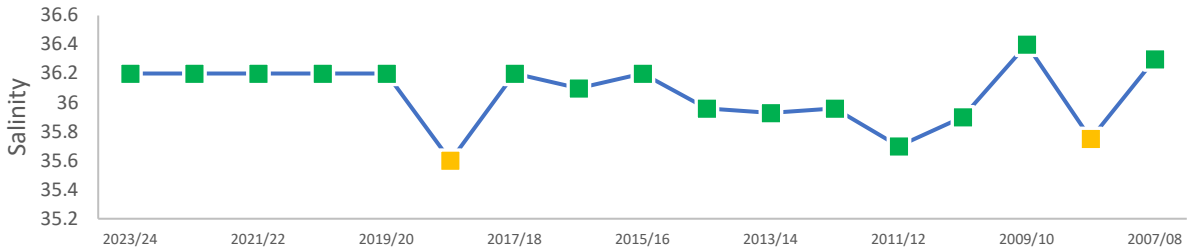
1. EQG = Environmental Quality Guideline; EQS = Environmental Quality Standard



Notes:

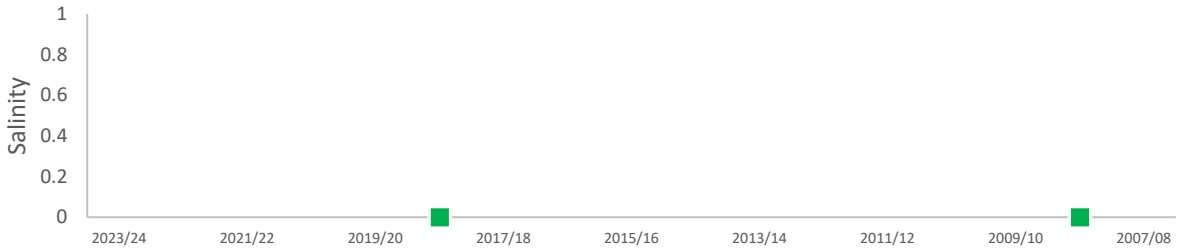
1. Error bars represent ±95% confidence intervals.
2. Salinity measured 0–0.5 m below the sea surface.
3. Dark blue line = 80th percentile of reference sites over the same period; light blue dashed line = 20th percentile of reference sites over the same period.
4. LEPA = low ecological protection area (notional); HEPA = high ecological protection area.
5. Data for each distance were pooled across ~6 salinity measurements in each field trip (n=48) over December 2023–March 2024.

Figure 27 Median salinity compared to the 20th and 80th percentile of reference sites data during the summer monitoring period



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) symbols represent an exceedance of the EQG.

Figure 28 Median salinity down-current of the Ocean Reef outlets over time



1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Standard (EQS) was met; and red (■) symbols represent an exceedance of the EQS.

Figure 29 Assessment against the EQS (when triggered) over time

4 Microbiological contaminants and algal biotoxins

4.1 Thermotolerant coliforms

TTC were sampled eight times over the 2023–2024 summer period (yielding a total of 40 samples). NHMRC (2008) guidelines and EPA (2005) require a minimum of 100 samples for an accurate assessment of the EQC. Data from multiple years can be pooled where there are <100 samples provided local pollution conditions have not changed (NHRMC 2008). Assuming conditions have not changed, data collected over three summers (summer 2021–24) were pooled to yield 120 samples.

The median and 90th percentile TTC concentrations derived from the 3 years of pooled samples were both equal to the limit of reporting (<10 CFU/100 mL; Table 16; Appendix H) and less than the 14 and 21 CFU/100 mL criteria, respectively, meeting the EQG (Table 15). Median (Figure 30) and 90th percentile (Figure 31) thermotolerant coliform concentrations have generally been equivalent to the limit of reporting over time and have never exceeded the 14 or 21 CFU/100 mL criteria, respectively.

