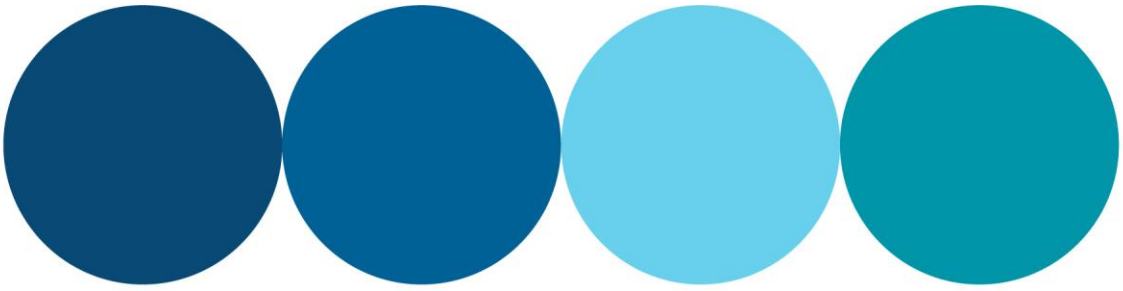
# Perth Long Term Ocean Outlet Monitoring Program (PLOOM)

2021–2022 Annual Report

Ocean Reef



WATER CORPORATION

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## Document history

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| Revision | Author | Recipients | Organisation | No. copies & format | Date |
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## Quality Assurance

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:

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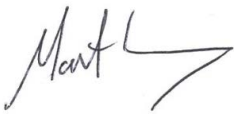

**Director (or delegate)**
Date: 19/10/2022

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## Executive summary

This report documents the findings of the 2021–2022 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 is required annually to demonstrate achievement against Environmental Quality Objectives (EQOs):

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

The results are summarised in Report Card format (Table ES 1). The report card contains colour-coded results, with the individual colours representing the extent to which the Environmental Quality Criteria (EQC) were met (Table ES 2 – Table ES 4).

**Table ES 1 Summary report card legend**

| Management response | Colour |
|---|---|
| **Monitor**: EQG or 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.

### *EQO 'Maintenance of Ecosystem Integrity'*

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

Toxicants in treated wastewater: There are four EQGs relating to toxicants in the TWW, all of which are tested annually. EQG 1 and 2 relate to bioaccumulating and non-bioaccumulating toxicants, respectively. EQG 3 and 4 relate to the total toxicity of the mixture (TTM) and the results of WET testing, respectively.

To meet EQG 1, bioaccumulating toxicant (specifically, cadmium and mercury) concentrations must be below their respective 80% species protection guidelines prior to dilution with seawater. Concentrations of bioaccumulating toxicants were below the 80% species protection guidelines in all cases, thus meeting the EQG.

To meet EQG 2, non-bioaccumulating contaminants must not exceed the ANZG (2018) guideline for 99% species protection at the LEPA boundary, located 100 m from the diffuser. Initial dilution modelling found that the Ocean Reef outlets were achieving worst-case average initial dilution of 1:134. This was sufficient to dilute contaminants to concentrations below the respective 99% species protection guidelines. EQG 2 for toxicants in TWW was therefore met (Table ES 2).

EQG 3 requires that the TTM for the additive effect of ammonia, copper and zinc in the diluted TWW plume is less than 1.0. The calculated TTM following initial dilution was 0.76, which is below the ANZG (2018) guideline value and meets the EQG.

To assess EQG 4 for TWW toxicants, WET testing is used to measure effluent toxicity by exposing sea urchin gametes to different concentrations of TWW and then measuring fertilisation success. The highest concentration of TWW at which there is no statistically significant observed effect on gamete fertilisation (NOEC) is used to establish whether the EQG was met; for this, the NOEC must be greater than 1.0% TWW concentration (i.e. less than a 100-fold dilution). WET tests were undertaken in July 2021, October 2021, January 2022 and April 2022. The lowest NOEC recorded during the four sampling events was 25% , thus meeting EQG 4. (Table ES 2).

Water quality monitoring – receiving environment: Ocean water quality was assessed fortnightly between December 2021 to March 2022 as part of the TCM program. Samples were collected at fixed distance intervals down-current of the outlets. Current direction was determined using a drogue to select the vector. The TCM program includes analyses of nutrients (ammonium, nitrate+nitrite and orthophosphate), chlorophyll-a (a measure of phytoplankton biomass) and physical properties (water temperature, salinity, dissolved oxygen and light attenuation coefficient). Data collected over the 2021–2022 monitoring period indicated that all EQGs bar EQG1 for nutrient enrichment and EQGs 1 and 2 for phytoplankton biomass were met. (Table ES 2). The EQS for nutrient enrichment was not triggered as median chlorophyll-a values in 2020–21 were below 80$^{th}$ percentile of reference sites. Assessment against the EQS suggest that the EQS 1 and 2 criteria for phytoplankton biomass were both met (Table ES 2).

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

| Environmental quality indicator | | EQC | Comments | Compliance |
|---|---|---|---|---|
| Toxicants in treated wastewater (TWW) | Bioaccumulating toxicants | EQG 1 | Concentrations of cadmium and mercury in the undiluted TWW stream were below the 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 23/02/2022 (1:134 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 |
|---|---|---|---|---|
| | Total toxicity of the mixture (TTM) | EQG 3 | The TTM for the additive effect of ammonia, copper and zinc after initial dilution (0.61) was below the ANZG (2018) guideline value of 1.0 |  |
| | Whole of effluent toxicity testing | EQG 4 | The lowest NOEC during the reporting period was 25%. Only 4 dilutions with background seawater are required to achieve this NOEC which is lower than the dilutions typically achieved at the LEPA boundary. |  |
| Nutrient enrichment | Chlorophyll-a | EQG | Median chlorophyll-a concentration within the high ecological protection area (HEPA) (0.6 µg/L) was higher than the 80$^{th}$ percentile of historical reference site concentrations (0.4 µg/L). |  |
| | Chlorophyll-a | EQS | Median chlorophyll-a concentration within the high ecological protection area (HEPA) was not higher than the 80$^{th}$ percentile of historical reference site across a second consecutive year |  |
| | Light attenuation coefficient (LAC) | EQG | Median LAC within the HEPA (0.090 $Log_{10}$/m) was lower than the 80$^{th}$ percentile of historical reference sites (0.093 $Log_{10}$/m). |  |
| Phytoplankton biomass | Phytoplankton biomass (measured as chlorophyll-a) | EQG | Median chlorophyll-a concentrations exceeded three times the median of reference sites on two occasions (1 December 2021 and 8 February 2022) |  |
| | | | Phytoplankton biomass measured as chlorophyll-a did exceed three times median chlorophyll-a concentration of historical reference sites, on two occasions during non-river flow period and in two consecutive years. |  |

| Environmental quality indicator | | EQC | Comments | Compliance |
|---|---|---|---|---|
| | | EQS | Median chlorophyll-a concentration exceeded three times the median of reference sites on two occasions in the 2021–2022 non-river flow period but did not exceed on more than one occasion in two consecutive years (exceeded once in 2020–2021). |  |
| | | | Chlorophyll-a concentration exceeded three-times the median chlorophyll-a concentration of reference sites on 25% of occasions during the non-river flow period, but only 18.75% of occasions in two consecutive years. |  |
| Physical chemistry | Organic enrichment | EQG | Dissolved oxygen saturation within the HEPA, was above 90% saturation at all times. |  |
| | Salinity | EQG | Median salinity was between the 20$^{th}$ and 80$^{th}$ 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 Criteria (EQC) were met; amber (■) and red (■) symbols represent an exceedance of the Environmental Quality Guideline or Environmental Quality Standard (EQS), respectively.
2. NOEC = no observed effect concentration; the highest concentration of TWW at which there is no statistically significant observed effect on gamete fertilisation.

### *EQO 'Maintenance of Seafood for Human Consumption'*

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

TTC were sampled fortnightly at fixed sites over the December–March monitoring period. The ANZG (2018) EQG for Maintenance of Seafood for Human Consumption states that 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 90$^{th}$ percentile of TTC concentrations must not exceed 21 CFU/100 mL.

For the present reporting period, the EQC for TTC were assessed based on pooled data from three sampling seasons (2019–20, 2020–21 and 2021–22), with a sample size (n=120) that allowed for appropriate comparison with the EQC (EPA 2005)[1]. The median value for TTC concentrations was at the limit of detection (<10 CFU/100 mL), and therefore below the 14 CFU/100mL EQG. Over the three seasons, the 90$^{th}$ percentile was equal to the limit of detection (<10 CFU/100 mL), and less than the 21 CFU/100 mL criteria. As the 90$^{th}$ percentile was below the criteria, the EQG was met (Table ES 3).

The EQG for 'Maintenance of Seafood for Human Consumption' states that 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 2016) concentrations. There was one instance, on 13 January 2022, where the toxic phytoplankton species of the *Pseudo-nitzschia seriata* group (337 600 cells/L) were recorded at greater density than the WASQAP guidelines. However, the reference site for the same sampling date also recorded an exceedance of the same species, thus meeting the EQG.

[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 for Human Consumption'**

| Environmental quality indicator | | Comments | Compliance |
|---|---|---|---|
| Faecal pathogens | Thermotolerant coliforms (TTC) | Median TTC concentrations derived from 120 samples collected over the 2019–2020, 2020–2021 and 2021–2022 sampling seasons was at the limit of detection (<10 CFU/100 mL) and below the 14 CFU/100 mL criteria | ■ |
| | | The 90th percentile was equal to the limit of detection (<10 CFU/100 mL), and less than the 21 CFU/100 mL criteria | ■ |
| Algal biotoxins | Toxic phytoplankton species | There was one instance where toxic phytoplankton species of were recorded in excess of Western Australian Shellfish Quality Guidelines during the 2021-22 monitoring. However, this exceedance also occurred at a reference site. | ■ |

Notes:

1. Green (■) symbols indicate the Environmental Quality Criteria (EQC) were met; amber (■) and red (■) symbols represent an exceedance of the Environmental Quality Guideline (EQG) or Environmental Quality Standard (EQS), respectively.
2. TTC results below the analytical detection limit (<10 CFU/mL) were halved (=5 CFU/mL) to calculate median value.
3. TTC = Thermotolerant coliforms.

***EQO '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.

The EQG for primary contact recreation requires that the 95$^{th}$ percentile value of faecal pathogens (*Enterococci* spp.) not exceed 200 MPN/100 mL outside the OZI boundary. To meet the EQG for secondary contact recreation, the 95$^{th}$ percentile is not to exceed 2000 MPN/100 mL. The EQG for microbiological contaminants was assessed based on pooled data (n=120) from three sampling seasons (2019–2020, 2020–2021 and 2021–2022). The 95$^{th}$ percentile of *Enterococci* spp. concentrations equalled 10 MPN/100 mL and met the EQG for both primary and secondary contact recreation (Table ES 4).

