GHD

Review of Past Water Quality and Sediment Quality

Koombana Bay Marine Structures SPER

South West Development Commission

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→ The Power of Commitment

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Executive summary

The South West Development Commission is the proponent for a proposed upgrade of the Bunbury Marine Facilities precinct, referred to as the Koombana Bay Marine Structures (KBMS) project. The Western Australia Environmental Protection Authority (EPA) has determined it to be assessed as a strategic proposal at the Public Environment Review level (SPER). In this report the past water quality and sediment quality data in the vicinity of the KBMS proposal is reviewed to meet some of the EPA requirements, namely:

- An overview of the historical development of Koombana Bay.
- As the water quality, and to a lesser degree the sediment quality, is linked to the metocean dynamics, a summary of the past metocean measurements and hydrodynamic/wave modelling in the vicinity of the KBMS is provided.
- Characterisation of the water and sediment quality of the KBMS proposal locale, and evaluation of its acceptability in terms of relevant guidelines and/or trigger values.

This review serves to inform the marine environmental quality impact assessment of the proposed construction and operational activities of the KBMS SPER, and the preparation of relevant construction and operational management plans.

Over the past ~150 years Koombana Bay has undergone substantive physical changes since its pre-European condition including the following key developments:

- The Outer Harbour timber jetty was established 1864 with a length of ~425 m that was increased to 1,400 m by 1952.
- Casuarina Point breakwater was established in 1897-1899 with extensions through 1961.
- ‘The Cut’ was established in 1951 to re-position the confluence of the Collie River and Preston River with Koombana Bay from Point MacLeod to prevent river-induced siltation of the Outer Harbour.
- The Inner Harbour was established from 1971-1976 with associated Preston River realignment, capital dredging and reclamation (~9.4 Mm^3), and cutting the opening to Leschenault Inlet at ‘The Plug’.
- Maintenance dredging activities have been carried out since 1961 with disposal to offshore spoil grounds since 1967.

The land-sea breeze cycle is the dominant feature of the wind climate, typically with morning easterlies and afternoon southerlies to westerlies. Waves are greater in winter than summer with the largest waves locally generated and approaching from the northwest. Surface current patterns in Koombana Bay are strongly wind dependent, however, deep-channel flushing of the Inner Harbour is enhanced through upwelling of the Shipping Channel waters into the Inner Harbour and adjacent portions of southeastern Koombana Bay. Wind directions tend to strongly affect current directions in western Koombana Bay with northerly winds transporting waters from the centre of Koombana Bay towards the southern shoreline, and conversely, southerly winds transporting shallow waters to the northern bay’s deeper waters.

Past simulations of the e-folding time scales (i.e. time to flush ~63% of a water body’s volume) for Casuarina Boat Harbour range from 1.5-1.9 days. A rhodamine dye study’s estimate in Casuarina Boat Harbour was 1.9-2.5 days in reasonable agreement with model predictions.

On the basis of physico-chemical monitoring over periods from 2007-2020 of Koombana Bay and its adjacent water bodies of interest (i.e. Inner Harbour, Outer Harbour, Casuarina Boat Harbour, Leschenault Inlet) typically had the following ranges:

- 15-25°C for water temperature.
- 34-37 psu for salinity.
- 90-100% percentage dissolved oxygen (DO) saturation, generally between 5-12 mg/L total suspended solids concentration, and generally surface turbidity <10 nephelometric units (NTU).

Metals and metalloids in the waters of Koombana Bay, Inner Harbour, Casuarina Boat Harbour, Leschenault Inlet and proximal open inshore coastal reference sites were below ANZG (2018) toxicant default guideline values over periods from 2007-2020. There is some evidence to suggest lead and silver, and particularly manganese, exhibit gradients with higher levels in the Inner Harbour. Over six (6) surveys in 2012, dissolved copper, cadmium, lead, zinc and mercury had at least one exceedance of the ANZG (2000) toxicant trigger values across eight stations in Koombana Bay and the Inner Harbour.