Table 15 Environmental Quality Guideline for thermotolerant coliforms

EQG	Median TTC concentrations at sites at the boundary of the Observed Zone of Influence (OZI) are not to exceed 14 CFU/100 mL and the 90th percentile of TTC concentrations must not exceed 21 CFU/100 mL

Notes:

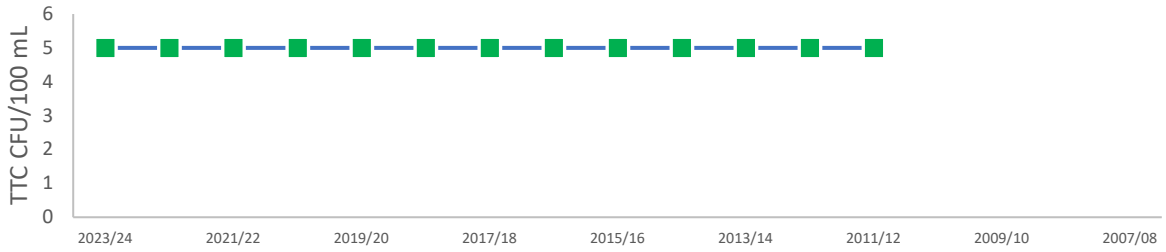
1. EQG = Environmental Quality Guideline.
2. OZI = Observed Zone of Influence, refers to the Seafood Management Zone; TTC = thermotolerant coliforms.
3. TTC concentrations are measured using the membrane filtration method.
4. Marine Biotoxin Monitoring and Management Plan 2016: Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH 2016).

Table 16 Median and 90th percentile of thermotolerant coliform concentrations at the fixed monitoring sites for the Ocean Reef outlets for 2021–2024 and comparison to the EQC

Sampling period	Median	90th percentile	Compliance (EQG)
Dec 2021–Mar 2022 Dec 2022–Mar 2023 Dec 2023–Mar 2024	<10 CFU/100 mL	<10 CFU/100 mL	■

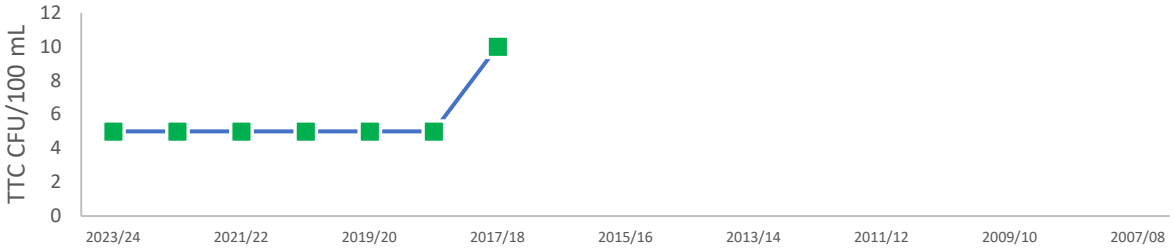
Notes:

1. Green symbols (■) indicate the Environmental Quality Criteria (EQC) were met.
2. represent an exceedance of the Environmental Quality Guideline (EQG) and Environmental Quality Standard (EQS), respectively.
3. Thermotolerant coliform results below the analytical limit of reporting (<10 CFU/100 mL) were halved (=5 CFU/100 mL) to calculate the median and 90th percentile.
4. Environmental Quality Criteria are based on EPA (2017).



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

Figure 30 Median thermotolerant coliforms over time



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

Figure 31 90th percentile thermotolerant coliforms over time

4.2 Toxic phytoplankton species

The EQG for toxic phytoplankton species states that concentrations of potentially toxic algae are not to exceed the WASQAP guideline concentrations in any samples (DoH, DPIRD and Industry 2020). Table 17 lists the phytoplankton species known to produce toxins that may be concentrated in shellfish and their WASQAP (DoH, DPIRD and Industry 2020) guideline concentrations (alert level to initiate flesh testing).

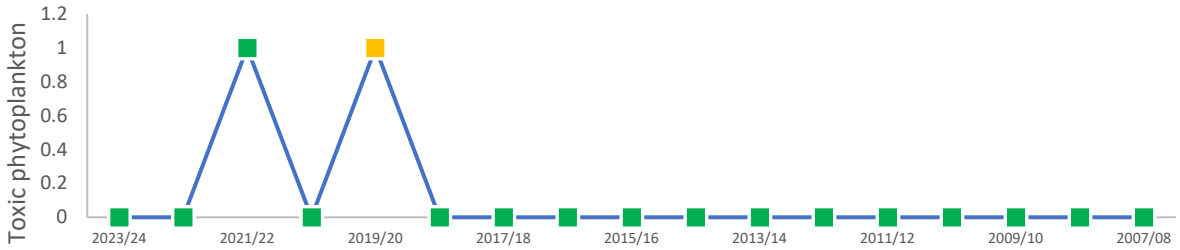
Table 17 Environmental Quality Guideline for toxic phytoplankton species