To evaluate the EQC for phytoplankton cell concentrations, phytoplankton samples were collected at fixed monitoring sites along the boundary of the OZI at approximately fortnightly intervals over the December to March monitoring period.

The EQG for algal biotoxins states:

- the median total phytoplankton cell concentration for the area of concern is not to exceed 10 000 cells/mL or
- Department of Health watch list species must not be detected in exceedance with their trigger levels

Phytoplankton densities at individual sites monitored during 2021–2022 were below 10 000 cells/mL but a Department of Health watch list species (*Trichodesmium* spp) did exceed their trigger levels (detected for *Trichodesmium*), not meeting the EQG and triggering the EQS. (Table ES 4).

The EQS for algal biotoxins states:

- the median total phytoplankton cell concentration for the area of concern is not to exceed 50 000 cells/mL or
- Department of Health watch list species must not be detected in exceedance with their action levels

Phytoplankton densities at individual sites monitored during 2021–2022 were below 50 000 cells/mL and a Department of Health watch list species did not exceed their action levels (presence of algal scums for *Trichodesmium*), meeting the EQS. (Table ES 4).

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

| Environmental Quality Indicator | | EQC | Comments | Compliance |
|---|---|---|---|---|
| Faecal pathogens | *Enterococci* spp. | EQG1 (primary contact) | The 95th percentile of *Enterococci* spp. concentrations (10 MPN/100 mL) was lower than the 200 MPN/100 mL (EQG1) and 2000 MPN/100 mL (EGQ2) | ■ |
| | | EQG2 (secondary contact) | | |
| Algal biotoxins | Phytoplankton (cell concentration) | EQG | Estimated total Phytoplankton cell count at individual sites were < 10 000 cells/mL at each site and sampling occasion during 2021–2022 monitoring but a Department of Health watch list species did exceed its trigger level | ■ |
| | Phytoplankton (cell concentration) | EQS | Estimated total Phytoplankton cell count at individual sites were < 50 000 cells/mL at each site and sampling occasion during 2021–2022 monitoring the Department of Health watch list species did not exceed its action level | ■ |

Note:

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

# Introduction

## Document purpose

This annual report documents the findings of the 2021–2022 ocean monitoring around the Ocean Reef ocean outlets. Monitoring was completed according to Western Australia's Environmental Quality Management Framework (EQMF; EPA 2016).

## Wastewater treatment plant 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. A proposed 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.

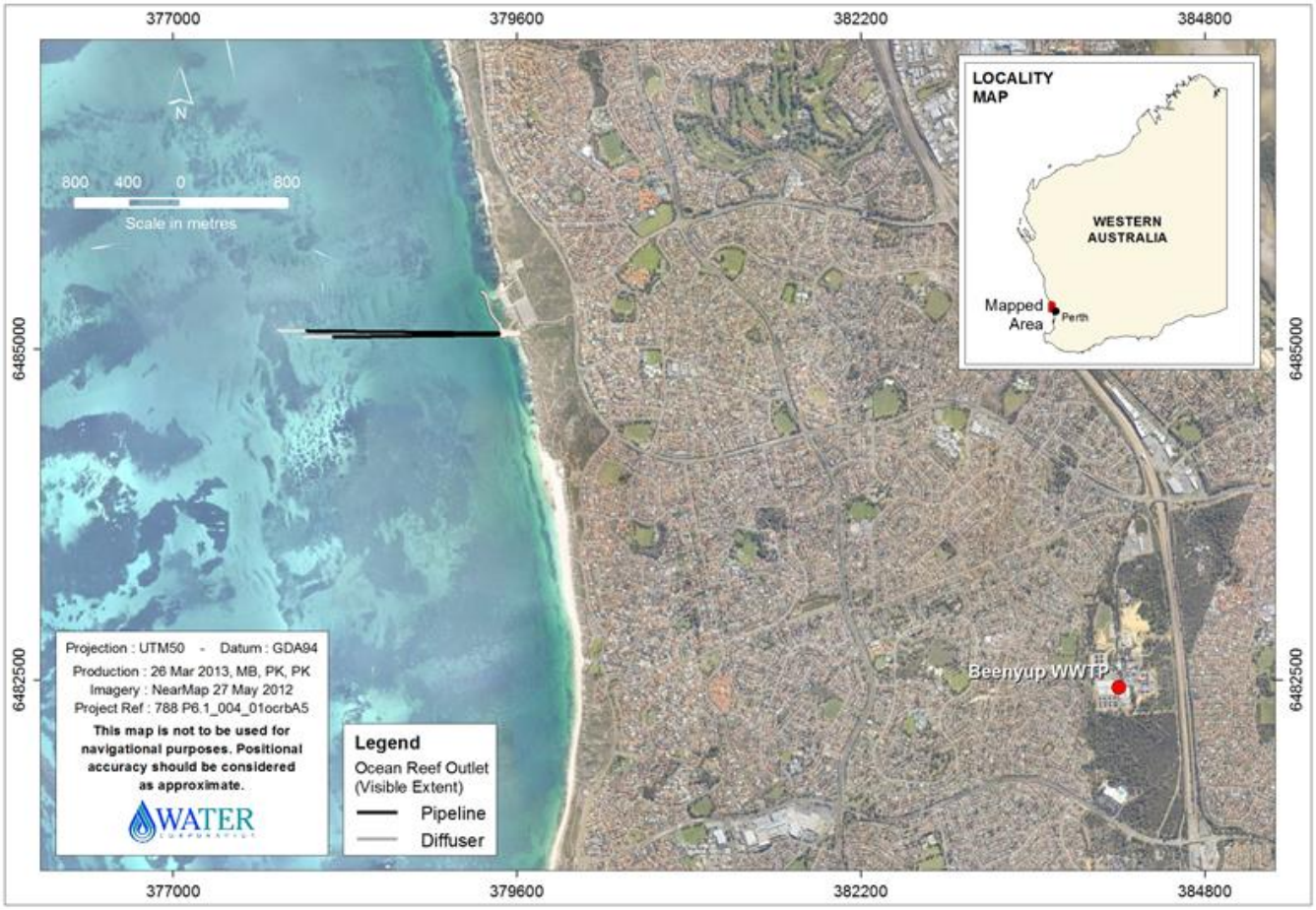
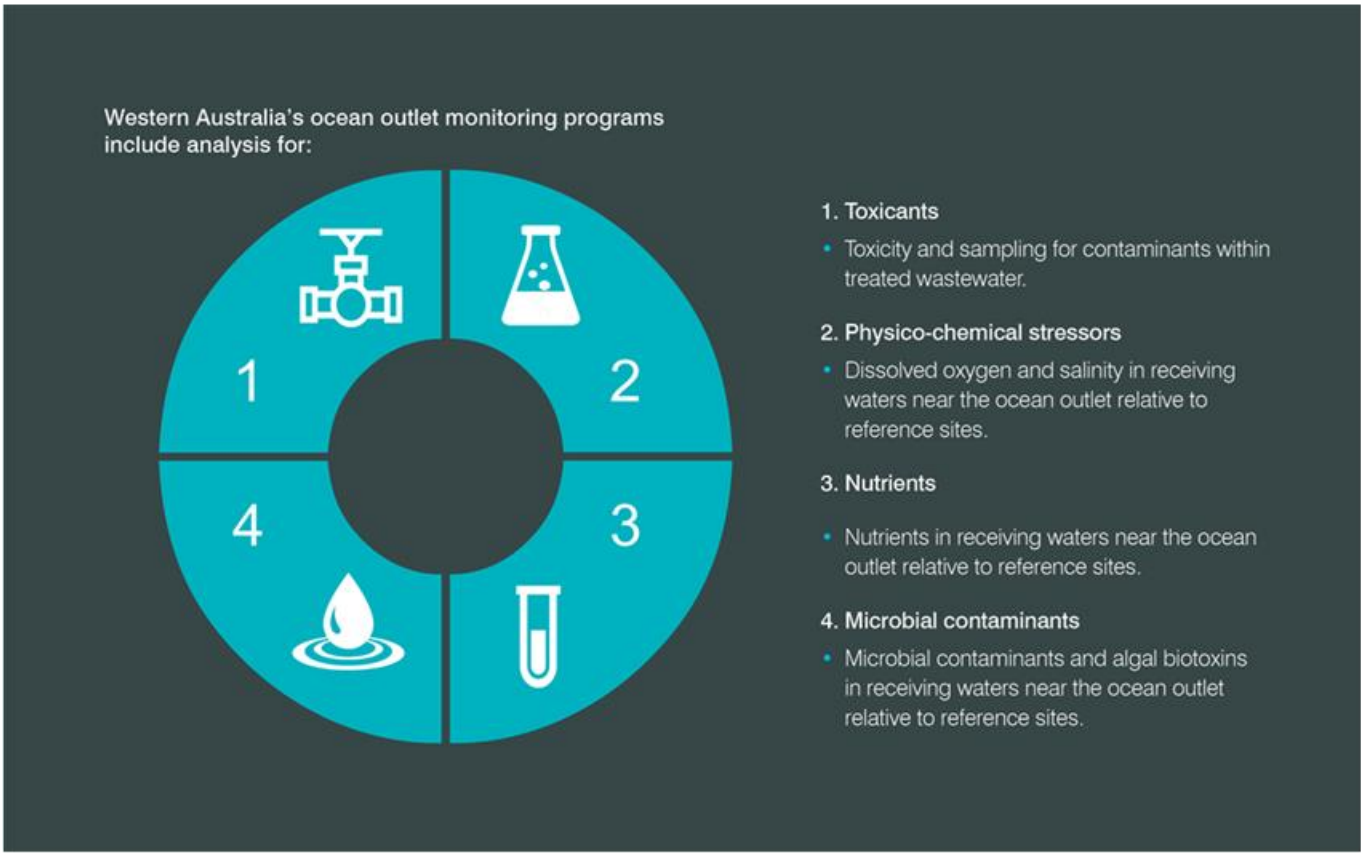



**Figure 1 Location of Beenyup WRRF and Ocean Reef ocean outlets**

## Potential stressors in treated wastewater




### 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 environmental guidelines. To account for the synergistic effects of multiple toxicants and toxicants without guidelines, the overall toxicity of the TWW is determined using whole of effluent toxicity (WET) testing (also known as direct toxicity assessment).

### Physico-chemical stressors

TWW contains organic matter, 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 outlets provide an indication of the risk posed by deoxygenation.

