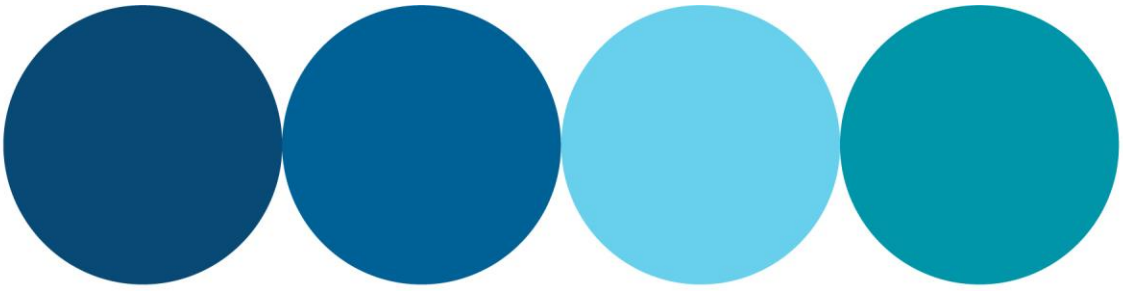
Perth Long Term Ocean Outlet Monitoring Program (PLOOM)

2018-2019 Annual Report

Ocean Reef



WATER CORPORATION

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Document history

Distribution

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Review

Revision	Reviewer	Intent	Date
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Quality Assurance

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

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 Western 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.

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Director (or delegate)
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Acronyms

ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
CFU	Colony forming unit
DoH	Western Australian Department of Health
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
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
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

Executive Summary

This report documents the findings of the 2018–2019 Ocean Reef ocean monitoring program. Results are reported in the context of the Environmental Quality Management Framework (EQMF) described in EPA (2017). The results are summarised in Report Card format (Table ES 1). The report card contains colour-coded results, with the individual colours representing the extent to which the Environmental Quality Criteria (EQC) were met (Table ES 2–Table ES 4).

Table ES 1 Summary report card legend

Management response	Colour
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.

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

Environmental quality indicator		EQC	Comments	Compliance
Toxicants in treated wastewater (TWW)	Bioaccumulating toxicants	EQG	Concentrations of cadmium and mercury in the undiluted TWW stream were below the ANZG (2018) 80% species protection guideline	
	Non-bioaccumulating toxicants and initial dilution	EQG	Initial dilution on 5 February 2019 (1:168) was sufficient to reduce non-bioaccumulating contaminant concentrations to below their ANZG (2018) 99% species protection guidelines	
	Total toxicity of the mixture (TTM)	EQG	The TTM for the additive effect of ammonia, copper and zinc after initial dilution (0.54) was below the ANZG (2018) guideline value of 1.0	
	Whole of effluent toxicity testing	EQG	The lowest NOEC during the reporting period was 50%. Only 2 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) was lower than the 80th percentile of historical reference site concentrations	■
	Light attenuation coefficient (LAC)	EQG	Median LAC within the HEPA was lower than the 80th percentile of historical reference sites.	■
Phytoplankton blooms	Phytoplankton biomass (measured as chlorophyll-a)	EQG	On 21 March 2019 the median chlorophyll-a concentrations exceeded three times the median of reference sites	■
			Chlorophyll-a concentration exceeded 3-times the median chlorophyll-a concentration of reference sites on 12.5% of occasions (<25% of occasions).	■
		EQS	Median chlorophyll-a concentration did not exceed 3-times the median of reference sites on more than one occasion in the 2018-2019 non-river flow period or on any occasion in the 2017-2018 non-river flow period.	■
			Chlorophyll-a concentration did not exceed 3 times the median chlorophyll-a concentration of reference sites on 25% or more occasions in 2018-2019 or the 2017-2018 non-river flow periods.	■
Physical chemistry	Organic enrichment	EQG	Within the HEPA, dissolved oxygen saturation remained above 90% saturation at all times.	■
	Salinity	EQG	Median salinity at 100 m was below the 20th percentile of the natural salinity range	■
			There were no reported deaths of marine organisms from anthropogenically sourced salinity stress at Ocean Reef over the summer monitoring period.	■

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.

Table ES 3 Summary report card for the Environmental Quality Objective 'Maintenance f Seafood for Human Consumption

Environmental quality indicator		Comments	Compliance
Microbial contaminants	Thermotolerant coliforms (TTC)	Median TTC concentrations derived from 120 samples collected over the 2016–2017, 2017–2018 and 2018–2019 sampling seasons was at the limit of detection (<10 CFU/100 mL)	■
		The 90th percentile was equal to the limit of detection (<10 CFU/100 mL), and less than 21 CFU/100 mL	■
Algal biotoxins	Toxic phytoplankton species	Toxic phytoplankton species were not recorded in excess of Western Australian Shellfish Quality Guidelines during 2018–2019 monitoring	■

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.

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 streptococci	*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 2018-2019 monitoring	■

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 2018–2019 ocean monitoring around the Ocean Reef ocean outlet. 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.