EQG	Cell counts of potentially toxic algae species at sites at the boundary of the OZI are not to exceed the WASQAP[2] guideline concentrations for any of the following: • *Alexandrium* spp[4]. (200 cells/L) • *Gymnodinium catenatum* (1,000[4] cells/L) • *Dinophysis* spp. (1,000 cells/L) • *Prorocentrum lima* (500 cells/L) • *Pseudo-nitzchia* group[5] (500,000 cells/L) • *Karenia brevis* (1,000 cells/L) • *Karenia/Karlodinium/Gymnodinium* group[6] (250,000 cells/L)

Note:

1. EQG = Environmental Quality Guideline; OZI = Observed Zone of Influence, refers to the Seafood Management Zone.
2. Marine Biotoxin Monitoring and Management Plan 2020 version 2: Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH, DPIRD and Industry, 2020).
3. *Alexandrium* species may be difficult to identify when numbers are low, and they are being treated as potentially toxic.
4. Species within the *Pseudo-nitzschia* groups are difficult to identify, and they are being treated as potentially toxic.
5. The *Karenia/Karlodinium/Gymnodium* group includes *Karenia bidigitata*, *Karenia brevisulcata, Karenia mikimotoi, Karenia papilionacea, Karenia selliformis, Karlodinium micrum* and *Gymnodinium impudicum*.
6. If the EQG is exceeded, assessment will proceed against the EQS for sentinel mussel tissues.

There were no instances where toxic phytoplankton species were present at densities greater than the WASQAP (DoH, DPIRD and Industry, 2020) guideline values (Table 18; Appendix I). Historically, the EQG has been exceeded on one occasion (Figure 32).



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

Figure 32 Exceedance of the toxic phytoplankton EQG over time

Table 18 Estimated cell densities of phytoplankton species known to produce toxins

Date	Site[1]	Species	Estimated density (cells/L)	WASQAP Guideline[2] (cells/L)	Compliance
06/12/2023	ORR3	*Dinophysis caudata*	80	1,000	
		GK Complex (*Gymnodinium-Karenia* Complex)	80	250,000	
		Gymnodinium spp.	400	250,000	
		Karenia papilionaceae	80	250,000	
		Pseudo-nitzschia “delicatissima” group	1,520	500,000	
		Pseudo-nitzschia “seriata” group	960	500,000	
	OR22	*Dinophysis caudata*	160	1,000	
		Karlodinium spp	720	250,000	
		Karenia papilionaceae	80	1,000	
		Pseudo-nitzschia “delicatissima” group	1,680	500,000	
		Pseudo-nitzschia “seriata” group	360	500,000	
19/12/2023	ORR1	*Gymnodinium* spp.	160	250,000	
		Pseudo-nitzschia “delicatissima” group	880	500,000	
		Pseudo-nitzschia “seriata” group	80	500,000	
	OR26	*Pseudo-nitzschia* “delicatissima” group	2000	500,000	
		Pseudo-nitzschia “seriata” group	160	500,000	
12/01/2024	ORR4	*Pseudo-nitzschia* “seriata” group	80	500,000	
	OR24	*Gymnodinium* spp.	160	250,000	
		Pseudo-nitzschia “delicatissima” group	1,920	500,000	
		Pseudo-nitzschia “seriata” group	720	500,000	
23/01/2024	ORR3	*Gymnodinium* spp.	640	250,000	
		Karlodinium spp.	80	250,000	
		Pseudo-nitzschia “delicatissima” group	20,800	500,000	
		Pseudo-nitzschia “seriata” group	160	500,000	
	OR22	*Gymnodinium* spp.	240	250,000	

Date	Site[1]	Species	Estimated density (cells/L)	WASQAP Guideline[2] (cells/L)	Compliance
		Karlodinium spp.	320	250,000	
		Pseudo-nitzschia “delicatissima” group	4,480	500,000	
		Pseudo-nitzschia “seriata” group	560	500,000	
05/02/2024	ORR1	*Pseudo-nitzschia* “delicatissima” group	480	500,000	
	OR21	*Pseudo-nitzschia* “delicatissima” group	7,920	500,000	
		Pseudo-nitzschia “seriata” group	400	500,000	
16/02/2024	ORR1	*Pseudo-nitzschia* “delicatissima” group	1,360	500,000	
		Pseudo-nitzschia “seriata” group	80	500,000	
	OR17	*Pseudo-nitzschia* “delicatissima” group	1,440	500,000	
		Pseudo-nitzschia “seriata” group	160	500,000	
		Gymnodinium spp.	80	250,000	
08/03/2024	ORR4	*Pseudo-nitzschia* “delicatissima” group	1,200	500,000	
		Pseudo-nitzschia “seriata” group	320	500,000	
		Gymnodinium spp.	240	250,000	
	OR24	*Pseudo-nitzschia* “delicatissima” group	7,600	500,000	
		Pseudo-nitzschia “seriata” group	11,120	500,000	
		Gymnodinium spp.	80	250,000	
19/03/2024	ORR3	*Pseudo-nitzschia* “delicatissima” group	80	500,000	
		Pseudo-nitzschia “seriata” group	560	500,000	
		Gymnodinium spp.	880	250,000	
	OR26	*Pseudo-nitzschia* “delicatissima” group	480	500,000	
		Pseudo-nitzschia “seriata” group	1200	500,000	
		Gymnodinium spp.	720	250,000	