Nutrients and chlorophyll a (chl-a) in the Koombana Bay locale can be characterised as:

– Averages from five Bunbury Ocean Outfall Monitoring program reference sites meet the adopted ANZECC (2000) default trigger values for slightly disturbed South West Australian inshore marine waters and seasonally varying ANZG (2018) default guideline values for the Leeuwin-Naturaliste Interim Marine and Coastal Region of Australia for all nutrients and chl-a.
– Generally, Casuarina Boat Harbour, Koombana Bay and the Inner Harbour are below the relevant adopted guideline criteria for total nitrogen (TN), but often exceed those for chl-a, oxidised inorganic nitrogen, reduced inorganic nitrogen and total phosphorus, but less so for filtered reactive phosphorus.
– Recent surveys of Koombana Bay and Casuarina Boat Harbour (monthly September 2016-September 2017) and at a northern shoreline station of Leschenault Inlet (semi-annual from May 2014-November 2017) indicate that the nutrient climate has been similar over the past ~20 (Koombana Bay, Casuarina Boat Harbour) to ~40 (Leschenault Inlet) years.

Inputs from the Preston River and Collie River into Leschenault Estuary, Bunbury Port activities and the surrounding urban area are likely the major contributors of nutrient loads to Koombana Bay, thereby contributing to elevated chl-a relative to the proximal exposed inshore coastal waters. However, chl-a levels are relatively consistent in Koombana Bay and the adjacent water bodies even though there are variations in nitrogen and phosphorus, as well as flushing time scales.

During November 2006 coarser sediments were measured at greater wave-exposed inshore waters relative to more protected Koombana Bay with predominately coarse silt (38-63 µm) in the Shipping Channel, very fine sand (63-90 µm) in the Inner Harbour and Outer Harbour, and medium sand (250-500 µm) at the spoil ground. Median particle diameters of surficial sediments of western Koombana Bay ranged from medium sand (250-500 µm) to coarse silt (38-63 µm). In terms of the KBMS proposal's sediments slated for dredging, >60% fine material comprised of silt and clay occurs in the phase 1 Casuarina Boat Harbour northern breakwater footprint, ~27% in the phase 2 Casuarina Boat Harbour sediments, and ~13% of the Koombana Bay Sailing Club marina sediments.

The metals and metalloids, and TBT in the marine sediments of Koombana Bay, Casuarina Boat Harbour and Outer Harbour indicate that potential contaminants of concern in Casuarina Boat/Outer Harbour and Koombana Bay are Sb, As, Ag and TBT. However, though these exceedances are above the ANZG (2018) toxicant default guideline values for sediment quality, they do not approach the ANZG (2018) 'high' toxicant default guideline values for sediment quality.

During surveys in 2007, 2010-2011, 2015 and 2020 the total polycyclic aromatic hydrocarbons, total petroleum hydrocarbons, and organophosphate/organochlorine pesticides were below NAGD (2009) screening levels.

Metals and metalloids in blue mussels over six (6) surveys from May 2008-June 2011 in the Inner Harbour, Outer Harbour and reference sites were compared to the EPA (2017) environmental quality guidelines and standards. Exceedances and spatial patterns generally co-occur across the three sites, which suggests metals and metalloids levels in biota respond to regional drivers.

This report is subject to, and must be read in conjunction with, the limitations, assumptions and qualifications contained throughout the Report.

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Acronyms and abbreviations

Acronym / Abbreviation	Description
Ag	Silver
Al	Aluminium
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Guidelines
As	Arsenic
BoM	Bureau of Meteorology
BTEX	Benzene, Toulene, Ethylbenzene and Xylene
CD	Chart Datum
Cd	Cadmium
Chl-a	Chlorophyll-a
CI	Confidence Interval
cm/s	Centimeters per Second
Co	Cobalt
Cr	Chromium
CrIII	Chromium III
CrVI	Chromium VI
Cu	Copper
DDC	Dolphin Discovery Centre
DGVPC	Default Guideline Value for Physical and Chemical Stressors
DGVTS	Default Guideline Value for Toxicants in Sediments
DGVTS -high	High Default Guideline Value for Toxicants in Sediments
DGVT	Default Guideline Value for Toxicants
DO	Dissolved Oxygen
DoW	Department of Water
DoT	Department of Transport
DTVPC	Default Trigger Value for Physical and Chemical Stressors
DWER	Department of Water and Environmental Regulation
EFSA	European Food Safety Authority
EPA	Environmental Protection Authority
ESD	Environmental Scoping Document
Fe	Iron
FRP	Filterable Reactive Phosphorus
H_S	Significant Wave Height
Hg	Mercury
ha	Hectare
hr	Hour
IMCRA	Integrated Marine and Coastal Regionalisation of Australia