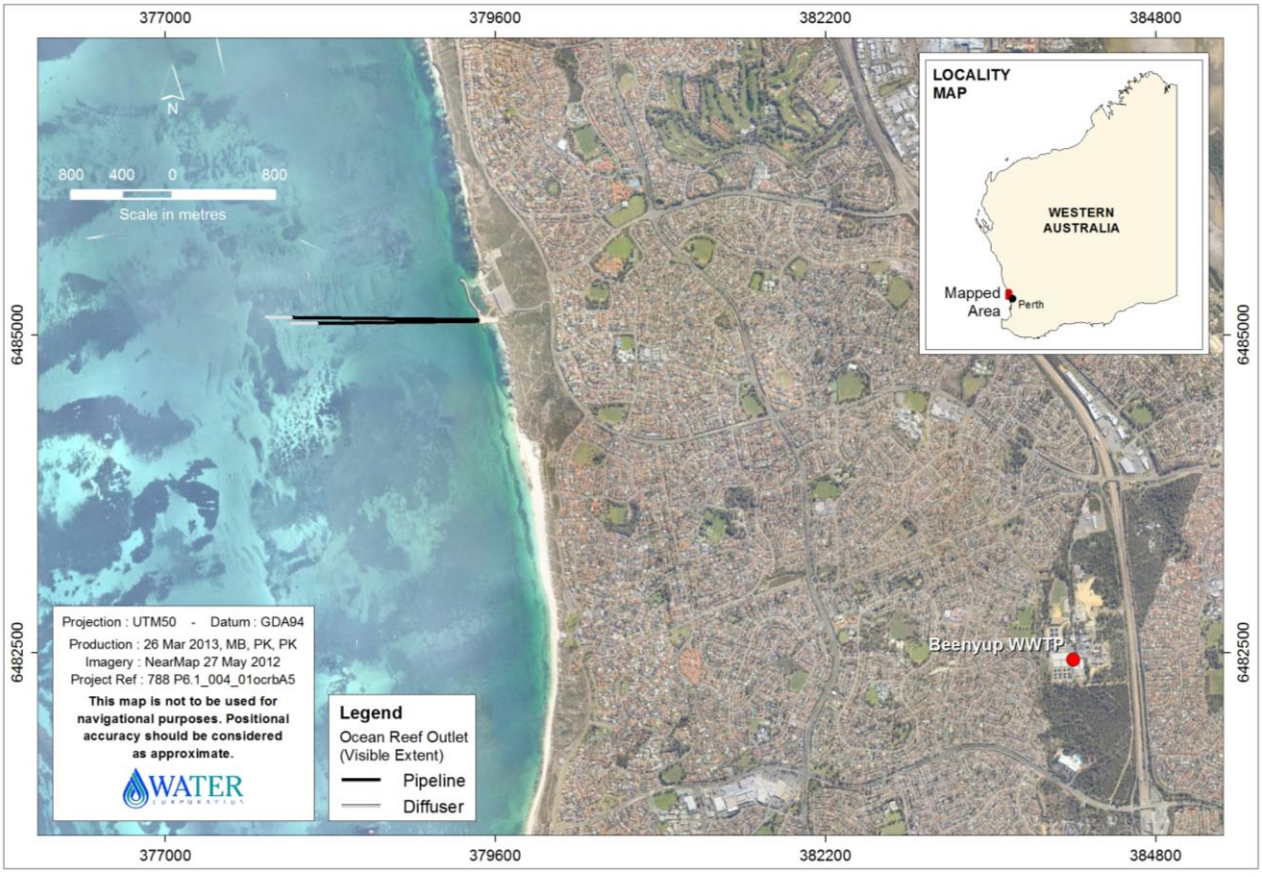
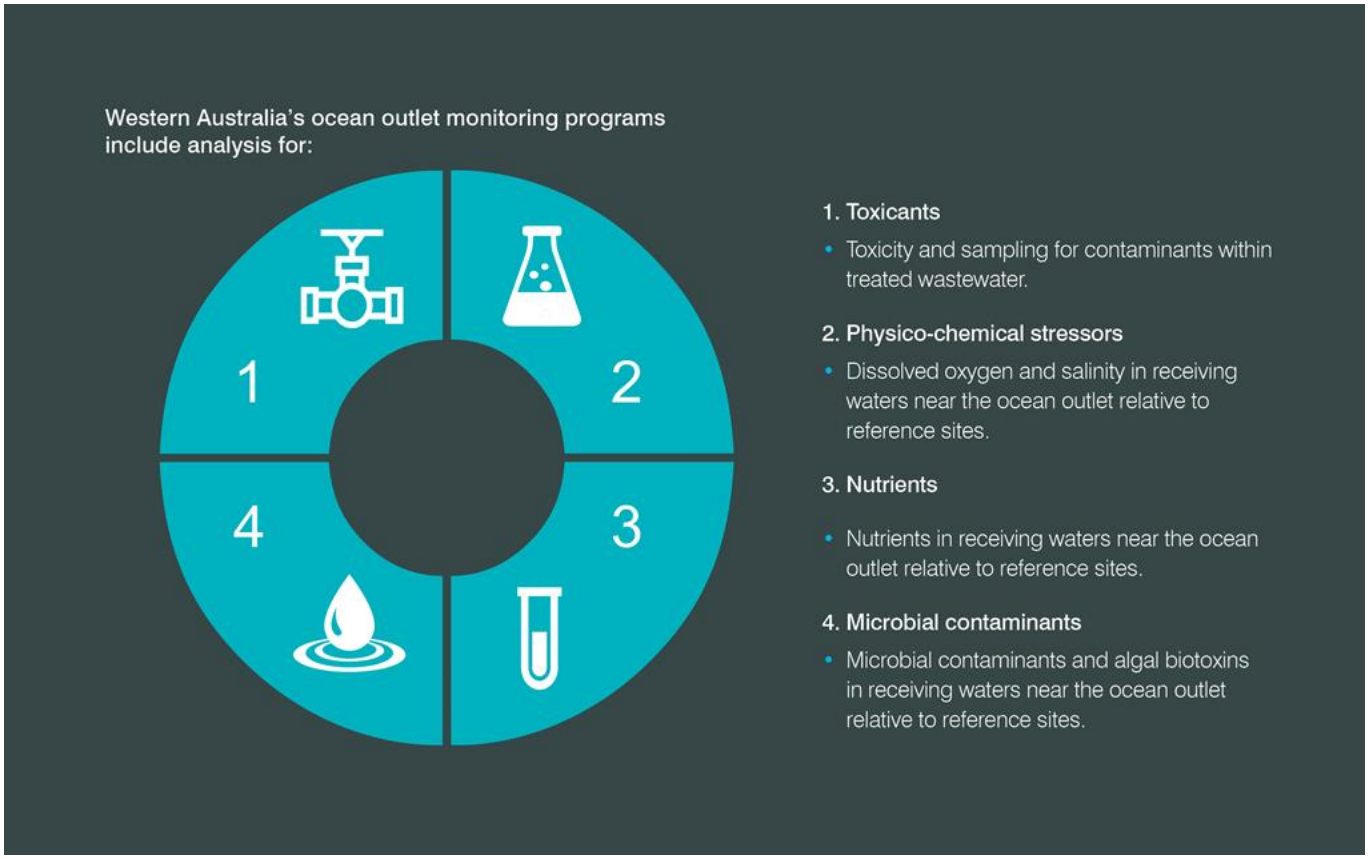


Figure 1 Location of Beenyup WRRF and Ocean Reef ocean outlets

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 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 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, relative to measurements at the reference sites 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. 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).

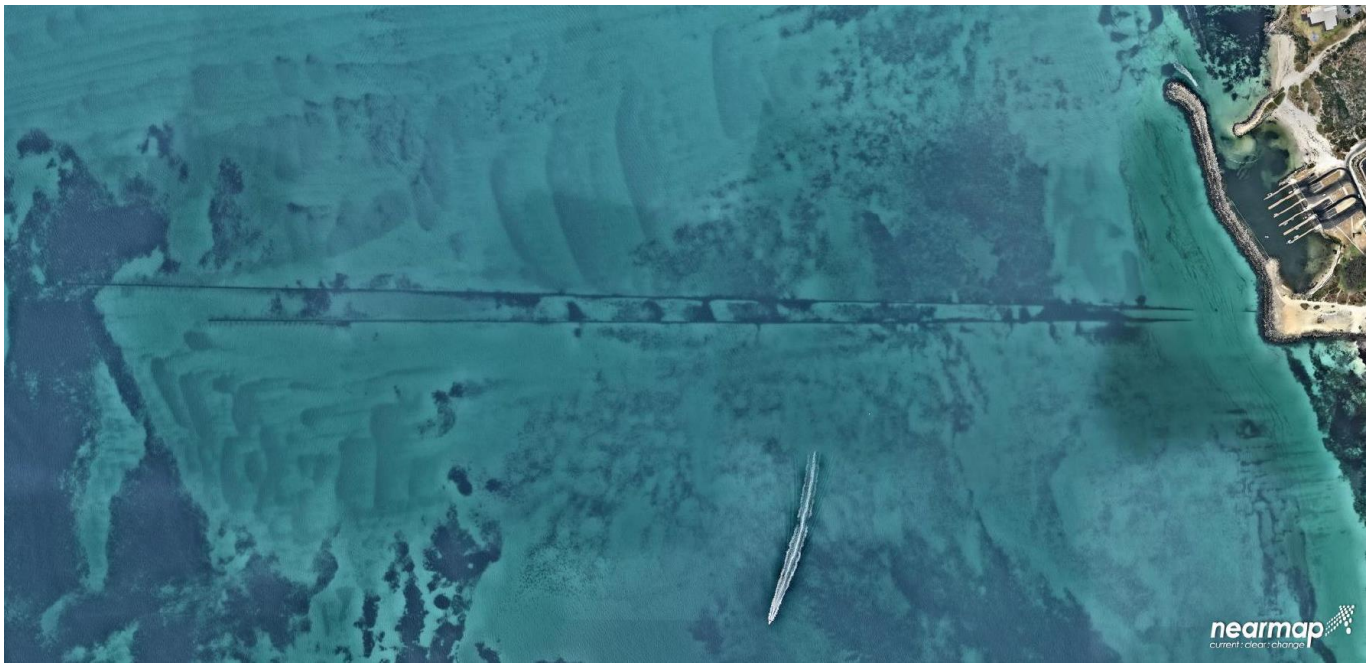
Although most algal blooms are harmless, some contain species that produce toxins that may be harmful to swimmers (via ingestion or skin contact) or poison seafood. Phytoplankton species composition and cell concentrations are monitored to ensure concentrations are within acceptable limits.

