# Cockburn Sound environmental monitoring report July 2020–December 2021

Assessment against the environmental quality objectives and criteria set in the State Environmental (Cockburn Sound) Policy

Cockburn Sound Management Council

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National Relay Service 13 36 77


July 2023

FIRST 116001



**Acknowledgments**

The Cockburn Sound Management Council would like to thank the public authorities who have provided environmental monitoring data and information for inclusion in this report.

The Council would like to thank Mrs Rebecca James and Ms Melissa Manns (Fremantle Ports), Dr Julia Phillips (Water Corporation), Ms Tracey Stamp and Mr Jared Koutsoukos (Environmental Health Directorate, Department of Health) and Emeritus Professor Kateryna Longley for reviewing sections of the draft report.



The Department of Water and Environmental Regulation was established by the Government of Western Australia on 1 July 2017. It is a result of the amalgamation of the Department of Environment Regulation, Department of Water and the Office of the Environmental Protection Authority. This publication may contain references to previous government departments and programs. Please contact CSMC@DWER.wa.gov.au to clarify any specific information.

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# Executive summary

The Environmental Protection Authority (EPA) has established an environmental quality management framework for the Cockburn Sound marine area through the *State Environmental (Cockburn Sound) Policy 2015* (Government of Western Australia 2015). An essential component of the framework is environmental quality monitoring. The monitoring provides data for the measurement of environmental performance against the Cockburn Sound environmental quality criteria (EQC) as described in the *Environmental quality criteria reference document for Cockburn Sound* (EPA 2017). The Cockburn Sound Management Council reports annually to the Western Australian Minister for Environment on the environmental quality monitoring results for Cockburn Sound with specific reference to the Cockburn Sound EQC.

In January 2021, the water quality monitoring program for Cockburn Sound changed from weekly water sampling in the summer months only to monthly water sampling throughout the year. This report presents the findings of the monthly water quality monitoring and other environmental quality monitoring programs in Cockburn Sound from 1 July 2020 to 31 December 2021.

## Environmental value: ecosystem health

*Nutrient enrichment and phytoplankton biomass*

The relevant nutrient enrichment EQG for chlorophyll *a* were met at all sites in the ecological protection areas except in the High Protection Area South (HPA-S). The monthly chlorophyll *a* measurement exceeded the relevant nutrient enrichment EQG at all HPA-S sites in February 2021 and two HPA-S sites – CS13 and MB – in March 2021. The water monitoring sites that exceeded the nutrient enrichment EQG, were found to have met the relevant nutrient enrichment environmental quality standards (EQS). The relevant nutrient enrichment EQG for light attenuation were met in the ecological protection areas.

The relevant phytoplankton biomass (measured as chlorophyll *a*) EQG were met in all ecological protection areas except for the Moderate Protection Area Northern Harbour (MPA-NH).

*Other physical and chemical stressors*

The moderate protection dissolved oxygen concentration (DO concentration) EQG was met in the bottom waters at each site in the moderate protection areas, except for sites CS9 and NH3, in March 2021. The high protection DO concentration EQG were not met in the bottom waters at two High Protection Area North (HPA-N) sites in March 2021, two HPA-S sites in February 2021 and all HPA-S sites in March 2021. The water monitoring sites that exceeded the DO concentration EQG, were found to have met the relevant DO concentration EQS.

The surface water salinity EQG was met at all sites in January and March 2021, but not in February 2021. Sites CS9 and CS12 in Moderate Protection Area Eastern

Sound (MPA-ES) were the only sites that did not meet the bottom water salinity EQG in January 2021. Site CS9 also did not meet the bottom water salinity EQG in February and March 2021. The relevant salinity EQS were met at all water monitoring sites that exceeded the salinity EQG.

The surface and bottom water temperatures exceeded the high protection water temperature EQG at all HPA-N sites in February 2021, two HPA-S sites in January 2021 and one HPA-S in February 2021. The surface water temperature at HPA-S site CS11 also exceeded the high protection water temperature EQG in February 2021, while the site's bottom water temperature met the high protection water temperature EQG. At the sites in the moderate protection areas, the surface temperature exceeded the moderate protection water temperature EQG at only one site – NH3 – in January 2021 and only two sites – NH3 and G1 – in February 2021. Similarly, the bottom water temperature exceeded the moderate protection water temperature EQG at one site – CS9 – in January 2021 and three sites – NH3, CS9 and CS12 – in February 2021. The water monitoring sites that exceeded the water temperature EQG were found to have met the relevant temperature EQS.

The surface and bottom water pH measurements at all the sites in the high protection areas, except for site SF, met the high protection pH EQG in January 2021. The surface and bottom water pH measurements at all moderate protection area sites, except for site G1, met the moderate protection pH EQG in February 2021. The water monitoring sites that exceeded the pH EQG were found to have met the relevant pH EQS.

*Toxicants in marine waters*

The ammonium concentrations measured in the depth-integrated water samples collected from the 18 Cockburn Sound water monitoring sites were below the high protection ammonium EQG value of 500 µg/L. Discrete surface and bottom water samples were also taken at site CS13 in HPA-S and Warnbro Sound reference site WS4. At both sites, the median ammonium concentration of the discrete bottom water samples was higher than that of the discrete surface and integrated water samples for the same site. A statistical comparison could not be made to the ammonium EQG values because of the small number of measurements.

Water samples from the marine waters near the Kwinana Bulk Terminal and Kwinana Bulk Jetty were analysed for a range of toxicants including ammonia, filtered copper, total recoverable hydrocarbons (TRHs), and benzene, toluene, ethylbenzene and xylene (BTEX). Concentrations of the toxicants in these samples were below the relevant EQG values or the low reliability value (LRV) where relevant.

*Toxicants in sediments*

The median concentrations of arsenic, chromium, copper, lead, mercury and zinc in both sampling areas – the Kwinana Bulk Terminal and Kwinana Bulk Jetty – were below the relevant EQG values.

Elevated cadmium concentrations were reported in the sediment at two Kwinana Bulk Terminal sites, with the median concentration of cadmium in the sampling area above the EQG, but below the re-sampling trigger value. A slightly elevated concentration of mercury was recorded in one of the Kwinana Bulk Terminal samples.

Elevated concentrations of tributyltin (TBT), a highly toxic biocide previously used in antifouling paint, were also found in the sediment samples from the three Kwinana Bulk Jetty sites. The elevated concentrations of TBT in the sediment samples were below the EQG re-sampling value. It is likely the elevated TBT concentrations are from historical contamination.

These environmental monitoring results indicate a high degree of certainty that the environmental quality objective of maintenance of ecosystem integrity is being achieved in Cockburn Sound.

## Environmental value: fishing and aquaculture

Water and shellfish tissue samples were taken as part of the Western Australian Shellfish Quality Assurance Program (WASQAP). There were no exceedances of the faecal pathogens in water EQG from July 2020 to December 2021. The algal biotoxins EQG was met on all sampling occasions in the Kwinana Grain Terminal and Southern Flats shellfish harvesting areas. All Cockburn Sound shellfish samples taken as part of the WASQAP monthly screening program were found to be negative for biotoxins. The EQC for chemical concentration in seafood flesh were also met in those areas where sampling and analysis were undertaken.

The high protection DO concentration EQG was met in the bottom waters at two of the three Kwinana Bulk Terminal sites – KBT1 and KBT2 – and all three Kwinana Bulk Jetty sites. The DO concentration in the bottom waters at site KBT3 was 79% saturation, just below the moderate protection DO concentration EQG of 80% saturation or greater.

Based on these findings, there is a high degree of certainty that the fishing and aquaculture environmental quality objectives were achieved during the reporting period.

## Environmental value: recreation and aesthetics

A distinct southern algal bloom was observed in Cockburn Sound on 14 January 2021. Although surface phytoplankton scum was frequently observed on sampling days, it was not always associated with algal blooms.

In response to the persistent and frequent algal blooms throughout Cockburn Sound, phytoplankton samples were also collected from the integrated water samples taken at the water monitoring sites. The phytoplankton samples were analysed by the Phytoplankton Ecology Unit at the Department of Water and Environmental Regulation. Their analysis found very low counts of phytoplankton in the water samples.

Based on the results from the environmental monitoring programs, there were no recorded exceedances of the EQC for the environmental quality objectives of maintenance of primary contact recreation values and maintenance of secondary contact recreation values. Therefore, there is a high degree of certainty that the environmental quality objectives were achieved, and the waters are safe for recreational activities.

## Environmental value: industrial water supply

Water Corporation's 2020–21 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant found minor exceedances of the EQG for total suspended solids and bromide. The Water Corporation also reported a reduction in efficiency of the desalination process from late January to mid-March 2021 because of the quality of the intake seawater. The reduced efficiency was related to an algal bloom consisting of high quantities of very small algae. The Water Corporation advised that the quality of the intake seawater during this period compromised the desalination process. The quality of the intake seawater was considered suitable for the desalination process in the months outside the algal bloom period.

Based on this information, the environmental quality objective of maintenance of water quality for industrial use was achieved during the reporting period.

# 1. Introduction

The Cockburn Sound Management Council reports annually to the Minister for Environment on the results of environmental monitoring of the Cockburn Sound marine area and the extent to which the results meet environmental quality objectives and criteria in the *State Environmental (Cockburn Sound) Policy 2015* (State Environmental Policy; Government of Western Australia 2015). In January 2021, the water quality monitoring program for Cockburn Sound changed from weekly water sampling in the summer to monthly water sampling all year round. This report presents the findings of the monthly water quality monitoring and other environmental quality monitoring programs in Cockburn Sound from 1 July 2020 to 31 December 2021.

## 1.1 Environmental quality management framework for Cockburn Sound

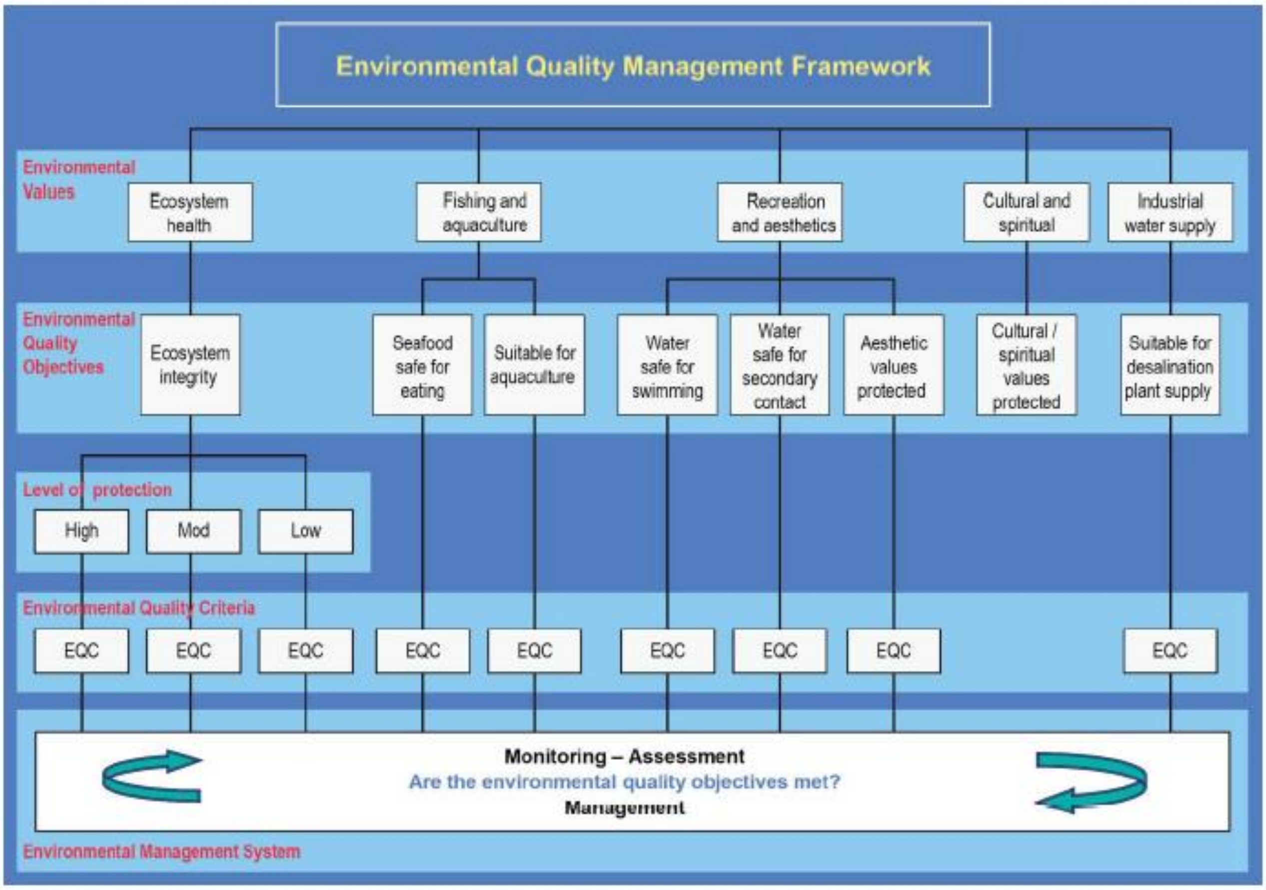
The Environmental Protection Authority (EPA) has established an environmental quality management framework for Cockburn Sound through the State Environmental Policy (Figure 1). This framework has been in place since 2005 under the first *State Environmental (Cockburn Sound) Policy 2005* (Government of Western Australia 2005). The framework's objective is to maintain Cockburn Sound's environmental quality to protect the integrity and biodiversity of the marine ecosystems, and current and projected future societal uses of these waters, from the effects of pollution, waste discharges and deposits (EPA 2017).

### 1.1.1 Environmental quality criteria for Cockburn Sound

The environmental quality management framework is underpinned by environmental values, environmental quality objectives and environmental quality criteria (EQC) (Figure 1). The EQC provide the quantitative benchmarks against which environmental quality and the performance of environmental management can be measured.

The EQC consist of environmental quality guidelines (EQG) and environmental quality standards (EQS). EQG are threshold numerical values or narrative statements which, if met, indicate a high degree of certainty that the associated environmental quality objective has been achieved and the environmental values protected. If the EQG are not met, a more comprehensive assessment against an EQS is required.

EQS are threshold numerical values or narrative statements that indicate a level beyond which there is a significant risk that the associated environmental quality objective has not been achieved and that the environmental values are at risk. If EQS are not met, investigation of the potential causes of the exceedance is needed. An adaptive management response is triggered if the EQS continue to be exceeded.




Source: Environmental Protection Authority (2017)

*Figure 1: Environmental quality management framework for Cockburn Sound*

The EPA has defined EQC for Cockburn Sound to enable assessment of whether the environmental quality meets the objectives set in the State Environmental Policy. The EQC for Cockburn Sound were developed specifically for the assessment of environmental quality during the non river-flow period in the summer months.

The EQC that support the policy, and the decision schemes that explain how they are applied, are documented in the EPA's *Environmental quality criteria reference document for Cockburn Sound* (reference document; EPA 2017). The framework adopted for applying EQC to Cockburn Sound was developed to be consistent with the recommended approaches and guideline values in the *Australian and New Zealand guidelines for fresh and marine waters* (ANZECC & ARMCANZ 2000).

## 1.2 Levels of ecological protection

The State Environmental Policy describes three levels of ecological protection (high protection, moderate protection and low protection) and where they apply spatially in the protected area so that overall ecological integrity can be maintained (Figure 2).

Most of Cockburn Sound is designated as having a high level of ecological protection. In 2013, in recognition that the southern area of Cockburn Sound has different environmental characteristics to the northern, better flushed area, the Cockburn Sound Management Council began reporting on two separate areas within the existing High Ecological Protection Area (HEPA). These two areas within HEPA are delineated as High Protection Area North (HPA-N) and High Protection Area South (HPA-S). EQC for maintaining a high level of environmental quality apply to these areas.

Two moderate ecological protection areas have been designated where waste disposal and other societal uses preclude a high level of ecological protection – Careening Bay at Garden Island (Moderate Protection Area Careening Bay [MPA-CB]); and the eastern margin of Cockburn Sound adjacent to the industrial area (Moderate Protection Area Eastern Sound [MPA-ES]). MPA-ES also includes several harbours and marinas, which are assessed individually as Moderate Protection Area Southern Harbour (MPA-SH) and Moderate Protection Area Northern Harbour (MPA-NH). EQC for maintaining a moderate level of environmental quality apply in these areas.

The reference document (EPA 2017) identifies that it may be appropriate to monitor a subset of indicators for some marinas and harbours, depending on potential threats to environmental quality and the benthic habitats present. For example, monitoring and assessment of chlorophyll *a* concentrations and light attenuation coefficients in a marina may be unnecessary if seagrass is not present.

A few small areas around outfalls in Cockburn Sound (less than 1% of the protected area) have been designated as having a low level of ecological protection. For these areas, EQG have been proposed for those toxicants identified as having the potential to adversely bioaccumulate or biomagnify.

The acceptance of different levels of ecological protection is based on the recognition that when managing environmental quality, other societal benefits also need to be considered (e.g. use of marine waters for receiving waste and the economic benefits of industrial development). These other benefits may preclude a high level of quality being achieved in some areas (EPA 2017). The levels of ecological protection represent the minimum acceptable level of environmental quality to be achieved through management of Cockburn Sound. They do not necessarily describe the current, or preferred, environmental condition of Cockburn Sound.

## 1.3 Monitoring programs for measuring environmental performance

An essential component of the environmental quality management framework is the implementation of appropriate monitoring programs to provide data for measuring environmental performance against the EQC (EPA 2017). The *Manual of standard operating procedures for environmental monitoring against the Cockburn Sound environmental quality criteria* (standard operating procedures; EPA 2005) specifies how samples should be collected and analysed, as well as how the results should be assessed against the EQC.

Under the State Environmental Policy, responsibility for monitoring against the EQC is shared across several public authorities, based on their roles and responsibilities.

Not all parameters for all EQC are, or need to be, monitored on a regular basis. The relevant public authorities determine what monitoring should be undertaken based on an assessment of risks and impacts. To facilitate the compilation and reporting of data and the adoption of appropriate responses, each year the public authorities provide the results of that monitoring to the Cockburn Sound Management Council.

### 1.3.1 Assessment against EQC for Cockburn Sound

Tables 1 to 3 summarise the environmental quality indicators measured by the monitoring programs for comparison against the EQC for Cockburn Sound, as well as the sources of these data.

The results are summarised and discussed in this report in the context of meeting the environmental quality objectives and EQC for Cockburn Sound and encompass:

- maintenance of ecosystem integrity (Section 2)
- maintenance of seafood safe for human consumption (Section 3)
- maintenance of aquaculture (Section 3)
- maintenance of primary and secondary contact recreation values and aesthetic values (Section 4)
- maintenance of water quality for industrial use (Section 5).

Ensuring the quality of Cockburn Sound's waters is sufficient to protect ecosystem integrity and the quality of seafood, allow people to recreate safely, and maintain aesthetic values, and may go some way towards maintaining cultural values in line with the environmental value of cultural and spiritual (EPA 2017). It is difficult to define spiritual values in terms of environmental quality requirements.

*Table 1: Environmental quality indicators and data sources for July 2020 to December 2021 reporting against the maintenance of ecosystem integrity environmental quality objective*

| Environmental quality criteria | | Indicator | Data source |
|---|---|---|---|
| Physical and chemical stressors | Nutrients | Nutrient enrichment<br>Chlorophyll *a* concentration<br>Light attenuation coefficient<br>Phytoplankton biomass | Department of Water and Environmental Regulation |
| | Other physical and chemical stressors | Dissolved oxygen concentration<br>Water temperature<br>Salinity<br>pH | Department of Water and Environmental Regulation, Water Corporation, Fremantle Ports |
| Toxicants (marine waters) | Metals and metalloids | Copper, lithium | Department of Water and Environmental Regulation, Fremantle Ports |
| | Non-metallic inorganics | Ammonia | |
| | Organics | Benzene, toluene, ethylbenzene, xylene (BTEX) | |
| | Oils and petroleum hydrocarbons | Total recoverable hydrocarbons (TRHs) | |
| Toxicants (sediments) | Metals and metalloids | Arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc | Fremantle Ports |
| | Organometallics | Tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT) | |
| | Organics | Polycyclic aromatic hydrocarbons (PAHs) | |
| | Oils and petroleum hydrocarbons | TRHs | |
| | Per- and polyfluoroalkyl substances (PFAS) | Perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and perfluorohexane sulfonate (PFHxS) | |

*Table 2: Environmental quality indicators and data sources for July 2020 to December 2021 reporting against the maintenance of seafood safe for human consumption and maintenance of aquaculture environmental quality objectives*

| Environmental quality objective | Environmental quality criteria | | Indicator | Data source |
|---|---|---|---|---|
| Maintenance of seafood safe for human consumption | Biological contaminants | | Faecal pathogens in water *Escherichia coli* (*E. coli*) in shellfish flesh<br>Algal biotoxins | WA Shellfish Quality Assurance Program (WASQAP)<br>Data supplied by Department of Health. |
| | Chemicals | Metals | Arsenic, cadmium, chromium, copper, lead, mercury, selenium, zinc | WASQAP (Harvest Road Export), Fremantle Ports |
| | | Organic chemicals | Polychlorinated biphenyls,<br>PAHs | |
| | | Organometallics | TBT, DBT, MBT | |
| Maintenance of aquaculture | Physical and chemical stressors | | Dissolved oxygen, pH | Department of Water and Environmental Regulation |
| | Toxicants | Non-metallic inorganic chemicals | Ammonia, nitrate–nitrite | Department of Water and Environmental Regulation, Fremantle Ports |
| | | Metals and metalloids | Copper | |

*Table 3: Environmental quality indicators and data sources for July 2020 to December 2021 reporting against the maintenance of primary contact recreation values, maintenance of secondary contact recreation values and maintenance of water quality for industrial use environmental quality objectives*

| Environmental quality objective | Environmental quality criteria | | Indicator | Data source |
|---|---|---|---|---|
| Maintenance of primary contact recreation values | Biological | | Faecal pathogens (mainly enterococci) | Department of Health |
| | Physical | | pH, water clarity | Department of Water and Environmental Regulation |
| | Toxic chemicals | Inorganic chemicals | Copper, nitrate–nitrite | Department of Water and Environmental Regulation, Fremantle Ports |
| | | Organic chemicals | BTEX | |
| Maintenance of secondary contact recreation values | Biological | | Faecal pathogens (mainly enterococci) | Department of Health |
| | Physical and chemical | | pH | Department of Water and Environmental Regulation |
| | | | Toxic chemicals | Department of Water and Environmental Regulation, Fremantle Ports |
| Maintenance of water quality for industrial use | Biological | | *E. coli* / enterococci | Water Corporation |
| | Physical and chemical | | Temperature, pH, dissolved oxygen, total suspended solids, hydrocarbons, boron, bromide | |

# 2. Assessment against environmental value: ecosystem health

## 2.1 Environmental quality objective

The environmental quality objective for the ecosystem health environmental value is maintenance of ecosystem integrity. Ecosystem integrity is considered in terms of structure (e.g. biodiversity, biomass and abundance of biota) and function (e.g. food chains and nutrient cycles) (EPA 2017). Achieving the environmental quality objective depends on ensuring that environmental quality is maintained within acceptable levels.

See Figure 2 and Table 4 for details of the water quality and sediment contaminant monitoring sites in each ecological protection area.

## 2.2 Water quality monitoring

In January 2021, the Cockburn Sound water quality monitoring program changed from weekly water sampling during the summer from December to March, to monthly water sampling throughout the year.

The Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University conducted water quality sampling at 18 water quality monitoring sites in Cockburn Sound and two reference water quality monitoring sites in Warnbro Sound – see Figure 2. Depth-integrated water samples were collected each month from each site from January to December 2021. Discrete surface and bottom water samples were collected at Cockburn Sound site CS13 and Warnbro Sound site WS4.

The depth-integrated water samples were analysed for nutrients (i.e. ammonium, nitrate–nitrite, filterable reactive phosphorus, total nitrogen and total phosphorus) and chlorophyll *a*. The discrete water samples were analysed for the same nutrients and analysis results were used to identify differences between the surface water and the water near the water/sediment interface at the two sites. Statistical comparisons for ammonium were made using a low-level ammonium fluorescence method with a laboratory reporting limit of less than 0.5 µg/L. For the statistical analyses, all samples below the limit of reporting were assigned half of the limit of reporting for the measured nutrients and chlorophyll *a*.

In addition to these analyses, physical and chemical parameters (i.e. water depth, water temperature, salinity, pH, turbidity, dissolved oxygen and chlorophyll *a* by fluorescence) were measured in situ at each site.