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

### Nutrients

TWW contains elevated concentrations of the biologically available nutrients ammonia, nitrite, nitrate and orthophosphate. Nutrients can 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 determined using in-water measures of chlorophyll-a (a proxy for phytoplankton biomass) and light attenuation (a measure of water clarity).

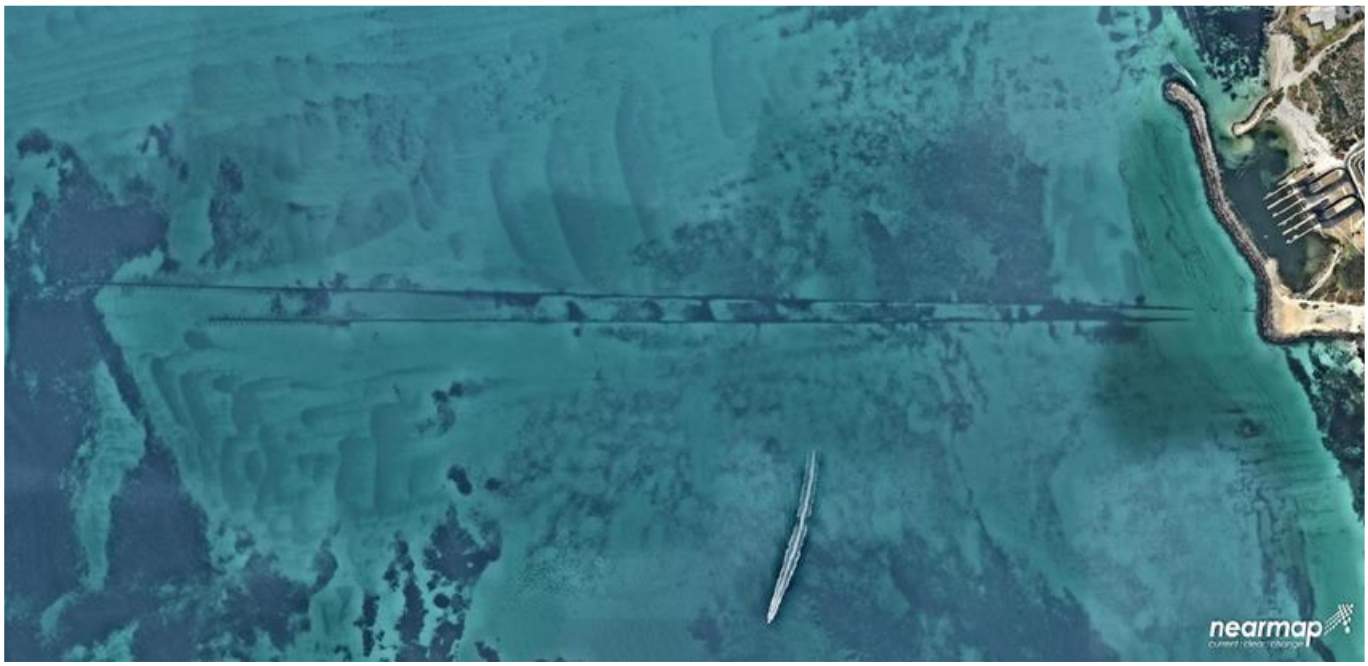
Although most algal blooms are harmless, some contain species that produce toxins that may be harmful to swimmers (via ingestion or skin contact) or poison seafood. Phytoplankton species composition and cell concentrations are monitored to ensure concentrations are within acceptable limits.

**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; EPA 2017) criteria for primary and secondary contact recreation and for seafood for human consumption.

## Environmental management approach

Water Corporation's formal environmental commitments for the Beenyup WRRF discharge are outlined in Ministerial Statements 382 and 569. To maintain consistency with the other metropolitan ocean outfall programs, the Ocean Reef outlets (Figure 2) are 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**

Stage 1 of the AWRP/GWRS operates under existing approvals. The change in discharge characteristics associated with Stage 2 requires a change to proposal/conditions under Sections 45c and 46 of the *Environmental Protection Act 1986* (EP Act). The approvals process includes development of an Environmental Monitoring and Management Plan (EMMP), which will bring the management framework into line with contemporary Department of Water and Environmental Regulation policy (EPA 2017) and establish formal management areas around the outlets. The EMMP and associated management zones do not apply until the stage 2 facility reaches full capacity and the existing monitoring approach will remain in place until then.

## 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 'trigger values' against which monitoring results can be compared.

There are two levels of EQC:

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

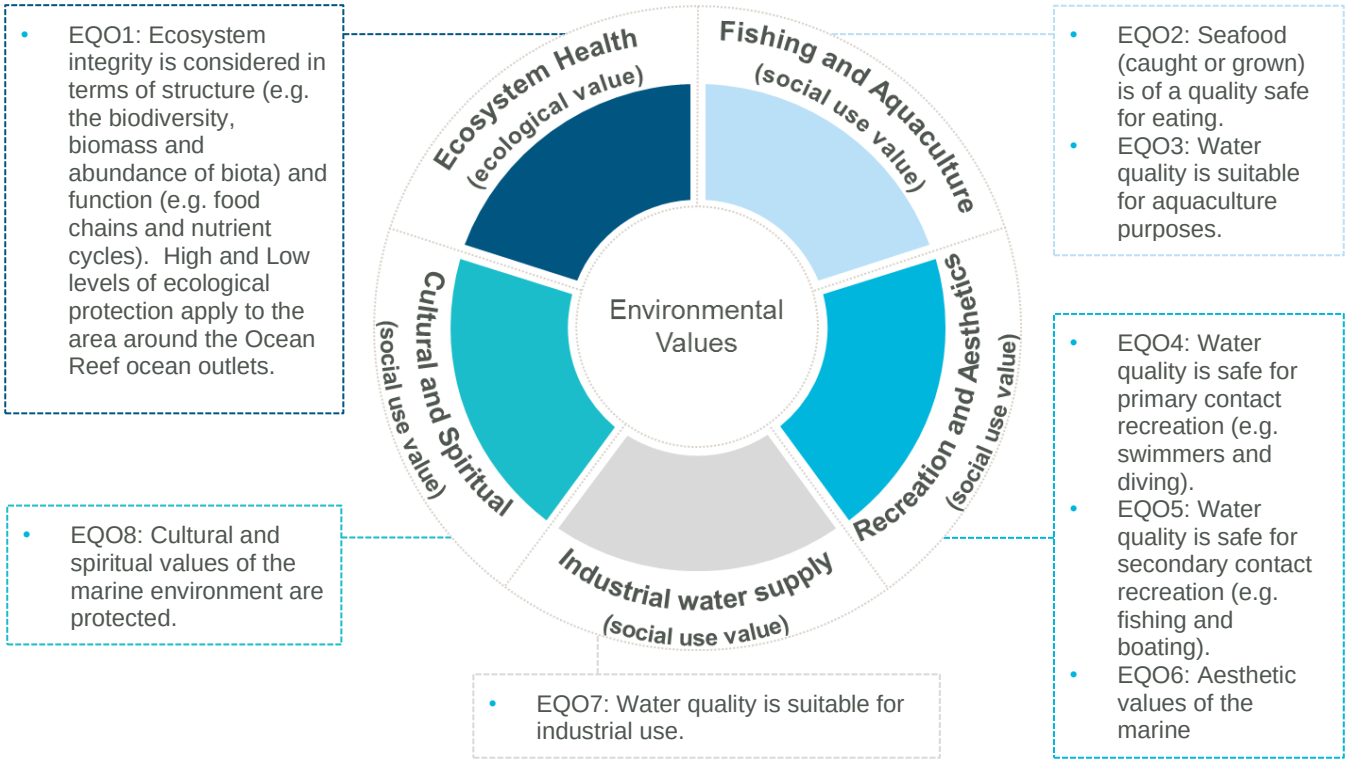



**Figure 3 Environmental Values and Environmental Quality Objectives (EQO) for the marine waters of Western Australia**

## '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).

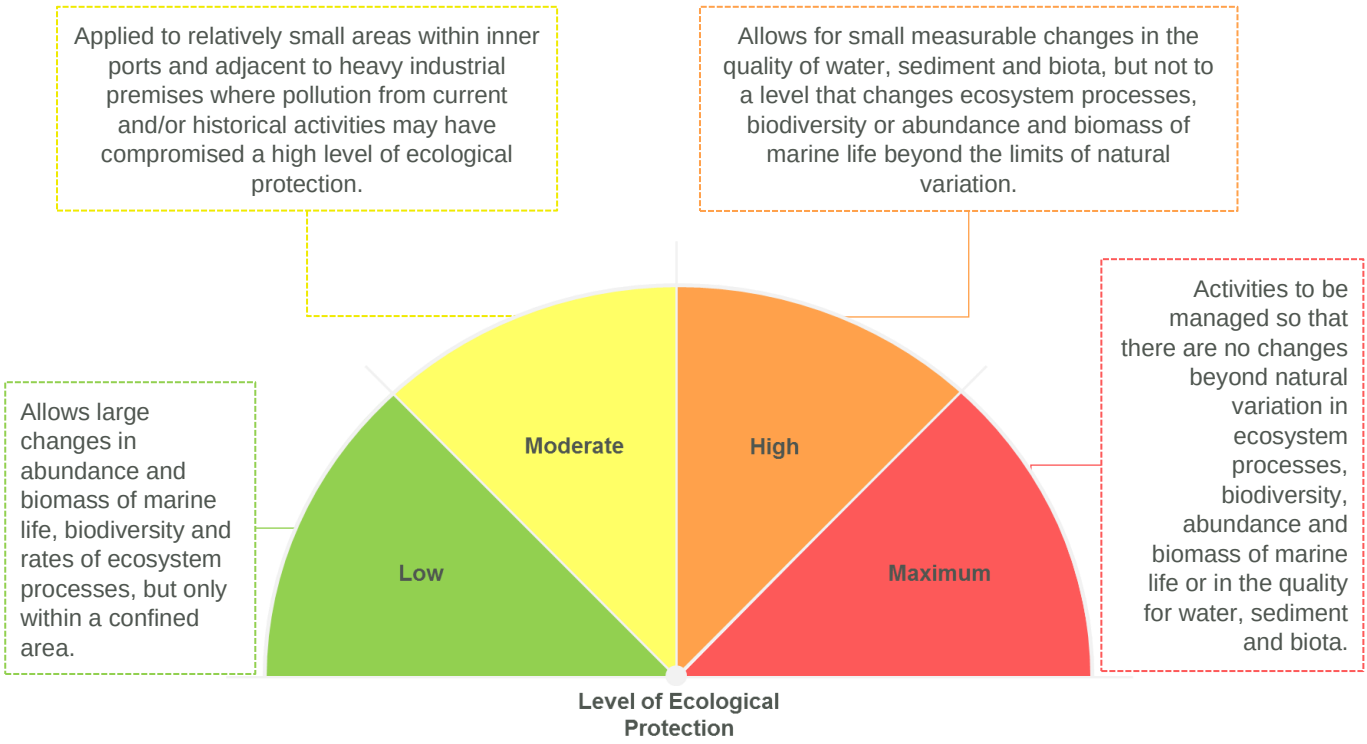



**Figure 4 Level of Ecological Protection**

A notional low ecological protection area (LEPA) has been established around the Ocean Reef outfalls and occupies the area within a 100 m radius of the diffusers (Figure 5). The LEPA size will be formalised as part of the AWRP approvals process. Waters outside the LEPA are maintained to a high level of ecological protection (HEPA; Figure 5).