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) criteria for primary and secondary contact recreation and for seafood for human consumption.

Environmental management approach

Water Corporation's environmental commitments for the Beenyup WRRF ocean discharge to Ocean Reef are outlined by Ministerial Statement. To maintain consistency with the other metropolitan ocean outfall monitoring programs, the Ocean Reef ocean outlets (Figure 2) are 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 conditions under Section 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. 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.

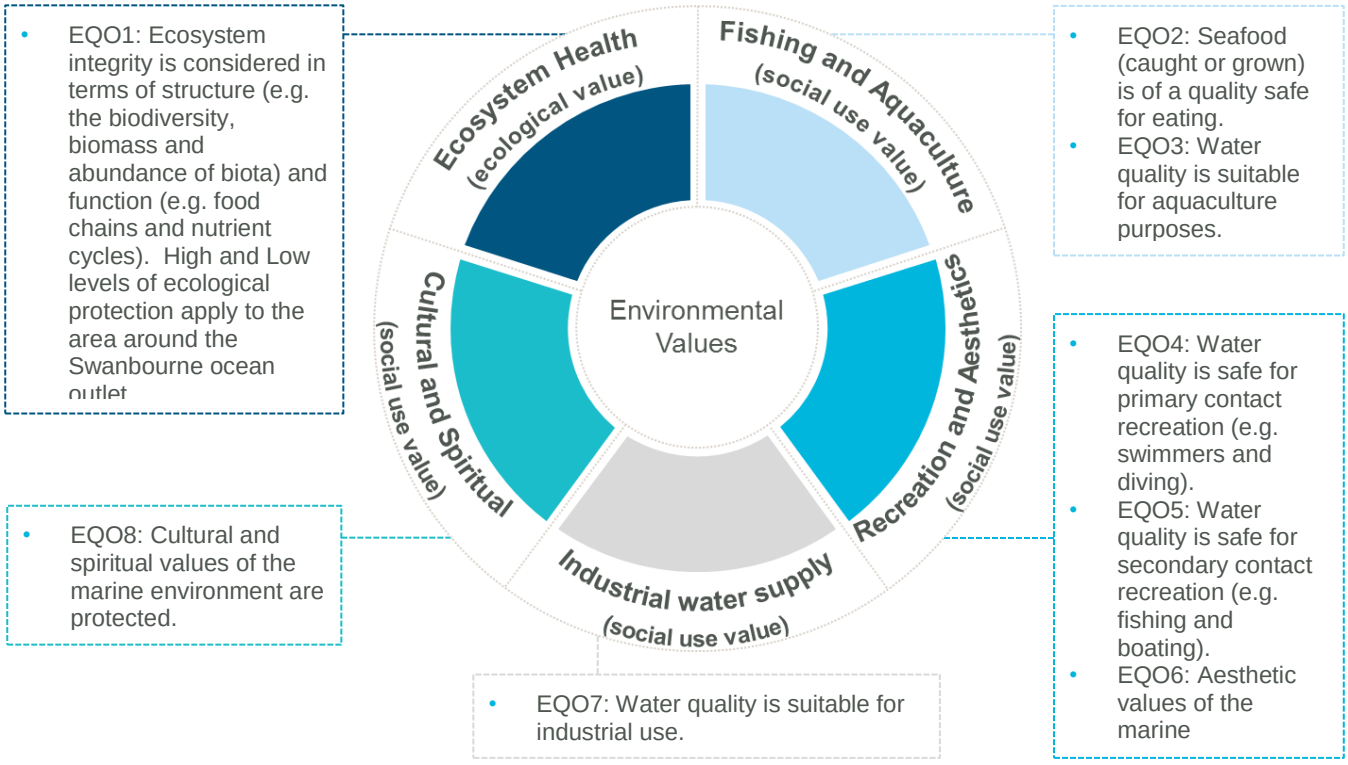


Figure 3 Environmental Values and Environmental Quality Objectives (EQO) for the marine waters of Western Australia

'Maintenance of Ecosystem Integrity' EQO

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

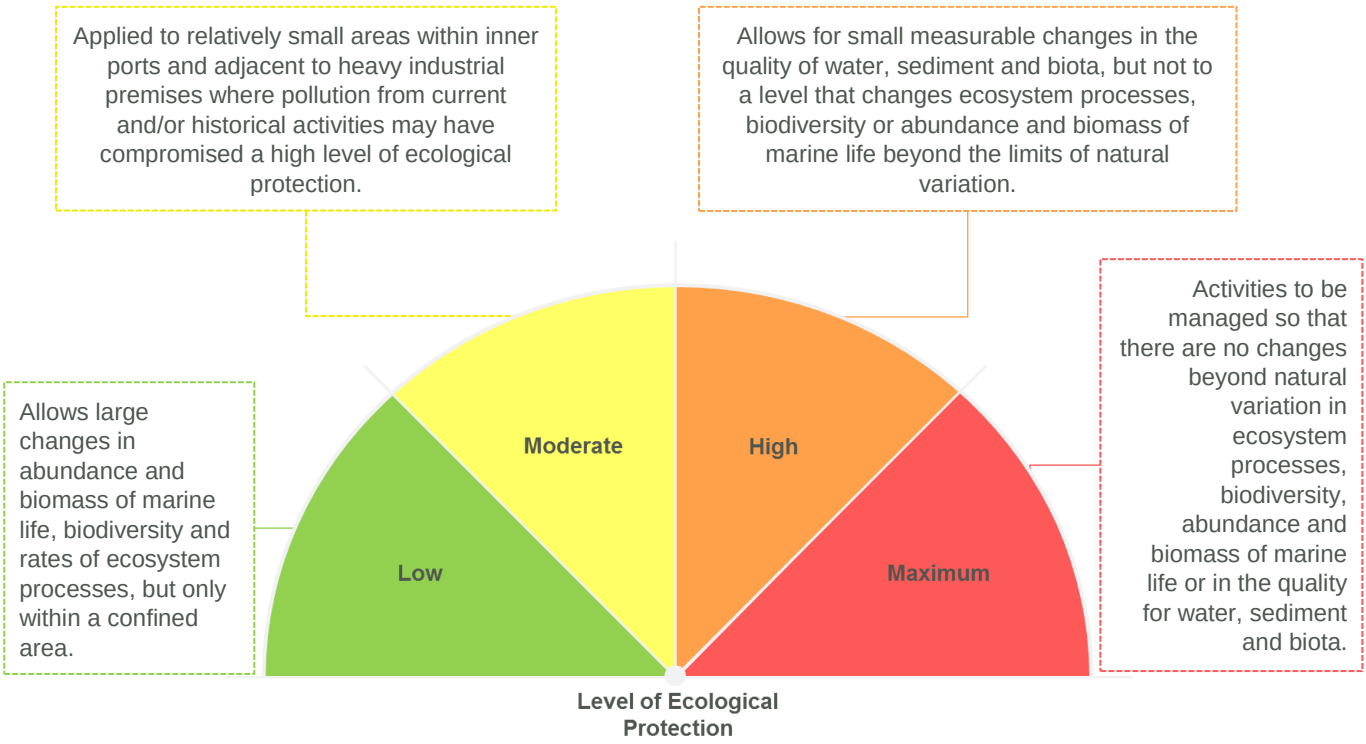


Figure 4 Level of Ecological Protection

A notional LEPA occupies the area within a 100 m radius of the diffusers at Ocean Reef (Figure 5). Waters outside the LEPA are maintained to a high level of ecological protection (HEPA; Figure 5). The LEPA boundary size is consistent with other EPA approved outlet boundaries, but as the original approval for the Ocean Reef ocean outlets occurred prior to the EPA formalising this management approach, the LEPA boundary is called notional as it was not part of an original approval process.