Notes:

1. Samples were analysed for one monitoring site and one reference site per sampling occasion. Reference results are not applicable (na) to compliance.
2. Marine Biotoxin Monitoring and Management Plan 2020 version 2: Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH, DPIRD and Industry, 2020).
3. Green (■) symbols indicate the Environmental Quality Criteria (EQC) were met.

4.3 *Enterococci* spp.

Samples were collected eight times over the 2023–2024 summer monitoring period (yielding a total of 40 samples) for faecal pathogens analyses (measured as *Enterococci* spp.). NHMRC (2008) guideline and EPA (2005) require a minimum of 100 samples over the monitoring period for accurate assessment of the EQC. Data from multiple years can be pooled where there are less than 100 samples provided local pollution conditions have not changed (NHMRC 2008). Assuming conditions have not changed data from the past three summers (2021–2024) were pooled to yield 120 samples. The EQG for primary and secondary contact recreation are outlined in Table 19.

Over the past three summers, the 95th percentile of *Enterococci* spp. concentrations at the boundary of the observed zone of influence (contact recreation management zone) for the Ocean Reef ocean outlets was equal to the limit of reporting (<10 MPN/100 mL; Table 20; Appendix H), and both the primary (<200 MPN/100 mL) and secondary (<2000 MPN/100mL) contact recreation EQG for faecal pathogens (Table 19) in the water were met. The 95th percentile *Enterococci* spp. concentrations have varied little over time and have never exceeded the primary (or secondary) contact EQG (Figure 33).

Table 19 Environmental Quality Guidelines for contact recreation

Primary[2]	**EQG**	The 95th percentile bacterial content of marine waters should not exceed 200 *Enterococci* MPN/100 mL
Secondary[3]	**EQG**	The 95th percentile bacterial content of marine waters should not exceed 2000 *Enterococci* MPN/100 mL

Notes:

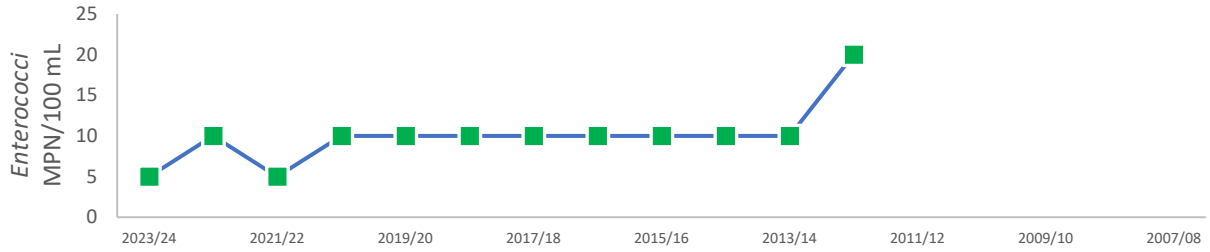
1. EQG = Environmental Quality Guideline
2. Primary contact recreation = activities where humans are in direct contact with the water (e.g. swimming, snorkelling and diving).
3. Secondary contact recreation = activities where humans are in secondary contact with the water (e.g. boating and fishing).

Table 20 The 95th percentile of *Enterococci* spp. concentrations at the boundary of the observed zone of influence for the Ocean Reef ocean outlets

Sampling period	95th percentile	Compliance	
		Primary contact	Secondary contact
Dec 2021–Mar 2022 Dec 2022–Mar 2023 Dec 2023–Mar 2024	<10 MPN/100 mL	■	■

Notes:

1. MPN = most probable number of Enterococci spp.
2. Enterococci spp. concentrations below the analytical limit of reporting (<10 Enterococci spp. MN/100 mL) were halved (=5 MPN/100 mL) to calculate the 95th percentile.
3. Green symbols (■) indicate the Environmental Quality Criteria (EQC) were met
4. represent an exceedance of the Environmental Quality Guideline (EQG) and Environmental Quality Standard (EQS), respectively.
5. Environmental Quality Criteria (EQC) based on EPA (2017) water quality guidelines for recreation waters.