### '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.

### '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).

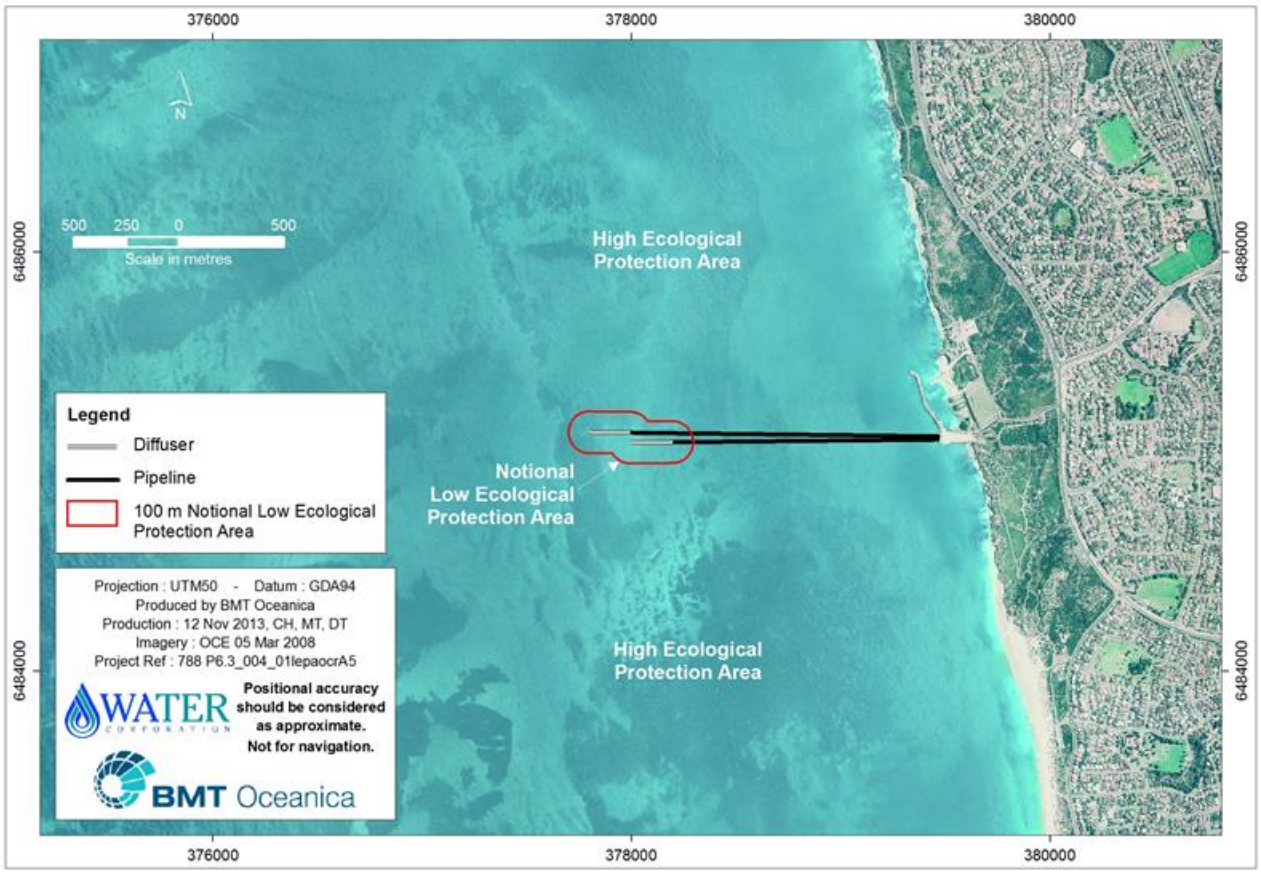



**Figure 5 Ocean Reef ocean outlets notional ecological protection areas**

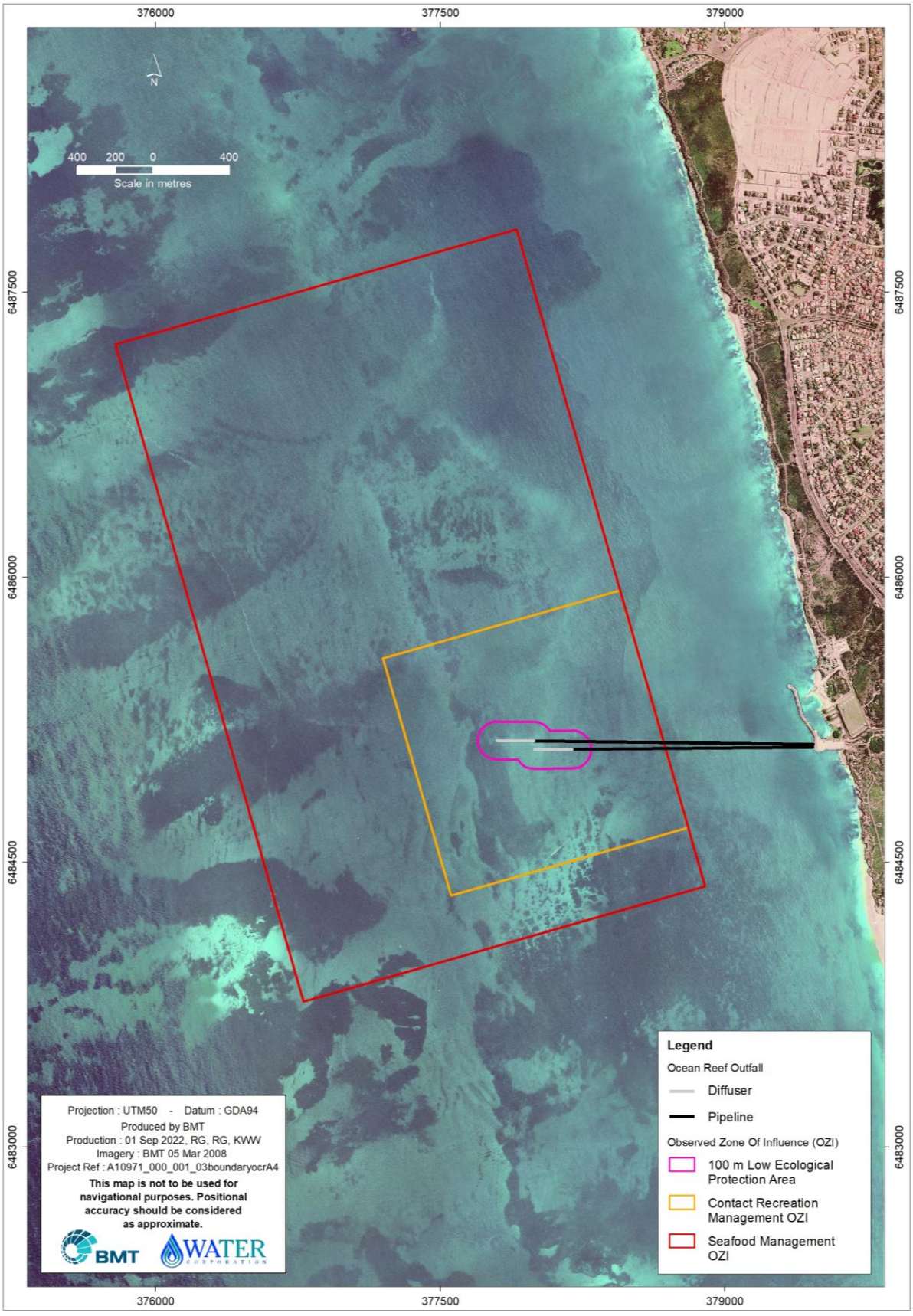



**Figure 6 Ocean Reef ocean outlet protection area and management zones.**

## Toxicants in treated wastewater

### Comprehensive treated wastewater characterisation (CTWWC)

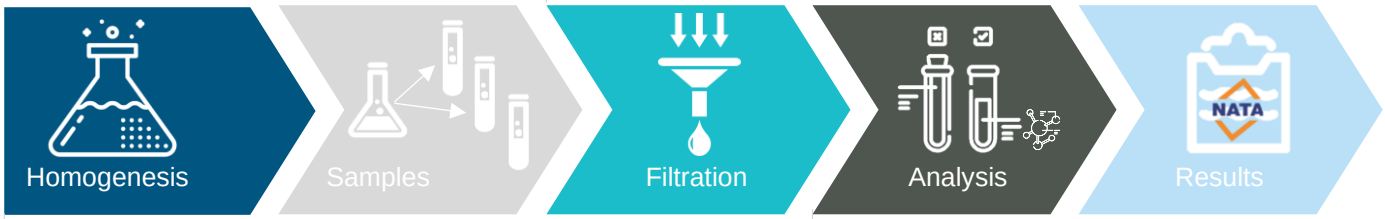
TWW (final effluent) from the Beenyup WRRF is analysed for potential contaminants of concern:

- nutrients (total nitrogen, ammonia, nitrate+nitrite, total phosphorus, orthophosphate)
- microbial 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.

A discrete sample was obtained from the Beenyup WRRF site on 8 February 2022. The sample was collected after the point where the Beenyup TWW and AWRP reject streams join and it is representative of the final (combined) discharge to the ocean.

Samples for bioavailable metals were filtered through a 0.45 µm filter prior to analyses (EPA 2005).

The following sections detail the toxicant results in TWW from the Beenyup WRRF (Appendix B), with assessment made against relevant EQGs.




The bulk sample was homogenised (agitated), split into individual sample containers and sent to a National Association of Testing Authorities (NATA)-accredited laboratory for analysis (Appendix A).

Analyses were completed using NATA-accredited methods.

### Bioaccumulating toxicants

Concentrations of cadmium and mercury (i.e. bioaccumulating toxicants) in the TWW sample were below their respective LoRs (<0.1 µg/L for cadmium and <0.05 µg/L for mercury) and 80% species protection guidelines (36 and 1.4 µg/L, respectively) (ANZG 2018), meeting the EQG (Table 1).