'Maintenance of Seafood Safe for Human Consumption' EQO

The intent of this EQO is to maintain seafood safe for human consumption (a social value) with the exception of a small area surrounding the ocean outlets where EQO 2 may not be achieved and seafood may be unsafe to eat. An informal management zone has been established based on microbiological observations from years of ocean monitoring data. 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 with the exception of areas around ocean outlets, where water quality may not be suitable for swimming. An informal zone has been developed for the Ocean Reef outlets encompassing the area containing elevated microbiological concentrations

As the EQO for the maintenance of primary contact recreation uses a higher water quality standard than secondary contact recreation, it is assumed that if the primary contact criteria are met, then the secondary contact criteria are also met by default.

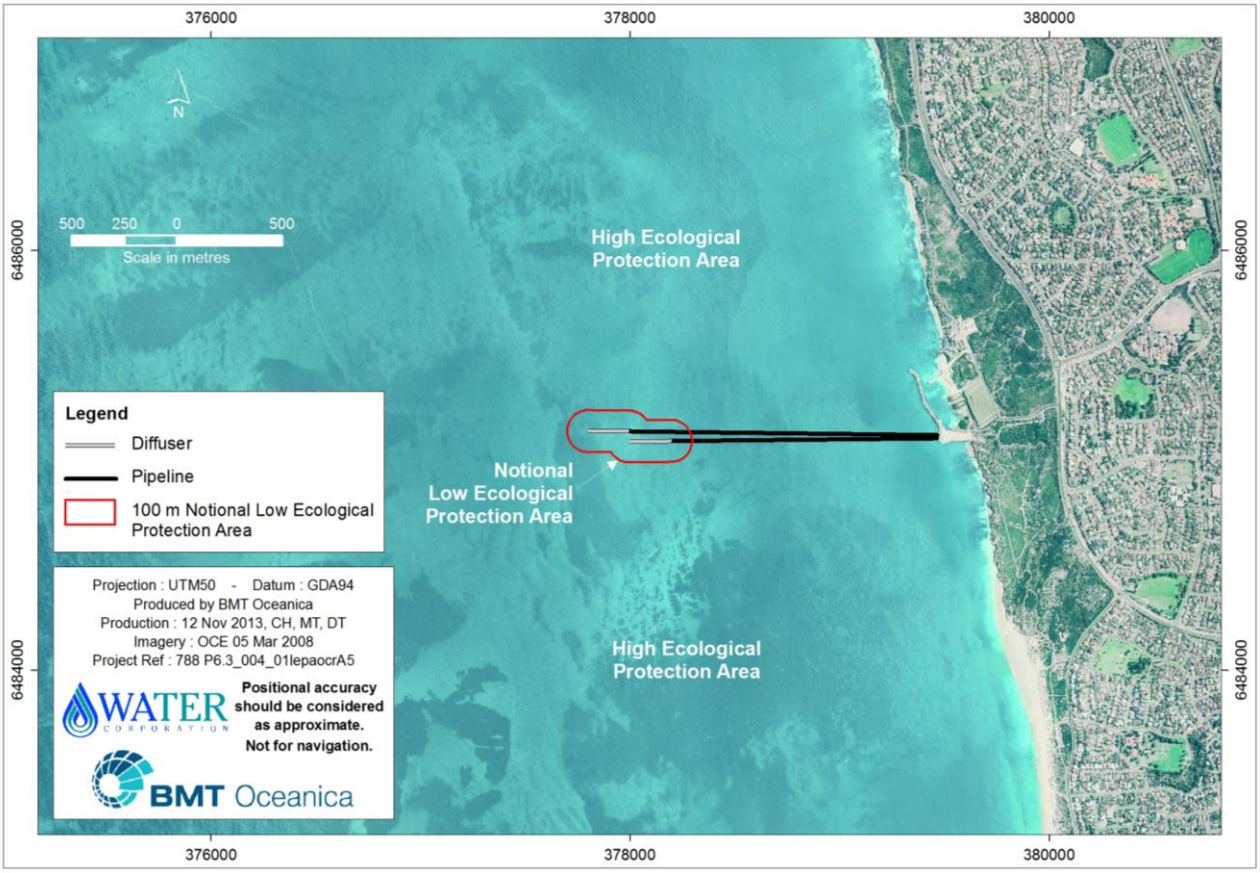


Figure 5 Ocean Reef ocean outlets notional ecological protection areas

Toxicants in treated wastewater

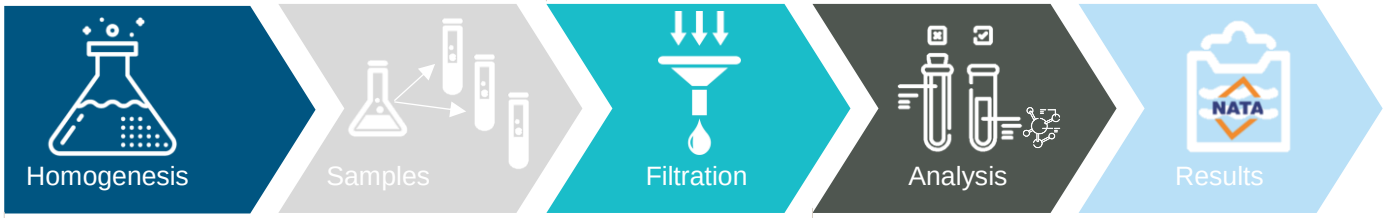
Comprehensive treated wastewater characterisation (CTWWC)

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

- nutrients (total nitrogen, ammonia, nitrate+nitrite, total phosphorus, orthophosphate)
- microbial contaminants (thermotolerant coliforms and *Enterococci* spp.)
- bioavailable contaminants (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 5 February 2019. 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 2005b).



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.

Analyses were completed using NATA-accredited methods (0, Appendix B and Appendix C)

Bioaccumulating toxicants

The EQG for bioaccumulating toxicants (cadmium and mercury) in the TWW is outlined in Table 1.

Table 1 Environmental Quality Guideline for bioaccumulating toxicants

EQG	Concentrations of contaminants will not exceed the ANZG (2018) 80% species protection guideline trigger levels for bioaccumulating toxicants in wastewater stream

Notes:

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

Concentrations of cadmium and mercury (i.e. bioaccumulating toxicants) in the TWW sample were both below the analytical limit of reporting (<0.1 µg/L; Table 3), and their respective 80% species protection guidelines (ANZG 2018), meeting the EQG.

Non-bioaccumulating toxicants

The EQG for non-bioaccumulating toxicants in the TWW is outlined in Table 2.

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 (with the exception of cobalt where the 95% guideline trigger level will apply) is 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

Modelling predicted average initial dilution of 1:189 at Outlet A and 1:168 at Outlet B (Appendix D). The worst-case initial dilution of 1:168 was used as a conservative estimate of the dilution expected at the LEPA boundary. Contaminant concentrations after the initial dilution of 1:168 were below the ANZG (2018) 99% species protection guidelines (Table 3), and the EQG for non-bioaccumulating toxicants was met.

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	490	4.4	500
Cadmium*	<0.1	–	36
Chromium*	<1	–	0.14 (Cr VI) 7.7 (Cr III)
Copper*	**9.1**	0.1	0.3
Lead*	<1	–	2.2
Mercury*	<0.1	–	1.4
Nickel*	2.3	0.01	7
Silver*	<0.8	–	0.8
Zinc*	**76**	0.6	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 = 1:168 (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 potential for cumulative toxic effects on marine organisms is assessed after initial dilution as per ANZG (2018). The EQG for the total toxicity of the mixture (TTM) is outlined in Table 4.

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. Note that 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).**

Notes:

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

The TTM for the combined effect of ammonia, copper and zinc following initial dilution (0.54; Table 5) was less than the ANZG (2018) guideline value of 1.0 and the EQG for TTM was met.