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

Figure 33 95th percentile *Enterococci* spp. concentrations over time

4.4 Phytoplankton cell concentrations

The concentrations of phytoplankton cells are determined based on the Environmental Quality Criteria (EQC) for toxic algae in marine recreational water. Table 21 presents the specific EQC values for toxic algae in marine recreational water as outlined in EPA (2017) and the approach with respect to watch list species described by DoH (2022).

Table 21 Environmental Quality Guideline for phytoplankton cell count

EQG	The phytoplankton cell count from a single site should not exceed 10 000 cells/mL; or detect the Department of Health watch list species or exceed their guideline levels (Appendix J).
EQS	The phytoplankton cell count from a single site should not exceed 50 000 cells/mL; or detect the Department of Health watch list species or exceed their action levels (Appendix J).

Notes:
1. EQG = Environmental Quality Guideline; EQS = Environmental Quality Standard

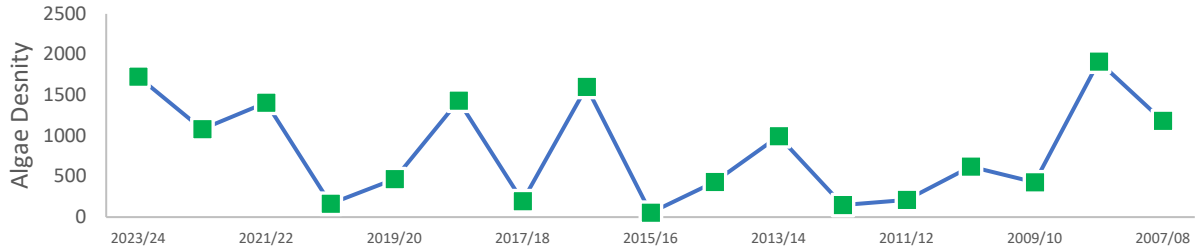
During the 2023–2024 monitoring period, the densities of phytoplankton at the individual monitoring sites remained below 10,000 cells/mL (Table 22). The Environmental Quality Guideline (EQG) for phytoplankton concentrations was therefore met. Historically, algal density has never exceeded 10000 cells/mL at any site (Figure 34).

Table 22 Estimated phytoplankton total cell densities collected at one of the fixed monitoring sites for contact recreation down-current of the Ocean Reef outlets

Date	Site	Total density (cells/mL)	Compliance
06/12/2023	OR7	1,727	
19/12/2023	OR10	450	
12/01/2024	OR5	1,037	
23/01/2024	OR8	278	
05/02/2024	OR8	21	
16/02/2024	OR15	445	
08/03/2024	OR5	601	
19/03/2024	OR9	28	

Note:
1. Green symbols (■) indicate the Environmental Quality Criteria (EQC) were met

2. represent an exceedance of the Environmental Quality Guideline (EQG) and Environmental Quality Standard (EQS), respectively.



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

Figure 34 Algal density over time

5 Shoreline Monitoring

5.1 Thermotolerant coliforms (TTC)

TTC were sampled at eight shoreline monitoring sites eight times over the 2023–2024 summer period (yielding a total of 64 samples). NHMRC (2008) guidelines and EPA (2005) recommend that a minimum of 100 samples are required for accurate assessment of the EQG. Data from multiple years can be pooled where there are <100 samples provided local pollution conditions have not changed (NHRMC 2008). Assuming conditions have not changed, data collected over two summers (summer 2022–2023 and 2023–2024) were pooled to yield 128 samples.

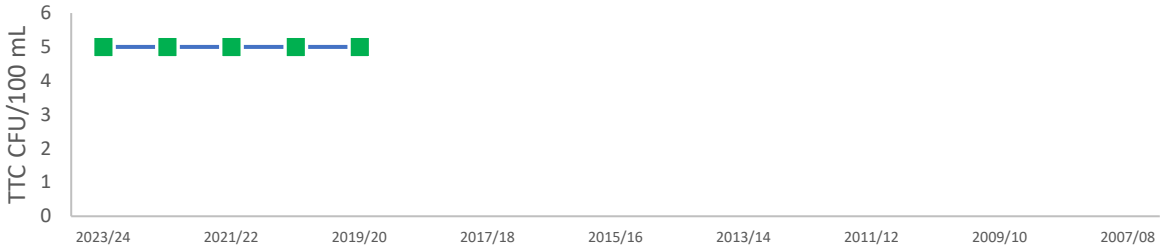
The shoreline sites are not formally assessed against the EQC, but the median and 90th percentile TTC concentrations derived from the 128 samples were at the limit of reporting (<10 CFU/100 mL; Table 23) and less than the 14 and 21 CFU/100 mL criteria, respectively meeting the EQG criteria (Table 15).