**Table 1 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 |

Notes:

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

## Non-bioaccumulating toxicants

Modelling predicted an average initial dilution of 1:155 at Ocean Outlet A and 1:134 at Outlet B (Appendix C). The worst-case initial dilution of 1:134 was used as a conservative estimate of the dilution expected at the LEPA boundary. Contaminant concentrations after the initial dilution of 1:134 were below the ANZG (2018) 99% species protection guidelines (Table 3), and the EQG for non-bioaccumulating toxicants (Table 2) was met.

**Table 2 Environmental Quality Guideline for non-bioaccumulating toxicants**

| | |
|---|---|
| **EQG** | Wastewater contaminant concentrations, in conjunction with initial dilution modelling, will be evaluated to determine that the ANZG (2018) 99% species protection guideline trigger levels for toxicants are achieved at the boundary of the low ecological protection area (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 3 Toxicants in the Beenyup TWW stream compared with relevant guideline trigger levels after initial dilution**

| Toxicant (ug/L) | Beenyup TWW concentration (µg/L) | Concentration after initial dilution (µg/L) | Trigger (µg/L) |
|---|---|---|---|
| Ammonia-N | 480 | 3.58 | 500 |
| Cadmium* | <0.1 | - | 36 |
| Chromium* | <1 | - | 0.14 (Cr VI)<br>7.7 (Cr III) |
| Copper* | 16 | 0.12 | 0.3 |
| Lead* | <1 | - | 2.2 |
| Mercury* | <0.05 | - | 1.4 |
| Nickel* | 2.3 | 0.02 | 7 |
| Silver* | <0.8 | - | 0.8 |
| Zinc* | 58 | 0.43 | 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 guideline values was undertaken only for those toxicants where trigger levels were available.
2. TWW – treated wastewater
3. Initial dilution = 1:134 (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 trigger values 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 detection 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.

### Total toxicity of the mixture (TTM)

The total toxicity of the mixture (TTM, an indicator of the potential for cumulative toxic effects on marine organisms) for the combined effect of ammonia, copper and zinc following initial dilution (0.76; Table 5) was less than the ANZG (2018) guideline value of 1.0 and the EQG for TTM (Table 4) was met.

**Table 4 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 trigger value 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
3. For metals, the assessment is to be based on bioavailable concentrations of metals in the wastewater (i.e. concentrations after filtering through a 0.45 µm filter.

**Table 5 Total toxicity of treated wastewater (TWW) at the edge of the initial mixing zone associated with the Ocean Reef ocean outlets**

| Natural concentrations in Perth's coastal waters | | | Initial dilution of TWW with seawater | Total toxicity of the mixture (TTM) |
|---|---|---|---|---|
| **Ammonia** | **Copper** | **Zinc** | | |
| 1.5 | 0.08 | 0.15 | 1:134 | 0.76 |

Notes:

1. Background concentrations for copper and zinc from McAlpine et al. (2005); Perth marine waters (99. 19; Table 12). Surface background concentration for ammonia calculated as median of reference site data from 2004–2019 (BMT, unpublished data).
2. TMM = [ammonia]/guideline + [copper]/guideline + [zinc]/guideline.
3. Initial dilution at outlet A was 1:155, initial dilution at outlet B was 1:134. Initial dilution at outlet B was used in TTM calculation as conservative estimate (Appendix C).

## Whole of effluent toxicity (WET) testing

WET testing is useful for assessing toxicity in the absence of 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 wastewater concentration where no significant effect is observed) (Appendix D).

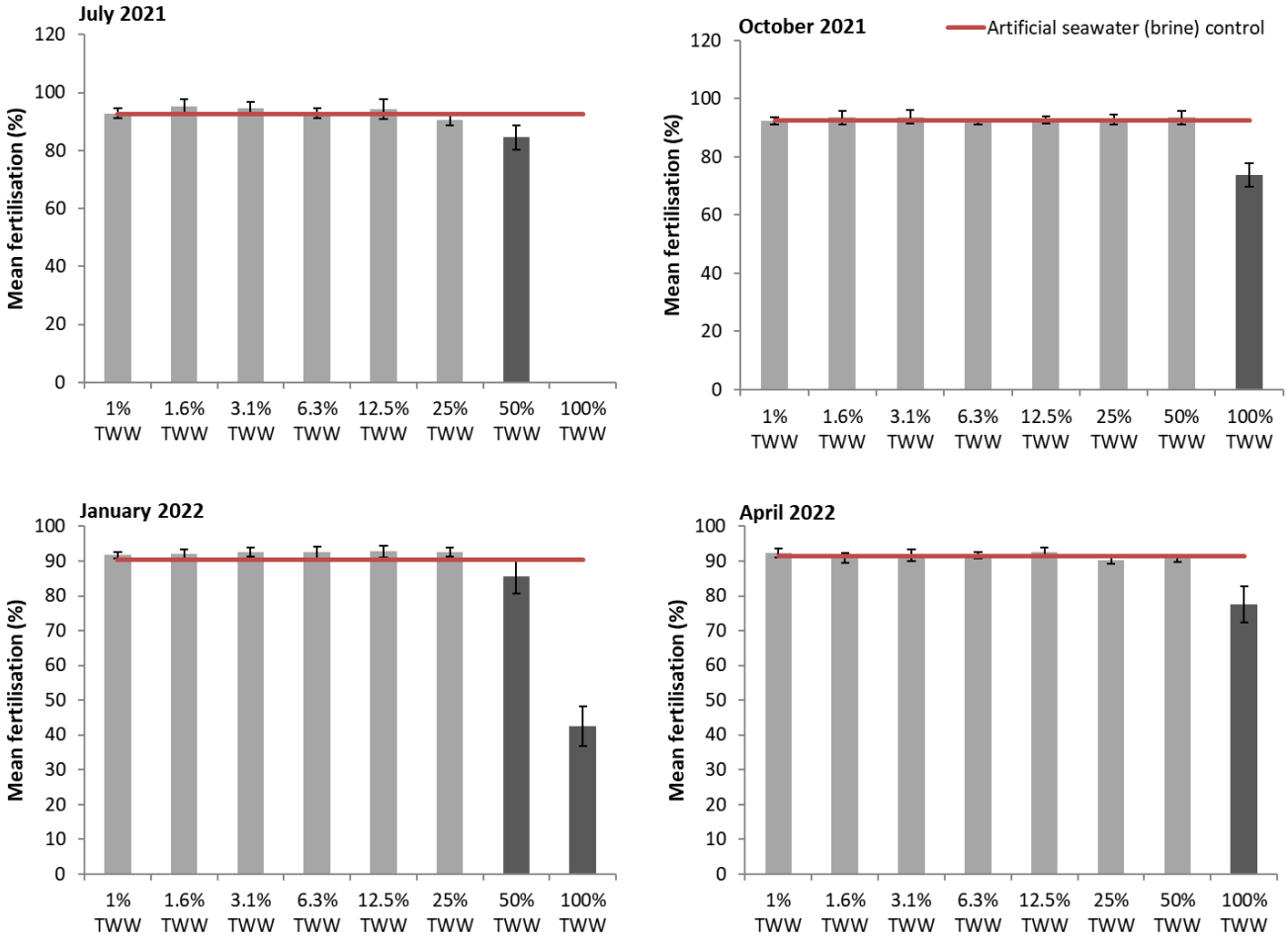
In October 2021 and April 2022, sea urchin fertilisation in samples exposed to 100% TWW concentration was significantly lower than an artificial seawater control (Figure 7). All other dilutions were not significantly different to the control; Figure 7; Appendix D). In July 2021 and January 2022, sea urchin fertilisation exposed to both the 50% and 100% TWW concentrations were significantly lower than the artificial seawater control (with all other concentrations not significantly different to the artificial seawater control; Figure 7; Appendix D). For all sampling dates, the NOEC was greater than 1% TWW (Table 7) and the EQG for WET testing (Table 6) was met.

## Table 6 Environmental Quality Guideline for whole of effluent toxicity testing

| | |
|---|---|
| **EQG** | The EQG will be exceeded if following the 1-hour sea urchin test:<br>$\frac{TDA}{DRNOEC} \leq 1.0$<br><br>where TDA = Typical Dilutions Achieved (constant based on 100-fold dilution)<br>DRNOEC = number of dilutions required to achieve the no observed effects concentration (NOEC).<br><br>Breaching the above triggers investigations against the EQS, which would comprise the full suite of WET tests (minimum of five species from four trophic groups). |

Note:

1. EQG = Environmental Quality Guideline.




Notes:

1. Error bars ± standard deviation.
2. TWW = treated wastewater.
3. Light grey bars represent concentrations of treated wastewater (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 7 Comparison of whole effluent toxicity TWW dilution results to artificial seawater control**

**Table 7 Calculated parameters from whole of effluent toxicity tests**

| Indicator | July 2021 | October 2021 | January 2022 | April 2022 |
|---|---|---|---|---|
| NOEC | 25% | 50% | 25% | 50% |
| Dilutions required to meet the NOEC | 4 | 2 | 4 | 2 |
| Dilutions required/dilutions achieved | 0.03 | 0.015 | 0.03 | 0.015 |
| ≤1 | Yes | Yes | Yes | Yes |

Note:

1. NOEC = No observed effect concentration.

## Water quality monitoring – receiving environment

Nutrients, phytoplankton biomass and physical and chemical stressors were monitored approximately fortnightly from the beginning of December 2021 to the end of March 2022 (coinciding with the summer non-river flow period) along a down-current gradient away from the diffusers (Table 8, Appendix E and Appendix F).

**Table 8 Water quality monitoring dates near the Ocean Reef ocean outlets between December 2021 and March 2022**

| Sample day | Date |
|---|---|
| 1 | 01/12/2021 |
| 2 | 21/12/2021 |
| 3 | 13/01/2022 |
| 4 | 27/01/2022 |
| 5 | 08/02/2022 |
| 6 | 28/02/2022 |
| 7 | 14/03/2022 |
| 8 | 23/03/2022 |

Wind direction, strength, current direction grid and cloud cover on the day of sampling were recorded (Table 9).

**Table 9 Weather and current direction grid during water quality monitoring near the Ocean Reef ocean outlets**

| Date | Wind direction | Wind strength (knots) | Cloud cover (%) | Current grid |
|---|---|---|---|---|
| 01/12/2021 | SSE, S | 12 | 10 | N |
| 21/12/2021 | S, SSW | 10–15 | 60 | N |
| 13/01/2022 | S | 5–14 | 0 | NE |
| 27/01/2022 | SW | 14–16 | 90–100 | NW |
| 08/02/2022 | SE, SW | 2–8 | 50–70 | NE |
| 28/02/2022 | SSE, SSW | 2–5 | 20–25 | S |
| 14/03/2022 | ESE | 14–16 | 0 | S |
| 23/03/2022 | W, SW | 1–6 | 0–10 | W |

Notes:

1. N = north, S = south, W = west, E = east, SW = south-west, SE = south-east, NW = north-west, NE = north-east, SSE = south-south-east, ENE = east-north-east, ESE = east-south-east, NNE = north-north-east
2. Winds are designated by the direction they come from while currents are designated by the direction they flow to.