Acronym / Abbreviation	Description
ISQG-low	Low Interim Sediment Quality Guideline Value
ISQG-high	High Interim Sediment Quality Guideline Value
K	Potassium
KBMS	Koombana Bay Marine Structures (the strategic proposal)
KBSC	Koombana Bay Sailing Club
KEF	Key Environmental Factor
km	Kilometer
km/hr	Kiolmeter per Hour
LOI	Loss on Ignition
LoR	Limit of Reporting
LRTV	Low Reliability Trigger Value
LSP	Level of Species Protection
m	Meter
m/s	Meter per Second
m^2/s	Square Meter per Second
m^3	Cubic Meter
MAFRL	Murdoch University Marine and Freshwater Research Laboratory
MEQ	Marine Environmental Quality
Mm^3	Million Cubic Meters
Mn	Manganese
NAGD	National Assessment Guidelines for Dredging
NH_X	Reduced Inorganic Nitrogen
Ni	Nickel
NO_X	Oxidised Inorganic Nitrogen
NODGDM	National Ocean Disposal Guidelines for Dredged Material
NTU	Nephlometric Turbidity Unit
OC/OP	Organochlorine and Organophosphate Pesticides
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PCB	Polychlorinated Biphenyl
PIANC	Permanent International Association of Navigational Congresses
PO_4	Phosphate
PSD	Particle Size Distribution
psu	Practical Salinity Unit
s	second
SPA	Southern Ports Authority
Sb	Antimony
Se	Selenium
SL	Screening Level
SPER	Strategic Public Environmental Review
SWDC	South West Development Commission

Acronym / Abbreviation	Description
TBT	Tributyltin
Th	Thorium
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TPH	Total Petroleum Hydrocarbons
TRH	Total Recoverable Hydrocarbons
TSS	Total Suspended Solids
TTV	Toxicant Trigger Value
U	Uranium
V	Vanadium
WA	Western Australia
WASQAP	Western Australian Shellfish Quality Assurance Program
Z	Zinc
~	Approximately
°	Degree
°C	Degrees Celsius
µg/L	Micrograms per Liter

1. Introduction

1.1 Proposal

The South West Development Commission (SWDC) is the proponent for the Koombana Bay Marine Structures (KBMS) proposal. In March 2015 the SWDC referred the KBMS proposal to the Western Australia Environmental Protection Authority (EPA), which determined the KBMS proposal to be assessed at the level of “Strategic Proposal” (Public Environment Review or SPER). The EPA approved an Environmental Scoping Document (ESD) for the KBMS SPER (Assessment Number 2049) on 26 June 2015.

The KBMS proposal (or the strategic proposal) is located within the City of Bunbury, about 174 kilometres (km) south of Perth, Western Australia. The marine structures subject to the KBMS strategic proposal are situated within Koombana Bay which neighbours the Bunbury Central Business District and the Marlston North residential and waterfront developments. Figure 1 illustrates the indicative KBMS proposal.

The KBMS strategic proposal aims to construct and operate the following marine structures within Koombana Bay:

1. Casuarina Boat Harbour.
2. Koombana Bay Sailing Club (KBSC) marina.
3. Dolphin Discovery Centre (DDC) finger jetty.

Collectively, the three (3) individual marine structures (Casuarina Boat Harbour, KBSC marina and the DDC finger jetty) are referred to as the KBMS strategic proposal. Individually, and because they will be constructed over different timescales, the three (3) individual marine structures are referred to as “future proposals”. This is consistent with the EPA’s assessment process and terminology under the *Environmental Protection Ac, 1986.*

1.1.1 General description of KBMS strategic proposal

A general description of the KBMS strategic proposal is provided in Table 1.