Median TTC concentrations were 5 CFU/100 mL (the proxy for concentrations below the LoR) at all sites along the shoreline (Table 23).

Table 23 Median and 90th percentile thermotolerant coliform concentrations at the shoreline monitoring sites for the Ocean Reef outlets for 2022–2024 and comparison to the EQG

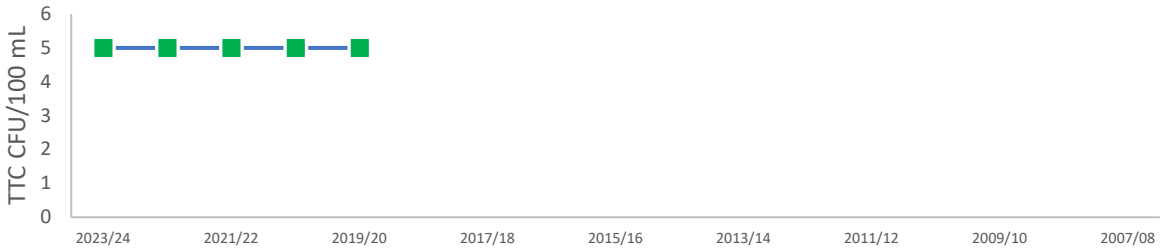
Sampling period	Median (CFU/100 mL)	90th percentile	Compliance
Dec 2022–Mar 2023 Dec 2023–Mar 2024	<10 CFU/100 mL	<10 CFU/100 mL	■

Notes:
1. EQG = Environmental Quality Guideline.
2. Green symbols (■) indicate the Environmental Quality Criteria (EQC) were met.
3. Thermotolerant coliform results below the analytical limit of reporting (<10 CFU/100 mL) were halved (=5 CFU/100 mL) to calculate the median and 90th percentile.
4. Environmental Quality Criteria are based on EPA (2017).



Notes:
1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) and red (■) symbols represent an exceedance of the EQG or Environmental Quality Standard (EQS), respectively.
2. Shoreline monitoring first assessed in 2019-2020.

Figure 35 Median shoreline TTC concentration over time



Notes:

1. Environmental Quality Criteria (EQC): Green (■) symbols indicate the Environmental Quality Guideline (EQG) was met; amber (■) and red (■) symbols represent an exceedance of the EQG or Environmental Quality Standard (EQS), respectively.
2. Shoreline monitoring first assessed in 2019-2020.

Figure 36 90th percentile shoreline TTC concentration over time

5.2 *Enterococci* spp.

Samples were collected eight times at eight shoreline monitoring sites over the 2023–2024 summer monitoring period (yielding a total of 64 samples) for faecal pathogens analyses. NHMRC guideline (2008) and EPA (2005) recommend a minimum of 100 samples over the monitoring period are required for accurate assessment of the EQC. Data from multiple years can be pooled where there are less than 100 samples provided local pollution conditions have not changed (NHMRC 2008). Assuming conditions have not changed, data collected over two summers (summer 2022–23 and 2023–24) were pooled to yield 128 samples.

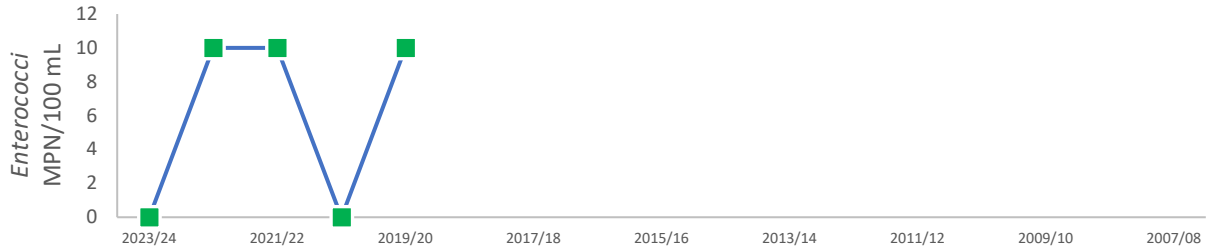
Shoreline sites are not formally assessed against the EQC, however the 95th percentile of *Enterococci* spp. concentrations at the shoreline monitoring sites for the Ocean Reef ocean outlets was <10 MPN/100 mL (Table 24, Appendix H), and met both the primary and secondary (<200 and <2000 MPN/100mL, respectively) contact recreation EQGs (Table 19).