### 2.2.1 Water Corporation water quality monitoring

The Water Corporation undertook quarterly measurements (in September 2020, January 2021, March 2021 and June 2021) of the physical-chemical parameters of dissolved oxygen, salinity and temperature as depth profiles through the water column. This was done at three sites in Cockburn Sound (South, Central, DIFF50W; Figure 2), as well as sites on Parmelia Bank and in Owen Anchorage. Additional measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 on these sampling occasions.


*Figure 2: The ecological protection areas in Cockburn Sound and the location of water quality and sediment quality monitoring sites in Cockburn Sound and reference sites in Warnbro Sound*

*Table 4: The high and moderate ecological protection areas for Cockburn Sound and the associated water quality and marine sediment monitoring sites*

| Ecological protection area | Water quality monitoring sites | Marine sediment and water monitoring sites |
|---|---|---|
| HPA-N | CS4, CS5, CS8, G2, G3 and CB; Central | - |
| HPA-S | CS11, CS13, Southern Flats (SF/SF-L) and Mangles Bay (MB/MB-L); South<br>Light attenuation measured at MB-L (since December 2014) and SF-L (since December 2015) located close to the shallow sites | - |
| MPA-CB | G1 | - |
| MPA-ES | CS6A, CS7, CS9, CS9A, CS10N and CS12; DIFF50W | Sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) monitored for toxicants in water and sediment |
| MPA-NH | Jervoise Bay Northern Harbour (NH3) | - |
| MPA-SH | Not currently monitored | - |
| Reference sites | WS4, WSSB/WSSB-L<br>Light attenuation measured at WSSB-L located close to the shallow site WSSB since December 2015 | - |

### 2.2.2 Fremantle Ports water quality monitoring

Fremantle Ports undertook monitoring of toxicants in marine waters at three sites around the Kwinana Bulk Terminal – KBT1, KBT2 and KBT3 (Figure 2) – and three sites around the Kwinana Bulk Jetty – KBJ1, KBJ2 and KBJ3 (Figure 2). Water quality samples were collected on 28 January 2021, along with measurements of the physical-chemical parameters of dissolved oxygen, salinity and temperature as depth profiles through the water column. The water quality samples were collected at each site from about 0.5 m below the surface and above the seabed.

The samples were processed in the field and stored on ice for transport to the laboratory. Samples were analysed by MAFRL for nutrients, chlorophyll, phaeophytin *a* and filtered copper. Samples were analysed by ChemCentre for TRHs and BTEX.

## 2.3 Marine sediment monitoring

Fremantle Ports undertook monitoring of toxicants in marine sediments at three sites around the Kwinana Bulk Terminal – KBT1, KBT2 and KBT3 (Figure 2) – and three sites around the Kwinana Bulk Jetty – KBJ1, KBJ2 and KBJ3 (Figure 2).

Sediment samples were collected on 23 March 2021 at all six sites. Five 100 mm diameter sediment cores were collected within 1 $m^2$ at each site using polycarbonate corers. The top 2 cm of each core was separated and homogenised into one composite sample from each site. The sediment samples were stored on ice for transport to the laboratory. The samples were analysed by ChemCentre for total organic carbon, metals (i.e. arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (i.e. TBT, DBT and MBT), PAHs, PFAS and TRHs.

Methods following those outlined in the standard operating procedures and standard laboratory analytical procedures were employed throughout. Laboratories with methods accredited by the National Association of Testing Authorities, Australia (or laboratories with demonstrated quality assurance/quality control procedures in place) undertook the analyses.

## 2.4 Assessment against the nutrient enrichment and phytoplankton biomass environmental quality criteria

The nutrient-related EQC address the issue of nutrient enrichment and were derived to achieve the following three key objectives:

- protect the remaining seagrass meadows in Cockburn Sound
- maintain a level of water quality that would enable seagrass meadows to re-establish along the eastern side of Cockburn Sound, including the Jervoise Shelf, to depths of up to 10 m
- minimise the occurrence and extent of phytoplankton blooms in Cockburn Sound (EPA 2017).

### 2.4.1 EQC for chlorophyll *a*, light attenuation coefficient, phytoplankton biomass and seagrass shoot density

For this assessment, EQC for chlorophyll *a*, light attenuation coefficient and phytoplankton biomass were based on ‘rolling’ percentiles calculated using weekly monitoring measurements collected at Warnbro Sound reference site WS4 during the 2019–20 summer non river-flow monitoring period. Seagrass shoot densities at seagrass monitoring sites were not measured in 2021; therefore, they were not included in this assessment.

For the duration of the monitoring program, chlorophyll *a* concentrations have increased at the Warnbro Sound reference site WS4 resulting in higher EQG values that afford less protection to the ecological protection areas.

The monthly measurements taken from January to March 2021 were assessed against the 2019–20 EQC in Table 5. The 2019–20 EQC were calculated using data from the 2019–20 summer and the sampling periods from the five previous summers.

*Table 5: The 2019–20 high protection and moderate protection Environmental Quality Guidelines for chlorophyll a concentration, light attenuation coefficient (LAC) and phytoplankton biomass*

| Indicator | High protection<br>Rolling 6-year 80th percentile | Moderate protection<br>Rolling 6-year 95th percentile |
|---|---|---|
| Chlorophyll *a* (µg/L) | 1.00 | 1.50 |
| LAC ($\log_{10}$ $m^{-1}$) | 0.097 | 0.115 |
| Phytoplankton biomass | 2.10 | 3.00 |

### 2.4.2 Assessment of compliance with the nutrient enrichment EQC

#### Chlorophyll *a* and light attenuation

Chlorophyll *a* concentrations and light attenuation coefficients were recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.2; Figure 2). The monthly measurement for each monitoring site recorded from January to March 2021 were assessed against the 2019–20 nutrient enrichment EQG (EPA 2017:26):

High protection: The median chlorophyll *a* concentration/light attenuation coefficient in HPA-N and HPA-S during the non river-flow period is not to exceed a chlorophyll *a* concentration of 1.00 µg/L or a light attenuation coefficient of 0.097 $\log_{10}$ $m^{-1}$.

Moderate protection: The median chlorophyll *a* concentration/light attenuation coefficient in MPA-ES and MPA-CB during the non river-flow period is not to exceed a chlorophyll *a* concentration of 1.50 µg/L or a light attenuation coefficient of 0.115 $\log_{10}$ $m^{-1}$.

The nutrient enrichment EQG were not applied to MPA-NH because of the absence of macro-benthic primary producers such as seagrass within the harbour.

*Chlorophyll* a *concentrations*

The nutrient enrichment EQG for chlorophyll *a* was not met in HPA-S (Table 6). Chlorophyll *a* concentrations measured at the HPA-S sites were above the relevant nutrient enrichment EQG in February 2021. The HPA-S sites CS13 and MB continued to have chlorophyll *a* concentrations above the relevant nutrient enrichment EQG in March 2021.

Site CB was the only site in HPA-N above the relevant nutrient enrichment EQG for chlorophyll *a*, which occurred in February 2021.

Chlorophyll *a* concentrations measured at MPA-ES sites CS10N and CS9A were above the relevant nutrient enrichment EQG for chlorophyll *a* in February and March 2021. The chlorophyll *a* concentration measured at MPA-ES site G1 was also above the relevant nutrient enrichment EQG in March 2021.

The highest chlorophyll *a* concentration, 2.7 µg/L, was measured at MPA-ES site CS10N in March 2021.

#### *Light attenuation coefficients*

The nutrient enrichment EQG for light attenuation was met in all ecological protection areas (Table 7). The light attenuation coefficients measured at the HPA-S sites were all above the relevant nutrient enrichment EQG for light attenuation in February 2021, except for site SF which approached the EQG. The HPA-S sites SF and MB had measured light attenuation coefficients above the relevant EQG in March 2021.

The HPA-N site G2 had a measured light attenuation coefficient above the relevant EQG in February, as did site CB in March 2021.

The MPA-ES sites CS10N and CS9A had measured light attenuation coefficients above the relevant nutrient enrichment EQG in February 2021 and site CS9A did in March 2021 as well.

The highest light attenuation coefficient, 0.150 $\log_{10}$ $m^{-1}$, was measured at MPA-ES site CS10N in February 2021.

#### *Nutrient enrichment EQS at HPA-S*

The high protection nutrient enrichment EQG for chlorophyll *a* was not met at HPA-S, which triggered a more detailed assessment against the high protection nutrient enrichment EQS(i)[1] (EPA 2017:26). The high protection nutrient enrichment EQS(i) states that nutrient enrichment EQG should not be exceeded in a second consecutive year.

An assessment of the 2019–20 chlorophyll *a* concentrations and light attenuation coefficients for HPA-S found the medians for chlorophyll *a* – 0.9 µg/L – and light attenuation – 0.096 $\log_{10}$ $m^{-1}$ – met the relevant high protection nutrient enrichment EQG. The nutrient enrichment EQS(i) at HPA-S was therefore considered to have been achieved for 2020–21.

See Appendix A for information on the monthly chlorophyll *a* concentrations and light attenuation coefficients recorded at the water monitoring sites from January to December 2021.

[1] Roman numerals are used for indicators for which multiple EQC are specified, as outlined in the *Environmental quality criteria reference document for Cockburn Sound*

*Table 6: Assessment of site and median ecological protection area chlorophyll a concentrations measured from January to March 2021 against the 2019–20 nutrient enrichment EQG*

| Ecological protection area | Site | 2019–20 EQG | January 2021 | February 2021 | March 2021 | 2021 ecological protection area median | Assessment |
|---|---|---|---|---|---|---|---|
| HPA-N | CS4[2] | 1.0 | 0.3 | 0.4 | 1.0 | 0.7 | EQG met |
| | CS5[1] | | 0.4 | 0.8 | 0.9 | | |
| | CS8[1] | | 0.3 | 0.7 | 0.7 | | |
| | CB[1] | | 0.3 | 1.4* | 0.9 | | |
| | G2[2] | | 0.4 | 0.7 | 0.8 | | |
| | G3[2] | | 0.3 | 0.4 | 0.7 | | |
| | Median | | 0.3 | 0.7 | 0.85 | | |
| HPA-S | CS11[2] | 1.0 | 0.7 | 1.7* | 0.8 | 1.15 | EQG not met |
| | CS13[2] | | 0.6 | 1.5* | 1.4* | | |
| | SF[1] | | 0.4 | 1.3* | 1.0 | | |
| | MB/MB-L[1] | | 1.0 | 1.7* | 1.4* | | |
| | Median | | 0.65 | 1.6* | 1.2* | | |
| MPA-CB | G1[2] | 1.5 | 0.6 | 1.2 | 1.6* | 1.2 | EQG met |
| MPA-ES | CS10N[1] | 1.5 | 0.9 | 2.0* | 2.7* | 0.9 | EQG met |
| | CS12[1] | | 0.7 | 1.2 | 0.8 | | |
| | CS6A[1] | | 0.6 | 0.6 | 0.8 | | |
| | CS7[1] | | 0.8 | 0.9 | 0.8 | | |
| | CS9[1] | | 0.9 | 1.3 | 1.4 | | |
| | CS9A[1] | | 1.4 | 1.9* | 1.8* | | |
| | Median | | 0.85 | 1.25 | 1.1 | | |
| MPA-NH | NH3[1] | - | 3.4 | 3.1 | 1.9 | 3.1 | - |

Note: exceedance of the EQG denoted by '*'

Monitoring dates: 1: 14/01/2021, 1/02/2021, 1/03/2021; 2: 15/01/2021, 2/02/2021, 2/03/2021

*Table 7: Assessment of site and median ecological protection area light attenuation coefficients measured from January to March 2021 against the 2019–20 nutrient enrichment EQG*

| **Ecological protection area** | **Site** | **2019–20 EQG** | **January 2021** | **February 2021** | **March 2021** | **2021 ecological protection area median** | **Assessment** |
|---|---|---|---|---|---|---|---|
| | CS4[2] | | 0.069 | 0.074 | 0.077 | | |
| | CS5[1] | | 0.071 | 0.075 | 0.081 | | |
| | CS8[1] | | 0.069 | 0.075 | 0.087 | | |
| HPA-N | CB[1] | 0.097 | 0.072 | 0.095 | 0.099* | 0.075 | EQG met |
| | G2[2] | | 0.074 | 0.098* | 0.081 | | |
| | G3[2] | | 0.075 | 0.074 | 0.081 | | |
| | Median | | 0.072 | 0.075 | 0.081 | | |
| | CS11[2] | | 0.096 | 0.127* | 0.096 | | |
| | CS13[2] | | 0.087 | 0.113* | 0.087 | | |
| HPA-S | SF[1] | 0.097 | 0.078 | 0.091* | 0.099* | 0.096 | EQG met |
| | MB/MB-L[1] | | 0.086 | 0.121* | 0.101* | | |
| | Median | | 0.086 | 0.117* | 0.098* | | |
| MPA-CB | G1[2] | 0.115 | 0.079 | 0.104 | 0.093 | 0.093 | EQG met |
| | CS10N[1] | | 0.088 | 0.150* | 0.100 | | |
| | CS12[1] | | 0.085 | 0.102 | 0.089 | | |
| | CS6A[1] | | 0.083 | 0.079 | 0.087 | | |
| MPA-ES | CS7[1] | 0.115 | 0.099 | 0.095 | 0.085 | 0.092 | EQG met |
| | CS9[1] | | 0.090 | 0.109 | 0.103 | | |
| | CS9A[1] | | 0.087 | 0.140* | 0.127* | | |
| | Median | | 0.088 | 0.106 | 0.095 | | |
| MPA-NH | NH3[1] | - | 0.141 | 0.137 | 0.113 | 0.137 | - |

Note: exceedance of the EQG denoted by '*'
Monitoring dates: 1: 14/01/2021, 1/02/2021, 1/03/2021; 2: 15/01/2021, 2/02/2021, 2/03/2021

See Appendix B for information on ammonium, total nitrogen and total phosphorus concentrations at the Cockburn Sound water quality monitoring sites from January to December 2021.

### Phytoplankton biomass

Phytoplankton biomass (measured as chlorophyll *a*) was recorded at 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.2; Figure 2). The monthly phytoplankton biomass measurement for each monitoring site recorded from January to March 2021 were assessed against the 2019–20 phytoplankton biomass EQG (EPA 2017:29–30):

| | |
|---|---|
| High protection: | i. Median phytoplankton biomass in HPA-N and HPA-S is not to exceed 2.10 µg/L on any occasion during the 2019–20 non river-flow period (EQG[i]).<br>ii. Phytoplankton biomass at any site is not to exceed 2.10 µg/L on 25% or more occasions during the 2019–20 non river-flow period (EQG[ii]). |
| Moderate protection: | i. Median phytoplankton biomass in MPA-ES is not to exceed 3.00 µg/L on more than one occasion during the 2019–20 non river-flow period (EQG[i]).<br>ii. Phytoplankton biomass at any site is not to exceed 3.00 µg/L on 50% or more occasions during the 2019–20 non river-flow period (EQG[ii]). |

The relevant phytoplankton biomass EQG were met at each site in HPA-N, HPA-S and MPA-ES (Table 8).

In March 2021, site CS10N in MPA-ES approached the first phytoplankton biomass EQG with a chlorophyll *a* concentration measurement of 2.7 µg/L. Sites CS10N and CS9A had the highest chlorophyll *a* concentrations of any of the MPA-ES sites in February and March 2021.

The first phytoplankton biomass EQG (EQG[i]) was not met at site NH3 in Jervoise Bay (MPA-NH) in January and February 2021.

*Table 8: Assessment of site and median ecological protection area chlorophyll* a *concentration measured from January to March 2021 against the 2019–20 phytoplankton biomass EQG*

| Ecological protection area | Site | 2019–2020 EQG Chlorophyll *a* concentration (µg/L) | January 2021 | February 2021 | March 2021 | Assessment |
|---|---|---|---|---|---|---|
| HPA-N | CS4 | 2.1 | 0.3 | 0.4 | 1.0 | EQG met |
| | CS5 | | 0.4 | 0.8 | 0.9 | |
| | CS8 | | 0.3 | 0.7 | 0.7 | |
| | CB | | 0.3 | 1.4 | 0.9 | |
| | G2 | | 0.4 | 0.7 | 0.8 | |
| | G3 | | 0.3 | 0.4 | 0.7 | |
| | Median | | 0.3 | 0.7 | 0.85 | |
| HPA-S | CS11 | 2.1 | 0.7 | 1.7 | 0.8 | EQG met |
| | CS13 | | 0.6 | 1.5 | 1.4 | |
| | SF | | 0.4 | 1.3 | 1.0 | |
| | MB/MB-L | | 1.0 | 1.7 | 1.4 | |
| | Median | | 0.65 | 1.6 | 1.2 | |
| MPA-CB | G1 | 3.0 | 0.6 | 1.2 | 1.6 | EQG met |
| MPA-ES | CS10N | 3.0 | 0.9 | 2.0 | 2.7 | EQG met |
| | CS12 | | 0.7 | 1.2 | 0.8 | |
| | CS6A | | 0.6 | 0.6 | 0.8 | |
| | CS7 | | 0.8 | 0.9 | 0.8 | |
| | CS9 | | 0.9 | 1.3 | 1.4 | |
| | CS9A | | 1.4 | 1.9 | 1.8 | |
| | Median | | 0.85 | 1.25 | 1.1 | |
| MPA-NH | NH3 | 3.0 | 3.4 | 3.1 | 1.9 | EQG and EQS not met |

*Phytoplankton biomass EQS at Jervoise Bay Northern Harbour (NH3)*

The moderate protection phytoplankton biomass EQG (EQG[i] and EQG[ii]) were not met in Jervoise Bay (site NH3), which triggered a more detailed assessment against two moderate protection phytoplankton biomass EQS (EQS[i] and EQS[ii]) (EPA 2017:29–30). The first phytoplankton biomass EQS (EQS[i]) for moderate protection areas states that the median phytoplankton biomass is not to exceed the EQC that are updated annually on more than three occasions during the non river-flow period and in two consecutive years. In 2019–20, the phytoplankton biomass exceeded the EQC on 13 occasions; therefore, the phytoplankton biomass at site NH3 did not meet the first phytoplankton biomass EQS (EQS[i]).

The second phytoplankton biomass EQS (EQS[ii]) for moderate protection areas states that the median phytoplankton is not to exceed the EQC that are updated annually on 50% or more occasions during the non river-flow period and in two consecutive years.

Assessment of phytoplankton biomass at site NH3 during the non river-flow period for 2019–20 and 2020–21 showed that phytoplankton biomass exceeded 3.00 µg/L on two of three sampling occasions (Table 9). The second phytoplankton biomass EQS for moderate protection was not met.

*Table 9: Assessment of chlorophyll* a *concentrations at Jervoise Bay Northern Harbour (NH3) against the second moderate protection phytoplankton biomass EQS over two consecutive years (2019–20 and 2020–21)*

| Site | Year | EQS | Number of occasions EQS was exceeded | Percentage of occasions EQS was exceeded | Assessment |
|---|---|---|---|---|---|
| NH3 | 2019–20 | Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions | 13 (of 16) | 81% | EQS not met |
| | 2020–21 | Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions | 2 (of 3) | 66% | |

## 2.5 Assessment against the environmental quality criteria for other physical and chemical stressors

### 2.5.1 Dissolved oxygen concentration

*Dissolved oxygen concentration*

Monthly measurements of dissolved oxygen concentrations (DO concentration(s); % saturation) recorded in the bottom waters[2] at the 18 water quality monitoring sites in Cockburn Sound (Figure 2, Section 2.2) from January to March 2021 were assessed against the 2019–20 dissolved oxygen concentration EQG (EPA 2017:30).

The DO concentration recorded at each site was compared with the relevant DO concentration EQG (Table 10). Sites not meeting the relevant DO concentration EQG were also assessed against the relevant DO concentration EQS.

[2] Waters within 50 cm of the sediment surface.

*Table 10: Assessment of dissolved oxygen concentrations (% saturation) in bottom waters at Cockburn Sound sites from January to March 2021 against the dissolved oxygen concentration EQC*

| Ecological protection area | Site(depth) | 2019–2020 EQG and EQS (% saturation) | January 2021 | February 2021 | March 2021 | Assessment |
|---|---|---|---|---|---|---|
| HPA-N | CS4 (21 m) | EQG: DO ≥ 90<br>EQS: DO ≥ 60 | 92.3 | 91.4 | 88.3 | EQG not met<br>EQS met |
| | CS5 (19 m) | | 97.4 | 97.0 | 88.1 | |
| | CS8 (20 m) | | 95.4 | 95.3 | 94.6 | |
| | CB (9.5 m) | | 94.9 | 98.3 | 92.6 | |
| | G2 (11 m) | | 98.7 | 96.6 | 97.8 | |
| | G3 (17 m) | | 95.5 | 92.0 | 94.8 | |
| HPA-S | CS11 (18 m) | EQG: DO ≥ 90<br>EQS: DO ≥ 60 | 90.4 | 85.6 | 76.7 | EQG not met<br>EQS met |
| | CS13 (20 m) | | 93.8 | 85.0 | 88.9 | |
| | SF (3.5 m) | | 100.0 | 100.0 | 85.1 | |
| | MB/MB-L (1.5 m) | | 100.0 | 100.0 | 81.5 | |
| MPA-CB | G1 (15 m) | EQG: DO ≥ 80<br>EQS: DO ≥ 60 | 97.2 | 84.9 | 86.8 | EQG met |
| MPA-ES | CS10N (16 m) | EQG: DO ≥ 80<br>EQS: DO ≥ 60 | 90.1 | 91.3 | 87.3 | EQG not met<br>EQS met |
| | CS12 (10 m) | | 94.2 | 97.6 | 96.1 | |
| | CS6A (10 m) | | 93.6 | 95.0 | 92.0 | |
| | CS7 (10.5 m) | | 95.1 | 94.0 | 90.8 | |
| | CS9 (13 m) | | 87.0 | 95.4 | 68.6 | |
| | CS9A (16 m) | | 91.4 | 95.3 | 94.0 | |
| MPA-NH | NH3 (10 m) | EQG: DO ≥ 80<br>EQS: DO ≥ 60 | 96.4 | 93.9 | 79.5 | EQG not met<br>EQS met |

Low DO concentrations occurred at the two deep HPA-S sites in February 2021 and all HPA-S sites in March 2021. Two of the three deep HPA-N sites also showed low DO concentrations in March 2021.

Site CS9 was the only site not to meet the moderate protection DO concentration EQG in March 2021.

*Dissolved oxygen concentrations at Water Corporation monitoring sites*

DO concentrations, measured as percentage saturation, were recorded quarterly in the bottom waters at three Water Corporation sites in Cockburn Sound and two sites located outside Cockburn Sound during the 2020–21 monitoring period (Table 11). Additional DO measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 in MPA-ES on each sampling occasion. The high protection DO concentration EQG was met in the bottom waters at the sites in HPA-N and HPA-S. The high protection DO concentration EQG was also met at sites CS9 and CS12 met on all sampling occasions.

*Table 11: Assessment of dissolved oxygen concentrations (% saturation) in the bottom waters at Water Corporation monitoring sites in Cockburn Sound*

| Ecological protection area | Site (approximate depth) | September 2020 | January 2021 | March 2021 | June 2021 |
|---|---|---|---|---|---|
| HPA-N | Central (21 m) | EQG met | EQG met | EQG met | EQG met |
| HPA-S | South (20 m) | EQG met | EQG met | EQG met | EQG met |
| MPA-ES | DIFF50W (10 m) | EQG met | EQG met | EQG met | EQG met |
| Sites outside Cockburn Sound | Parmelia Bank (7 m) | >90% | >90% | >90% | >90% |
| | Owen Anchorage (14 m) | >90% | >90% | >90% | >90% |

*DO concentrations at Fremantle Port monitoring sites*

DO concentrations, measured as percentage saturation, were recorded at three Kwinana Bulk Jetty sites – KBJ1, KBJ2 and KBJ3 (Figure 2) – and three Kwinana Bulk Terminal sites – KBT1, KBT2 and KBT3 (Figure 2) – surveyed by Fremantle Ports on 28 January 2021. The Kwinana Bulk Jetty sites ranged in depth from 14.2 m to 15.6 m and the Kwinana Bulk Terminal sites ranged in depth from 10.2 m to 12.3 m.

The high protection DO concentration EQG was met in the bottom waters at two Kwinana Bulk Terminal sites – KBT1 and KBT2 – and all Kwinana Bulk Jetty sites. The DO concentration in the bottom waters at site KBT3 was 79% saturation, just below the moderate protection DO concentration EQG of 80% saturation or greater.

### Assessment against the environmental quality standard

In all instances where a site did not meet the relevant 2020–21 DO concentration

EQG, the relevant 2020–21 DO concentration EQS was met for the site (see Table 10).

The DO concentration EQS also states that there should be:

1. no significant change in any ecological or biological indicators affected by poorly oxygenated water (EQS[ii])
2. no deaths of marine organisms resulting from the deoxygenation (EQS[iii]).