Table 1 General strategic proposal description

Strategic proposal title	Koombana Bay Marine Structures
Strategic proponent name	South West Development Commission
Short description	The strategic proposal is to develop areas in Koombana Bay for small craft marine infrastructure (Figure 1). The proposed marine infrastructure includes jetties, boat ramps and boat pens. The identified future proposals under the strategic proposal are for the construction and operation of: – **Casuarina Boat Harbour** – **Koombana Bay Sailing Club Marina** – **Dolphin Discovery Centre Finger Jetty** The construction of future proposals will be undertaken in stages. The marine infrastructure is located adjacent to, or in close proximity to existing infrastructure in Koombana Bay, Bunbury.

1.1.2 Identified future proposal description and elements

A description and elements of the KBMS future proposals are provided in Table 2.

Table 2 Identified future proposal description and elements

Proposal element	Location / Description	Maximum Extent, Capacity or Range
Casuarina boat harbour This future proposal includes a dredging and dredge spoil disposal, piling activities, land reclamation and construction of a breakwater and revetment walls. The marine infrastructure includes the construction and operation of floating jetties, boat ramps and boat pens.		
Proposal element	**Location / Description**	**Maximum Extent, Capacity or Range**
Physical elements		
Development Envelope	Figure 1	Up to 40 ha
(Indicative) Casuarina Boat Harbour (CBH) disturbance footprint	Figure 1	Up to 32 ha within CBH disturbance footprint
Breakwater	Figure 1	Up to 3.5 ha within CBH disturbance footprint
Reclamation	Figure 1	Up to 3.5 ha within CBH disturbance footprint
Marine infrastructure	Within CBH	Floating jetties, boat ramps and boat pens within CBH disturbance footprint.
Koombana Bay Sailing Club marina This future proposal includes a dredging component, a piling component, land reclamation (including onshore dredge spoil disposal) and construction of breakwaters. The marine infrastructure includes the construction and operation of floating jetties, boat ramps and boat pens.		
Proposal element	**Location / Description**	**Maximum Extent, Capacity or Range**
Physical elements		
Development Envelope	Figure 1	Up to 16 ha
(Indicative) Koombana Bay Sailing Club (KBSC) marina disturbance footprint	Figure 1	Up to 10 ha within KBSC disturbance footprint
Breakwaters	Figure 1	Up to 2.5 ha within KBSC disturbance footprint
Reclamation	Figure 1	Up to 2 ha within KBSC disturbance footprint
Marine infrastructure	Within KBSC	Floating jetties, boat ramps and boat pens within KBSC disturbance footprint
Dolphin Discovery Centre finger jetty This future proposal includes a finger jetty, a piling component and a temporary onshore construction laydown area.		
Proposal element	**Location / Description**	**Maximum Extent, Capacity or Range**
Physical elements		
Development Envelope	Figure 1	Up to 0.5 ha
(Indicative) Dolphin Discovery Centre (DDC) jetty disturbance footprint	Figure 1	Up to 0.15 ha within DDC disturbance footprint
Marine infrastructure	Figure 1	Jetty up to 110 metres long

Figure 1 ***Development envelope, indicative disturbance footprint and marine elements***

1.2 Purpose of this report

Four (4) key environmental factors (KEFs) were identified in the ESD, namely:

1. ***Marine Environmental Quality*** (MEQ) with the EPA objective 'to maintain the quality of water, sediment and biota so that the environmental values (both ecological and social) are protected'.
2. ***Benthic Habitats*** with the EPA objective 'to protect benthic communities and habitats so that biological diversity and ecology integrity are maintained'.
3. ***Marine Fauna*** with the EPA objective 'to protect marine fauna so that biological diversity and ecological integrity are maintained'.
4. ***Coastal Processes*** with the EPA objective 'to maintain the geophysical processes that shape coastal morphology so that the environmental values of the coast are protected'.

The ESD sets out the information that the EPA will require to allow evaluation of the impacts of the strategic proposal on the basis of these KEFs.

This report provides an overview of past water quality and sediment quality measurements in the vicinity of the three (3) KBMS SPER future proposals to:

– Provide an overview of the historical development of Koombana Bay in terms of modifications to its physical setting.
– Summarise the metocean climate in the vicinity of the KBMS proposal including characterisation of past measurements, hydrodynamic modelling and wave modelling.
– Characterise the water quality and sediment quality to inform threats and pressures to marine water quality and sediment quality from the proposed construction and operations of the KBMS proposal.