Table 24 The 95th percentile of *Enterococci* spp. concentrations at the shoreline monitoring sites for the Ocean Reef ocean outlets for 2022–2024 and comparison to the EQG

Sampling period	95th percentile	Compliance[4]	
		Primary contact	Secondary contact
Dec 2022–Mar 2023 Dec 2023–Mar 2024	<10 MPN/100 mL	■	■

Notes:

1. MPN = most probable number of *Enterococci* spp.
2. *Enterococci* spp. concentrations below the analytical limit of reporting (<10 *Enterococci* spp. MN/100 mL) were halved (=5 MPN/100 mL) to calculate the 95th percentile.
3. Green symbols (■) indicate the Environmental Quality Criteria (EQC) were met.
4. Environmental Quality Criteria (EQC) based on EPA (2017) water quality guidelines for recreation waters.



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

Figure 37 95th percentile shoreline *Enterococci* spp. concentration over time

6 Aesthetics

Aesthetic quality was assessed fortnightly via a questionnaire completed by field personnel on eight occasions during the non-river flow period (Table 25). On each occasion, the questionnaire was completed at one location on the recreation contact boundary down-current of the Outlets. Water clarity around the outlet (mean LAC at 350 m from the diffuser, pooled from all days) was compared against water clarity at a greater distance from the outlet (mean LAC at 1500 m from the diffuser from all days pooled) to assess whether aesthetic differences exist. Water Corporation also maintains complaints register for the Ocean Reef PLOOM program.

Table 25 Environmental Quality Criteria for Recreation and Aesthetics

Indicator	Environmental Quality Criteria	
	EQG	EQS
Nuisance organisms	Macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae and sewage fungus should not be present in excessive amounts.	There should be no overall decrease in the aesthetic water quality values of the marine receiving environment using direct measures of the community's perception of aesthetic value.
Faunal deaths	There should be no reported incidents of large-scale deaths of marine organisms relating from unnatural causes.	
Water clarity	The natural visual clarity of the water should not be reduced by more than 20%.	
Colour	The natural hue of the water should not be changed by more than ten points on the Munsell scale.	
Surface films	Oil and petrochemicals should not be noticeable as a visible film on the water or detectable by odour.	
Surface debris	Water surfaces should be free of floating debris, dust and other objectionable matter, including substances that cause foaming.	
Odour	There should be no objectionable odour.	
Fish tainting substances	Concentrations of contaminants will not exceed the aesthetics guidelines for fish tainting substances at the Shellfish Harvesting Safety Zone boundary.	There should be no detectable tainting of edible fish harvested outside the Shellfish Harvesting Safety Zone boundary.

Notes:
1. EQG = Environmental Quality Guideline; EQS = Environmental Quality Standard.

The field surveys found algae/plant material visible on the surface on 50% of occasions (Table 26). No dead marine organisms were visible on any occasion (Table 26). There was noticeable colour variation on 75% of occasions (Table 26). There were no films or oil on the surface on any sampling occasion. There was no floating debris visible on the surface on any sampling occasion (Table 26). There was no noticeable odour associated with the water on any of the sampling occasions (Table 26). The observed colour changes in 75% of sampling events triggered assessment against the EQS. Water Corporation received complaints in the 2023-2024 non-river flow period. The complaints pertain to a *Trichodesmium* bloom at Mullaloo Beach and were unrelated to the operation of the outlet so the EQS for the community's perception of the aesthetic values for the Ocean Reef ocean outlets was met.

Mean LAC at 350 m from the ocean outlet (0.0962 Log_{10}/m) was slightly higher than at 1500 m distance from the outlet (0.0902 Log_{10}/m) suggesting that light was more quickly attenuated at 350 m than 1500 m (Table 27). Overall, water clarity was decreased by ~6% and therefore the EQG that the natural visual clarity of the water should not be reduced by more than 20% was met.