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	1:168	0.54

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 1:189, initial dilution at outlet B was 1:168. Initial dilution at outlet B was used in TTM calculation as conservative estimate (Appendix E).

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%) pf TWW was used to calculate a No Observed Effect Concentration (NOEC, the highest wastewater concentration where no significant effect is observed) (Appendix F). The EQG for the whole of effluent toxicity (WET) testing is outlined in Table 6.

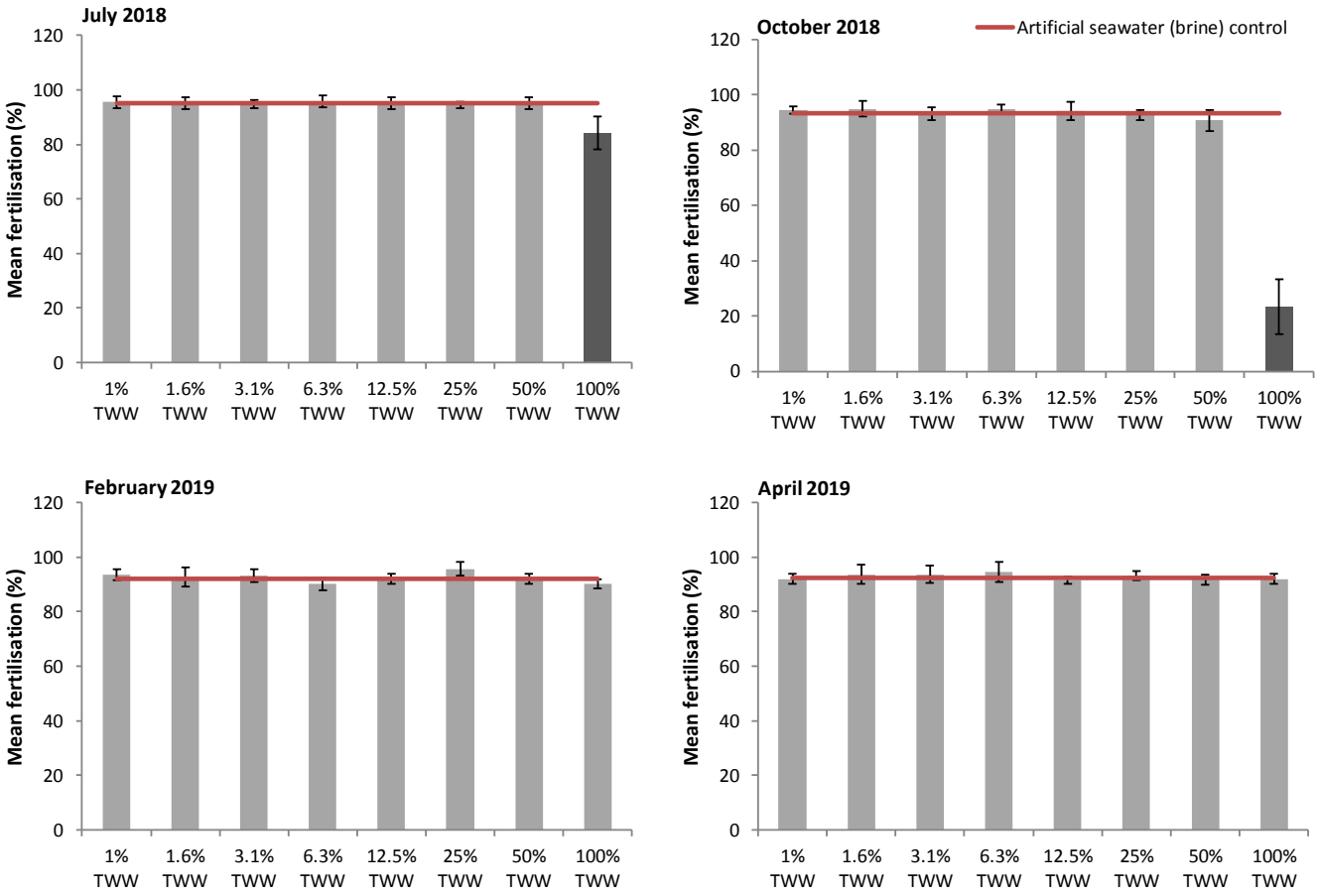
Table 6 Environmental Quality Guideline for whole of effluent toxicity testing

EQG	**The EQG will be exceeded if following the 1-hour sea urchin test:** $\frac{TDA}{DRNOEC} \leq 1.0$ **where TDA = Typical Dilutions Achieved (constant based on 100-fold dilution)** **DRNOEC = number of dilutions required to achieve the no observed effects concentration (NOEC).** **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

In July and October 2018, sea urchin fertilisation was significantly lower than the artificial seawater control when exposed to 100% TWW concentration (with all other concentrations not significantly different to the control; Figure 5; Appendix F). There were no significant differences in fertilisation between the artificial seawater control and any TWW dilutions of 24-hour flow-weighted composite samples collected in February and April 2019 (Figure 6; Appendix F). For all four sampling dates, the NOEC was greater than 1% TWW (Table 7) and the EQG for WET testing was met.



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

Table 7 Calculated parameters from whole of effluent toxicity tests

Indicator	July 2018	October 2018	February 2019	April 2019
NOEC	50%	50%	100%	100%
Dilutions required to meet the NOEC	2	2	0	0
Dilutions required/dilutions achieved	0.01	0.01	0	0
≤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 2018 to the ed of March 2019 (coinciding the summer non-river flow period) along a down-current gradient away from the diffusers (Table 8, Appendix G)

Table 8 Water quality monitoring dates near the Ocean Reef ocean outlets between December 2018 and March 2019

Sample day	Date
1	11/12/2018
2	20/01/2018
3	4/01/2019
4	15/01/2019
5	12/02/2019
6	27/02/2019
7	5/03/2019
8	21/03/2019

Nutrient enrichment

The EQGs for nutrient enrichment in receiving waters are outlined in Table 9.

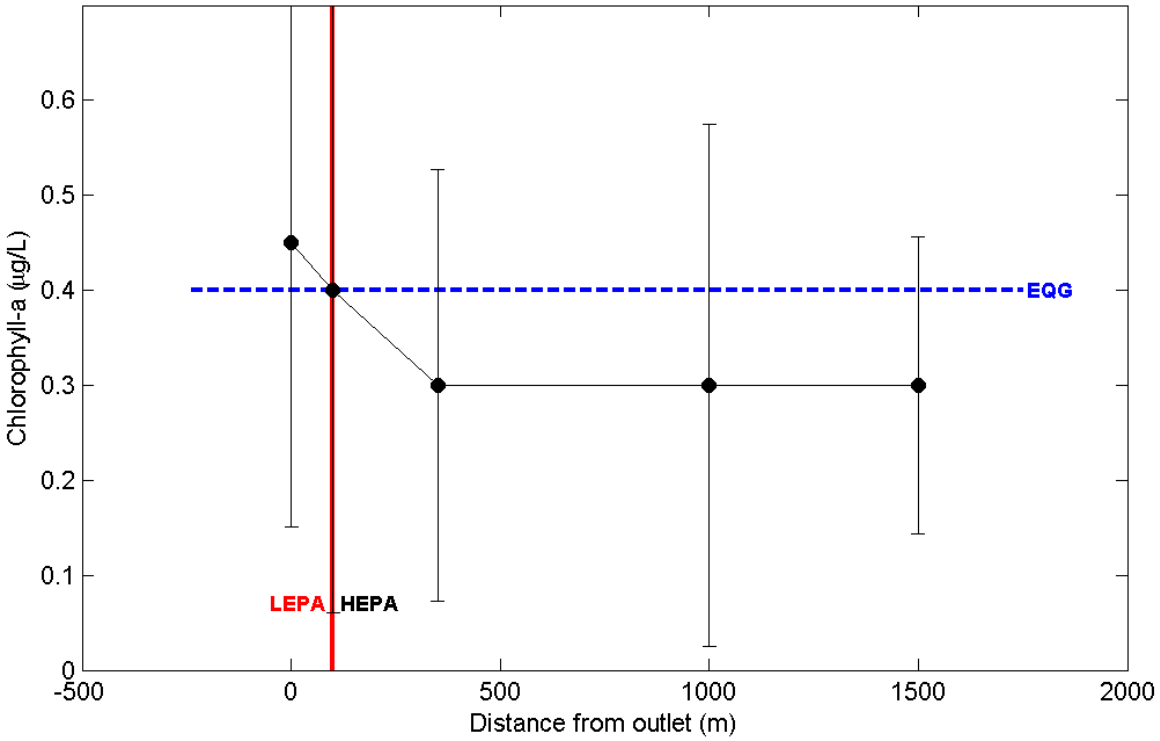
Table 9 Environmental quality guidelines for nutrients