This review serves to inform the MEQ impact assessment of the construction and operational activities of the three (3) derived proposals of the KBMS SPER, and the preparation of relevant construction and operational management plans.

1.3 Limitations

This report: has been prepared by GHD for South West Development Commission and may only be used and relied on by South West Development Commission for the purpose agreed between GHD and South West Development Commission as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than South West Development Commission arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

2. Koombana Bay history and past dredging

2.1 Port history

A brief overview of the historical development of the Port of Bunbury includes:

- The port was established in 1864 with the construction of a timber jetty (length ~425 m) that was continually lengthened through 1952 to ~1,400 m.[1]
- Between 1897 and 1899 a breakwater northwards from Casuarina Point (length of 980 m) was constructed to protect the jetty with a number of extensions through 1961.[1]
- Construction of a spur groyne near the breakwater abutment on the ocean side (the western spur) commenced in 1948, and was extended in 1961, which was effective in trapping littoral sand, and soon became saturated. A further spur groyne (the eastern spur) was constructed in 1949 by extending the original main breakwater in a northeasterly direction (SKM 2010a).
- In 1951 the natural outlet for Leschenault Inlet into Koombana Bay at Point MacLeod was closed to eliminate river silt accumulation in the old port area, and a connection to the ocean was cut through the sand dunes opposite the mouth of the Collie River (The Cut) (SKM 2010a).
- In 1968–1969 the Preston River downstream of the Australind Road Bridge was realigned to allow for the construction of the Inner Harbour (SKM 2010a).
- In 1971, work on the Inner Harbour commenced, cutting off the southernmost part of the Leschenault Estuary. On completion of the Inner Harbour in 1976, a channel was cut at Point MacLeod (The Plug) to allow circulation and vessel traffic between Lechenault Inlet and Koombana Bay (SKM 2010a).

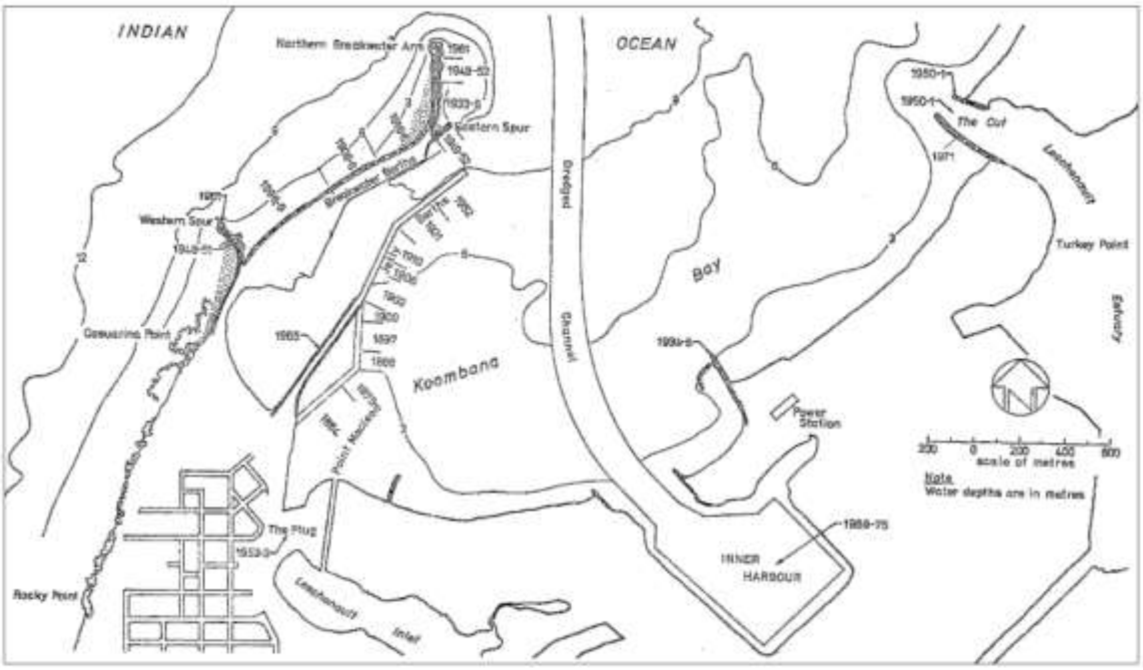


Figure 2 Historical development of the Port of Bunbury (PWD 1978).