There were no reported deaths of marine organisms or significant changes in any ecological or biological indicators from poorly oxygenated water on the days that Cockburn Sound water quality sampling was undertaken during the 2021 sampling period (EQS[ii] and EQS[iii]). The DO concentration EQS(ii) and (iii) were therefore considered to have been met at the sites.

### 2.5.2 Water temperature

Monthly measurements of surface[3] and bottom[4] water temperatures at 18 water quality monitoring sites[5] (Section 2.2; Figure 2) from January to March 2021 were assessed against the water temperature EQG (EPA 2017:31):

| | |
|---|---|
| High protection: | Median temperature at an individual site during the non river-flow period, measured according to the standard operating procedures, is not to exceed the 80th percentile of the natural temperature range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period. |
| Moderate protection: | Median temperature at an individual site during the non river-flow period, measured according to the standard operating procedures, is not to exceed the 95th percentile of the natural temperature range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period. |

The 80th and 95th percentiles of the temperatures measured monthly at reference sites WS4 and WSSB from January to March 2021 were lower than those reported for the weekly water sampling that was done from December 2019 to March 2020 (Table 12). The 80th and 95th percentiles of the temperatures measured in January to March 2021 were therefore used for the assessment.

The surface and bottom temperature recorded at each site was assessed against the relevant water temperature EQG (Tables 13 and 14). The surface and bottom water temperatures exceeded the high protection water temperature EQG at all HPA-N sites in February 2021. The surface and bottom water temperatures at HPA-S sites

[3] Measured at 50 cm below the water surface.

[4] Measured at 50 cm above the sediment surface.

[5] Note that this indicator has been developed for use at the local scale (e.g. around an outfall) rather than broader scales (EPA 2017).

MB and SF exceeded the high protection water temperature EQG in January 2021. The bottom water temperature at site SF and surface water temperature at site CS11 also exceeded the high protection water temperature EQG in February 2021.

At the sites in the moderate protection areas, the surface temperature exceeded the moderate protection water temperature EQG at only one site – NH3 – in January 2021 and only two sites – NH3 and G1 – in February 2021. Similarly, the bottom water temperature exceeded the moderate protection water temperature EQG at one site – CS9 – in January 2021 and three sites – NH3, CS9 and CS12 – in February 2021.

*Table 12: Comparison of the 80th and 95th percentiles of surface and bottom water temperatures at Warnbro Sound reference sites WS4 and WSSB for monitoring periods December 2019–March 2020, January–March 2020 and January–March 2021*

| Reference site | Depth | Percentile | Temperature (°C) | | |
|---|---|---|---|---|---|
| | | | 2019–20[a] | 2020[b] | 2021[c] |
| WS4 | Surface | 80th | 24.3 | 24.3 | 23.6 |
| | | 95th | 24.5 | 24.5 | 23.8 |
| | Bottom | 80th | 23.7 | 23.8 | 23.5 |
| | | 95th | 24.0 | 24.0 | 23.7 |
| WSSB | Surface | 80th | 23.9 | 23.9 | 23.1 |
| | | 95th | 25.2 | 25.1 | 23.7 |
| | Bottom | 80th | 23.4 | 23.4 | 23.1 |
| | | 95th | 25.2 | 25.0 | 23.6 |

a = weekly measurements from 1 December 2019 to 30 March 2020

b = weekly measurements from 1 January to 30 March 2020

c = monthly measurements from 1 January to 30 March 2021

### Assessment against the environmental quality standard

The water temperature EQG were not met at multiple sites, which triggered a more detailed assessment against the high and moderate protection temperature EQS (EPA 2017:31).

The high protection water temperature EQS states there should be:

1. no significant change beyond natural variation in any ecological or biological indicators affected by water temperature (EQS[i])
2. no deaths of marine organisms attributed to thermal stress from anthropogenic sources (EQS[ii]).

The moderate protection temperature EQS states there should be:

1. no persistent (e.g. four weeks or longer) change in any ecological or biological indicators affected by water temperature (EQS[i])

2. no deaths of marine organisms attributed to thermal stress from anthropogenic sources (EQS[ii]).

There were no reported deaths of marine organisms or significant changes in any ecological or biological indicators affected by water temperature on the days that water quality sampling was undertaken in January to March 2021 (EQS[i] and EQS[ii]). The temperature EQS were therefore considered to have been met in the ecological protection areas.

*Table 13: Assessment of surface water temperatures at 18 water quality monitoring sites in Cockburn Sound from January to March 2021 against the surface water temperature EQG*

| Ecological protection area | Site | Surface water temperature (°C) | | | | Assessment |
|---|---|---|---|---|---|---|
| | | 2021 EQG | January 2021 | February 2021 | March 2021 | |
| HPA-N | CS4 | ≤23.6 | 23.2 | 24.3 | 23.2 | EQG not met; EQS met |
| | CS5 | | 23.5 | 24.0 | 23.1 | EQG not met; EQS met |
| | CS8 | | 23.5 | 23.8 | 22.9 | EQG not met; EQS met |
| | CB | | 23.4 | 23.7 | 22.7 | EQG not met; EQS met |
| | G2 | | 23.3 | 24.3 | 23.1 | EQG not met; EQS met |
| | G3 | | 23.3 | 24.3 | 23.3 | EQG not met; EQS met |
| HPA-S | CS11 | ≤23.6 | 22.8 | 23.7 | 22.2 | EQG not met; EQS met |
| | CS13 | | 23.1 | 23.6 | 22.5 | EQG met |
| | SF | ≤23.1 | 23.5 | 23.8 | 22.5 | EQG not met; EQS met |
| | MB | | 23.5 | 22.1 | 22.0 | EQG not met; EQS met |
| MPA-CB | G1 | ≤23.8 | 23.3 | 24.1 | 22.8 | EQG not met; EQS met |
| MPA-ES | CS10N | ≤23.8 | 23.3 | 23.6 | 22.6 | EQG met |
| | CS12 | | 23.0 | 23.6 | 22.6 | EQG met |
| | CS6A | | 23.5 | 23.7 | 23.2 | EQG met |
| | CS7 | | 23.3 | 23.6 | 23.1 | EQG met |
| | CS9 | | 23.0 | 23.5 | 22.4 | EQG met |
| | CS9A | | 23.2 | 23.6 | 22.5 | EQG met |
| MPA-NH | NH3 | ≤23.8 | 24.2 | 24.4 | 23.1 | EQG not met; EQS met |

*Table 14: Assessment of the bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound from January to March 2021 against the bottom water temperature EQG*

| Ecological protection area | Site | Bottom water temperature (°C) | | | | Assessment |
|---|---|---|---|---|---|---|
| | | 2021 EQG | January 2021 | February 2021 | March 2021 | |
| HPA-N | CS4 | ≤23.5 | 22.7 | 23.6 | 22.8 | EQG not met; EQS met |
| | CS5 | | 23.3 | 23.8 | 23.1 | EQG not met; EQS met |
| | CS8 | | 23.2 | 23.6 | 22.9 | EQG not met; EQS met |
| | CB | | 23.0 | 23.7 | 22.8 | EQG not met; EQS met |
| | G2 | | 23.3 | 23.9 | 23.0 | EQG not met; EQS met |
| | G3 | | 23.3 | 23.7 | 23.0 | EQG not met; EQS met |
| HPA-S | CS11 | ≤23.5 | 22.5 | 23.3 | 22.1 | EQG met |
| | CS13 | | 23.1 | 23.2 | 22.4 | EQG met |
| | SF | ≤23.1 | 23.5 | 23.8 | 22.5 | EQG not met; EQS met |
| | MB | | 23.5 | 22.1 | 22.0 | EQG not met; EQS met |
| MPA-CB | G1 | ≤23.7 | 23.0 | 23.4 | 22.5 | EQG met |
| MPA-ES | CS10N | ≤23.7 | 23.0 | 23.4 | 22.6 | EQG met |
| | CS12 | | 23.7 | 23.9 | 22.7 | EQG not met; EQS met |
| | CS6A | | 23.5 | 23.7 | 23.3 | EQG met |
| | CS7 | | 23.3 | 23.6 | 22.9 | EQG met |
| | CS9 | | 23.9 | 24.1 | 23.0 | EQG not met; EQS met |
| | CS9A | | 23.1 | 23.5 | 22.6 | EQG met |
| MPA-NH | NH3 | ≤23.7 | 23.5 | 23.9 | 23.3 | EQG not met; EQS met |

### 2.5.3 Salinity

Monthly measurements of surface[6] and bottom[7] water salinities recorded at the 18 water quality monitoring sites[8] (Section 2.2; Figure 2) in January to March 2021 were assessed against the 2019–20 salinity EQG (EPA 2017:32):

| | |
|---|---|
| High protection: | Median salinity at an individual site over the 2019–20 non river-flow period, measured according to the standard operating procedures, is not to deviate beyond the 20th and 80th percentiles of the natural salinity range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period. |
| Moderate protection: | Median salinity at an individual site over the 2019–20 non river-flow period, measured according to the standard operating procedures, is not to deviate beyond the 5th and 95th percentiles of the natural salinity range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period. |

See Table 15 for the percentiles of the salinity range for 2019–20 and 2021.

[6] Measured at 50 cm below the water surface.
[7] Measured at 50 cm above the sediment surface.
[8] Note that this indicator has been developed for use at the local scale (e.g. around an outfall) rather than broader scales (EPA 2017).

*Table 15: Comparison of percentiles of the salinity range at Warnbro Sound reference sites WS4 and WSSB for December 2019–March 2020, January–March 2020 and January–March 2021*

<table>
<tr><th rowspan="2">Reference site</th><th rowspan="2">Depth</th><th rowspan="2">Ecological protection area</th><th rowspan="2">Percentile</th><th colspan="3">Salinity (practical salinity units [psu])</th></tr>
<tr><th>2019–20[a]</th><th>2020[b]</th><th>2021[c]</th></tr>
<tr><td rowspan="8">WS4</td><td rowspan="4">Surface</td><td rowspan="2">High</td><td>20th</td><td>36.5</td><td>36.8</td><td>36.9</td></tr>
<tr><td>80th</td><td>37.0</td><td>37.0</td><td>37.0</td></tr>
<tr><td rowspan="2">Moderate</td><td>5th</td><td>36.2</td><td>36.8</td><td>36.8</td></tr>
<tr><td>95th</td><td>37.0</td><td>37.0</td><td>37.0</td></tr>
<tr><td rowspan="4">Bottom</td><td rowspan="2">High</td><td>20th</td><td>36.5</td><td>36.8</td><td>36.9</td></tr>
<tr><td>80th</td><td>37.0</td><td>37.0</td><td>37.0</td></tr>
<tr><td rowspan="2">Moderate</td><td>5th</td><td>36.3</td><td>36.8</td><td>36.8</td></tr>
<tr><td>95th</td><td>37.1</td><td>37.1</td><td>37.0</td></tr>
<tr><td rowspan="4">WSSB</td><td rowspan="2">Surface</td><td rowspan="2">High</td><td>20th</td><td>36.6</td><td>36.9</td><td>36.9</td></tr>
<tr><td>80th</td><td>37.0</td><td>37.1</td><td>37.1</td></tr>
<tr><td rowspan="2">Bottom</td><td rowspan="2">High</td><td>20th</td><td>36.6</td><td>36.9</td><td>36.9</td></tr>
<tr><td>80th</td><td>37.0</td><td>37.1</td><td>37.1</td></tr>
</table>

a = weekly measurements from 1 December 2019 to 30 March 2020
b = weekly measurements from 1 January to 30 March 2020
c = monthly measurements from 1 January to 30 March 2021

The percentiles of the surface and bottom water salinity range for January to March 2020 and 2021 were similar (Table 15).

The surface and bottom salinity measurements recorded at each site were assessed against the relevant 2019–20 salinity EQG (Tables 16 and 17). The surface water salinity EQG were met at all sites in January and March, but not in February 2021. Sites CS9 and CS12 in MPA-ES were the only sites that did not meet the bottom water salinity EQG in January 2021. Site CS9 also did not meet the bottom water salinity EQG in February and March 2021.

*Table 16: Assessment of the monthly surface salinity measurements at 18 water quality monitoring sites from January to March 2021 against the 2019–20 surface water salinity EQG*

| Ecological protection area | Site | 2019–21 EQG | January 2021 | February 2021 | March 2021 | Assessment |
|---|---|---|---|---|---|---|
| HPA-N | CS4 | $36.5 \leq x \leq 37.0$ | 36.8 | 36.6 | 37.0 | EQG met |
| | CS5 | | 36.8 | 37.0 | 37.0 | EQG met |
| | CS8 | | 36.7 | 37.0 | 37.0 | EQG met |
| | CB | | 36.7 | 37.1 | 37.0 | EQG not met; EQS met |
| | G2 | | 36.7 | 37.0 | 37.0 | EQG met |
| | G3 | | 36.7 | 36.7 | 37.0 | EQG met |
| HPA-S | CS11 | $36.5 \leq x \leq 37.0$ | 36.9 | 37.1 | 36.9 | EQG not met; EQS met |
| | CS13 | | 36.8 | 37.1 | 37.0 | EQG not met; EQS met |
| | SF | $36.6 \leq x \leq 37.0$ | 36.8 | 37.1 | 37.0 | EQG not met; EQS met |
| | MB | | 37.0 | 37.0 | 36.9 | EQG met |
| MPA-CB | G1 | $36.2 \leq x \leq 37.0$ | 36.8 | 37.0 | 37.0 | EQG met |
| MPA-ES | CS10N | $36.2 \leq x \leq 37.0$ | 36.8 | 36.9 | 37.0 | EQG met |
| | CS12 | | 36.8 | 37.1 | 36.9 | EQG not met; EQS met |
| | CS6A | | 36.9 | 37.1 | 36.9 | EQG not met; EQS met |
| | CS7 | | 36.9 | 37.1 | 37.0 | EQG not met; EQS met |
| | CS9 | | 36.8 | 37.0 | 36.8 | EQG met |
| | CS9A | | 36.8 | 37.0 | 36.9 | EQG met |
| MPA-NH | NH3 | $36.2 \leq x \leq 37.0$ | 36.8 | 37.0 | 36.8 | EQG met |

*Table 17: Assessment of the monthly bottom salinity measurements at 18 water quality monitoring sites from January to March 2021 against the 2019–20 bottom water salinity EQG*

| Ecological protection area | Site | 2019–20 EQG | January 2021 | February 2021 | March 2021 | Assessment |
|---|---|---|---|---|---|---|
| HPA-N | CS4 | $36.5 \leq x \leq 37.0$ | 36.8 | 37.0 | 37.0 | EQG met |
| HPA-N | CS5 | $36.5 \leq x \leq 37.0$ | 36.8 | 37.1 | 37.0 | EQG not met; EQS met |
| HPA-N | CS8 | $36.5 \leq x \leq 37.0$ | 36.7 | 37.0 | 37.0 | EQG met |
| HPA-N | CB | $36.5 \leq x \leq 37.0$ | 36.7 | 37.1 | 37.0 | EQG not met; EQS met |
| HPA-N | G2 | $36.5 \leq x \leq 37.0$ | 36.7 | 37.0 | 37.0 | EQG met |
| HPA-N | G3 | $36.5 \leq x \leq 37.0$ | 36.7 | 37.0 | 37.0 | EQG met |
| HPA-S | CS11 | $36.5 \leq x \leq 37.0$ | 36.9 | 37.1 | 37.0 | EQG not met; EQS met |
| HPA-S | CS13 | $36.5 \leq x \leq 37.0$ | 36.8 | 37.1 | 37.0 | EQG not met; EQS met |
| HPA-S | SF | $36.6 \leq x \leq 37.0$ | 36.8 | 37.1 | 37.0 | EQG not met; EQS met |
| HPA-S | MB | $36.6 \leq x \leq 37.0$ | 37.0 | 37.0 | 37.0 | EQG met |
| MPA-CB | G1 | $36.3 \leq x \leq 37.1$ | 36.8 | 37.0 | 37.0 | EQG met |
| MPA-ES | CS10N | $36.3 \leq x \leq 37.1$ | 36.8 | 37.0 | 37.0 | EQG met |
| MPA-ES | CS12 | $36.3 \leq x \leq 37.1$ | 37.5 | 37.9 | 37.1 | EQG not met; EQS met |
| MPA-ES | CS6A | $36.3 \leq x \leq 37.1$ | 36.9 | 37.1 | 37.0 | EQG met |
| MPA-ES | CS7 | $36.3 \leq x \leq 37.1$ | 36.9 | 37.1 | 37.1 | EQG met |
| MPA-ES | CS9 | $36.3 \leq x \leq 37.1$ | 37.5 | 37.8 | 37.6 | EQG not met; EQS met |
| MPA-ES | CS9A | $36.3 \leq x \leq 37.1$ | 36.8 | 37.0 | 37.0 | EQG met |
| MPA-NH | NH3 | $36.3 \leq x \leq 37.1$ | 36.7 | 37.0 | 37.0 | EQG met |

Note: Sites MB and SF were assessed against the reference site WSSB which is of similar depth.

### Assessment against the environmental quality standard

The salinity EQG were not met in the surface and bottom waters at multiple sites, which triggered more detailed assessment against the high and moderate protection salinity EQS (EPA 2017:32).

| | |
|---|---|
| High protection: | No significant change beyond natural variation in any ecological or biological indicators that are affected by changing salinity unless that change can be demonstrably linked to a factor other than salinity stress (EQS[i]).<br>No deaths of marine organisms resulting from anthropogenically-sourced salinity stress (EQS[ii]). |
| Moderate protection: | No persistent (i.e. greater or equal to four weeks) and significant change beyond natural variation in any ecological or biological indicators that are affected by changing salinity unless that change can be demonstrably linked to a factor other than salinity stress (EQS[i]).<br>No deaths of marine organisms resulting from anthropogenically-sourced salinity stress (EQS[ii]). |

The surface and bottom water salinities at the sites that did not meet the salinity EQG were below the default moderate protection salinity trigger values[9] in the reference document (EPA 2017). The risk of a persistent and significant change beyond natural variation in any ecological or biological indicators as a result of elevated salinity is therefore considered to be low (salinity EQS[i]).

Median bottom salinities at CS9 and CS12 have exceeded the salinity EQG since the 2006–07 monitoring period. These exceedances possibly reflect localised effects from saline water discharge because of the site's proximity to the Perth Seawater Desalination Plant, which began operations in late 2006.

There were no reports of deaths of marine organisms attributed to salinity stress from anthropogenic sources (salinity EQS[ii]) from January to March 2021.

### 2.5.4 pH

The monthly measurements of surface[10] and bottom[11] water pH recorded at 18 water quality monitoring sites[12] (Section 2.2; Figure 2) from January to March 2021 were assessed against the 2019–20 pH EQG (EPA 2017:32–33):

[9] High protection surface waters = 38.2 practical salinity units (the median of suitable reference site data ± 1.3; 36.9 + 1.3); moderate protection bottom waters = 38.3 practical salinity units (the median of suitable reference site data ± 1.4; 36.9 + 1.4); high protection bottom waters = 38.3 practical salinity units (the median of suitable reference site data ± 1.3; 37.0 + 1.3)

[10] Measured at 50 cm below the water surface.

[11] Measured at 50 cm above the sediment surface.

[12] Note that this indicator has been developed for use at the local scale (e.g. around an outfall) rather than broader scales (EPA 2017).

| | |
|---|---|
| High protection: | Median pH at an individual site over the 2019–20 non river-flow period, measured according to the standard operating procedures, is not to deviate beyond the 20th and 80th percentiles of the natural pH range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period. |
| Moderate protection: | Median pH at an individual site over the 2019–20 non river-flow period, measured according to the standard operating procedures, is not to deviate beyond the 5th and 95th percentiles of the natural pH range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period. |

A comparison of the percentiles of the pH range measured at Warnbro Sound reference sites WS4 and WSSB from January to March in 2020 and 2021 showed the pH range to be less variable in 2021 (Table 18). There were 12 weekly water samples from January to March 2020 and three monthly water samples from January to March 2021. This difference in the number of samples may account for the differences observed in the pH percentiles.

*Table 18: Comparison of percentiles of pH at Warnbro Sound reference sites WS4 and WSSB for December 2019–March 2020, January–March 2020 and January–March 2021*

| Reference site | Depth | Ecological protection area | Percentile | pH (pH units) | | |
|---|---|---|---|---|---|---|
| | | | | 2019–20[a] | 2020[b] | 2021[c] |
| WS4 | Surface | High | 20th | 8.17 | 8.18 | 8.22 |
| | | | 80th | 8.21 | 8.22 | 8.23 |
| | | Moderate | 5th | 8.15 | 8.18 | 8.22 |
| | | | 95th | 8.23 | 8.24 | 8.23 |
| | Bottom | High | 20th | 8.16 | 8.17 | 8.22 |
| | | | 80th | 8.21 | 8.21 | 8.23 |
| | | Moderate | 5th | 8.13 | 8.16 | 8.22 |
| | | | 95th | 8.23 | 8.23 | 8.23 |
| WSSB | Surface | High | 20th | 8.12 | 8.13 | 8.17 |
| | | | 80th | 8.21 | 8.20 | 8.22 |
| | Bottom | High | 20th | 8.14 | 8.14 | 8.18 |
| | | | 80th | 8.21 | 8.21 | 8.22 |

a = weekly measurements from 1 December 2019 to 30 March 2020

b = weekly measurements from 1 January to 30 March 2020

c = monthly measurements from 1 January to 30 March 2021

The surface and bottom water pH recorded at each site were assessed against the relevant 2019–20 pH EQG (Tables 19 and 20).

The surface and bottom water pH measurements at all the sites in the high protection areas except for site SF met the applicable high protection pH EQG in January 2021. The surface and bottom water pH measurements at all moderate protection area sites except for site G1 in Careening Bay met the moderate protection pH EQG in February 2021.

*Table 19: Assessment of surface pH at 18 water quality monitoring sites in Cockburn Sound from January to March 2021 against the 2019–20 pH EQG*

| Ecological protection area | Site | 2019–20 EQG | pH (pH units) | | | Assessment |
|---|---|---|---|---|---|---|
| | | | January 2021 | February 2021 | March 2021 | |
| HPA-N | CS4 | 8.17 ≤ x ≤ 8.21 | 8.18 | 8.23 | 8.24 | EQG not met; EQS met |
| | CS5 | | 8.17 | 8.22 | 8.23 | EQG not met; EQS met |
| | CS8 | | 8.18 | 8.21 | 8.23 | EQG not met; EQS met |
| | CB | | 8.18 | 8.23 | 8.23 | EQG not met; EQS met |
| | G2 | | 8.17 | 8.22 | 8.26 | EQG not met; EQS met |
| | G3 | | 8.18 | 8.22 | 8.25 | EQG not met; EQS met |
| HPA-S | CS11 | 8.17 ≤ x ≤ 8.21 | 8.18 | 8.23 | 8.15 | EQG met |
| | CS13 | | 8.17 | 8.23 | 8.24 | EQG met |
| | SF | 8.12 ≤ x ≤ 8.21 | 8.25 | 8.26 | 8.18 | EQG not met; EQS met |
| | MB | | 8.21 | 8.22 | 8.20 | EQG not met; EQS met |
| MPA-CB | G1 | 8.15 ≤ x ≤ 8.23 | 8.22 | 8.24 | 8.23 | EQG not met; EQS met |
| MPA-ES | CS10N | 8.15 ≤ x ≤ 8.23 | 8.17 | 8.22 | 8.22 | EQG met |
| | CS12 | | 8.19 | 8.22 | 8.22 | EQG met |
| | CS6A | | 8.14 | 8.20 | 8.17 | EQG not met; EQS met |
| | CS7 | | 8.16 | 8.20 | 8.21 | EQG met |
| | CS9 | | 8.18 | 8.22 | 8.23 | EQG met |
| | CS9A | | 8.18 | 8.22 | 8.24 | EQG not met; EQS met |
| MPA-NH | NH3 | 8.15 ≤ x ≤ 8.23 | 8.15 | 8.21 | 8.16 | EQG met |

*Table 20: Assessment of bottom pH at 18 water quality monitoring sites in Cockburn Sound over the 2019–20 non river-flow period against the pH EQG*

| Ecological protection area | Site | 2019–21 EQG | pH (pH units) | | | Assessment |
|---|---|---|---|---|---|---|
| | | | January 2021 | February 2021 | March 2021 | |
| HPA-N | CS4 | 8.16 ≤ x ≤ 8.21 | 8.18 | 8.19 | 8.23 | EQG not met; EQS met |
| | CS5 | | 8.17 | 8.21 | 8.21 | EQG met |
| | CS8 | | 8.17 | 8.21 | 8.23 | EQG not met; EQS met |
| | CB | | 8.18 | 8.23 | 8.23 | EQG not met; EQS met |
| | G2 | | 8.18 | 8.22 | 8.26 | EQG not met; EQS met |
| | G3 | | 8.17 | 8.21 | 8.25 | EQG not met; EQS met |
| HPA-S | CS11 | 8.16 ≤ x ≤ 8.21 | 8.18 | 8.18 | 8.15 | EQG not met; EQS met |
| | CS13 | | 8.17 | 8.19 | 8.21 | EQG met |
| | SF | 8.14 ≤ x ≤ 8.21 | 8.25 | 8.27 | 8.17 | EQG not met; EQS met |
| | MB | | 8.21 | 8.22 | 8.19 | EQG not met; EQS met |
| MPA-CB | G1 | 8.13 ≤ x ≤ 8.23 | 8.23 | 8.21 | 8.22 | EQG met |
| MPA-ES | CS10N | 8.13 ≤ x ≤ 8.23 | 8.15 | 8.21 | 8.20 | EQG met |
| | CS12 | | 8.15 | 8.19 | 8.22 | EQG met |
| | CS6A | | 8.14 | 8.20 | 8.20 | EQG met |
| | CS7 | | 8.16 | 8.21 | 8.20 | EQG met |
| | CS9 | | 8.10 | 8.16 | 8.08 | EQG not met; EQS met |
| | CS9A | | 8.17 | 8.21 | 8.22 | EQG met |
| MPA-NH | NH3 | 8.13 ≤ x ≤ 8.23 | 8.14 | 8.20 | 8.14 | EQG met |

**Assessment against the environmental quality standard**

The pH EQG were not met at several sites in the high and moderate protection areas, which triggered a more detailed assessment against the high and moderate protection pH EQS (EPA 2017:32–33).

| | |
|---|---|
| High protection: | No significant change beyond natural variation in any ecological or biological indicators that are affected by changes in pH unless that change can be demonstrably linked to a factor other than altered pH (EQS[i]). |
| | No deaths of marine organisms resulting from anthropogenic-sourced changes in pH (EQS[ii]). |
| Moderate protection: | No persistent (i.e. greater or equal to four weeks) and significant change beyond natural variation in any ecological or biological indicators that are affected by changes in pH unless that change can be demonstrably linked to a factor other than altered pH (EQS[i]). |
| | No deaths of marine organisms resulting from anthropogenic-sourced changes in pH (EQS[ii]). |

The pH measurements for the surface and bottom waters across all monitored sites in Cockburn Sound and Warnbro Sound ranged between 8.08 and 8.26 pH units. For inshore coastal waters of Western Australia, the default trigger pH value is 8.0 for the lower limit and 8.4 for the upper limit (ANZECC & ARMCANZ 2000). The risk of a persistent and significant change beyond natural variation in any ecological or biological indicators as a result of changes in pH is therefore considered low (pH EQS[i]).