EQG	The median chlorophyll-a concentration in the HEPA (100 m plus) during the non-river flow period is not to exceed the 80th 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 80th percentile of historical reference site data.

Note:

1. EQG = Environmental Quality Guideline

The median chlorophyll-a concentration in the Ocean Reef HEPA (100 m plus) was 0.3 µg/L and below the 80th percentile of historical reference site data (0.5 µg/L; Figure 7; Appendix H, meeting the EQG (Table 9).

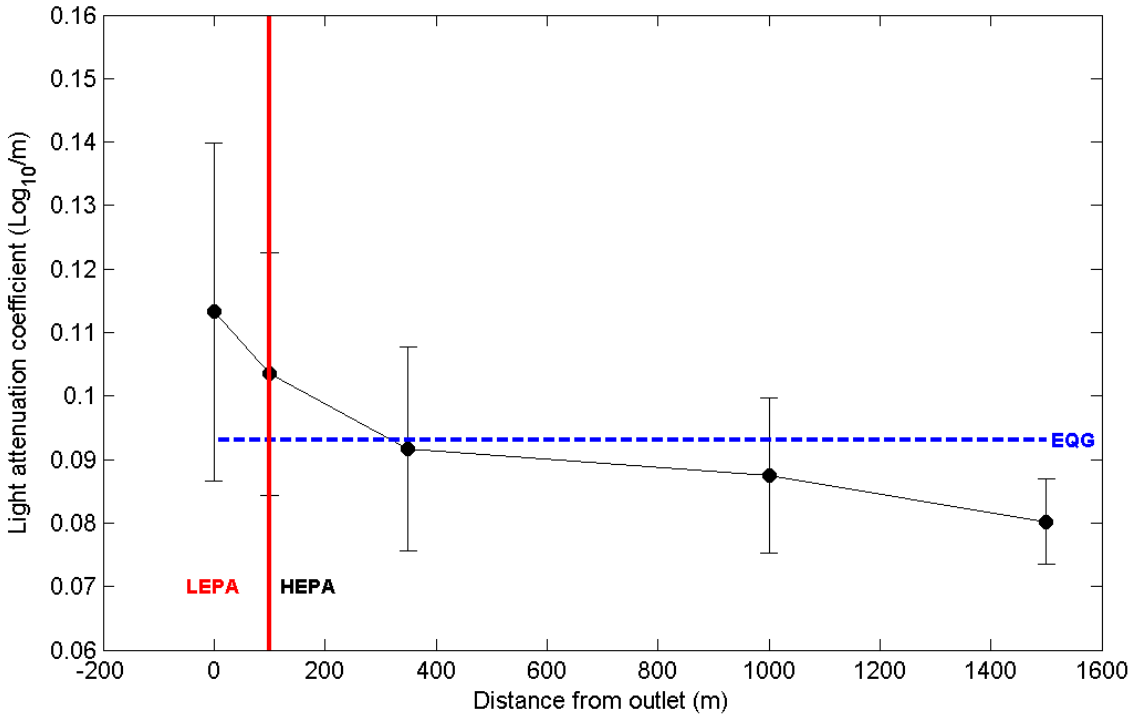


Notes:

1. Error bars represent ±95% confidence intervals.
2. Environmental Quality Guideline (EQG) is the 80th 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 2018–March 2019.

Figure 7 Median chlorophyll-a concentrations obtained at fixed monitoring sites above and down-current of the Ocean Reef outlets during the summer monitoring period

The median light attenuation in the Ocean Reef HEPA (100 m plus) was 0.090 Log10/m and lower than the 80th percentile of reference site data (Figure 8), meeting the EQG.



Notes:

1. Error bars represent ±95% confidence intervals.
2. Environmental Quality Guideline (EQG) is the 80th percentile of historical reference site data.
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 2018–March 2019.

Figure 8 Median light attenuation coefficient obtained at fixed monitoring sites above and down-current of the Ocean Reef outlets during the summer monitoring period

Phytoplankton blooms

The EQGs and EQSs for phytoplankton blooms in receiving waters are outlined in Table 10.

Table 10 Environmental Quality Guidelines and Environmental Quality Standards for phytoplankton in receiving waters

EQG1	Median phytoplankton biomass, measured as chlorophyll-a is not to exceed 3 times the median chlorophyll-a concentration of reference sites, on any occasion during the non-river flow period.
EQG2	Phytoplankton biomass measured as chlorophyll-a at any site does not exceed 3 times the median chlorophyll-a concentration of reference sites, on 25% or more occasions during the non-river flow period.
EQS1	Median phytoplankton biomass measured as chlorophyll-a not to exceed 3 times median chlorophyll-a concentration of reference sites, on more than one occasion during non-river flow period and in two consecutive years.

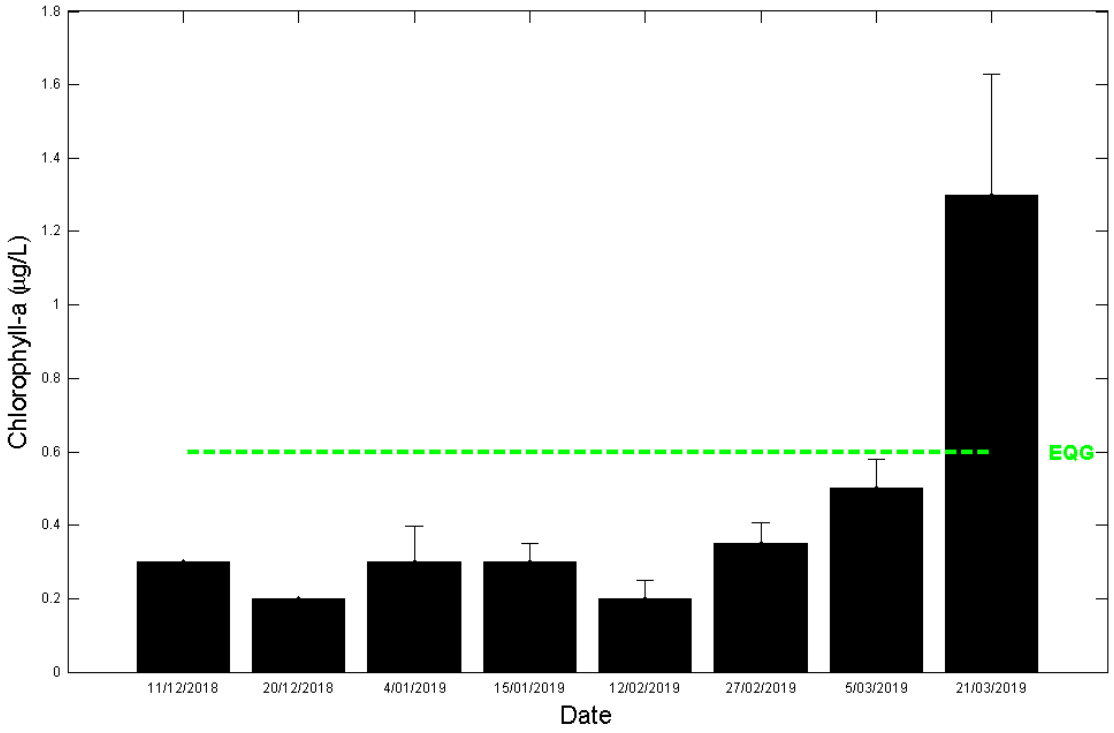
Note:

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

On 21 March 2019 the median chlorophyll-a concentrations exceeded three times the median of reference sites (0.6 µg/L; Figure 9), exceeding EQG1 and triggering assessment against the EQS.