[1] Port of Bunbury Southern Ports Authority website http://www.byport.com.au/ at 'History & Images' then 'Timeline of the history of Bunbury Port'

2.2 Dredging history

2.2.1 Inner Harbour capital dredging

There are no records of capital dredging and spoil disposal from the early Outer Harbour development (SKM 2010a). The Inner Harbour was developed through two (2) capital dredging programs (SKM 2010a):

– In the early 1970s ~7.4 Mm^3 of material was removed and used for reclamation.

– In 1991 removal of ~2 Mm^3 of material was disposed to the east of the Inner Harbour.

2.2.2 Maintenance dredging

Since completion of all breakwater and spur groyne extensions in 1961, and the construction of Berths 1 and 2, regular maintenance dredging has been carried out with Public Works Department dredges, private dredging contractors and grab dredging from the face of wharves (PWD 1978). Since 1967 maintenance dredging has been disposed to the Southern Ports Authority (SPA) offshore spoil ground. SKM's (2011c) summary of maintenance dredging activity from 1965-2010 is provided in Table 3.

Over recent years SPA maintenance dredging of 3-4 weeks duration has occurred on a semi-annual frequency (typically May and October) with a trailer hopper section dredge with overflow with dredge material disposal to the offshore spoil ground. The volume of dredged material during these semi-annual maintenance dredging activities ranges from 50,000-100,000 m^3 and is of a similar scale to those proposed for the phase 1 dredging of the Casuarina Boat Harbour derived proposal over the footprint of the northern breakwater (up to 130,000 m^3). In fact, this phase 1 dredging is anticipated to use the same dredge plant immediately after an SPA maintenance dredging event. Though the phase 2 dredging of the Casuarina Boat Harbour derived proposal will have a similar dredge volume (up to 110,000 m^3) as the offshore disposal, the dredging plant will be comprised of a backhoe dredge and several split hopper dredges rather than a trailer suction hopper dredge. Lastly, dredging of the KBSC marina derived proposal will be comprised of a substantially lower volume (up to 26,000 m^3) with onshore reclamation primarily that will utilise a backhoe dredge or a cutter suction dredge.

Table 3 Past maintenance dredging year, disposal location and dredged volume from 1965-2010 (SKM 2011c)

Year	Disposal Location	Volume (m^3)
1965-66	Reclamation	Unknown
1966–67	Reclamation	~70,000
1967–68	Southern spoil grounds	Unknown
1969–70	Southern spoil grounds	Unknown
1971–72	Southern spoil grounds	~76,630
1973–74	Southern spoil grounds	320,000
1974–75	Southern spoil grounds	~6,200
1975–76	Southern spoil grounds	Unknown
1976–77	Eastern section of Existing spoil ground	~17,000
1977	Pumped to ocean side of breakwater	~19,000
1979	Eastern section of Existing spoil ground	Unknown
1982	Eastern section of Existing spoil ground	~300,000
1985	Eastern section of Existing spoil ground	~140,000
1988-89	Eastern section of Existing spoil ground	~1,650,000
1990	Eastern section of Existing spoil ground	627,000
1992	Existing spoil ground	~900,000
1994	Existing spoil ground	416,518
1997	Existing spoil ground	656,000

Year	Disposal Location	Volume (m^3)
2001	Existing spoil ground	665,500
2004	Existing spoil ground	506,354
2007	Existing spoil ground	603,123
2008	Existing spoil ground	1,040,250
2010	Existing spoil ground	165,000
TOTAL KNOWN		8,178,575

2.2.3 Spoil ground

The SPA's existing spoil ground has been in use since at least 1976. The spoil ground location does not pose a shipping hazard and does not re-enter harbours and channels (SKM 2010a). SKM (2010a) notes that in 1988 the Department of Marine and Harbours stated the following regarding a proposed spoil ground further offshore (DM&H 1988):