Table 26 Aesthetic observations and measurements near the Ocean Reef ocean outlet from December 2022 to March 2023

Date	Site	Algae/plant material?	Dead marine organisms?	Secchi depth (m)	Colour variation?	Oil or other films?	Floating debris?	Odour?	Cotton buds?
06/12/2023	OR7	No	No	3.5	No	No	No	No	No
19/12/2023	OR12	No	No	8	Yes (Green)	No	No	No	No
12/01/2024	OR7	Yes (Seagrass)	No	5.7	Yes (Green)	No	No	No	No
23/01/2024	OR8	Yes (Seagrass)	No	5.6	Yes (Green)	No	No	No	No
05/02/2024	OR9	No	No	7.5	Yes (Green)	No	No	No	No
16/02/2024	OR3	Yes (Seagrass)	No	7.9	Yes (Green)	No	No	No	No
08/03/2024	OR7	No	No	5.5	Yes (Green)	No	No	No	No
19/03/2024	OR9	Yes (Seagrass wrack)	No	5	No	No	No	No	No

Table 27 Light attenuation coefficient at sites 350 m and 1500 m from the Ocean Reef ocean outlet from December 2023 to March 2024

Date	Light attenuation coefficient (Log^{10}/m)	
	350 m (site ORT-350 m)	1500 m (site ORT – 1500 m)
06/12/2023	0.0946	0.0704
19/12/2023	0.0880	0.0734
12/01/2024	0.0852	0.0877
23/01/2024	0.0954	0.0919
05/02/2024	0.097	0.088
16/02/2024	0.0807	0.0884
08/03/2024	0.1042	0.0993
19/03/2024	0.1223	0.0989
Mean	**0.0962**	**0.0902**

7 References

ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines

BMT (2019) Perth Long Term Ocean Outlet Monitoring Program (PLOOM): 2018-2019 Annual Report. Prepared for Water Corporation by BMT Commercial Australia Pty Ltd, Report No. R-1120_05-1/Rev0, Perth, Western Australia, August 2019

BMT (2020) Perth Long Term Ocean Outlet Monitoring Program (PLOOM): 2019-2020 Annual Report. Prepared for Water Corporation by BMT Commercial Australia Pty Ltd, Report No. R-1120_05-3, Perth, Western Australia, August 2020

BMT (2021) Perth Long Term Ocean Outlet Monitoring Program (PLOOM): 2020-2021 Annual Report. Prepared for Water Corporation by BMT Commercial Australia Pty Ltd, Report No. R-10172-1, Perth, Western Australia, September 2021

BMT (2022) Perth Long Term Ocean Outlet Monitoring Program (PLOOM): 2021-2022 Annual Report. Prepared for Water Corporation by BMT Commercial Australia Pty Ltd, Report No. R-10971-1, Perth, Western Australia, September 2022

BMT (2023) Perth Long Term Ocean Outlet Monitoring Program (PLOOM): 2022-2023 Annual Report. Prepared for Water Corporation by BMT Commercial Australia Pty Ltd, Report No. R-000932-1, Perth, Western Australia, September 2023

DoH, DPIRD and Industry (2020) Marine Biotoxin Monitoring and Management Plan version 2: Western Australian Shellfish Quality Assurance Program (WASQAP). Department of Health, Perth, Western Australia, September 2020.

DoH (2022) Environmental quality criteria for toxic algae in marine recreational water. Prepared for the Department of Health for the general public, Editor. East Perth, Western Australia, 14 October 2022, version 3.

EPA (2005) Manual of Standard Operating Procedures – For Environmental Monitoring against the Cockburn Sound Environmental Quality Criteria (2003 – 2004) – A supporting document to the State Environmental (Cockburn Sound) Policy 2005. Environmental Protection Authority, Report No. 21, Perth, Western Australia, January 2005

EPA (2016) Technical Guidance Protecting the Quality of Western Australia's Marine Environment. Environmental Protection Authority, Perth, Western Australia, December 2016

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

Government of Western Australia (2015). State Environmental (Cockburn Sound) Policy 2015. Prepared by Environmental Protection Authority for the general public, Editor. 2015: Perth, Western Australia. p. 15.

McAlpine KW, Wenziker KJ, Apte SC, Masini RJ (2005) Background quality for coastal marine waters of Perth, Western Australia. Department of Environment, Report No. 117, Perth, Western Australia, March 2005

NHMRC (2008) Guidelines for Managing Risks in Recreational Water. National Health and Medical Research Council, Canberra, Australian Capital Territory, February 2008

Water Corporation (2023) Beenyup Ocean Outlets Monitoring and Management Plan. Prepared for Water Corporation by BMT Pty Ltd, Report No. R-1639_00-1, Perth, Western Australia, October 2023