Chlorophyll-a concentration at any site exceeded 3-times the median chlorophyll-a concentration of reference sites on 12.5% of occasions (<25% of occasions) and EQG2 was met.

Median chlorophyll-a concentration exceeded 3-times the median chlorophyll-a concentration of reference sites one occasion in the 2018-2019 non-river flow period (Figure 9) but on no occasion in the 2017-2018 non-river flow period (BMT 2018). As median chlorophyll-a concentration exceeded 3-times the median chlorophyll-a concentration of reference sites on the one occasion EQS1 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 outlet within the notional low ecological protection area (LEPA).
4. Data were pooled across four sites within the high ecological protection area (HEPA).

Figure 9 Median phytoplankton biomass during the summer monitoring period, pooling data from fixed sites ≥100 m down-current of the Ocean Reef ocean outlets

Physical-chemical stressors

Dissolved oxygen (DO)

The EQG for dissolved oxygen is outlined in Table 11.

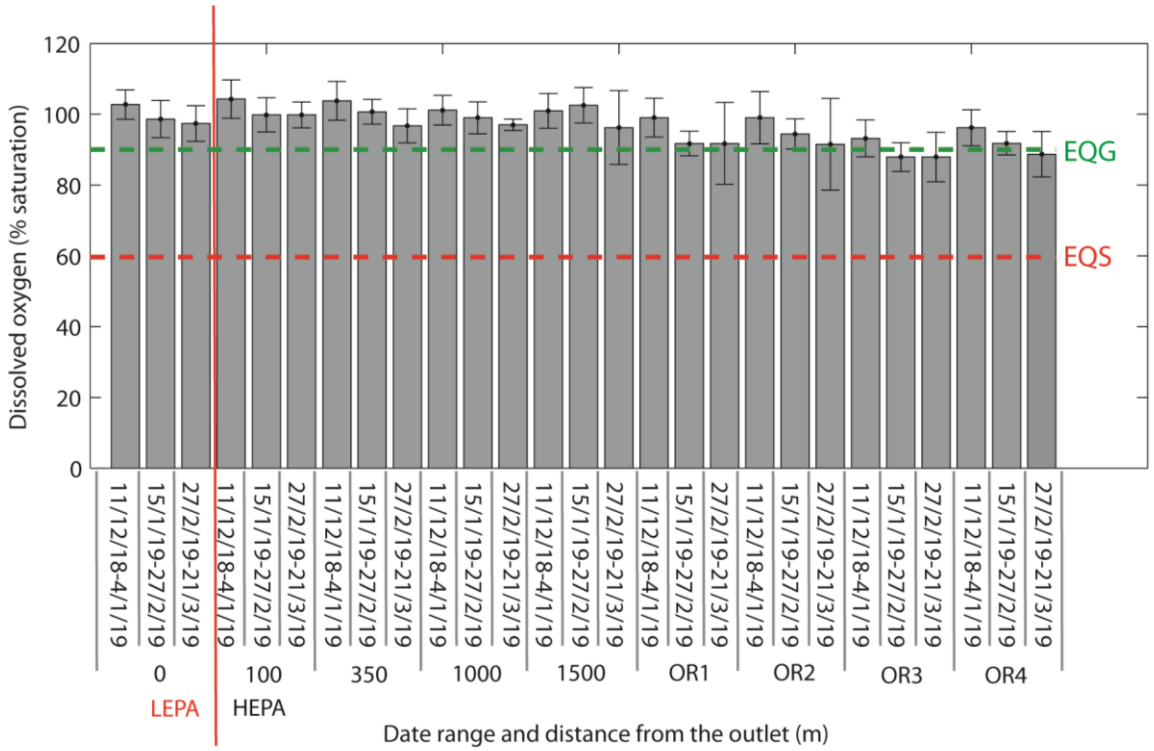
Table 11 Environmental Quality Guideline for dissolved oxygen

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

Bottom (0–0.5 m) DO saturation at HEPA sites (100, 350, 1000 and 1500 m) were >90% at all times throughout the summer survey period (Figure 10), and the EQG for organic enrichment was met. Bottom DO saturation fell below the 90% DO saturation but at the reference sites OR3 and OR4 well beyond the influence of the TWW suggesting another naturally occurring factor may be influencing DO at the broader scale.



Notes:

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

Figure 10 Median dissolved oxygen for defined periods of ≤6 weeks during the summer monitoring period

Salinity

The EQG and EQS for salinity are outlined in Table 12.

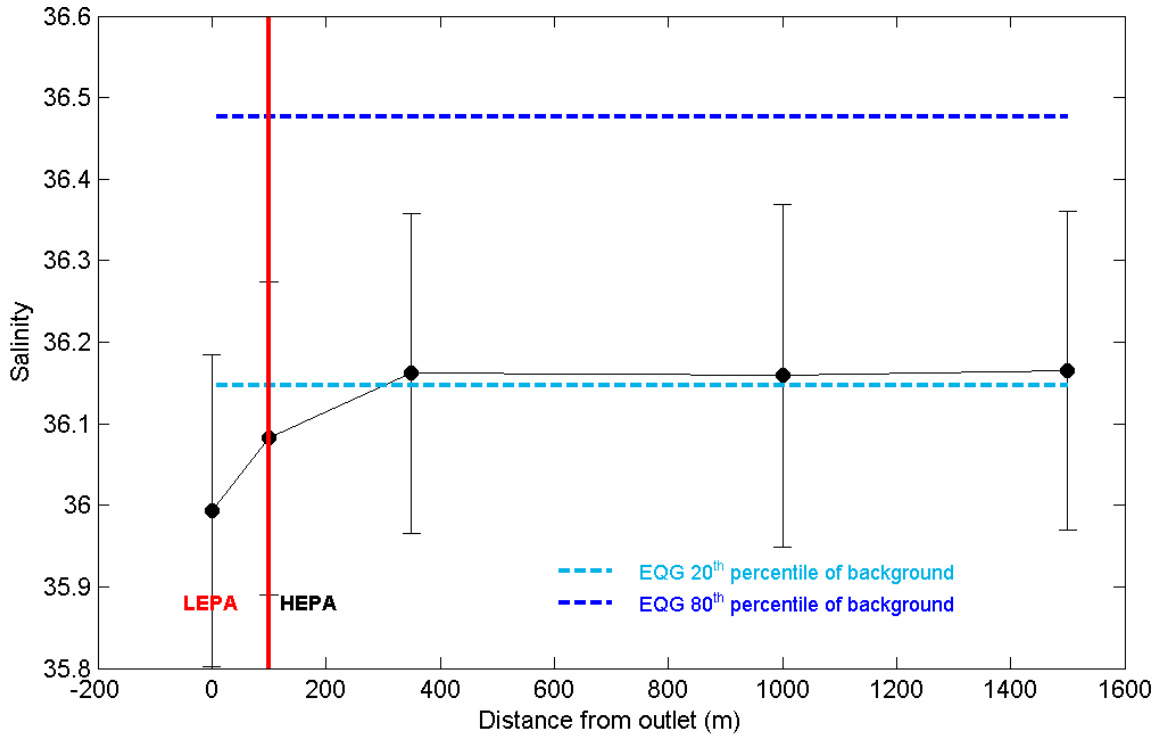
Table 12 Environmental Quality Guideline for salinity

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

Median salinity at 100 m was below the 20th percentile of the natural salinity range leading to an exceedance of the EQG (Figure 11). Median salinity at all other sites within the HEPA (350, 1000 and 1500 m from the outlets) was between the 20th and 80th percentile of the natural salinity range as required by the EQG (Figure 11). There were no reported deaths of marine organisms from anthropogenically sourced salinity stress at Ocean Reef over the summer monitoring period, meeting the EQS.