### Nutrient enrichment

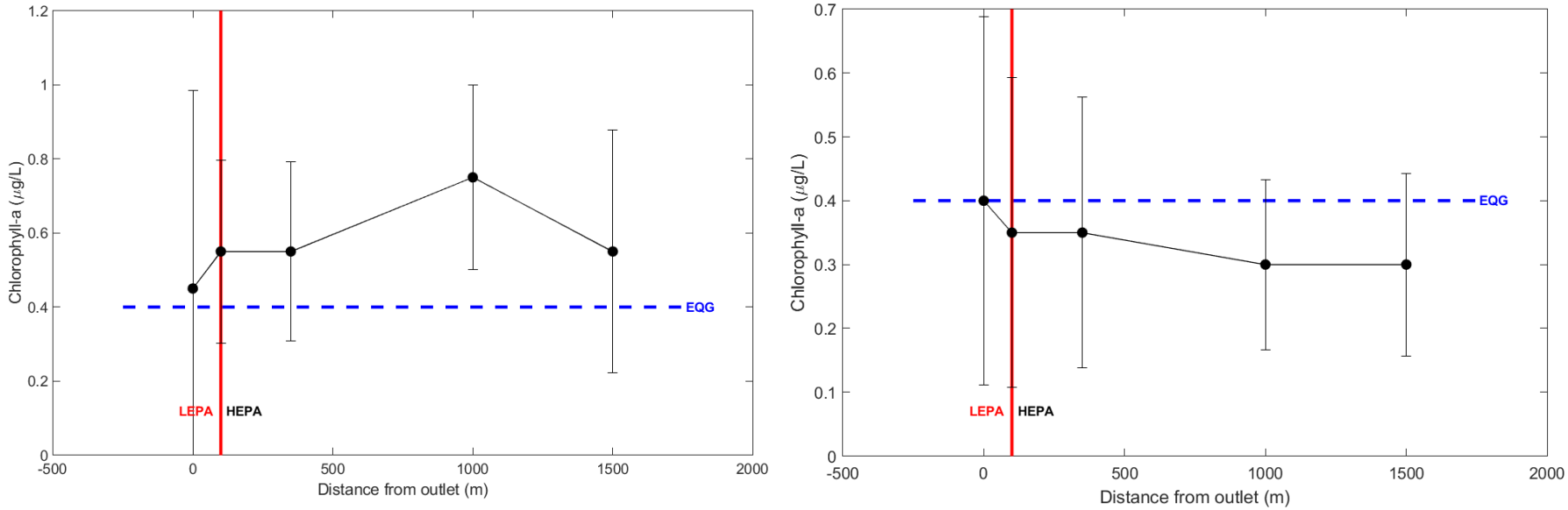
The median chlorophyll-a concentration in the Ocean Reef HEPA (100 m plus) was 0.6 µg/L and was greater than the 80$^{th}$ percentile of historical reference site data (0.4 µg/L; Figure 8), which exceeded the EQG (Table 10). The EQS for chlorophyll-a states that the EQG must not be exceeded in two consecutive years. Median chlorophyll-a concentration in the Ocean Reef HEPA (100 m plus) during 2020–21 was below the 80$^{th}$ percentile of historical reference site data (0.4 µg/L; Figure 8) and the EQG was not exceeded in a second consecutive year therefore the EQS was met (Table 10).

## Table 10 Environmental Quality Criteria for nutrients

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

Note:

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

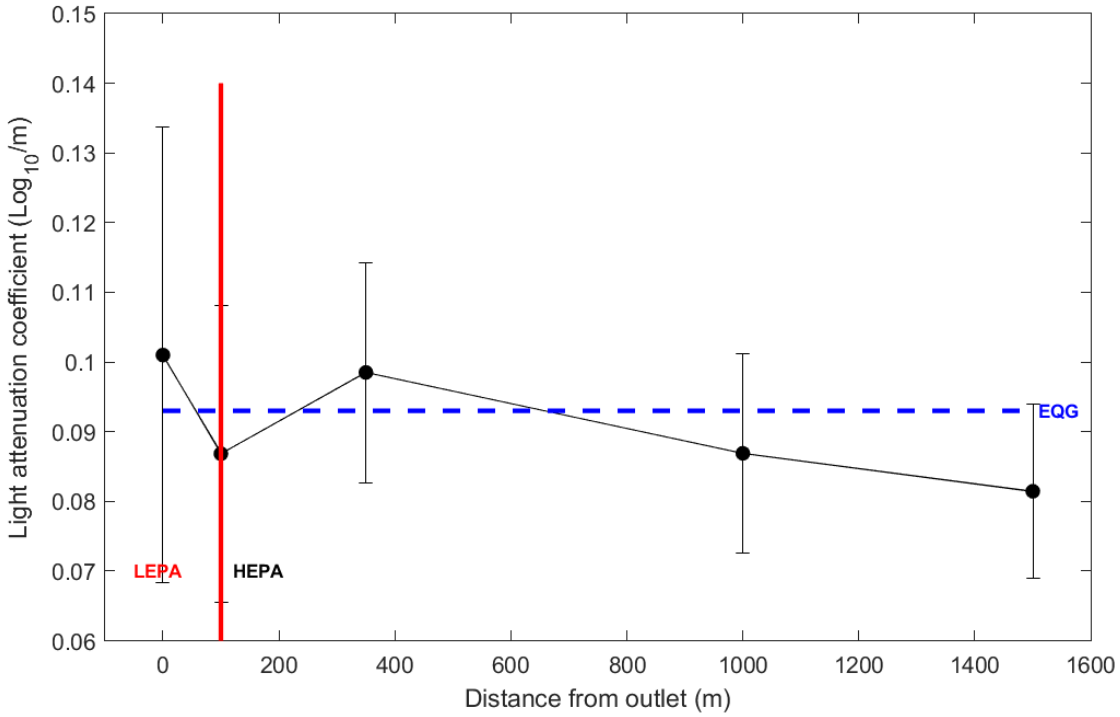



Notes:

1. Error bars represent ±95% confidence intervals.
2. Environmental Quality Guideline (EQG) is the 80$^{th}$ percentile of historical reference site data (0.4 µg/L chlorophyll-a).
3. LEPA = notional low ecological protection area; HEPA = high ecological protection area.
4. Data for each distance were pooled across eight sampling days over December 2021–March 2022.

**Figure 8 Median chlorophyll-a concentrations obtained at fixed monitoring sites above and down-current of the Ocean Reef outlets during the summer monitoring period. Left graph shows results from the 2021–22 monitoring period while the right graph shows results from the 2020–21 monitoring period.**

The median light attenuation in the Ocean Reef HEPA (100 m plus) was 0.0895 $Log_{10}$/m and lower than the 80th percentile of reference sites data (0.093 $Log_{10}$/m), meeting the EQG (Figure 9).




Notes:

1. Error bars represent ±95% confidence intervals.
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 = notional low ecological protection area; HEPA = high ecological protection area.
4. Data for each distance were pooled across eight sampling occasions (n=8) over December 2021–March 2022.

**Figure 9 Median light attenuation coefficient obtained at fixed monitoring sites above and down-current of the Ocean Reef outlets during the summer monitoring period**

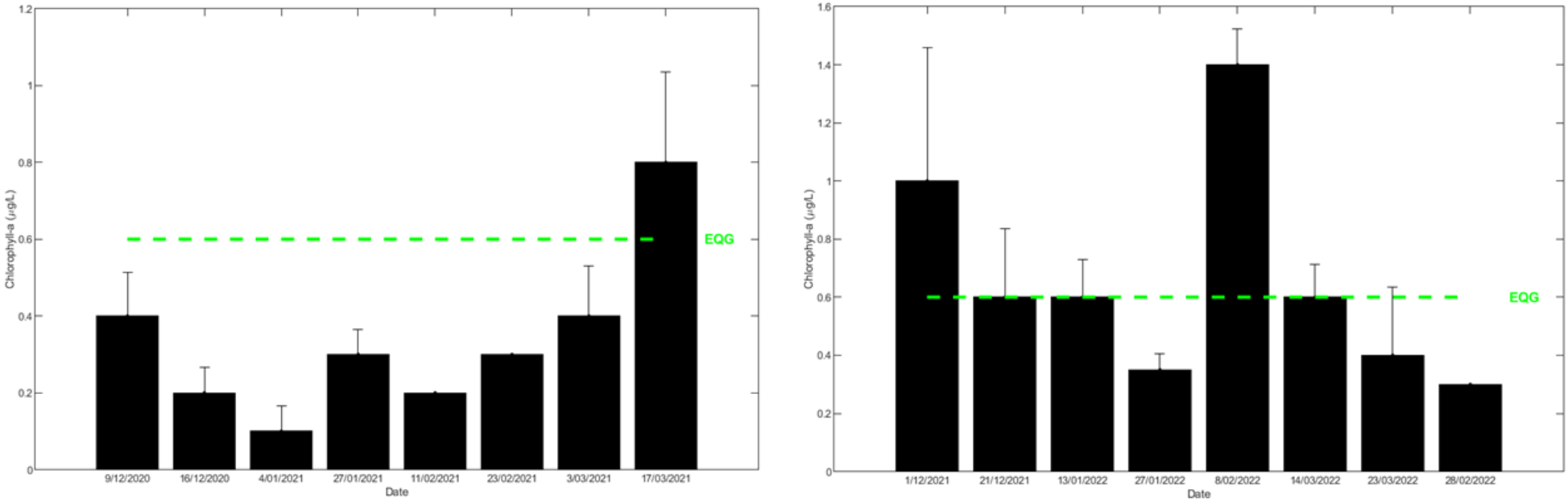
## Phytoplankton biomass

Median phytoplankton biomass measured as chlorophyll-a exceeded three times the median chlorophyll-a concentration of historical reference sites (0.6 µg/L; Figure 10) on two occasions (1.0 µg/L on 1 December 2021 and 1.4 µg/L on 8 February 2022) exceeding EQG1 (Table 11) and triggering assessment against EQS1. Median phytoplankton biomass measured as chlorophyll-a did not exceed three times median chlorophyll-a concentration of historical reference sites, on more than one occasion in two consecutive years (only exceeding once in 2020–21, 17 March 2021) therefore meeting EQS1.