There were no known reports of deaths of marine organisms from January to March 2021 attributed to changes in pH from anthropogenic sources (pH EQS[ii]).

## 2.6 Assessment against the environmental quality criteria for toxicants in marine waters

### 2.6.1 Non-metallic inorganics (ammonia) in marine waters of Cockburn Sound

Ammonium concentrations were measured monthly at the 18 water quality monitoring sites (Section 2.2; Figure 2) in Cockburn Sound from January to December 2021. For the months from January to March 2021, the monthly ammonium concentrations at water monitoring sites in Cockburn Sound, excluding the Northern Harbour site NH3, ranged from below the limit of reporting of less than 0.5 µg/L to a maximum concentration of 4.2 µg/L measured at CS6A on 1 March 2021. The highest monthly ammonium concentration measured in Cockburn Sound in 2021 was 13 µg/L at site CB on 2 August 2021.

For the months from January to March 2021, the highest monthly ammonium concentration measured at site NH3 was 15 µg/L on 1 March 2021. The highest monthly ammonium concentration measured in 2021 was 23 µg/L at site NH3 on 6

May 2021.

The monthly ammonium concentrations at the two Warnbro Sound reference sites ranged from below the limit of reporting of less than 0.5 µg/L to a maximum concentration of 5.6 µg/L for the months from January to March 2021. The highest ammonium concentration measured at either site was 7.2 µg/L on 3 August 2021.

The ammonium concentrations in the discrete bottom water samples taken at site CS13 and Warnbro Sound reference site WS4 were higher than in the surface and integrated water samples taken at the same sites. The highest ammonium concentration measured in the discrete bottom water samples was 43 µg/L at Warnbro Sound reference site WS4 on 7 April 2021. On the same day, the maximum ammonium concentration of 20 µg/L was recorded in the discrete bottom water sample at site CS13.

*Comparison to the ammonium EQG values*

The reference document (Table 2a, EPA 2017) specifies that the 95th percentile of the sample concentrations from a single site or a defined area (either from one sampling run or all samples over an agreed period) should not exceed the EQG values of 500 µg/L for high protection areas and 1,200 µg/L for moderate protection areas.

A statistical comparison could not be made to the ammonium EQG values because of the small number of measurements; however, none of the monthly ammonium measurements exceeded the high protection EQG value of 500 µg/L.

### 2.6.2 Toxicants in marine waters around the Kwinana Bulk Terminal and Kwinana Bulk Jetty

Surface marine water samples were collected on 28 January 2021 at six sites around the Kwinana Bulk Terminal – KBT1, KBT2, KBT3 – and the Kwinana Bulk Jetty – KBJ1, KBJ2, KBJ3 – in MPA-ES (Section 2.2; Figure 2). The samples were analysed for ammonia, filtered copper, TRHs and BTEX. Bottom marine water samples were also collected at the six sites and analysed for ammonia.

The reference document (EPA 2017) recommends a minimum of five samples should be taken for comparison with the EQG and where less than 20 samples have been taken, the maximum sample concentration should be less than the guideline. Given the small sample size, concentrations of contaminants in the water samples collected at each of the sites were compared against the relevant EQG values or, where no EQG value was available, against the relevant low reliability value (LRV).

Concentrations of copper and ammonia were below the relevant EQG values for toxic effects at all the sites around the Kwinana Bulk Terminal and Jetty (Table 21). The ammonia concentrations in the bottom water samples at the six sites were also below the ammonia EQG value for toxic effects. Concentrations of BTEX were below the analytical limits of reporting and below the relevant EQG values or LRVs. Concentrations of TRHs were below the analytical limits of reporting.

At all sites, the total toxicity of the mixture (TTM)[13], based on the effects of ammonia, copper and benzene, was below one (Table 21). The combined additive effect of these contaminants was therefore not expected to result in adverse effects on marine flora or fauna near the sampling sites.

*Table 21: Assessment of toxicants in marine waters sampled at three sites around the Kwinana Bulk Terminal and three sites around the Kwinana Bulk Jetty against the moderate protection EQG or LRV for toxicants in marine waters*

| Toxicant (µg/L) | EQG/LRV (µg/L) | KBT1 | KBT2 | KBT3 | KBJ1 | KBJ2 | KBJ3 |
|---|---|---|---|---|---|---|---|
| Ammonia | EQG: 1,200 | $4^{S}$ | $4^{S}$ | $4^{S}$ | $<1.5^{S}$ | $<1.5^{S}$ | $<1.5^{S}$ |
| | | $5^{B}$ | $3^{B}$ | $6^{B}$ | $5^{B}$ | $10^{B}$ | $4^{B}$ |
| Copper (filtered) | EQG: 3.0 | 0.4 | 0.4 | 0.5 | 0.3 | 0.4 | 0.4 |
| Benzene | EQG: 900 | <1 | <1 | <1 | <1 | <1 | <1 |
| Toluene | LRV: 230 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ethylbenzene | LRV: 5.0[1] | <1 | <1 | <1 | <1 | <1 | <1 |
| Xylene | m-xylene LRV: 75[1]<br>p-xylene LRV: 200[1]<br>o-xylene LRV: 350[1] | <1 | <1 | <1 | <1 | <1 | <1 |
| Total recoverable hydrocarbons (C10–C36) | LRV: 7[1, 2] | <250 | <250 | <250 | <250 | <250 | <250 |
| Total toxicity of mixture (TTM) | If TTM>1, mixture exceeded water quality guideline | <1 | <1 | <1 | <1 | <1 | <1 |

'<' signifies the result is less that the limit of quantitation for the method

S = surface water sample

B = bottom water sample

1 High protection LRV (there is no moderate protection LRV)

2 LRV for total petroleum hydrocarbons.

## 2.7 Assessment against the environmental quality criteria for toxicants in sediments

Surface (top 2 cm) sediment samples were collected at sites around the Kwinana Bulk Terminal – KBT1, KBT2, KBT3 – and the Kwinana Bulk Jetty – KBJ1, KBJ2, KBJ3 – in MPA-ES (Section 2.2; Figure 2). The samples were analysed for total organic carbon, metals (i.e. arsenic, cadmium, chromium, copper, lead, mercury and zinc), non-metals (i.e. selenium and phosphorus), organotins (i.e. TBT, DBT and

[13] TTM = Σ ($C_i/EQG_i$), where C is the concentration of the 'i'th component in the mixture and EQG is the guideline for that component.

MBT), PAHs, TRHs, PFOS and PFOA.

The concentrations of contaminants in sediments were compared against the EQG (EPA 2017:56–57):

A. Median total contaminant concentration in sediments from a single site or defined sampling area should not exceed the environmental quality guideline value for high, moderate and low ecological protection areas.

B. Total contaminant concentration at individual sample sites should not exceed the environmental quality guideline re-sampling trigger.

There are no EQG values for selenium.

The median concentrations of arsenic, chromium, copper, lead, mercury and zinc in both sampling areas – the Kwinana Bulk Terminal and Kwinana Bulk Jetty – were below the relevant EQG values (Table 22).

Elevated cadmium concentrations were reported in the sediment at Kwinana Bulk Terminal sites KBT1 and KBT2, with the median concentration of cadmium in the sampling area above the EQG, but below the re-sampling trigger value. A slightly elevated concentration of mercury was recorded in one of the Kwinana Bulk Terminal samples – KBT1.

After normalisation to 1% total organic carbon[14], median concentrations of TBT in the Kwinana Bulk Terminal samples were below the EQG value (Table 23). Elevated concentrations of TBT were recorded in all three Kwinana Bulk Jetty samples. The TBT concentrations in these samples were below the EQG re-sampling trigger value.

There are no ECG values for the TBT breakdown products DBT or MBT. Two of the three Kwinana Bulk Terminal samples – KBT1 and 2 – had a butyltin degradation index (BDI) greater than one (Table 23), suggesting that the TBT originally deposited in this area had been degraded into DBT and MBT. The BDI for the Kwinana Bulk Jetty samples were below one as a result of the elevated TBT concentrations in this sampling area.

The median concentrations of PAHs reported for all Kwinana Bulk Terminal and Kwinana Bulk Jetty sites were below the relevant EQG values (Table 24a). The concentrations of PAHs in all samples were below the analytical limit of reporting.

There are no EQG values for TRHs (Table 24b). The concentrations of TRHs were below the analytical limit of reporting for all sites. The concentrations of PFOS and PFOA were below or close to the analytical limit of reporting at all reported sites.

[14] Consistent with the reference document (EPA 2017), where total organic carbon concentrations were within the range of 0.5% to 10%, the concentrations of organometallic/organic contaminants were normalised to 1% organic carbon before assessing against the EQG. Note that contaminant concentrations less than the analytical limit of reporting were not normalised.

*Table 22: Assessment of toxicants (metals) in sediment collected from sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments*

| Chemical (milligrams per kilogram [mg/kg]) | Environmental quality criteria | | Kwinana Bulk Terminal | | | | Kwinana Bulk Jetty | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EQG | Re-sampling trigger | KBT1 | KBT2 | KBT3 | Median | KBJ1 | KBJ2 | KBJ3 | Median |
| Metals | | | | | | | | | | |
| Arsenic | 20 | 70 | 5.6 | 2.8 | 2.6 | 2.8 | 5.9 | 6.6 | 5.3 | 5.9 |
| Cadmium | 1.5 | 10 | 4.9 | 2.3 | 0.5 | 2.3 | 0.1 | 0.1 | 0.2 | 0.1 |
| Chromium | 80 | 370 | 30 | 15 | 15 | 15 | 29 | 20 | 17 | 20 |
| Copper | 65 | 270 | 22 | 27 | 7.3 | 22 | 27 | 25 | 29 | 27 |
| Lead | 50 | 220 | 11.0 | 2.9 | 5.1 | 5.1 | 13.0 | 9.2 | 8.4 | 9.2 |
| Mercury | 0.15 | 1 | 0.22 | 0.03 | 0.08 | 0.08 | 0.09 | 0.06 | 0.05 | 0.06 |
| Selenium | - | - | 0.67 | 0.37 | 0.28 | 0.37 | 0.38 | 0.28 | 0.23 | 0.28 |
| Zinc | 200 | 410 | 83 | 38 | 25 | 38 | 55 | 33 | 64 | 55 |

*Table 23: Assessment of toxicants (organotins) in sediment collected from sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments*

| Chemical (milligrams per kilogram [mg/kg]) | Environmental quality criteria | | Kwinana Bulk Terminal | | | | Kwinana Bulk Jetty | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EQG | Re-sampling trigger | KBT1 | KBT2 | KBT3 | Median | KBJ1 | KBJ2 | KBJ3 | Median |
| **Organotins** (µg Sn/kg normalised to 1% total organic carbon [TOC]) | | | | | | | | | | |
| **Tributyltin** | **5** | **70** | 0.57 | 1.99 | 4.06 | 1.99 | 20.43 | 11.64 | 10.00 | 11.64 |
| **Dibutyltin** | **-** | **-** | 0.82 | 1.70 | 1.25 | 1.25 | 4.35 | 2.81 | 3.60 | 3.60 |
| **Monobutyltin** | **-** | **-** | 0.41 | 0.85 | 0.84 | 0.84 | 0.52 | 0.58 | 0.43 | 0.52 |
| **Butylin degradation index (BDI)** | **-** | **-** | 2.2 | 1.3 | 0.5 | - | 0.2 | 0.3 | 0.4 | - |

*Table 24a: Assessment of toxicants (organics) in sediment collected from sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments*

| Chemical (milligrams per kilogram [mg/kg]) | Environmental quality criteria | | Kwinana Bulk Terminal | | | | Kwinana Bulk Jetty | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EQG | Re-sampling trigger | KBT1 | KBT2 | KBT3 | Median | KBJ1 | KBJ2 | KBJ3 | Median |
| **Organics** (mg/kg normalised to 1% TOC) | | | | | | | | | | |
| Acenaphthene | 0.016 | 0.5 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Acenaphthelene | 0.044 | 0.64 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Anthracene | 0.085 | 1.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Benzo(a)anthracene | 0.261 | 1.6 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Benzo(a)pyrene | 0.43 | 1.6 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Chrysene | 0.384 | 2.8 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Dibenzo(a,h)anthracene | 0.063 | 0.26 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Fluoranthene | 0.6 | 5.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Fluorene | 0.019 | 0.54 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Naphthalene | 0.16 | 2.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Phenathrene | 0.24 | 1.5 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Pyrene | 0.665 | 2.6 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |

*Table 24b: Assessment of toxicants (organics) in sediment collected from sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments*

| Chemical (milligrams per kilogram [mg/kg]) | Environmental quality criteria | | Kwinana Bulk Terminal | | | | Kwinana Bulk Jetty | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EQG | Re-sampling trigger | KBT1 | KBT2 | KBT3 | Median | KBJ1 | KBJ2 | KBJ3 | Median |
| **Organics** (mg/kg normalised to 1% TOC) | | | | | | | | | | |
| **Total recoverable hydrocarbons (C10–C36)** | - | - | <250 | <250 | <250 | <250 | <250 | <250 | <250 | <250 |
| **Total PFOS** | - | - | <0.0002 | <0.0002 | NA | <0.0002 | 0.0008 | 0.0008 | 0.0002 | 0.0008 |
| **Total PFOA** | - | - | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |

## 2.8 Conclusion

With respect to nutrient enrichment in Cockburn Sound, the monitoring results from 1 July 2020 to 31 December 2021 indicate a low risk that the environmental quality objective of maintenance of ecosystem integrity was not achieved during this period.

### 2.8.1 Low dissolved oxygen concentrations

Low dissolved oxygen concentrations occurred at multiple water monitoring sites during the late summer period. The DO concentration EQG was not met in the bottom waters at six of 10 water quality monitoring sites in the high protection areas, HPA-N and HPA-S. All four sites in HPA-S were below the DO concentration EQG in March 2021, while only two of six sites in HPA-N were found to be below the EQG that month. The two HPA-N sites – CS4 and CS5 – are in the northern-most section of HPA-N, which suggests that the factor(s) contributing to the low dissolved oxygen concentrations at the two HPA-N sites may have been different from the factors affecting the HPA-S sites. The bottom water temperatures did not appear to be a contributing factor.

# 3. Environmental value: fishing and aquaculture

## 3.1 Environmental quality objectives

The environmental quality objectives for the fishing and aquaculture environmental value are maintenance of seafood safe for human consumption and maintenance of aquaculture. The EQC for these environmental quality objectives set a level of environmental quality to ensure a low risk of any effect on human health from the consumption of seafood and the health and productivity of aquaculture species (EPA 2017).

Protecting wild seafood populations from the effects of environmental contamination is maintained through the EQC for maintenance of ecosystem integrity (EPA 2017).

## 3.2 Water quality and seafood monitoring

For filter-feeding shellfish (excluding scallops and pearl oysters), any assessment against the environmental quality objective must use data collected from a comprehensive monitoring program consistent with the requirements of the *Western Australia Shellfish Quality Assurance Program operations manual* (WASQAP operations manual; Department of Health 2017). The WASQAP operations manual sets out the requirements for bacteriological monitoring (of water and shellfish), phytoplankton and shellfish biotoxin monitoring, and the chemical analysis of shellfish in the shellfish growing areas in Cockburn Sound (Figure 3). Sampling between July 2020 and December 2021 was undertaken by Blue Lagoon Mussels as part of the WASQAP and administered by the Department of Health. The Kwinana Grain Terminal harvesting area in Cockburn Sound was in commercial closure from 23 February 2021 to the end of the sampling period.

Between July 2020 and December 2021, water samples for bacteriological monitoring were collected on 10 occasions from five sites – SF6, SF8, SF9, SF10, SF11 – in the Southern Flats harvesting area[15] and on 14 occasions from five sites – KGT1, KGT2, KGT3, KGT4, KGT5 – in the Kwinana Grain Terminal harvesting area.[16] Shellfish samples were also collected for bacteriological testing on six occasions from two Kwinana Grain Terminal sites – North and South – and on nine occasions from one Southern Flats site. Samples were analysed by PathWest Laboratory.

Depth-integrated water samples for phytoplankton identification and enumeration were collected about twice monthly on scheduled dates (during periods when shellfish were being harvested) at one of the Kwinana Grain Terminal sites – KGT3 – and one of the Southern Flats sites – SF11. Samples were collected from as close to the shellfish as possible and at the location where shellfish samples for flesh testing were taken. The samples were analysed by Dalcon Environmental for specific groups of phytoplankton species known to potentially produce toxins that may be

[15] Harvesting area classified as 'approved' under the WASQAP operations manual.
[16] Harvesting area classified as 'conditionally approved' under the WASQAP operations manual.

concentrated in shellfish. Composite samples of shellfish flesh were also collected for biotoxin testing in case the potentially toxic phytoplankton counts exceeded the ‘alert’ level to initiate flesh testing for biotoxins for the specific species.

In addition, shellfish flesh samples were collected for routine screening for amnesic shellfish poisoning, diarrhoetic shellfish poisoning and paralytic shellfish poisoning biotoxins following the *Marine biotoxin monitoring and management plan* (Department of Health 2016). Five shellfish flesh samples were collected between July 2020 and February 2021 at the Kwinana Grain Terminal harvesting area. Fourteen shellfish flesh samples were collected between July 2020 and December 2021 at the Southern Flats harvesting area.


*Source: Department of Health (2017)*

Note: Mussel Aquaculture Closed Safety Zones are designated areas around recognised contamination points that should not be considered as potential sites for shellfish aquaculture.

*Figure 3: Sampling locations near shellfish harvesting areas in Cockburn Sound*

Fremantle Ports undertook analysis of toxicants in mussels at three sites around the Kwinana Bulk Terminal – KBT1, KBT2, KBT3 (Figure 2) – and three sites around the Kwinana Bulk Jetty – KBJ1, KBJ2, KBJ3 (Figure 2). A minimum of 15 mussels of uniform size (about 55–90 mm shell length) were collected on 23 March 2021 from lines with baskets suspended about 1 m below the water surface. These were deployed for six weeks prior to collection. Mussel samples were analysed for metals (i.e. inorganic arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (TBT, DBT and MBT) and PAHs. Analyses for metals, organotins and PAHs were undertaken by ChemCentre.

## 3.3 Assessment against the seafood safe for human consumption environmental quality criteria

### 3.3.1 Assessment of compliance with the faecal pathogens in water EQC

Thermotolerant coliform concentrations (expressed as colony forming units/100 millilitres [CFU/100 mL]) recorded at five sites in each of the harvesting areas in Cockburn Sound between July 2020 and December 2021 were assessed against the faecal pathogens in water EQG (EPA 2017:66):

> The median faecal coliform concentration in samples from a single site must not exceed 14 CFU/100 mL and the estimated 90th percentile must not exceed 21 CFU/100 mL measured using the membrane filtration method.

See Table 25 for the results of the assessment against the EQG. Both components of the faecal pathogens in water EQG were met at all sites in the Kwinana Grains Terminal and Southern Flats harvesting areas between July 2020 and December 2021.

### 3.3.2 Assessment of compliance with the algal biotoxins EQC

Concentrations of toxic phytoplankton recorded in the two harvesting areas in Cockburn Sound from July 2020 to December 2021 were assessed against the algal biotoxins EQG (Table 26). The algal biotoxins EQG are the phytoplankton alert levels that trigger management action identified in the WASQAP *Marine biotoxin monitoring and management plan 2016* (Department of Health 2016).

See Tables 27a–b and 28a–c for the results of the assessment against the EQG. The algal biotoxins EQG was met on all sampling occasions in the Kwinana Grain Terminal and Southern Flats shellfish harvesting areas between July 2020 and December 2021.

Under WASQAP, routine monthly biotoxin screening was introduced in 2015 for all harvesting areas. All the samples for Cockburn Sound between July 2020 and December 2021 were negative for PSP, DSP and ASP biotoxins (Table 29).