Notes:

1. Error bars represent ±95% confidence intervals.
2. Salinity measured 0–0.5 m below the sea surface.
3. Dark blue dashed line = 80th percentile of background Environmental Quality Guideline
4. Light blue dashed line = 20th percentile of background Environmental Quality Guideline
5. LEPA = notional low ecological protection area; HEPA = high ecological protection area.
6. Data for each distance was pooled across seven sampling occasions over December 2018–March 2019.

Figure 11 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 2018–2019 summer period (yielding a total of 40 samples). NHMRC (2008) guidelines and EPA (2005) require that 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 (since summer 2016–17) were pooled to yield 120 samples. The EQG for thermotolerant coliforms is outlined in Table 13.

Table 13 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. OZI = Observed Zone of Influence; 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).

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

Table 14 Median and 90th percentile of thermotolerant coliform concentration at the fixed monitoring sites for the Ocean Reef outlets for 2016–2019 and comparison to the EQC

Sampling period	Median (CFU/100 mL)	90th percentile	Compliance (EQG)
Dec 2016–Mar 2017 Dec 2017–Mar 2018 Dec 2018–Mar 2019	<10	<10	■

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 90th percentile.
3. Environmental Quality Criteria are based on EPA (2017).

Toxic phytoplankton species

The EQG for toxic phytoplankton species is outlined in Table 15.

Table 15 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: • *Alexandrium* spp. (200 cells/L) • *Gymnodinium catenatum* (1000 cells/L) • *Karenia brevis* (1000 cells/L) • Karenia/Karlodinium/Gymnodinium group (250 000 cells/L) • *Dinophysis* spp. (1000 cells/L) • *Prorocentrum lima* (500 cells/L) • *Pseudo-nitzchia* delicatissima group (500 000 cells/L) • *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).

There were no instances where toxic phytoplankton species were present at densities greater than the Western Australian Shelffish Quality Assurance Program (WASQAP; DoH 2016) guideline values (Table 16; Appendix J).

Table 16 Estimated cell densities of phytoplankton species known to produce toxins

Date	Site1	Species	Estimated density	WASQAP Guideline2	Compliance
5/12/2018	OR19	*Pseudo nitzschia* “delicatissima group”	8370		■
		Pseudo nitzschia “seriata group”	372		
	ORR1	*Pseudo nitzschia* “delicatissima group”	1116		na
20/12/2018	OR25	*Pseudo nitzschia* “delicatissima group”	1302		■
		Gymnodinium spp.	186		
	ORR1	*Pseudo nitzschia* “delicatissima group”	1488		na
4/01/2019	OR26	*Pseudo nitzschia* “delicatissima group”	558		■
	ORR4	*Pseudo nitzschia* “delicatissima group”	5208		na
		Pseudo nitzschia “seriata group”	930		
15/01/2019	OR26	*Pseudo nitzschia* “delicatissima group”	5766		■
		Pseudo nitzschia “seriata group”	2046		
		Gymnodinium spp.	186		
	ORR3	*Pseudo nitzschia* “delicatissima group”	3348		na
		Pseudo nitzschia “seriata group”	3906		
12/02/2019	OR22	*Pseudo nitzschia* “delicatissima group”	16740		■
		Pseudo nitzschia “seriata group”	744		
		Dinophysis acuminata	186		
	ORR2	*Pseudo nitzschia* “delicatissima group”	1860		na
		Pseudo nitzschia “seriata group”	1116		
		Gymnodinium spp.	186		
27/02/2019	OR30	*Pseudo nitzschia* “delicatissima group”	5952		■
		Pseudo nitzschia “seriata group”	2790		
	ORR3	*Pseudo nitzschia* “delicatissima group”	558		na
		Pseudo nitzschia “seriata group”	372		
5/03/2019	OR26	*Pseudo nitzschia* “delicatissima group”	5394		■
	ORR4	*Pseudo nitzschia* “delicatissima group”	1488		na
		Pseudo nitzschia “seriata group”	2790		
21/03/2019	OR30	*Pseudo nitzschia* “delicatissima group”	35898		■
		Pseudo nitzschia “seriata group”	1302		
	ORR1	*Pseudo nitzschia* “delicatissima group”	3162		na

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.

Faecal streptococci (Enterococci spp.)

Samples were collected eight times over the 2018–2019 summer monitoring period (yielding a total of 35 samples) for faecal streptococci analyses. The EQG for primary and secondary contact recreation are outlined in Table 17. 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 were pooled to yield 120 samples.

Table 17 Environmental quality guidelines for contact recreation

Primary1	**EQG**	**The 95th percentile bacterial content of marine waters should not exceed 200 enterococci/100 mL**
Secondary2	**EQG**	**The 95th percentile bacterial content of marine waters should not exceed 2000 enterococci/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.

Over the past three summers, the 95th percentile of Enterococci spp. concentrations at the boundary of the observed zone of influence for the Ocean Reef ocean outlet was 10 MPN/100 mL (Table 18), and both the primary (<200) and secondary (<2000 Enterococci spp./100mL) contact recreation EQG for faecal pathogens in water were met.

Table 18 The 95th percentile of Enterococci spp. concentrations at the boundary of the observed zone of influence for the Ocean Reef ocean outlet

Sampling period	95th percentile (MPN/100 mL)	Compliance	
		Primary contact	Secondary contact
Dec 2016–Mar 2017 Dec 2017–Mar 2018 Dec 2018–Mar 2019	10	■	■

Notes:

1. MPN = most probable number of Enterococci spp.
2. Enterococci spp. concentrations below the analytical detection limit (<10 Enterococci spp. MPN/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.

Phytoplankton cell concentrations

The EQG for phytoplankton cell concentrations are outlined in Table 19.

Table 19 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

Phytoplankton densities at individual sites monitored during 2018–2019 were below 10 000 cells/mL, meeting the EQG (Table 20).

Table 20 Estimated phytoplankton total cell densities collected at one of the fixed monitoring sites for contact recreation down-current of the Ocean Reef outlet

Date	Site	Total density (cells/mL)	Compliance
5/12/2018	OR5	96	
20/12/2018	OR9	81	
4/01/2019	OR9	71	
15/01/2019	OR9	278	
12/02/2019	OR7	1432	
27/02/2019	OR14	273	
5/03/2019	OR9	584	
21/03/2019	OR14	285	

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.

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

DoH (2016) Marine Biotoxin Monitoring and Management Plan: Western Australian Shellfish Quality Assurance Program (WASQAP). Department of Health, Perth, Western Australia, May 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

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

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

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

The following Appendices are available from Water Corporation on request:

Appendix A Analytical laboratories and methods
Appendix B Comprehensive treated wastewater characterisation
Appendix C Treated wastewater laboratory results
Appendix D Initial dilution model output
Appendix E Detailed methodologies
Appendix F Whole of effluent toxicity testing laboratory results
Appendix G Site coordinates
Appendix H Nutrient results
Appendix I Microbiology results
Appendix J Phytoplankton result