**Table 11 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 measures 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. |

Phytoplankton biomass, measured as chlorophyll-a, exceeded three times the median chlorophyll-a concentration of historical reference sites (0.6 µg/L) on 2 (25%) occasions during the non-river flow period exceeding EQG2 (Table 11) 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 25% of occasions in the 2021–22 non-river flow period but exceeded on only 18.75% over two consecutive years (17 March 2021, 1 December 2021 and 8 February 2022), therefore EQS2 was met.




Notes:

1. Error bars represent ±95% confidence intervals.
2. Environmental Quality Guideline (EQG) is three times the median chlorophyll-a concentration of reference site data.
3. Values measured at 0 m are not included in the figure or EQG assessment, as the 0 m site is situated directly above the outlets within the notional low ecological protection area (LEPA).
4. Data were pooled across four sites within the high ecological protection area (HEPA).

**Figure 10 Median phytoplankton biomass during the summer monitoring period, pooling data from fixed sites ≥100 m down-current of the Ocean Reef ocean outlets; left) 2020–21 monitoring period, right) 2021–22 monitoring period.**

## Physical-chemical stressors

### Dissolved oxygen (DO)

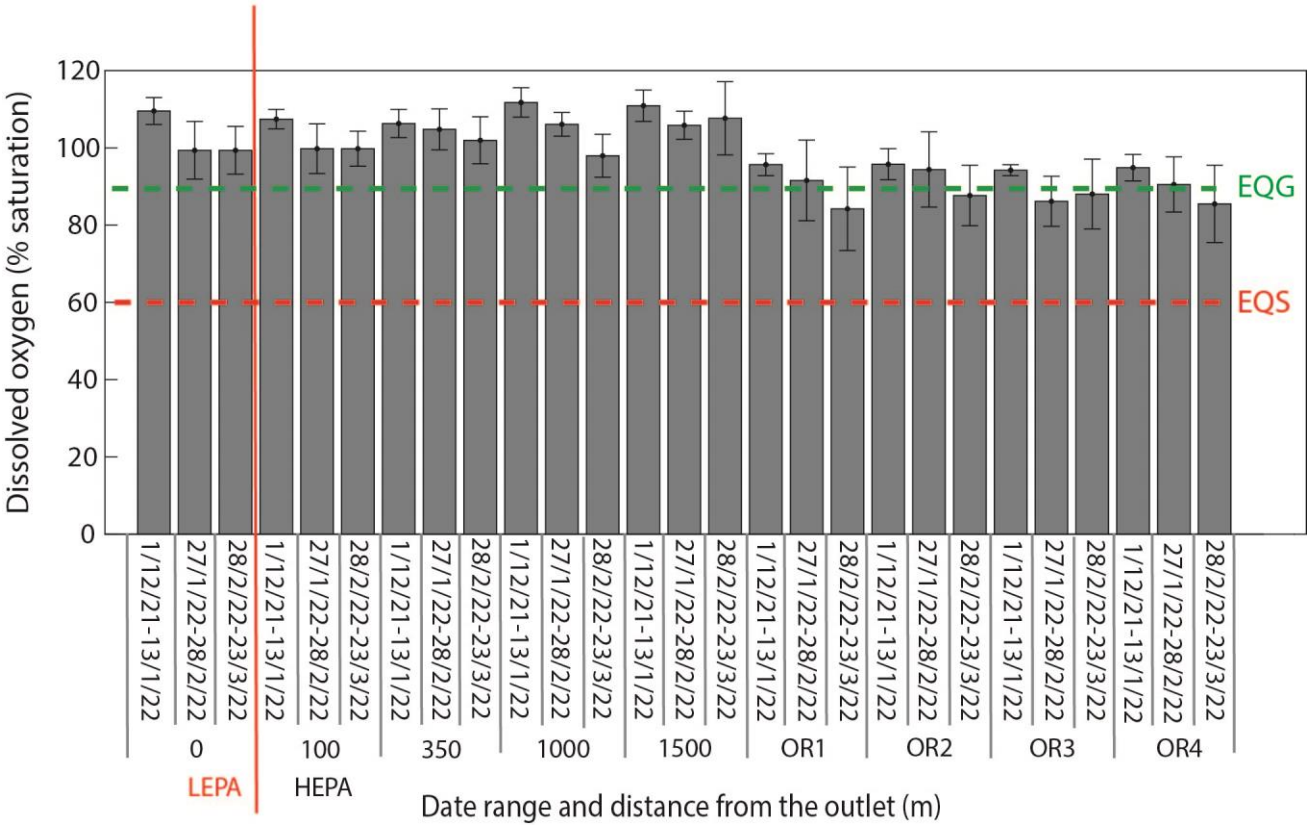
Bottom (0–0.5 m) dissolved oxygen saturation at HEPA sites (100, 350, 1000 and 1500 m) was >90% at all sites and times throughout the summer survey period (Figure 11), and the EQG for organic enrichment (Table 12) was met.

**Table 12 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. |

Note:

1. EQG = Environmental Quality Guideline




Notes:

1. Error bars ±95% confidence intervals
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; HEPA = high ecological protection area.
6. Reference site data (OR1–OR4) are compared against EQG for contextual purposes only.

**Figure 11 Median dissolved oxygen for defined periods of ≤6 weeks during the summer monitoring period**

## Salinity

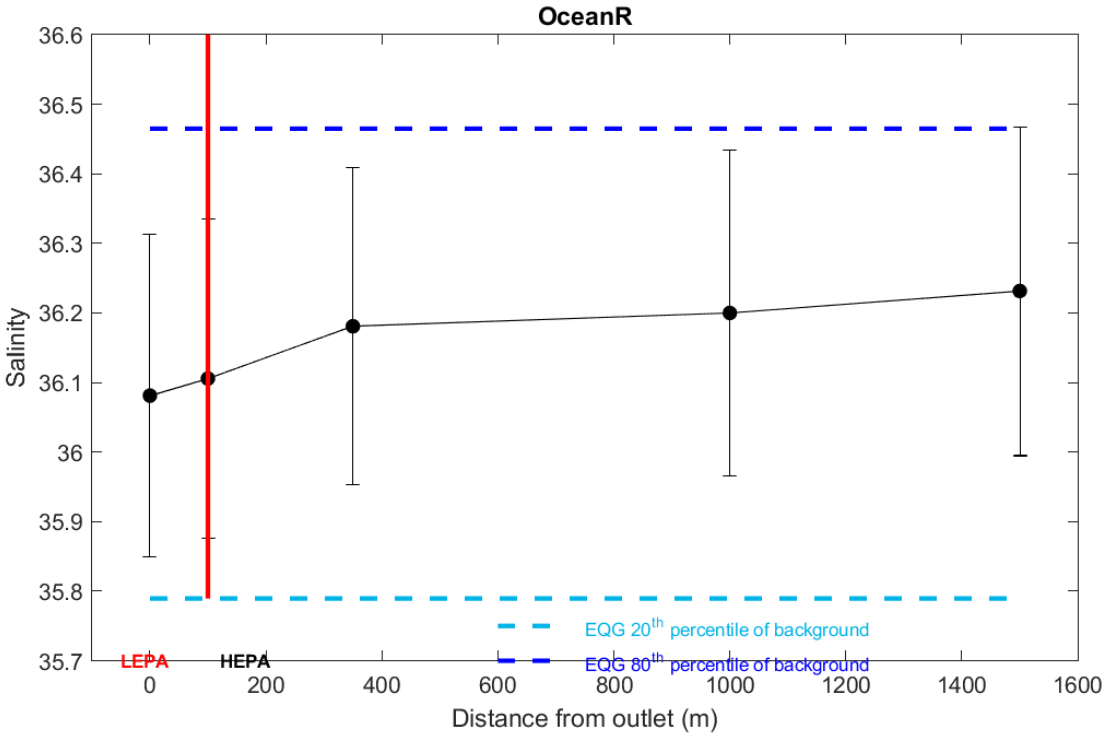
Median salinity was between the 20th and 80th percentile of the natural salinity range within the notional HEPA (at 100, 350, 1000 and 1500 m from the outlet), meeting the EQG (Table 13 and Figure 12).

### Table 13 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 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 historical reference sites; light blue dashed line = 20th percentile of historical reference sites
4. LEPA = notional low ecological protection area; HEPA = high ecological protection area.
5. Data for each distance were pooled across eight sampling occasions (n=8) over December 2020–March 2022.

### Figure 12 Median salinity compared to the 20th and 80th percentile of reference site data during the summer monitoring period

## Microbiological contaminants and algal biotoxins

### Thermotolerant coliforms

TTC were sampled eight times over the 2021–2022 summer period (yielding a total of 40 samples). NHMRC (2008) guidelines and EPA (2005) require a minimum of 100 samples for 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 2019–22 were pooled to yield 120 samples.

The median and 90$^{th}$ percentile TTC concentrations derived from the 3 years of pooled samples were both equal to the limit of detection (<10 CFU/100 mL; Table 15, Appendix H) and less than the 14 and 21 CFU/100 mL criteria, respectively meeting the EQG (Table 14).

**Table 14 Environmental Quality Guideline for thermotolerant coliforms**

| | |
|---|---|
| **EQG** | **M**edian TTC concentrations at sites at the boundary of the Observed Zone of Influence (OZI) are not to exceed 14 CFU/100 mL and the 90$^{th}$ percentile of TTC concentrations must not exceed 21 CFU/100 mL |

Notes:

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

**Table 15 Median and 90$^{th}$ percentile of thermotolerant coliform concentrations at the fixed monitoring sites for the Ocean Reef outlets for 2019–2022 and comparison to the EQC**

| Sampling period | Median | 90$^{th}$ percentile | Compliance (EQG) |
|---|---|---|---|
| Dec 2019–Mar 2020<br>Dec 2020–Mar 2021<br>Dec 2021–Mar 2022 | <10 CFU/100 mL | <10 CFU/100 mL | ■ |

Notes:

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

## Toxic phytoplankton species

### Table 16 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[1] trigger concentrations for any of the following:<br>• *Alexandrium* spp. (200 cells/L)<br>• *Gymnodinium catenatum* (1000 cells/L)<br>• *Karenia brevis* (1000 cells/L)<br>• *Karenia/Karlodinium/Gymnodinium* group (250 000 cells/L)<br>• *Dinophysis* spp. (1000 cells/L)<br>• *Prorocentrum lima* (500 cells/L)<br>• *Pseudo-nitzchia* delicatissima group (500 000 cells/L)<br>• *Pseudo-nitzchia* seriata group (50 000 cells/L) |

Note:

1. Marine Biotoxin Monitoring and Management Plan 2016: Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH 2016).
2. OZI = Observed Zone of Influence, refers to the Seafood Management Zone.
3. If the EQG is exceeded, assessment will proceed against the EQS for sentinel mussel tissues.