*Table 25: Assessment of thermotolerant (faecal) coliforms in water samples collected from five sites in each of the two shellfish harvesting areas in Cockburn Sound between July 2020 and December 2021 against the faecal pathogens in water EQG*

| Site | Median faecal coliform concentration (CFU/100 mL) | 90th percentile faecal coliform concentration (CFU/100 mL) | Assessment |
|---|---|---|---|
| | EQG: Median faecal coliform concentration ≤ 14 CFU/100 mL | EQG: 90th percentile ≤ 21 CFU/100 mL | |
| KGT1 | 1.0 | 6.9 | EQG met |
| KGT2 | 1.0 | 1.7 | EQG met |
| KGT3 | 1.0 | 1.7 | EQG met |
| KGT4 | 1.0 | 1.0 | EQG met |
| KGT5 | 1.0 | 1.7 | EQG met |
| SF6 | 1.0 | 3.3 | EQG met |
| SF8 | 1.0 | 1.0 | EQG met |
| SF9 | 1.0 | 1.1 | EQG met |
| SF10 | 1.0 | 1.0 | EQG met |
| SF11 | 1.0 | 1.0 | EQG met |

*Table 26: The phytoplankton levels that trigger management action*

| Type of toxin | Phytoplankton species | Alert level (cells/L) (notify Department of Health) | Alert level (cells/L) (initiate flesh testing) |
|---|---|---|---|
| Paralytic shellfish poison | Alexandrium catenella | 100 | 200 |
| | Alexandrium minutum | 100 | 200 |
| | Alexandrium ostenfeldii | 100 | 200 |
| | Alexandrium tamarense | 100 | 200 |
| | Gymnodinium catenatum | 500 | 1,000 |
| Diarrhoetic shellfish poison | Dinophysis acuminata | 1,000 | 1,000 |
| | Dinophysis acuta | 500 | 1,000 |
| | Dinophysis caudata | 500 | 1,000 |
| | Dinophysis fortii | 500 | 1,000 |
| | Prorocentrum lima | 500 | 500 |
| Amnesic shellfish poison | Pseudo-nitzschia seriata group | 50,000 | 50,000 |
| | Pseudo-nitzschia delicatissima group | 500,000 | 500,000 |
| Neurotoxic shellfish poison | Karenia brevis | 500 | 1,000 |
| | Karenia/Karlodinium/Gymnodinium group | 100,000 | 250,000 |

*Table 27a: Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound between July and December 2020 against the algal biotoxins EQG*

| **Site** | | **Kwinana Grain Terminal** | **Southern Flats** |
|---|---|---|---|
| **Sampling date** | **Toxic algae recorded** | **Cell density (cells/L)** | **Cell density (cells/L)** |
| 13/07/2020 | *Pseudo-nitzschia* delicatissima group | 1,200 | 1,000 |
| | Pseudo-nitzschia seriata group | 140 | 120 |
| | Dinophysis caudata group | 40 | Not detected |
| | Prorocentrum rhathymum | Not detected | 100 |
| 27/07/2020 | *Pseudo-nitzschia* delicatissima group | 200 | Not detected |
| | Dinophysis caudata pediculata group | 100 | 100 |
| 10/08/2020 | *Pseudo-nitzschia* delicatissima group | 200 | Not detected |
| | Prorocentrum lima group | 10 | Not detected |
| 24/08/2020 | No toxic algae detected | - | - |
| 15/09/2020 | *Pseudo-nitzschia* delicatissima group | 400 | Not detected |
| | Dinophysis acuminata group | 80 | 40 |
| | Dinophysis caudata group | 20 | Not detected |
| 29/09/2020 | Dinophysis acuminata group | 100 | 300 |
| 14/10/2020 | Dinophysis caudata group | - | 100 |
| | Gymnodinium group | - | 600 |
| 15/10/2020 | Gymnodinium group | 400 | - |
| 26/10/2020 | Dinophysis acuminata group | 10 | Not detected |
| | Prorocentrum rhathymum group | 10 | Not detected |
| 9/11/2020 | Gymnodinium group | 400 | Not detected |
| | Dinophysis acuminata group | Not detected | 10 |
| 23/11/2020 | Dinophysis caudata group | 20 | Not detected |
| | Gymnodinium group | Not detected | 10 |

*Table 27b: Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound between July and December 2020 against the algal biotoxins EQG*

| Site | | Kwinana Grain Terminal | Southern Flats |
|---|---|---|---|
| **Sampling date** | **Toxic algae recorded** | **Cell density (cells/L)** | **Cell density (cells/L)** |
| 7/12/2020 | Gymnodinium group | 100 | - |
| 8/12/2020 | Dinophysis acuminata group | - | 10 |
| 16/12/2020 | No toxic algae detected | - | - |

*Table 28a: Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound from January to December 2021 against the algal biotoxins EQG*

| **Site** | | **Kwinana Grain Terminal** | **Southern Flats** |
|---|---|---|---|
| **Sampling date** | **Toxic algae recorded** | **Cell density (cells/L)** | **Cell density (cells/L)** |
| 4/01/2021 | *Pseudo-nitzschia* delicatissima group | Not detected | 800 |
| | Dinophysis caudata group | Not detected | 100 |
| | Prorocentrum rhathymum group | Not detected | 300 |
| 18/01/2021 | *Pseudo-nitzschia* delicatissima group | 1,900 | 1,800 |
| | Dinophysis caudata group | 10 | Not detected |
| | Prorocentrum rhathymum group | 100 | Not detected |
| 9/02/2021 | *Pseudo-nitzschia* delicatissima group | Not detected | 1,500 |
| 6/04/2021 | Prorocentrum rhathymum group | - | 200 |
| 20/04/2021 | *Pseudo-nitzschia* delicatissima group | - | 1,600 |
| | Pseudo-nitzschia seriata group | - | 2,100 |
| | Prorocentrum rhathymum group | - | 100 |
| 18/05/2021 | *Pseudo-nitzschia* delicatissima group | - | 600 |
| 26/05/2021 | *Pseudo-nitzschia* delicatissima group | - | 200 |
| | Dinophysis caudata group | - | 20 |
| | Prorocentrum rhathymum group | - | 200 |
| 23/06/2021 | *Pseudo-nitzschia* delicatissima group | - | 200 |
| | Dinophysis caudata group | - | 200 |
| | Prorocentrum rhathymum group | - | 100 |
| 16/07/2021 | Dinophysis caudata group | 230 | Not detected |
| | *Pseudo-nitzschia* delicatissima group | 300 | 300 |
| | Pseudo-nitzschia seriata group | Not detected | 800 |

*Table 28b: Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound from January to December 2021 against the algal biotoxins EQG*

| Site | | Kwinana Grain Terminal | Southern Flats |
|---|---|---|---|
| **Sampling date** | **Toxic algae recorded** | **Cell density (cells/L)** | **Cell density (cells/L)** |
| 23/08/2021 | *Pseudo-nitzschia* delicatissima group | 3,600 | 9,200 |
| | Pseudo-nitzschia seriata group | 26,000 | 15,800 |
| | Dinophysis acuminata group | Not detected | 20 |
| | Dinophysis caudata group | Not detected | 10 |
| | Karenia/Karlodinium/Gymnodinium group | 800 | 1,000 |
| 7/09//2021 | *Pseudo-nitzschia* delicatissima group | 600 | Not detected |
| | Pseudo-nitzschia seriata group | 30,400 | 29,000 |
| | Dinophysis acuminata group | 100 | 60 |
| | Dinophysis caudata group | 20 | Not detected |
| | Karenia/Karlodinium/Gymnodinium group | 400 | 600 |
| 20/09/2021 | Dinophysis acuminata group | - | 90 |
| | Dinophysis caudata group | - | 20 |
| | Karenia/Karlodinium/Gymnodinium group | - | 1000 |
| 4/10/2021 | Pseudo-nitzschia seriata group | - | 200 |
| | Dinophysis acuminata group | - | 120 |
| | Phalochroma rotundatum group | - | 20 |
| | Karenia/Karlodinium/Gymnodinium group | - | 7,400 |
| 18/10/2021 | Pseudo-nitzschia seriata group | - | 400 |
| | Karenia/Karlodinium/Gymnodinium group | - | 1,000 |
| | Trichodesmium erythraeum group | - | 15,000 |

*Table 28c: Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound from January to December 2021 against the algal biotoxins EQG*

| **Site** | | **Kwinana Grain Terminal** | **Southern Flats** |
|---|---|---|---|
| **Sampling date** | **Toxic algae recorded** | **Cell density (cells/L)** | **Cell density (cells/L)** |
| 8/11/2021 | Karenia/Karlodinium/Gymnodinium group | - | 200 |
| 16/11/2021 | Karenia/Karlodinium/Gymnodinium group | 600 | 800 |
| | Trichodesmium erythraeum group | Not detected | 5,200 |
| **Assessment** | EQG was met at Kwinana Grain Terminal and Southern Flats shellfish harvesting areas on all sampling occasions. | | |

*Table 29: Results of biotoxin screening between 1 July 2020 and 31 December 2021*

| Sampling date | Amnesic shellfish poison | | Diarrhoetic shellfish poison | | Paralytic shellfish poison | |
|---|---|---|---|---|---|---|
| | EQS: < 20 mg/kg | | EQS: < 0.2 mg/kg | | EQS: < 0.8 mg/kg Saxitoxin equivalents | |
| | Kwinana Grain Terminal | Southern Flats | Kwinana Grain Terminal | Southern Flats | Kwinana Grain Terminal | Southern Flats |
| 3/07/2020 | - | Negative | - | Negative | - | Negative |
| 13/07/2020 | Negative | Negative | Negative | Negative | Negative | Negative |
| 15/09/2020 | Negative | Negative | Negative | Negative | Negative | Negative |
| 10/11/2020 | Negative | Negative | Negative | Negative | Negative | Negative |
| 7/12/2020 | Negative | Negative | Negative | Negative | Negative | Negative |
| 4/01/2021 | Negative | Negative | Negative | Negative | Negative | Negative |
| 29/03/2021 | - | - | - | - | - | - |
| 6/04/2021 | - | Negative | - | Negative | - | Negative |
| 18/05/2021 | - | Negative | - | Negative | - | Negative |
| 8/06/2021 | - | Negative | - | Negative | - | Negative |
| 16/07/2021 | - | Negative | - | Negative | - | Negative |
| 3/08/2021 | - | Negative | - | Negative | - | Negative |
| 7/09/2021 | - | Negative | - | Negative | - | Negative |
| 4/10/2021 | - | Negative | - | Negative | - | Negative |
| 8/11/2021 | - | Negative | - | Negative | - | Negative |

### 3.3.3 Assessment of compliance with the *Escherichia coli* (*E. coli*) in fish flesh EQS

Escherichia coli (E. coli) counts (expressed as most probable number per gram [MPN/g]) recorded in the flesh of mussels collected at each of the sites in the harvesting areas in Cockburn Sound between 1 July 2020 and 31 December 2021 were assessed against the *E. coli* in fish flesh EQS (EPA 2017:66):

> Shellfish destined for human consumption should not exceed a limit of 2.3 MPN E. coli/g of flesh (wet weight) in two or more representative samples out of five, and no single sample should exceed 7 MPN *E. coli*/g.

See Table 30 for the results of the assessment against the EQS. Both components of the EQS were met in both harvesting areas between July 2020 and December 2021.

*Table 30: Assessment of* E. coli *counts in mussel flesh collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2020 and December 2021 against the* E. coli *in shellfish flesh EQS*

| Sampling date | *E. coli* count (MPN/g) | | | Assessment |
|---|---|---|---|---|
| | Kwinana Grain Terminal (North) | Kwinana Grain Terminal (South) | Southern Flats | |
| EQG | 2 or more representative samples out of 5 ≤ 2.3 MPN *E. coli*/g flesh and no single sample > 7 MPN *E. coli*/g | | | |
| 3/07/2020 | - | - | 1.8 | EQS met |
| 13/07/2020 | 1.8 | 1.8 | 1.8 | EQS met |
| 21/07/2020 | 1.8 | 1.8 | - | EQS met |
| 15/09/2020 | 1.8 | 1.8 | 1.8 | EQS met |
| 10/11/2020 | 1.8 | 4.5 | 1.8 | EQS met |
| 13/11/2020 | 1.8 | 1.8 | - | EQS met |
| 19/11/2020 | 1.8 | - | - | EQS met |
| 1/12/2020 | 1.8 | - | - | EQS met |
| 16/12/2020 | 1.8 | - | - | EQS met |
| 18/12/2020 | 1.8 | - | - | EQS met |
| 4/01/2021 | 2.0 | - | <1.8 | EQS met |
| 6/04/2021 | - | - | <1.8 | EQS met |
| 16/07/2021 | - | - | <1.8 | EQS met |
| 7/09/2021 | - | - | <1.8 | EQS met |
| 8/11/2021 | - | - | <1.8 | EQS met |

Note: 1.8 *E. coli* MPN/g is the laboratory's lowest limit of detection for the analysis.

### 3.3.4 Assessment of compliance with the chemical concentration in seafood flesh EQC

Concentrations of chemicals in mussel flesh were assessed against the chemical concentration in seafood flesh EQG (EPA 2017:67–68):

> Median chemical concentration in the flesh of seafood should not exceed the environmental quality guidelines:
>
> | | | |
> |---|---|---|
> | Copper | 30 mg/kg | (molluscs) |
> | Selenium | 1.0 mg/kg | (molluscs) |
> | Zinc | 290 mg/kg | (oysters). |

Concentrations were also assessed against the chemical concentration in seafood flesh EQS (EPA 2017:67–68):

> Chemical concentrations (except for mercury) in the flesh of seafood should not exceed the environmental quality standards:

| | | |
|---|---|---|
| Arsenic (inorganic) | 1.0 mg/kg | (molluscs) |
| Cadmium | 2.0 mg/kg | (molluscs) |
| Lead | 2.0 mg/kg | (molluscs) |

Mercury concentration in the flesh of seafood should not exceed the environmental quality standard in accordance with Standard 1.4.1 Contaminants and natural toxicants of the Australia New Zealand Food Standards Code (Schedule 19 – Maximum levels of contaminants and natural toxicants):

| | | |
|---|---|---|
| Mercury | 0.5 mg/kg (mean level) | (molluscs). |

Pesticide residue concentrations in the flesh of seafood should not exceed the maximum residue limits and extraneous residue limits in Schedules 20 and 21 respectively of the Australia New Zealand Food Standards Code.[17]

See Table 31 for the results of the assessment against the EQC. Where there are EQC, the concentrations of metals in mussel flesh at sites in Cockburn Sound were below the relevant EQG or EQS at the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites. The concentrations of PAHs in mussel flesh sampled from mussels at these sites were all below the analytical limits of reporting.

[17] Maximum residue limits from Schedule 20 and Extraneous residue limits from Schedule 21 of the *Australia New Zealand Food Standards Code* (accessed on 12 July 2017).

*Table 31a: Assessment of chemicals in mussels collected at sites in Cockburn Sound against the chemical concentration in seafood flesh EQC*

| Chemical (mg/kg) | Environmental quality criteria (mg/kg) | | Kwinana Bulk Terminal (mg/kg) | | | | Kwinana Bulk Jetty (mg/kg) | | | | Kwinana Grain Terminal (mg/kg) | Southern Flats (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EQG | EQS | KBT1 | KBT2 | KBT3 | Median | KBJ1 | KBJ2 | KBJ3 | Median | | |
| **Metals** | | | | | | | | | | | | |
| Arsenic (total) | - | - | - | - | - | - | - | - | - | - | - | 2.9, 3.9 |
| Arsenic (inorganic)[1] | - | 1.0 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | Not measured | |
| Cadmium | - | 2.0 | 0.09 | 0.11 | 0.12 | 0.11 | 0.14 | 0.12 | 0.14 | 0.14 | - | 0.46, 0.56 |
| Chromium | - | - | 0.11 | 0.08 | 0.12 | 0.11 | 0.12 | 0.12 | 0.14 | 0.12 | Not measured | |
| Copper | 30 | - | 1.2 | 0.8 | 1.2 | 1.2 | 0.7 | 1.0 | 1.7 | 1.0 | - | Not measured |
| Lead | - | 2.0 | 0.09 | 0.06 | 0.09 | 0.09 | 0.11 | 0.11 | 0.11 | 0.11 | - | 0.09, 0.09 |
| Mercury | - | 0.5 (mean level) | < 0.01 | 0.01 | < 0.01 | < 0.01 | 0.01 | < 0.01 | 0.01 | 0.01 | - | <0.01, 0.02 |
| Selenium | 1.0 | - | 0.24 | 0.23 | 0.28 | 0.24 | 0.34 | 0.29 | 0.38 | 0.34 | Not measured | |
| Zinc (EQG for oysters) | 290 | - | 13 | 14 | 15 | 14 | 20 | 17 | 21 | 20 | - | 83.4 |

1 10% of total arsenic is assumed to be present as the inorganic form (Stewart & Turnbull 2015).

*Table 31b: Assessment of chemicals in mussels collected at sites in Cockburn Sound against the chemical concentration in seafood flesh EQC*

| Chemical (mg/kg) | Environmental quality criteria (mg/kg) | | Kwinana Bulk Terminal (mg/kg) | | | | Kwinana Bulk Jetty (mg/kg) | | | | Kwinana Grain Terminal (mg/kg) | Southern Flats (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EQG | EQS | KBT1 | KBT2 | KBT3 | Median | KBJ1 | KBJ2 | KBJ3 | Median | | |
| **Tributyltin** | - | - | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | Not measured | |
| **Organics** | | | | | | | | | | | | |
| **Polychlorinated biphenyls (fish)** | - | 0.5 | Not measured | | | | Not measured | | | | Not measured | |
| **PAHs** | - | - | All below limits of reporting | | | | All below limits of reporting | | | | Not measured | |

‘<’ signifies the result is less than the limit of quantitation for the method

## 3.4 Assessment against the maintenance of aquaculture production environmental quality criteria

### 3.4.1 Assessment of compliance with the physical-chemical stressors EQG

Dissolved oxygen (DO) and pH measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound – CS9A, CS10N, CS11 and CS13 – during the non river-flow period between January and March 2021 (Section 2.3; Figure 2) were assessed against the physical-chemical stressors EQG (EPA 2017:73):

> The median of the sample concentrations from the defined sampling area on each sampling occasion over the non river-flow period should meet the following environmental quality guideline values:
>
> Dissolved oxygen ≥ 5 mg/L
>
> pH 6–9.

DO (milligrams per litre [mg/L]) and pH were recorded in the surface waters and at the depth of the mussel lines (8–10 m) at all four sites. These depths represent the approximate greatest depths of the mussel lines in the Kwinana Grain Terminal harvesting area and the Southern Flats harvesting area. Given the small number of samples, the DO concentrations and pH of surface waters and at depth for each sample was assessed against the physical-chemical stressors EQG.

See Tables 32 and 33 for the results. The DO concentrations and pH of surface waters and at depth for each sample in the defined sampling area met the relevant EQG on all sampling occasions between January and March 2021.

*Table 32: Assessment of dissolved oxygen concentrations in surface waters and at depth, measured against the physical-chemical stressors EQG at four sites adjacent to the shellfish harvesting areas in Cockburn Sound between January and March 2021*

| Indicator | Sampling date | Sites adjacent to shellfish harvesting areas | | | | EQG | Assessment |
|---|---|---|---|---|---|---|---|
| | | CS9A | CS10N | CS11 | CS13 | | |
| Surface waters dissolved oxygen (milligrams/ litre [mg/L]) | 14/01/2021 | 6.5 | 6.5 | - | - | ≥ 5 mg/L | EQG met on all sampling occasions and at all sites |
| | 15/01/2021 | - | - | 6.2 | 6.2 | | |
| | 1/02/2021 | 6.6 | 6.5 | - | - | | |
| | 2/02/2021 | - | - | 6.6 | 6.9 | | |
| | 1/03/2021 | 6.8 | 6.7 | - | - | | |
| | 2/03/2021 | - | - | 5.8 | 6.6 | | |
| Depth waters dissolved oxygen (mg/L) | 14/01/2021 | 6.3 | 6.2 | - | - | ≥ 5 mg/L | EQG met on all sampling occasions and at all sites |
| | 15/01/2021 | - | - | 6.3 | 6.5 | | |
| | 1/02/2021 | 6.6 | 6.2 | - | - | | |
| | 2/02/2021 | - | - | 5.9 | 5.9 | | |
| | 1/03/2021 | 6.6 | 6.1 | - | - | | |
| | 2/03/2021 | - | - | 5.4 | 6.2 | | |

*Table 33: Assessment of pH in surface waters and at depth, measured against the physical-chemical stressors EQG at four sites adjacent to the shellfish harvesting areas in Cockburn Sound between January and March 2021*

| Indicator | Sampling date | Sites adjacent to shellfish harvesting areas | | | | EQG | Assessment |
|---|---|---|---|---|---|---|---|
| | | CS9A | CS10N | CS11 | CS13 | | |
| Surface waters pH | 14/01/2021 | 8.2 | 8.2 | - | - | 6–9 | EQG met on all sampling occasions and at all sites |
| | 15/01/2021 | - | - | 8.2 | 8.2 | | |
| | 1/02/2021 | 8.2 | 8.2 | - | - | | |
| | 2/02/2021 | - | - | 8.2 | 8.2 | | |
| | 1/03/2021 | 8.2 | 8.2 | - | - | | |
| | 2/03/2021 | - | - | 8.2 | 8.2 | | |
| Depth waters pH | 14/01/2021 | 8.2 | 8.2 | - | - | 6–9 | EQG met on all sampling occasions and at all sites |
| | 15/01/2021 | - | - | 8.2 | 8.2 | | |
| | 1/02/2021 | 8.2 | 8.2 | - | - | | |
| | 2/02/2021 | - | - | 8.2 | 8.2 | | |
| | 1/03/2021 | 8.2 | 8.2 | - | - | | |
| | 2/03/2021 | - | - | 8.2 | 8.2 | | |

### 3.4.2 Assessment of compliance with the toxicants EQG

Concentrations of ammonia and nitrate–nitrite measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound – CS9A, CS10N, CS11 and CS13 – from January to March 2021 (Section 2.3; Figure 2) were assessed against the toxicants EQG for the maintenance of aquaculture production (EPA 2017:73–74).

The concentrations of selected toxicants (ammonia, nitrate–nitrite and copper) in surface water samples collected at sites around the Kwinana Bulk Terminal – KBT1, KBT2, KBT3 – and the Kwinana Bulk Jetty – KBJ1, KBJ2, KBJ3 – on one occasion on 28 January 2021 (Section 2.3; Figure 2) were also assessed against the toxicants EQG for the maintenance of aquaculture production.

Table 5 in the EPA reference document (2017:73) specifies:

> The 95th percentile of the sample concentrations from the defined sampling area (either from one sampling run or all samples over an agreed period of time, or from a single site over an agreed period of time) should not exceed the environmental quality guideline value.

Given the small number of samples, concentrations of copper, ammonia and nitrate–nitrite in each of the water samples collected at the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites were assessed against the relevant toxicants EQG values.

See Table 34 for the results of the assessment. The toxicant concentrations recorded at the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites were below the relevant EQG values.

*Table 34: Assessment of concentrations of ammonia, nitrate–nitrite and copper at sites near the shellfish harvesting areas in Cockburn Sound against the toxicants EQG*

| Site | Ammonia (µg N/L) | | | Nitrate–Nitrite (µg N/L) | | | Copper (µg/L) | |
|---|---|---|---|---|---|---|---|---|
| | EQG | Surface | Bottom | EQG | Surface | Bottom | EQG | Surface |
| KBT1 | ≤1,000 | 4 | 5 | Nitrite-N ≤100 Nitrate-N ≤100,000 | 2 | 3 | ≤5 | 0.4 |
| KBT2 | | 4 | 3 | | < 2 | < 2 | | 0.4 |
| KBT3 | | 4 | 6 | | < 2 | < 2 | | 0.5 |
| KBJ1 | | < 3 | 5 | | < 2 | < 2 | | 0.3 |
| KBJ2 | | < 3 | 10 | | < 2 | < 2 | | 0.4 |
| KBJ3 | | < 3 | 4 | | < 2 | < 2 | | 0.4 |
| CS13 | | 1.5 | 2.9 | | < 2 | < 2 | | Not measured |
| CS9A | | 95th percentile = 3.3 | | | 95th percentile < 2 | | | Not measured |
| CS10N | | 95th percentile = 2.9 | | | 95th percentile < 2 | | | Not measured |
| CS11 | | 95th percentile = 1.7 | | | 95th percentile = 2.9 | | | Not measured |

## 3.5 Conclusions

Based on the Cockburn Sound monitoring program results from 1 July 2020 to 31 December 2021, there is a high degree of certainty that the environmental quality objective of maintenance of seafood safe for human consumption and maintenance of aquaculture were achieved in the approved and conditionally approved shellfish harvesting areas in southern Cockburn Sound. There is no information available from other areas in Cockburn Sound or for wild shellfish or fish.

Accredited quality assurance monitoring programs based on the requirements of the WASQAP operations manual are conducted for approved and conditionally approved shellfish harvesting areas in southern Cockburn Sound where shellfish are grown commercially for the food market. The Department of Health (2010, 2016) recommends only eating shellfish harvested commercially under strict quality assurance monitoring programs.

# 4. Environmental value: recreation and aesthetics

## 4.1 Environmental quality objectives

The environmental quality objectives for the environmental value of recreation and aesthetics are:

- **maintenance of primary contact recreation values** – primary-contact recreation (e.g. swimming) is safe to undertake
- **maintenance of secondary contact recreation values** – secondary-contact recreation (e.g. boating) is safe to undertake
- **maintenance of aesthetic values** – the aesthetic values are protected (EPA 2017).

The EQC for these environmental quality objectives set a level of environmental quality that will ensure:

- people undertaking primary contact recreational activities where the participant comes into frequent direct contact with the water, either as part of the activity or accidentally, are protected from ill effects caused by poor water quality
- people undertaking secondary contact recreational activities where the participant comes into direct contact with the water infrequently, either as part of the activity or accidentally, are protected from ill effects caused by poor water quality
- the visual amenity of the waters of Cockburn Sound is maintained (EPA 2017).

## 4.2 Water quality monitoring

The cities of Cockburn, Kwinana and Rockingham undertook bacterial water sampling at several popular recreational beaches (program sites) around Cockburn Sound between November 2020 and March 2021 (Figure 12). The Department of Health administered the program and encouraged the minimum collection of 65 samples between November and early May (the time of year when most people participate in recreational activities) over five consecutive years. This was based on its revised approach to the National Health and Medical Research Council's (2008) recommendation of 100 samples collected over five consecutive years. The minimum of 65 samples is equivalent to 13 samples per season (equivalent to about one sample collected each fortnight). This minimum number of samples maintains statistical confidence when assigning a site classification (beach grades) following the National Health and Medical Research Council (2008) guidelines.[18]

In addition, local governments monitor other sites (non-core sites) for their own

[18] For more information on beach grades go to the Department of Health's website: ww2.health.wa.gov.au/Articles/A_E/Beach-grades-for-Western-Australia

purposes outside of the program sites, generally at less frequent intervals (e.g. five or fewer samples per season).

Samples were analysed for enterococci by PathWest Laboratory. Enterococci are the bacterial indicator recommended by the National Health and Medical Research Council (2008).