There was one instance, on 13 January 2022, where the toxic phytoplankton species of the *Pseudo-nitzschia seriata* group (337 600 cells/L) were recorded at greater density than the Western Australian Shellfish Quality Assurance Program (WASQAP; DoH 2016) guideline value (50 000 cells/L) leading to an EQG exceedance. The reference site (ORR3) also recorded a *Pseudo-nitzschia seriata* group density (64 000 cells/L) greater than the WASQAP guideline (50 000 cells/L), suggesting that the toxic phytoplankton was widespread and not related to the operation of the outlet. There were no other instances where toxic phytoplankton species were present at densities greater than the WASQAP guideline values (Table 17; Appendix I).

**Table 17 Estimated cell densities of phytoplankton species known to produce toxins**

| Date | Site[1] | Species | Estimated density | WASQAP Guideline[2] | Compliance |
|---|---|---|---|---|---|
| 1/12/2021 | ORR3 | *Gymnodinium* spp | 80 | 2000 | |
| | OR22 | *Gymnodinium* spp | 1040 | 2000 | ■ |
| | | *Pseudo-nitzschia seriata* group | 80 | 50 000 | |
| | | *Prorocentrum* spp | 80 | 500 | |
| 22/12/2021 | ORR3 | No Toxic Species | NA | NA | ■ |
| | OR22 | *Pseudo-nitzschia seriata* group | 80 | 50 000 | |
| 13/01/2022 | ORR3 | *Pseudo-nitzschia seriata* group | 64000 | 50 000 | |
| | OR19 | *Pseudo-nitzschia seriata* group | 337600 | 50 000 | ■ |
| | | *Gymnodinium* spp | 80 | 2000 | |
| 27/01/2022 | ORR3 | *Pseudo-nitzschia seriata* group | 80 | 50 000 | |
| | OR27 | *Pseudo-nitzschia seriata* group | 640 | 50 000 | ■ |
| | | *Gymnodinium* spp | 160 | 2000 | |
| 8/02/2022 | ORR2 | *Gymnodinium* spp | 80 | 2000 | |
| | | *Pseudo-nitzschia seriata* group | 560 | 50 000 | ■ |
| | | *Pseduo-nitzschia delicatissima* group | 320 | 500 000 | |
| | OR19 | *Pseudo-nitzschia seriata* group | 320 | 50 000 | |
| | | *Pseduo-nitzschia delicatissima* group | 160 | 500 000 | ■ |
| | | *Gymnodinium* spp | 160 | 2000 | |
| 28/02/2022 | ORR2 | *Pseudo-nitzschia seriata* group | 80 | 50 000 | |
| | | *Gymnodinium* spp | 160 | 2000 | ■ |
| | OR19 | *Gymnodinium* spp | 480 | 2000 | |
| 14/03/2022 | ORR2 | *Gymnodinium* spp | 160 | 2000 | |
| | OR32 | *Gymnodinium* spp | 320 | 2000 | ■ |
| 23/03/2022 | ORR2 | *Pseduo-nitzschia delicatissima* group | 80 | 500 000 | |
| | OR28 | *Pseduo-nitzschia delicatissima* group | 4480 | 500 000 | ■ |

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 2016: Western Australian Shellfish Quality Assurance Program (WASQAP) (DoH 2016).
3. Green (■) symbols indicate the Environmental Quality Criteria (EQC) were met.
4. Species within the *Pseudo-nitzschia* groups are difficult to identify (WASQAP; DoH 2016

## Faecal pathogens (*Enterococci* spp.)

Samples were collected eight times over the 2021–2022 summer monitoring period (yielding a total of 40 samples) for faecal pathogens analyses (measured as *Enterococci* spp) . NHMRC 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 (2019–2022) were pooled to yield 120 samples. The EQG for primary and secondary contact recreation are outlined in Table 18.

Over the past three summers, the 95$^{th}$ 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 detection (<10 MPN/100 mL; Table 19), and both the primary (<200 MPN/100 mL) and secondary (<2000 MPN/100mL) contact recreation EQG for faecal pathogens (Table 18) in the water were met.

**Table 18 Environmental Quality Guidelines for contact recreation**

| | | |
|---|---|---|
| **Primary[1]** | **EQG** | The 95$^{th}$ percentile bacterial content of marine waters should not exceed 200 *Enterococci* MPN/100 mL |
| **Secondary[2]** | **EQG** | The 95$^{th}$ percentile bacterial content of marine waters should not exceed 2000 *Enterococci* MPN/100 mL |

Notes:

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

**Table 19 The 95$^{th}$ percentile of *Enterococci* spp. concentrations at the boundary of the observed zone of influence for the Ocean Reef ocean outlets**

| Sampling period | 95$^{th}$ percentile | Compliance | |
|---|---|---|---|
| | | Primary contact | Secondary contact |
| Dec 2019–Mar 2020<br>Dec 2020–Mar 2021<br>Dec 2021–Mar 2022 | <10 MPN/100 mL | ■ | ■ |

Notes:

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

## Phytoplankton cell concentrations

### Table 20 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 trigger 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). |

Phytoplankton densities at individual sites monitored during 2021–2022 were below 10 000 cells/mL (Table 21) but a Department of Health watch list species (*Trichodesmium* spp) did exceed their trigger levels (detected for *Trichodesmium*, Appendix J), not meeting the EQG and triggering the EQS. (Table 20).

Phytoplankton densities at individual sites monitored during 2021–2022 were below 50 000 cells/mL (Table 21) and Department of Health watch list species did not exceed their action levels (Appendix J, presence of algal scums for *Trichodesmium*), meeting the EQS. (Table 20).

### Table 21 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 |
|---|---|---|---|
| 1/12/2021 | OR7 | 1408 | |
| 22/12/2021 | OR7 | 982 | |
| 13/01/2022 | OR5 | 676 | |
| 27/01/2022 | OR9 | 1 | |
| 8/02/2022 | OR5 | 318 | |
| 28/02/2022 | OR15 | 40 | |
| 14/03/2022 | OR15 | 75 | |
| 22/03/2022 | OR11 | 44 | |
| 28/02/2022 | OR15 | *Trichodesmium* spp (1.5) | |
| 28/02/2022 | OR15 | *Trichodesmium* spp (no algal scum recorded) | |

Note:

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

## Shoreline monitoring

### Thermotolerant coliforms

TTC were sampled at eight shoreline monitoring sites eight times over the 2021–2022 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 2020–21 and 2021–22) were pooled to yield 128 samples.

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

Median TTC concentrations were 5 CFU/100 mL (the proxy for concentrations below the LoR) at all sites down current of the diffuser (Figure 13).

**Table 22 Median and 90$^{th}$ percentile thermotolerant coliform concentrations at the shoreline monitoring sites for the Ocean Reef outlets for 2020–2022 and comparison to the EQG**

| Sampling period | Median (CFU/100 mL) | 90$^{th}$ percentile | Compliance (EQG) |
|---|---|---|---|
| Dec 2020–Mar 2021<br>Dec 2021–Mar 2022 | <10 CFU/100 mL | <10 CFU/100 mL | ■ |

Notes:

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

### Faecal pathogens (*Enterococci* spp.)

Samples were collected eight times at eight shoreline monitoring sites over the 2021–2022 summer monitoring period (yielding a total of 64 samples) for faecal pathogens analyses. NHMRC guideline 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 2020–21 and 2021–22) were pooled to yield 128 samples.

Shoreline sites are not formally assessed against the EQC but over the 2021–2022 summer monitoring period, the 95$^{th}$ percentile of *Enterococci* spp. concentrations at the shoreline monitoring sites for the Ocean Reef ocean outlets was 10 MPN/100 mL (Table 23), and met both the primary and secondary (<200 and <2000 *Enterococci* spp.MPN/100mL, respectively) contact recreation EQG criteria (Table 18).

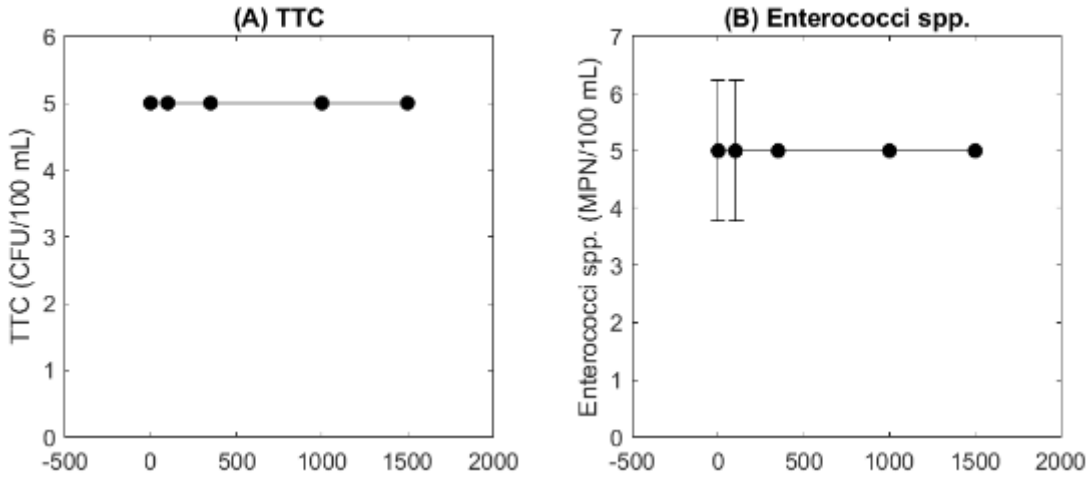
Median *Enterococci* spp. concentrations were 5 MPN/100 mL (the proxy for concentrations below the LoR) at all sites down current of the diffuser (Figure 13).

**Table 23 The 95th percentile of *Enterococci* spp. concentrations at the shoreline monitoring sites for the Ocean Reef ocean outlets for 2020–2022 and comparison to the EQG**

| Sampling period | 95th percentile | Compliance | |
|---|---|---|---|
| | | Primary contact | Secondary contact |
| Dec 2020–Mar 2021<br>Dec 2021–Mar 2022 | 10 MPN/100 mL | ■ | ■ |

Notes:

1. MPN = most probable number of *Enterococci* spp.
2. *Enterococci* spp. concentrations below the analytical detection limit (<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; amber (■) and red (■) symbols represent an exceedance of the Environmental Quality Guideline (EQG) and Environmental Quality Standard (EQS), respectively.
4. Environmental Quality Criteria (EQC) based on EPA (2017) water quality guidelines for recreation waters.




Notes:

1. Error bars represent ±95% confidence intervals

**Figure 13 Median a) TTC and b) *Enterococci* spp. at 0, 100, 350, 1000, and 1500 m from the Ocean Reef outlet from December 2021to March 2022**

## References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