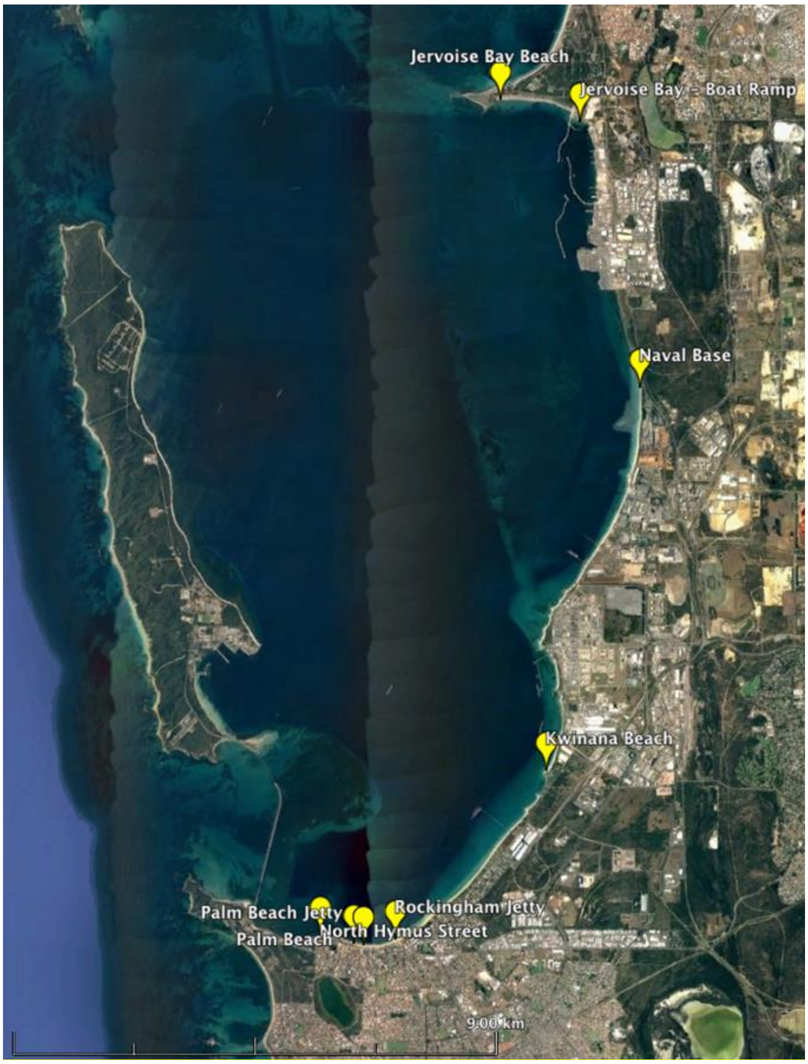



*Figure 4: Sampling locations near recreational beaches in Cockburn Sound*

## 4.3 Assessment against the maintenance of primary and secondary contact recreation environmental quality criteria

### 4.3.1 Assessment of compliance with the faecal pathogens EQG

Enterococci counts (expressed as most probable number per 100 millilitres [MPN/100 mL]) recorded at each of eight locations around Cockburn Sound between November 2020 and March 2021 were assessed against the faecal pathogens EQG for primary contact recreation (EPA 2017:80):

> The 95th percentile bacterial count of marine waters should not exceed 200 enterococci/100 mL.

Enterococci counts were also assessed against the faecal pathogens EQG for secondary contact recreation (EPA 2017:92):

> The 95th percentile bacterial count of marine waters should not exceed 2,000 enterococci/100 mL.

The faecal pathogens EQG for both primary and secondary contact recreation were met at all of the sites monitored. See Table 35 for the results.

*Table 35: Assessment of the 95th percentile of enterococci counts (samples collected between 2016–17 and 2020–21) at eight locations around Cockburn Sound against the faecal pathogens EQG*

| Location | Type of site | No. of measurements | EQG | | Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml) |
|---|---|---|---|---|---|
| | | | Primary contact | Secondary contact | |
| North Hymus Street[1] | Program | 52 | 200 | 2,000 | 130 |
| Jervoise Bay Beach[1] | Program | 56 | | | 105 |
| Rockingham Beach and Jetty[1] | Program | 39 | | | 65 |
| Palm Beach Jetty[1] | Program | 48 | | | 34 |
| Naval Base[1] | Program | 17 | | | 2 |
| Kwinana Beach[1] | Program | 17 | | | 6 |
| Jervoise Bay Boat Ramp[1] | Non-core | 58 | | | 50 |
| Palm Beach[1] | Non-core | 42 | | | 130 |
| **Assessment** | | Primary contact and secondary contact recreation EQG met at all sites | | | |

1 Sample size did not meet the minimum number of samples required for analysis; therefore, results must be treated with caution.

Note: The 95th percentiles were calculated using the Department of Health's Enterotester V200v2. The Enterotester is a Microsoft® Excel template predicated on a risk management approach to recreational water surveillance (Lugg et al. 2012).

### 4.3.2. Assessment of compliance with the physical EQG

Water clarity and pH were recorded at each of the 18 water quality monitoring sites during the non river-flow period between January and March 2021 (Section 2.2; Figure 2) and assessed against the physical EQC for primary contact recreation (EPA 2017:80):

Water clarity EQG: To protect the visual clarity of waters used for swimming, the horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m.[19]

pH EQS: The median of the sample concentrations from the area of concern (either from one sampling run or from a single site over an agreed period of time) should not exceed the range of 5–9 pH units.

The pH was also assessed against the physical EQG for secondary contact recreation (EPA 2017:92):

pH EQG: The median of the sample concentrations from a defined sampling area (either from one sampling run or from a single site over an agreed period of time) should not exceed the range of 5–9 pH units.

Water clarity and pH met the relevant physical EQC for primary and secondary contact recreation at all the sites. See Table 36 for the results.

[19] The former Office of the Environmental Protection Authority (now the Department of Water and Environmental Regulation) advised that it is reasonable to use vertical Secchi disc measurements in marine waters.

*Table 36: Assessment of pH and water clarity (Secchi disc) at 18 water quality monitoring sites in Cockburn Sound during the non river-flow period between January and March 2021 against the physical EQC for primary and secondary contact recreation*

| Site | pH EQC | Median pH (surface) | Median pH (bottom) | Water clarity EQG | Range of Secchi disc measurements (m ± 0.1 m) | Assessment |
|---|---|---|---|---|---|---|
| CS4 | Not to exceed the range of 5–9 pH units | 8.2 | 8.2 | >1.6 m | 7.5–11.0 | EQC met at all sites |
| CS5 | | 8.2 | 8.2 | | 6.2–6.5 | |
| CS6A | | 8.2 | 8.2 | | 5.2–7.1 | |
| CS7 | | 8.2 | 8.2 | | 4.1–7.3 | |
| CS8 | | 8.2 | 8.2 | | 5.0–9.3 | |
| CS9 | | 8.2 | 8.1 | | 4.8–5.4 | |
| CS10N | | 8.2 | 8.2 | | 3.1–6.0 | |
| CS11 | | 8.2 | 8.2 | | 5.1–7.1 | |
| CS12 | | 8.2 | 8.2 | | 4.8–5.7 | |
| CS13 | | 8.2 | 8.2 | | 5.8–7.8 | |
| CS9A | | 8.2 | 8.2 | | 3.4–4.9 | |
| CB | | 8.2 | 8.2 | | 4.5–6.5 | |
| G1 | | 8.2 | 8.2 | | 5.7–6.0 | |
| G2 | | 8.2 | 8.2 | | 5.0–6.4 | |
| G3 | | 8.2 | 8.2 | | 7.1–9.5 | |
| SF | | 8.3 | 8.3 | | 3.0–3.6 | |
| MB | | 8.2 | 8.2 | | 1.2*–1.6* | |
| NH3 | | 8.2 | 8.2 | | 2.9–5.0 | |

* Maximum depth at site at time of monitoring

### 4.3.3. Assessment of compliance with the toxic chemicals EQC

In general, the levels of toxicants required to impact on the health of people recreating in marine waters are greater than the levels necessary to protect ecosystem health. The toxicant concentrations were below the relevant ecosystem health EQC (see Section 2.7). Hence the waters can also be considered safe for human recreation.

## 4.4 Indicators of aesthetic quality

The community highly values the ecological, recreational and aesthetic attributes of Cockburn Sound, thus EQC have been developed to protect its aesthetic values (EPA 2017). Many of the guidelines for aesthetic quality are subjective and relate to the general appreciation and enjoyment of Cockburn Sound by the community as a whole. Additional factors are considered, such as whether the observations are of an intensity or in a location likely to trigger community concern and whether the impacts are transient, persistent or regular events.

MAFRL made qualitative observations of the following indicators of aesthetic quality near each of the 18 water quality monitoring sites during the non river-flow period between January and March 2021 (Section 2.2; Figure 2):

- nuisance organisms
- algal blooms
- faunal deaths
- water clarity
- colour variation
- surface films (e.g. oil and petrochemical films on the water)
- surface or submerged debris (e.g. grain and litter)
- odours.

See Tables 37a–b for the results.

Grain was observed on the water surface at site SF on 1 March 2021.

Odours were reported at sites adjacent to the industrial area on the eastern shore of Cockburn Sound (CS12 and CB).

Algal blooms were observed on five of the six sampling days. A distinct southern algal bloom was observed in Cockburn Sound on 14 January 2021. Although surface phytoplankton scum was frequently observed, it was not always associated with algal blooms.

The pattern of persistent algal blooms within the Northern Harbour (site NH3) continued as observed in previous years. The warmer water, reduced flushing and assimilation of nutrients in the Northern Harbour in the summer provide ideal conditions for algal blooms.

In response to the persistent and frequent algal blooms throughout Cockburn Sound, phytoplankton samples were collected from integrated water samples at the monitoring sites. The phytoplankton samples were analysed by the Phytoplankton Ecology Unit at the Department of Water and Environmental Regulation. Their analysis found very low counts of phytoplankton in the water samples.

These localised impacts to aesthetic quality require further studies to determine the extent to which they occur, both spatially and temporally.

*Table 37a: Qualitative observations of indicators of aesthetic quality at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound during the non river-flow period between January and March 2021*

| Sampling date | Nuisance organisms | Algal blooms | Faunal deaths | Water clarity | Water colour variation | Surface films or oils | Surface or submerged debris | Odours |
|---|---|---|---|---|---|---|---|---|
| 14/01/2021 | CS7, CS9, CS9A, CS12, CS10N (surface phytoplankton scum) | CS9A, CS10N, NH3 | - | NH3 | CS9A, CS10N, NH3 (green) | - | - | CS12 (industrial odours) |
| 15/01/2021 | WS4, CS4, CS11, CS13, G1 (surface phytoplankton scum) | - | - | CS4, CS11, CS13, G1, G2 | CS4, CS11, CS13, G1, G2 (green) | - | - | - |
| 1/02/2021 | CS5, CS6A, CS7, CS8, CS9, CS9A, CS10N, CS12, CB, MB, SF, NH3 (surface phytoplankton scum) | CS5, CS6A, CS7, CS8, CS9, CS9A, CS10N, CS12, CB, MB, SF, NH3 | - | CS5, CS6A, CS7, CS8, CS9, CS9A, CS10N, CS12, CB, MB, SF, NH3 | CS5, CS6A, CS7, CS8, CS9, CS9A, CS10N, CS12, CB, MB, SF, NH3 (green) | - | CS9 (dust from vessel unloading) | CS12 (industrial odours) |
| 2/02/2021 | WS4, CS11, CS13, G1 (surface phytoplankton scum) | WS4, CS11, CS13, G1 | - | WS4, CS11, CS13, G1 | WS4, CS11, CS13, G1 (green) | - | CS4, G3 (ash from bushfires) | - |

*Table 37b: Qualitative observations of indicators of aesthetic quality at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound during the non river-flow period between January and March 2021*

| Sampling date | Nuisance organisms | Algal blooms | Faunal deaths | Water clarity | Water colour variation | Surface films or oils | Surface or submerged debris | Odours |
|---|---|---|---|---|---|---|---|---|
| 1/03/2021 | - | CS9, CS9A, CB, NH3 | - | CS9, CS9A, CB, NH3 | CS9, CS9A, CB, NH3 (green) | - | SF (grain) | CB (industrial odours) |
| 2/03/2021 | G1, G2 (surface phytoplankton scum) | CS13 | - | G1, G2 | G1, G2 (green) | - | - | - |

## 4.5 Conclusions

Based on the results from the monitoring programs from 1 July 2020 to 31 December 2021 in Cockburn Sound, there were no recorded exceedances of the EQC for the environmental quality objectives of maintenance of primary contact recreation values and maintenance of secondary contact recreation values. Given this, there is a high degree of certainty that the environmental quality objectives were achieved, and the waters are safe for recreational activities.

# 5. Environmental value: industrial water supply

## 5.1 Environmental quality objective

The environmental quality objective for the environmental value of industrial water supply is:

- **maintenance of water quality for industrial use** – water is of suitable quality for industrial use (EPA 2017).

The Perth Seawater Desalination Plant (desalination plant), in the industrial zone along the eastern shore of Cockburn Sound, takes seawater from Cockburn Sound and uses reverse osmosis to produce drinking water for the Perth metropolitan area. The desalination plant produces about 18% of Perth's water supply. Seawater quality is fundamental to the desalination plant's operation. Seawater quality determines the level of pre-treatment required to ensure optimal performance of the reverse osmosis system and to prevent fouling and scaling.

A reduction in the quality of the incoming seawater would have a significant impact on the pre-treatment requirements, and potentially the efficiency of the reverse osmosis membranes, resulting in additional costs to produce drinking water. As there are significant development pressures in this area, water quality criteria have been defined for the intake seawater to ensure the efficacy of the desalination process and that the quality of the desalinated water is maintained (Table 9, EPA 2017).

No other guidelines have been defined for industrial water use (EPA 2017).

## 5.2 Perth Seawater Desalination Plant intake water quality monitoring

The Water Corporation undertakes real-time continuous monitoring of a suite of parameters including temperature, pH, dissolved oxygen and hydrocarbons in the intake seawater. All equipment at the desalination plant is routinely recalibrated to ensure accuracy and reliability.

The Water Corporation also monitors other parameters in the intake seawater via a routine sampling program. Parameters relevant to the water quality criteria include total suspended solids and bacterial indicators, which were monitored weekly during the reporting period; and boron and bromide, which were monitored three times. Sampling for the bacterial indicator *Escherichia coli* (*E. coli*) was replaced with sampling for enterococci in May 2017, as this gives a more robust pathogen indicator in salt water. For water quality parameters, water samples were collected by an in-house process chemist and analysed by accredited laboratories.

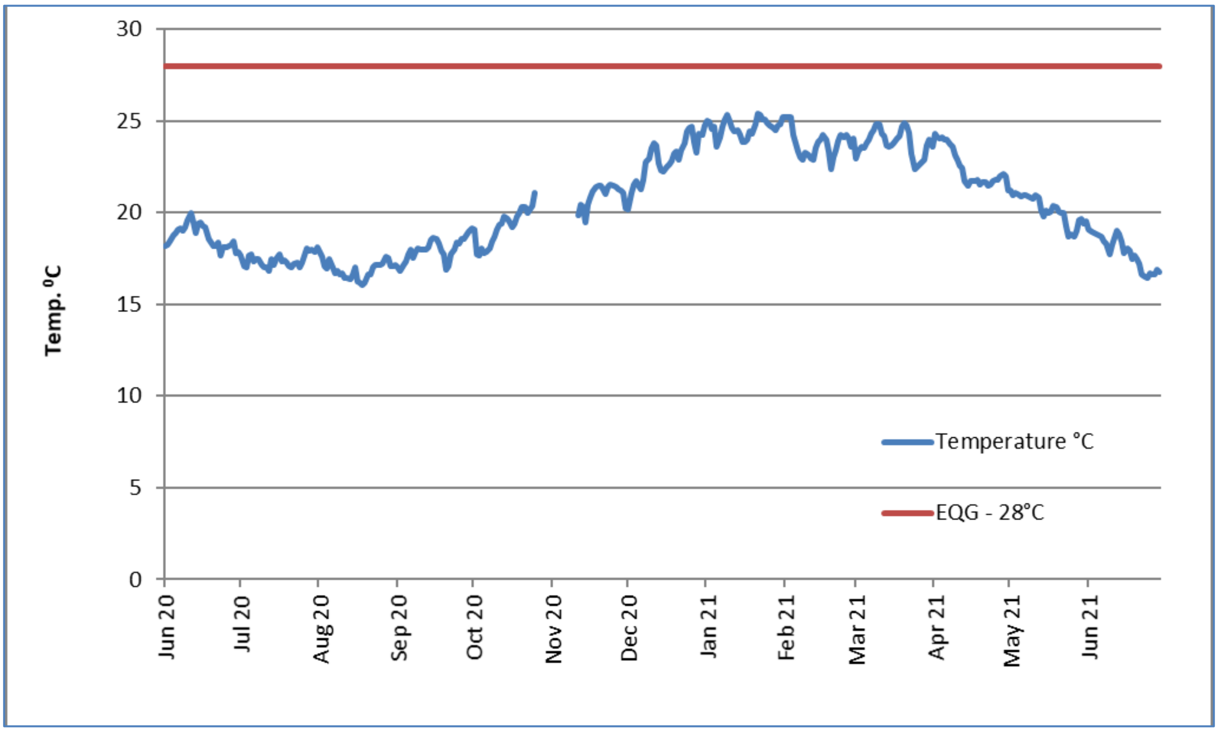
## 5.3 Assessment against the environmental quality criteria for maintenance of water quality for desalination plant intake water

### 5.3.1 Biological indicators

Enterococci did not exceed the EQG of 32 colony forming units per 100 millilitres (CFU/100 mL) on any sampling occasion over the July 2020 to June 2021 monitoring period. Enterococci was generally under the limit of reporting of <10 MPN/100 mL. The highest recording during the reporting period was 10 MPN/100 mL, which was recorded on two occasions.

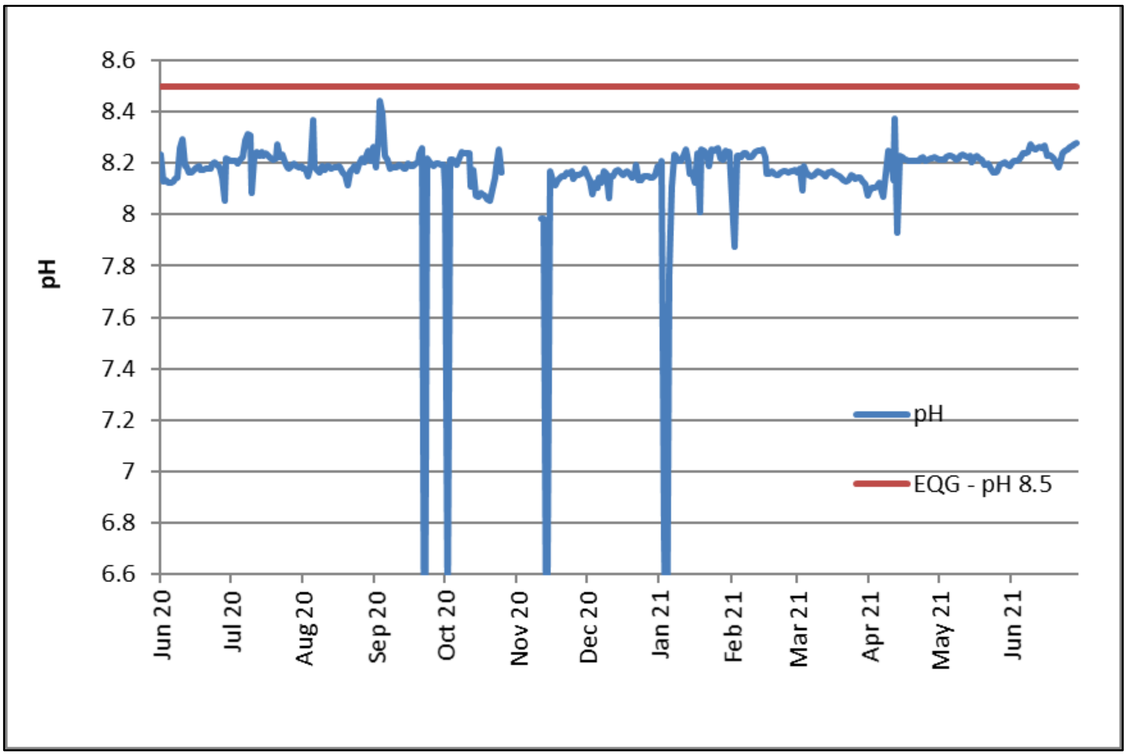
### 5.3.2 Physical and chemical indicators

Over the 2020–21 monitoring period, the temperature of the intake seawater was below the EQG of 28°C (Figure 5) and pH was below the EQG of 8.5 (Figure 6). DO concentrations were above the EQG of 2 milligrams per litre (mg/L) over the monitoring period (Figure 7).



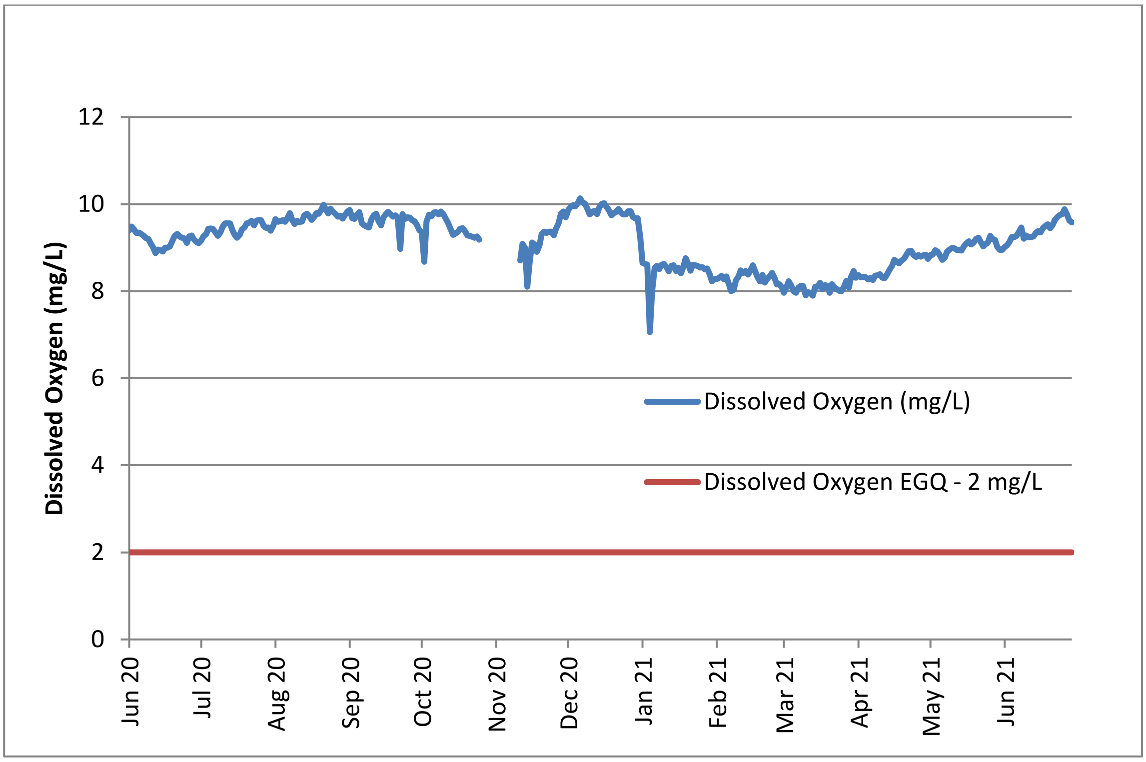

Note: Data recorded during the scheduled plant shutdown have been removed, as the data is not representative of seawater quality (data removed from 26/10/2020 to 10/11/2020).

*Figure 5: Daily average temperature of the intake seawater over the 2020–21 monitoring period*




Note: Data recorded during the scheduled plant shutdown have been removed, as the data is not representative of seawater quality (data removed from 26/10/2020 to 10/11/2020). Single point decreases in pH, such as what occurred on 13/11/2020, are also associated with short term plant shutdowns and the data is not representative of seawater quality.

*Figure 6: Daily average pH of the intake seawater over the 2020–21 monitoring period*




Note: Data recorded during the scheduled plant shutdown have been removed, as the data is not representative of seawater quality (data removed from 26/10/2020 to 10/11/2020).

*Figure 7: Daily average dissolved oxygen concentration of the intake seawater over the 2020–21 monitoring period*

The rolling four-week median concentration of total suspended solids exceeded the EQG of 4.5 mg/L intermittently for the periods of August, October and December 2020, and late January to early March and late April to June 2021 (Figure 8).

There were no exceedances of the Perth Seawater Desalination Plant limit (9 mg/L).

The Water Corporation advised that the dosing of coagulant in the desalination plant's pre-treatment process is automated to adjust to variance in total suspended solids up to the desalination plant's operational limit of 9 mg/L.

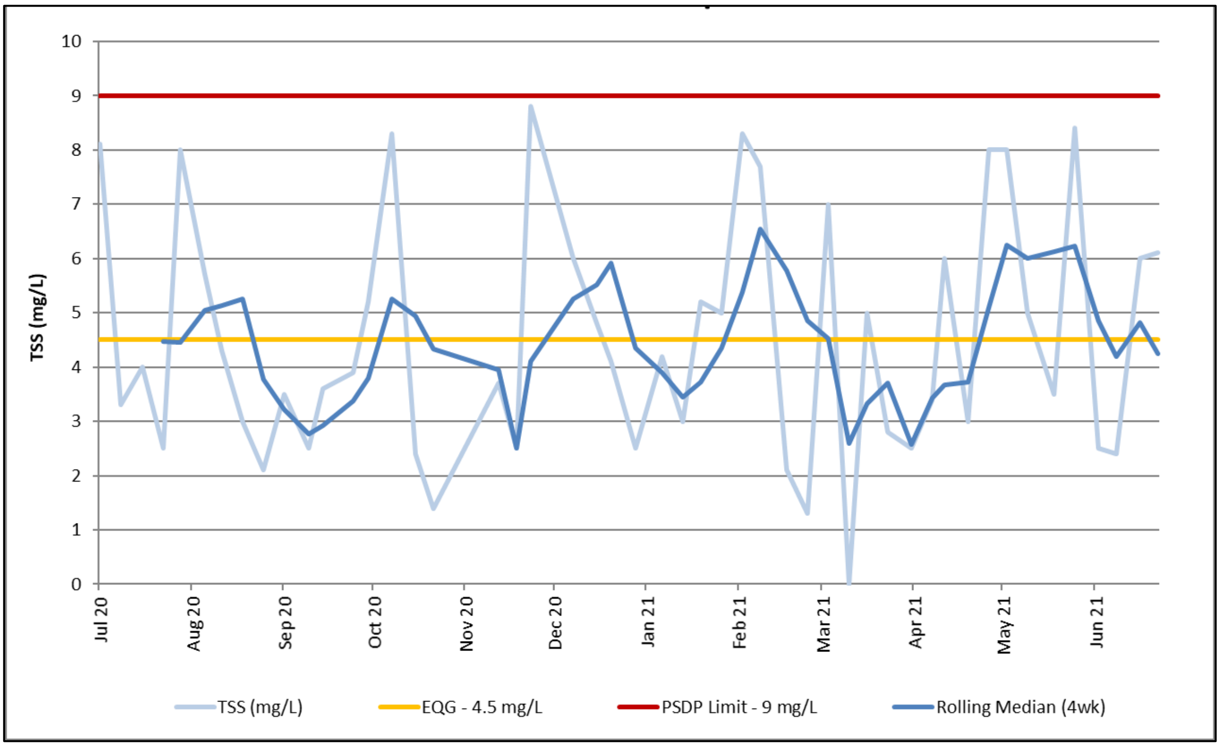



*Figure 8: Weekly and rolling four-weekly median total suspended solids (TSS) concentration in the intake seawater over the 2020–21 monitoring period*

Over the 2020–21 monitoring period, hydrocarbon concentrations in the intake seawater did not exceed the Water Corporation's limit, nor did boron concentrations exceed the EQG of 5.2 mg/L. Bromide concentrations exceeded the EQG of 77 mg/L on one sampling occasion (Table 38). The Water Corporation advised that boron and bromide are removed by the reverse osmosis process.

*Table 38: Quarterly concentrations of boron and bromide in the intake seawater over the 2020–21 monitoring period*

| Sampling occasion | Boron (mg/L) | | Sampling occasion | Bromide (mg/L) | |
|---|---|---|---|---|---|
| | EQG | Concentration | | EQG | Concentration |
| September 2020 | 5.2 | 4.8 | July 2020 | 77 | 74 |
| January 2021 | | 4.9 | October 2020 | | 69 |
| March 2021 | | 5.1 | February 2021 | | 73 |
| June 2021 | | 4.9 | April 2021 | | 79 |

The Water Corporation advised that it did report a significant reduction in efficiency of the desalination process from late January to mid-March 2021 because of the quality of the intake seawater. The reduced efficiency was related to an algal bloom consisting of high quantities of very small algae (<5 µm). Natural variation in the quality of the intake seawater was observed by the Water Corporation, outside the period discussed above, over the 2020–21 monitoring period as in previous years. However, these variances had minimal effect on the operation of the desalination plant.

## 5.4 Conclusions

The results from the 2020–21 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated there were minor exceedances of the EQG for total suspended solids and bromide. The suitability of the quality of the intake seawater for the desalination process was considered to have been compromised because of an algal bloom from late January to mid-March 2021. Outside of this timeframe, the quality of the intake seawater was considered suitable for the desalination process.

Therefore, the environmental quality objective of maintenance of water quality for industrial use was considered to have been achieved during the reporting period.

# List of shortened forms

| | |
|---|---|
| ASP | amnesic shellfish poison |
| BDI | butyltin degradation index |
| BTEX | benzene, toluene, ethylbenzene and xylene |
| CFU | colony forming unit |
| DBT | dibutyltin |
| DO | dissolved oxygen |
| DSP | diarrhoetic shellfish poison |
| EPA | Environmental Protection Authority |
| EQC | environmental quality criteria |
| EQG | environmental quality guideline(s) |
| EQS | environmental quality standard(s) |
| HPA-N | High Protection Area North |
| HPA-S | High Protection Area South |
| KBJ | Kwinana Bulk Jetty |
| KBT | Kwinana Bulk Terminal |
| LAC | light attenuation coefficient |
| LRV | low reliability value |
| MAFRL | Marine and Freshwater Research Laboratory |
| MBT | monobutyltin |
| MPA-CB | Moderate Protection Area Careening Bay |
| MPA-ES | Moderate Protection Area Eastern Sound |
| MPA-NH | Moderate Protection Area Northern Harbour |
| MPA-SH | Moderate Protection Area Southern Harbour |
| MPN | most probable number |
| PAH | polycyclic aromatic hydrocarbon |
| PFAS | perfluoroalkyl and polyfluoroalkyl substances |
| PFOA | perfluorooctanoic acid |
| PFOS | perfluorooctane sulfonate |
| pH | potential of hydrogen |
| PSP | paralytic shellfish poison |
| State Environmental Policy | State Environmental (Cockburn Sound) Policy 2015 |

| | |
|---|---|
| TBT | tributyltin |
| TOC | total organic carbon |
| TRH | total recoverable hydrocarbons |
| TTM | total toxicity of the mixture |
| WASQAP | Western Australia Shellfish Quality Assurance Program |

# Glossary

| | |
|---|---|
| Anthropogenic | Resulting from, or relating to, the influence of human beings on nature. |
| Approved shellfish harvesting area | A shellfish harvesting area classified as 'approved' for harvesting or collecting shellfish for direct marketing. |
| Butyltin degradation index (BDI) | The relationship between tributyltin (TBT) and its breakdown products dibutyltin (DBT) and monobutyltin (MBT) provides an indication of how recently contamination occurred.<br>BDI = (DBT + MBT)/TBT (Garg *et al*. 2009). A BDI of 1.0 indicates that half the TBT has broken down into DBT and MBT (in other words TBT in the sediment has reached its half-life). |
| Chlorophyll *a* | A complex molecule that can capture sunlight and convert it into a form that can be used for photosynthesis (a process which uses solar energy to convert carbon dioxide and water into carbohydrate). The concentration of chlorophyll *a* in water is used as a measure of phytoplankton biomass. |
| Conditionally approved shellfish harvesting area | The classification of a shellfish harvesting area which meets approved harvesting area criteria for a predictable period. The period depends upon established performance standards specific in a management plan. A 'conditionally approved' area is closed when it does not meet the approved harvesting area criteria. |
| Contaminant | Any physical, chemical or biological substance or property which is introduced into the environment. Does not imply any effect. |
| Environmental quality criteria (EQC) | The numerical values (e.g. cadmium 0.7 µg/L) or narrative statements (e.g. the 95th percentile of the bioavailable contaminant concentration in the test samples should not exceed the EQG value) that serve as benchmarks to determine whether a more detailed assessment of environmental quality is required (EQG), or whether a management response is required (EQS). |
| Environmental quality guideline (EQG) | A numerical value or narrative statement which, if met, indicates there is a high probability that the associated environmental quality objective has been achieved. |
| Environmental quality management framework | Provides the context within which management of existing activities and decisions about future activities occurs. The management framework does this by confirming the environmental objectives and establishing ambient environmental limits and triggers. |
| Environmental quality | A specific management goal for a part of the |

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| objective | environment, which is either ecologically based (by describing the desired level of health of the ecosystem) or socially based (by describing the environmental quality required to maintain specific human uses). |
| Environmental quality standard (EQS) | A numerical value or narrative statement which, if not met, indicates a high probability that the associated environmental quality objective has not been achieved and a management response is triggered. |
| Environmental value | A particular value or use of the marine environment that is important for a healthy ecosystem or for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharge and deposits. There are two types of environmental value: ecological and social. |
| Extraneous residue limit | The maximum concentration of a pesticide residue or contaminant arising from environmental sources (including former agricultural use) other than the direct or indirect use of a pesticide or contaminant substance that is legally permitted or accepted in a food. |
| High level of ecological protection | Allows for small changes in the quality of water, sediment or biota (e.g. small changes in contaminant concentrations with no resultant detectable changes beyond natural variation in the diversity of species and biological communities, ecosystem processes and abundance/biomass of marine life). |
| Light attenuation in water | The exponential decay of light intensity with increasing depth because of absorption and scattering.<br>A large light attenuation coefficient means that light is quickly ‘attenuated’ (i.e. weakened) as it passes through the water column; a small light attenuation coefficient means that the water is relatively transparent to light. |
| Low level of ecological protection | Allows for large changes in the quality of water, sediment or biota (such as large changes in contaminant concentrations that could cause large changes beyond natural variation in the diversity of species and biological communities, rates of ecosystem processes and abundance/biomass of marine life, but which do not result in bioaccumulation/biomagnification in nearby high ecological protection areas). |
| Low reliability value (LRV) | For a number of toxicants where there are insufficient toxicological data to develop reliable guideline trigger levels, low reliability values have been derived to give guidance in the absence of any higher reliability guidelines being available. LRVs should not be used as default guideline trigger values. However, it is assumed |

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| | that if ambient concentrations fall below the LRV, there is low risk of ecological impact. If concentrations are above an LRV, it does not necessarily mean an impact is likely. Exceedance of an LRV does not trigger mandatory assessment against the EQS, but does signal that the possibility of ecological impact should be considered, particularly if further increases beyond the LRV are likely. |
| Maximum residue limit | The highest concentration of a chemical residue that is legally permitted or accepted in a food. |
| Median | A measure used in statistics representing the ‘middle’ number in a sequence of numbers that has been arranged from the smallest value to the largest value. The main advantage of the median compared with the average or mean of a dataset, is that is it not influenced so much by very large or very small values and is therefore considered to be more representative of most values in a dataset. |
| Moderate level of ecological protection | Allows for moderate changes in the quality of water, sediment or biota (such as moderate changes in contaminant concentrations that could cause small changes beyond natural variation in ecosystem processes and abundance/biomass of marine life, but no detectable changes from the natural diversity of species and biological communities). |
| Non river-flow period | The main period for nutrient-related monitoring in Cockburn Sound. This is over summer when river flow is minimal and nutrient concentrations are most stable. |
| Normalisation | A procedure to adjust concentrations of contaminants in sediments for the influence of natural variability in sediment composition, particularly for grain size, organic matter content and mineralogy. |
| Nutrients | Elements or compounds, such as nitrogen and phosphorus, which are essential for organic growth and development. |
| Percentile | A measure used in statistics whereby the *p*th percentile of a distribution of data is the value that is greater than or equal to *p*% of all the values in the distribution. E.g. the 80th percentile is greater than or equal to 80% of all values; conversely, 80% of all values are less than or equal to the 80th percentile. |
| Perfluoroalkyl and polyfluoroalkyl substances (PFAS) | A group of synthetic fluorine-containing chemicals used in heat-, stain- and water-resistant products (such as non-stick cookware, specialised textiles, Scotchgard™) and that were used in firefighting foams. PFAS are highly persistent in the environment, are moderately soluble, |

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| | and can be transported long distances and transfer between soil, sediment, surface water and groundwater. They have been shown to be toxic to some animals and, because they break down very slowly, can bioaccumulate and biomagnify in some wildlife, including fish. This means that fish and animals higher in the food chain may accumulate higher concentrations of PFAS in their bodies.<br><br>Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are two of the best-known PFAS and are contaminants of emerging concern in Australia and internationally. They have been identified in the environment at several known and suspected contaminated sites in Western Australia. |
| Phytoplankton | Single-celled plants and other photosynthetic organisms (including cyanobacteria, diatoms and dinoflagellates) that live in the water column. |
| Re-sampling trigger | Where the total concentration of a contaminant in individual sediment sample sites exceeds the EQG re-sampling trigger, additional sampling of that potentially contaminated site will generally be required to better define the area of high concentration. |
| Shellfish | Under the *Western Australia Shellfish Quality Assurance Program (WASQAP) operations manual 2017* (Department of Health 2017) shellfish means all edible species of molluscan bivalves such as oysters, clams, scallops, pipis and mussels, either shucked or in the shell, fresh or frozen, whole or in part or processed. The definition does not include spat, scallops or *Pinctada* spp. where the consumed product is only the adductor mussel. |
| Social value | A particular value or use of the marine environment that is important for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharges and deposits. |
| State Environmental Policy | The *State Environmental (Cockburn Sound) Policy 2015* which is a non-statutory instrument developed by the Environmental Protection Authority under the *Environmental Protection Act 1986* that provides an important mechanism for the environmental management of Cockburn Sound. It is a flexible policy instrument which was developed through public consultation and adopted on a whole-of-government basis. |
| Total nitrogren; total phosphorus | In seawater the total nitrogen and total phosphorus concentrations are made up of a combination of soluble and insoluble organic and inorganic compounds. The |

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| | organic nutrients incorporate all organic particulate matter, including phytoplankton, zooplankton, bacteria and organic surface films on re-suspended sediments, detrital matter and some soluble organic compounds. The inorganic nitrogen compounds consist of dissolved nitrite, nitrate and ammonia in solution. Inorganic phosphorus is made up of dissolved inorganic ortho-phosphates. |
| Total toxicity of the mixture (TTM) | An interpretive tool used for estimating the potential toxicity of mixtures of up to five toxicants, where the interactions are simple and predictable. If the total toxicity of the mixture exceeds one, the mixture has exceeded the water quality guideline.<br>$TTM = \sum(C_i)/EQG_i)$, where $C_i$ is the concentration of the ‘i’th component in the mixture and $EQG_i$ is the guideline for that component. |

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# Appendix A: Monthly chlorophyll *a* concentrations and light attenuation

## Chlorophyll *a*

The chlorophyll *a* concentrations measured monthly at the water monitoring sites in Cockburn Sound generally peaked during late winter (Figures A1 to A3). The chlorophyll *a* concentrations measured during the winter peak were similar in High Protection Area North (HPA-N) and High Protection Area South (HPA-S). The HPA-S site MB was the only site that did not peak in the winter, instead having peaks in May and October 2021 (Figure A2). The Moderate Protection Area Eastern Sound (MPA-ES) site CS10N had the highest chlorophyll *a* concentration in MPA-ES in March 2021 and the lowest in MPA-ES in the winter peak in August 2021 (Figure A3).

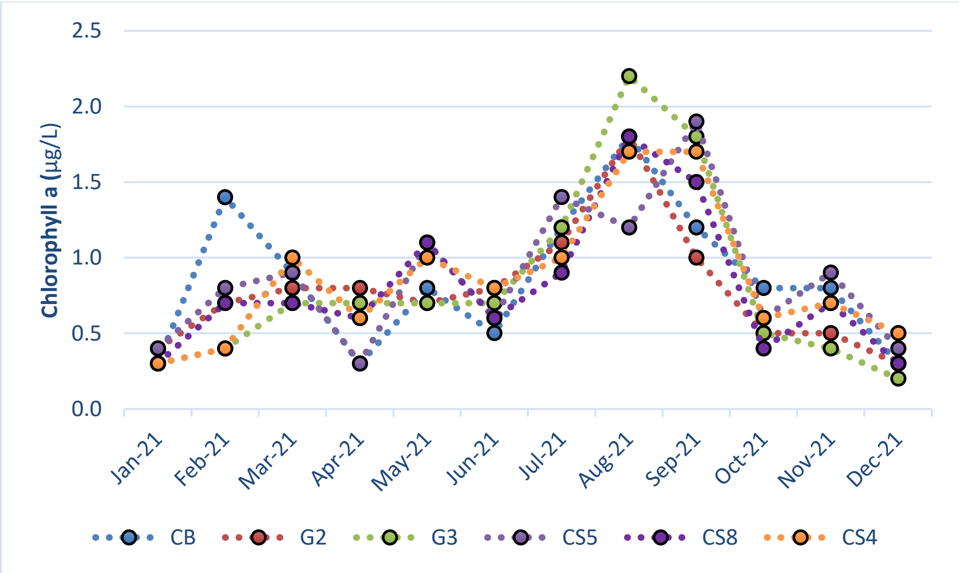


*Figure A1: Monthly chlorophyll* a *concentrations measured at water quality monitoring sites in HPA-N from January to December 2021*

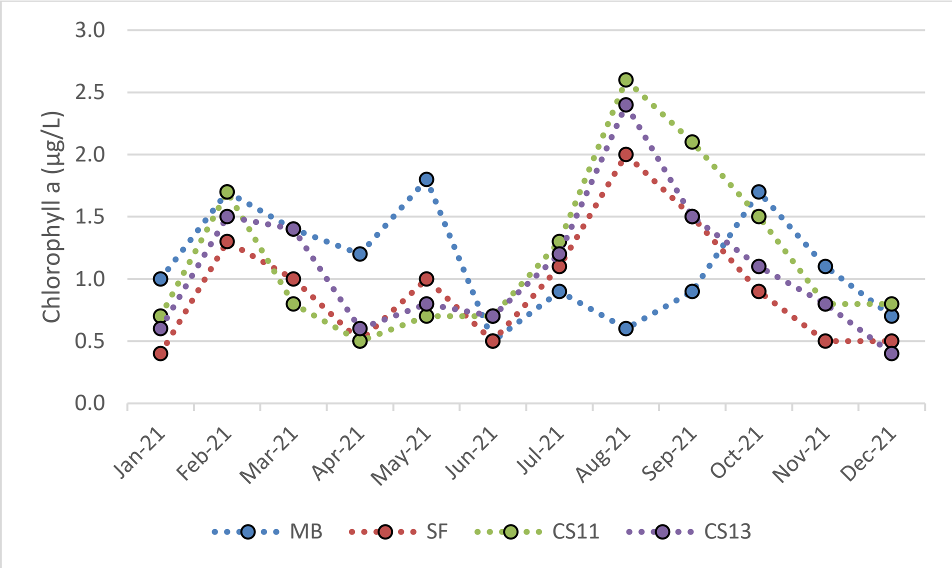


*Figure A2: Monthly chlorophyll a concentrations measured at water quality monitoring sites in HPA-S from January to December 2021*

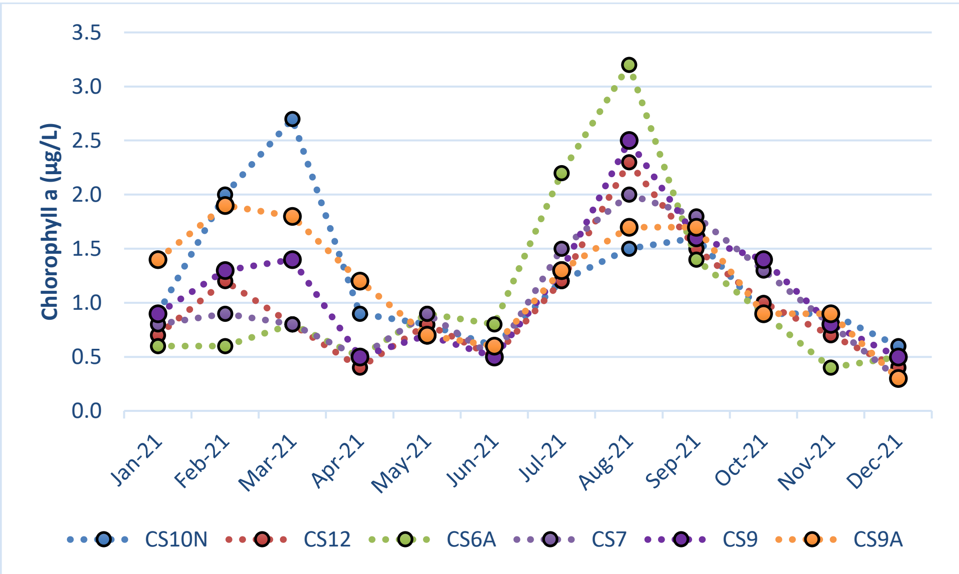


*Figure A3: Monthly chlorophyll a concentrations measured at water quality monitoring sites in MPA-ES from January to December 2021*

## Light attenuation coefficient

The light attenuation measured monthly at the water monitoring sites in Cockburn Sound also peaked in winter, with no discernible peak in the summer months except for sites CS9A and CS10N in MPA-ES (Figures A4 to A6). Site G2 in HPA-N peaked in July 2021, while the remainder of the water monitoring sites in HPA-N reached their peaks in the following month (Figure A4).

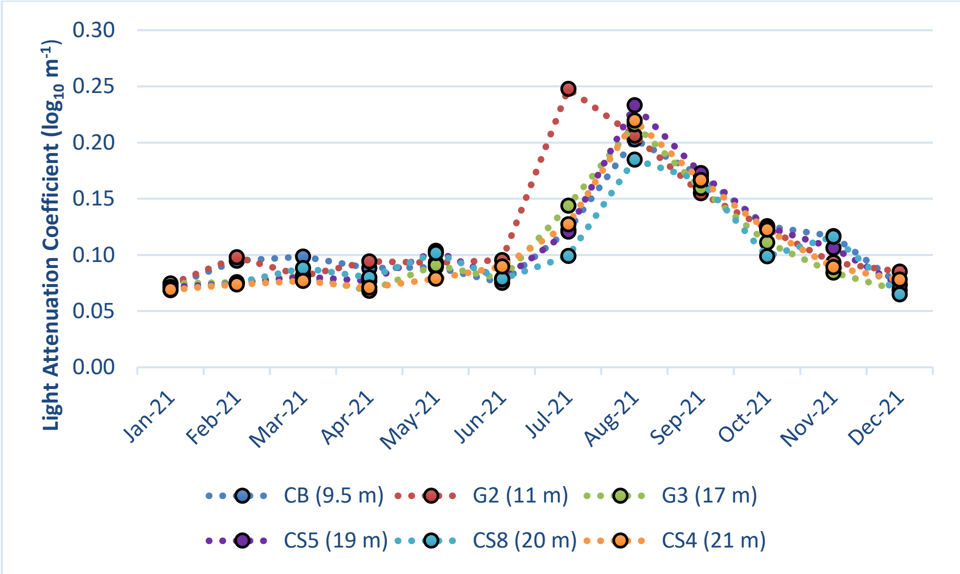


*Figure A4: Monthly light attenuation at water quality monitoring sites in HPA-N from January to December 2021; site depths are provided in brackets.*

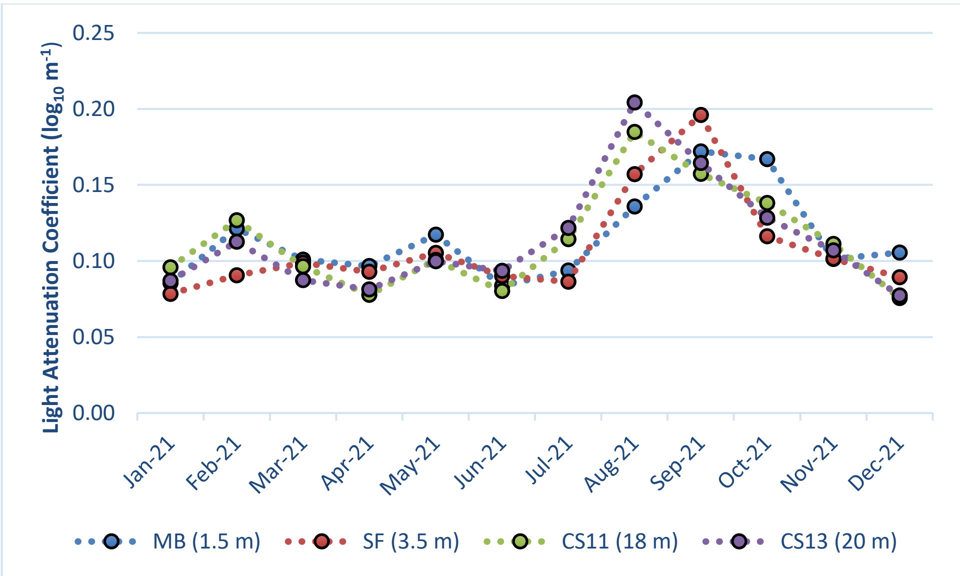


*Figure A5: Monthly light attenuation at water quality monitoring sites in HPA-S from January to December 2021; site depths are provided in brackets.*

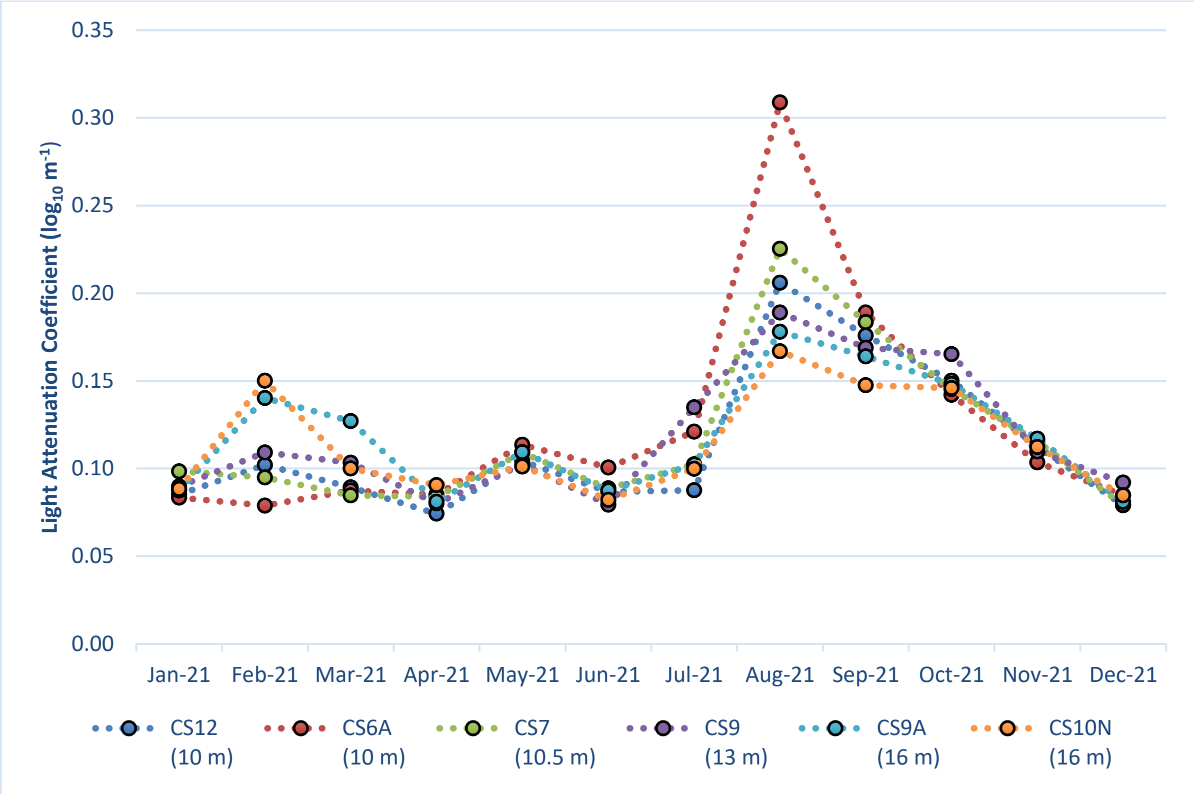


*Figure A6: Monthly light attenuation at water quality monitoring sites in MPA-ES from January to December 2021; site depths are provided in brackets.*

# Appendix B: Monthly nutrient concentrations

## Ammonium

The ammonium concentrations measured monthly at the water monitoring sites in High Protection Area North (HPA-N) peaked in August 2021 and dropped sharply in September 2021 (Figure B1). The monthly ammonium concentrations measured during the winter peak were generally higher at HPA-N water monitoring sites than High Protection Area South (HPA-S) water monitoring sites (Figure B2). The winter peak at the HPA-S sites occurred earlier than at HPA-N sites but showed a similar sharp drop in September 2021. The monthly ammonium concentrations showed a similar pattern at Moderate Protection Area Eastern Sound (MPA-ES) sites but with the addition of two smaller peaks at some sites in March and October/November 2021 (Figure B3).

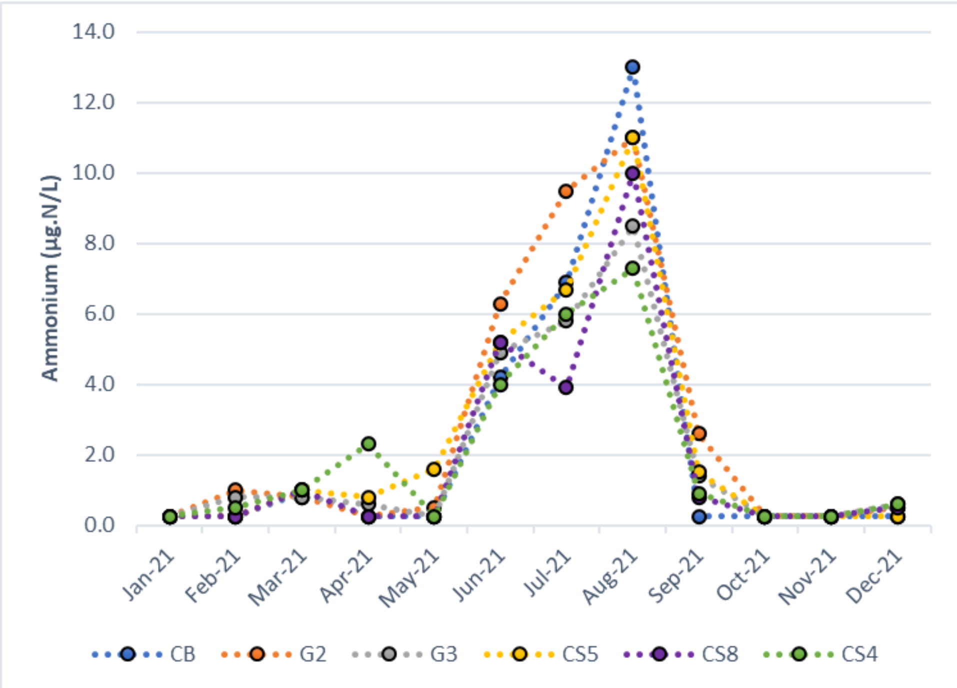


*Figure B1: Monthly ammonium concentrations at water quality monitoring sites in HPA-N from January to December 2021*

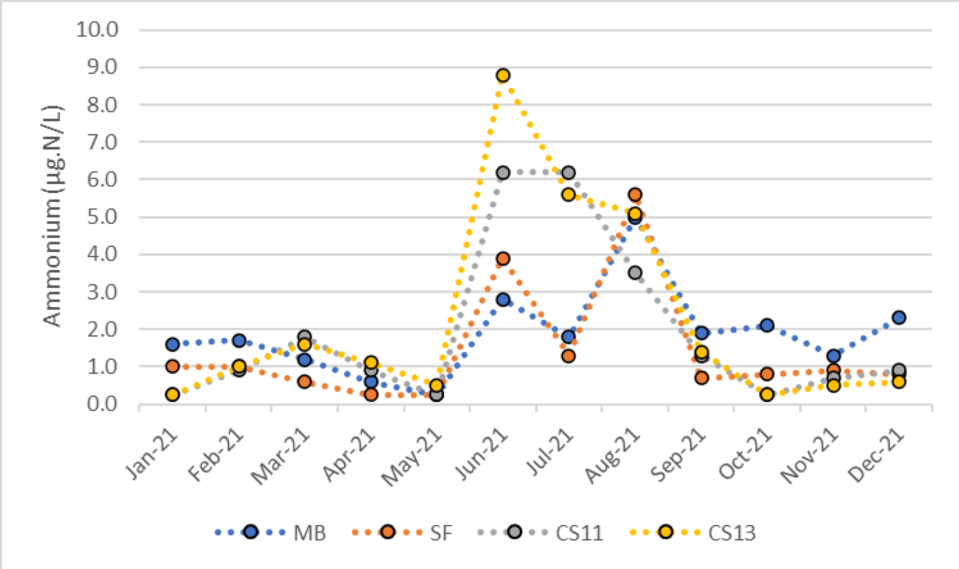


*Figure B2: Monthly ammonium concentrations at water quality monitoring sites in HPA-S from January to December 2021*

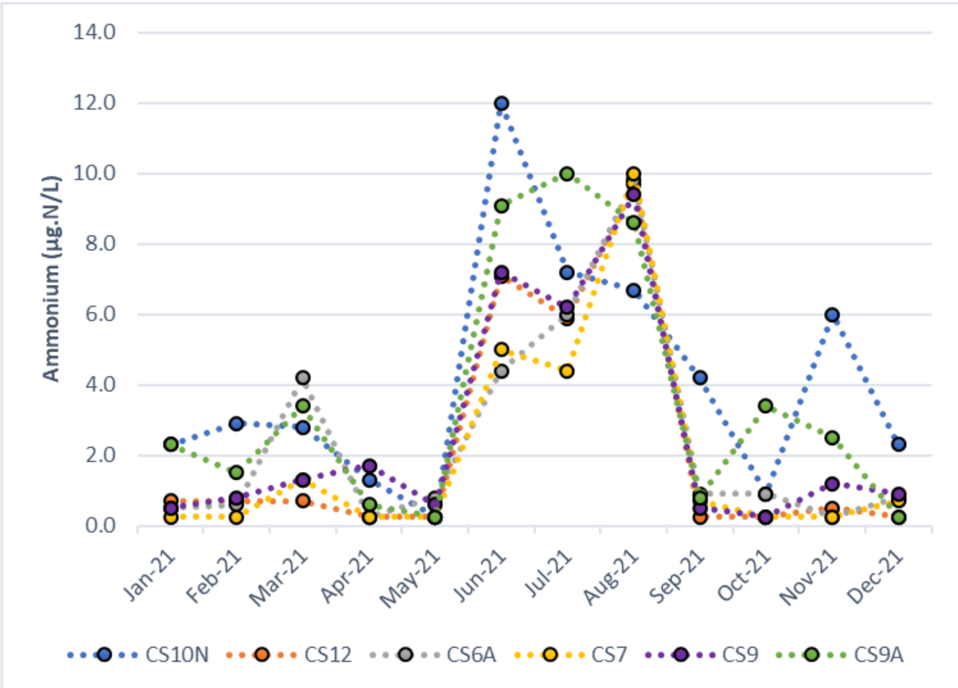


*Figure B3: Monthly ammonium concentrations at water quality monitoring sites in MPA-ES from January to December 2021*

## Total nitrogen

The monthly total nitrogen concentrations measured at the water monitoring sites in HPA-N peaked in August 2021, then began to decrease in September 2021 (Figure B4). The monthly total nitrogen concentrations measured during the winter peak were higher at HPA-N water monitoring site than at HPA-S sites, with the HPA-S site MB showing considerable variability throughout the year (Figure B5). The water monitoring sites in MPA-ES showed a similar pattern in monthly total nitrogen concentrations as was seen for HPA-N sites (Figure B6).

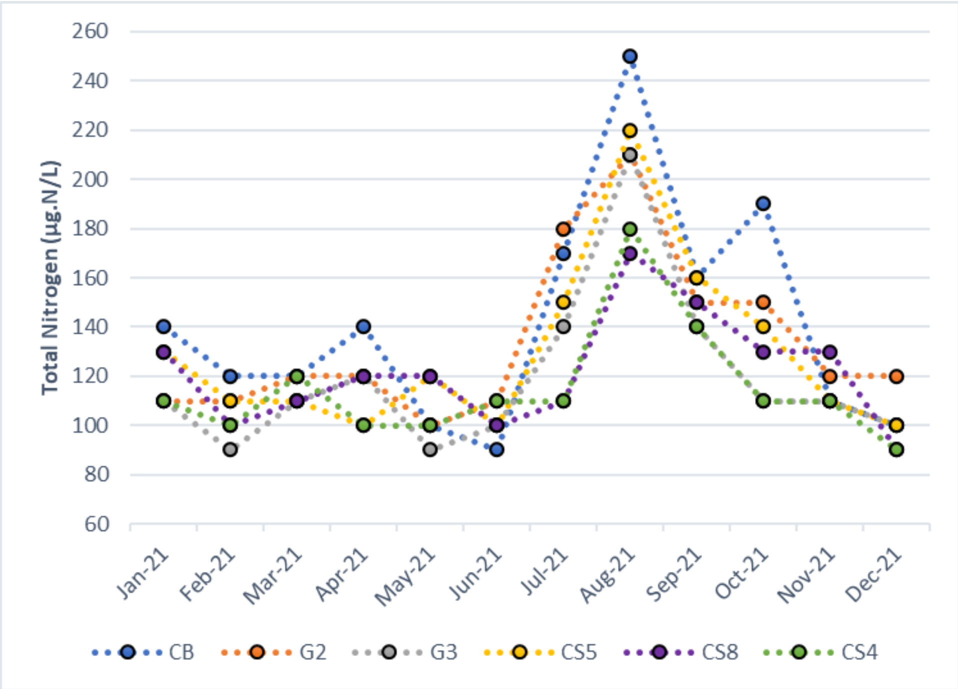


*Figure B4: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-N from January to December 2021*

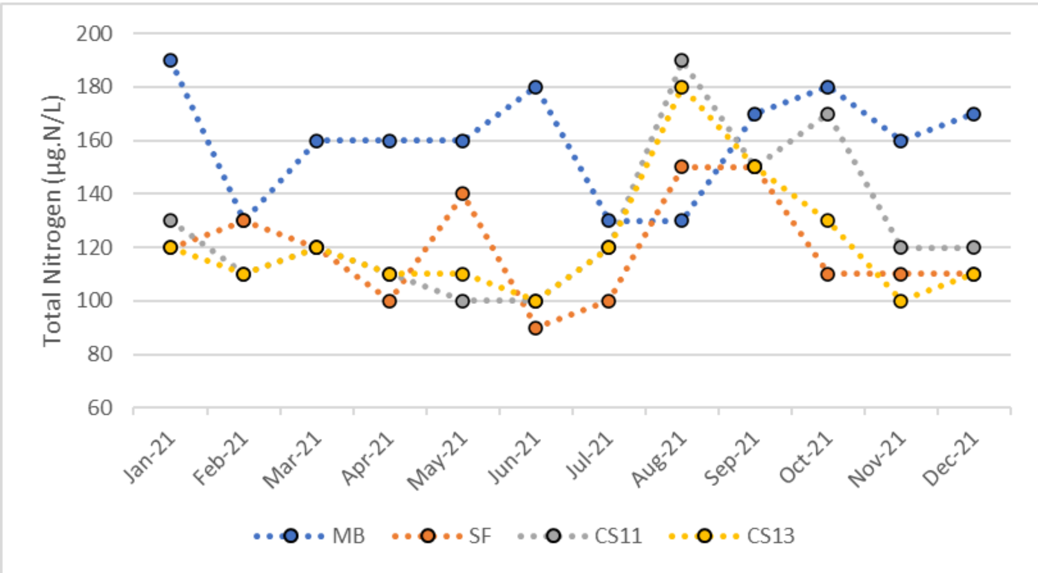


*Figure B5: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-S from January to December 2021*

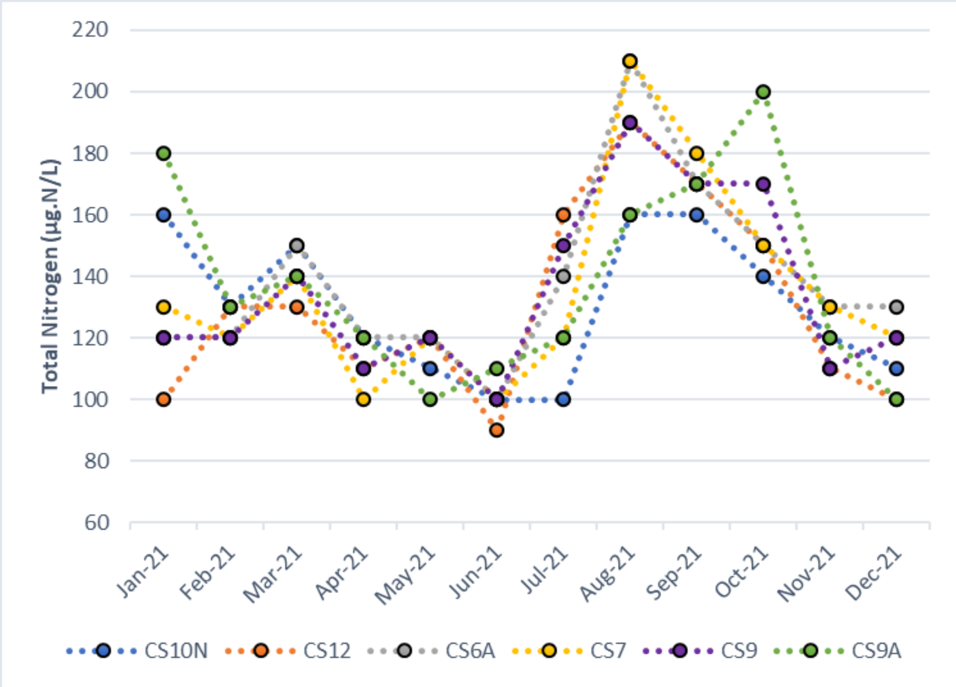


*Figure B6: Monthly total nitrogen concentrations at water quality monitoring sites in MPA-ES from January to December 2021*

## Total phosphorus

The monthly total phosphorus concentrations at water monitoring sites in HPA-N were variable with multiple peaks throughout the year (Figure B7). The monthly total phosphorus concentrations at HPA-S water monitoring sites displayed a different pattern of variability with multiple peaks (Figure B8). The lowest monthly total phosphorus concentration at HPA-S site MB occurred in August 2021, unlike the other HPA-S sites which showed a small peak in the monthly total phosphorus concentrations in August 2021. The monthly total phosphorus concentrations at water monitoring sites in MPA-ES showed distinct peaks in January/February, August and October 2021 (Figure B9).

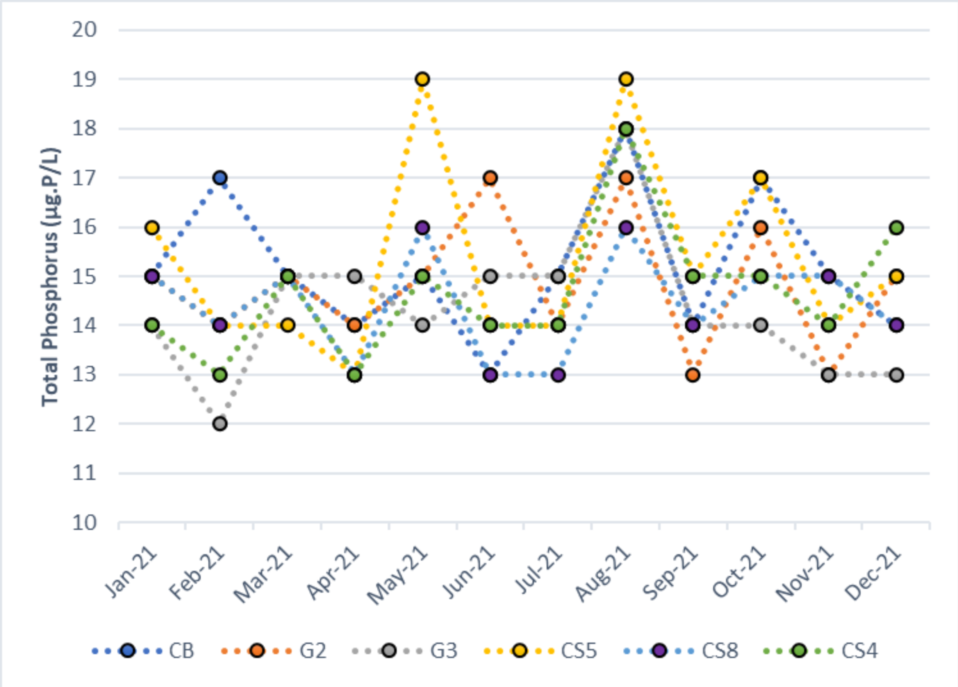


*Figure B7: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-N from January to December 2021*

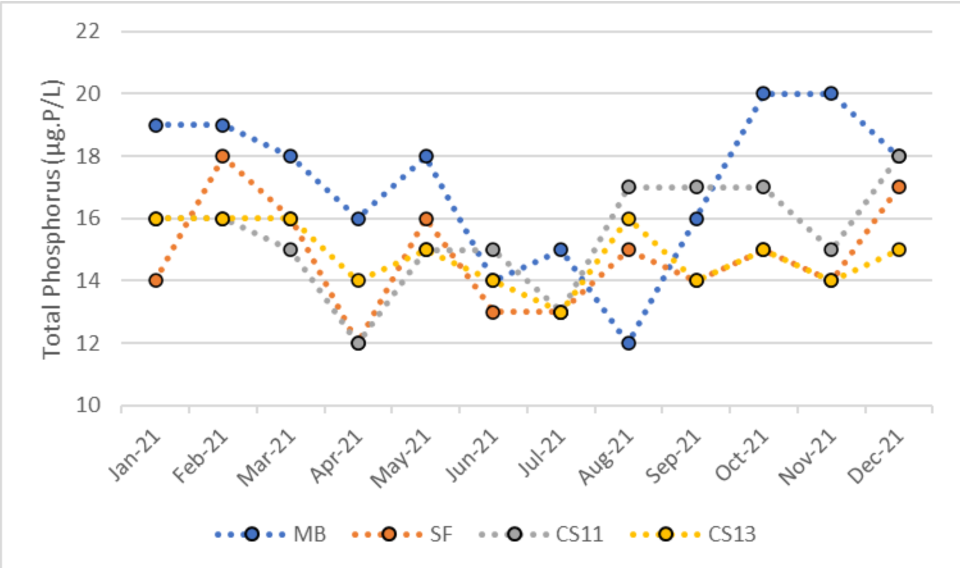


*Figure B8: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-S from January to December 2021*

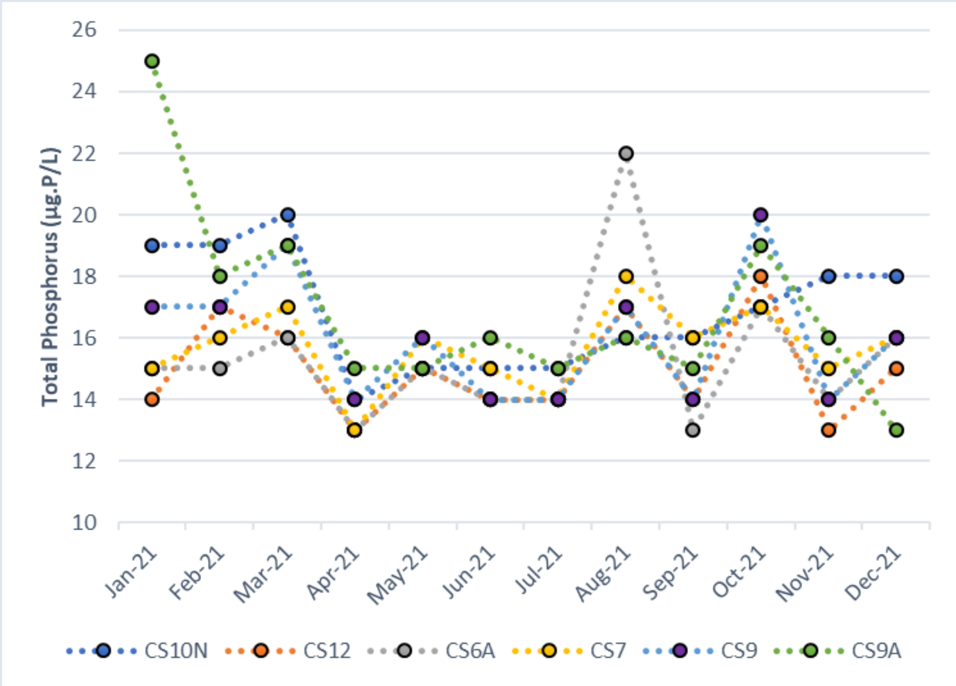


*Figure B9: Monthly total phosphorus concentrations at water quality monitoring sites in MPA-ES from January to December 2021*