'*This material should be placed in a position offshore from Leschenault Peninsula from where it may rejoin the coastal process system. The selection of the dumping grounds at about the 10 metre contour ensures that the rate at which the material rejoins the system is acceptable. Dumping sites to the west of Bunbury breakwater in deeper water would not be acceptable in this regard. Dumping at the preferred site during the periods 1976/77, 1979, 1982 and 1985 has been to the satisfaction of the Environmental Protection Authority.*'

3. Metocean

3.1 Wind climate

The land-sea breeze cycle is the dominant feature of the wind climate, typically with easterly winds in the morning and southerly to westerly winds in the afternoons.

3.1.1 Annual wind roses from BoM stations

The annual wind roses at two (2) locations in Bunbury and two (2) regional sites at Busselton and Cape Naturaliste are illustrated in Figure 3. All four (4) sites have similar morning (0900) wind roses with predominately easterlies to southeasterlies. In contrast there is variability in the afternoon (1500) wind roses with westerlies at the existing Bunbury station, southwesterlies to north-westerlies at the old Bunbury site, south-westerlies at Cape Naturaliste and a larger range of wind directions at Busselton (presumably because of land effects to the south).

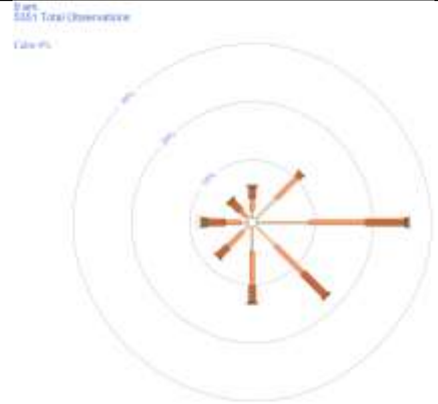
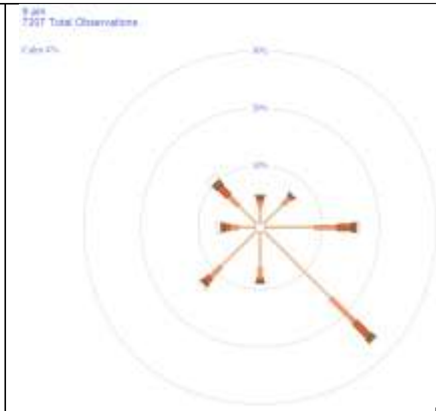
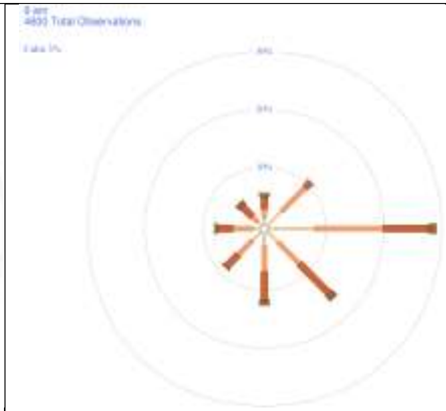
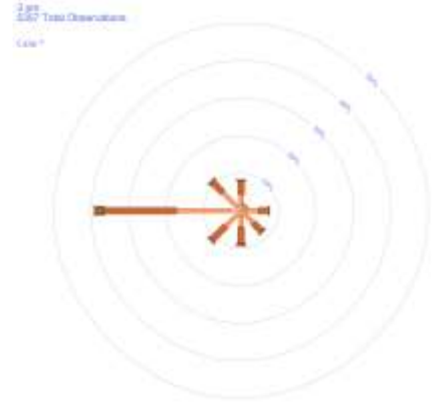
3.1.2 Monthly wind roses of inshore coastal Beacon 3

Monthly wind roses of measurements by the SPA at Beacon 3 just offshore of Casuarina Point from 2005-2013 are illustrated in Figure 4. Typical spring-summer (October-March) wind patterns are comprised predominately of southeasterly to southwesterly winds. During winter (June- September) winds are predominately westerly with elevated winds that correspond to storm fronts. April-May is typically the period with seasonal minima in wind speeds.

3.2 Wave climate

Hindcast modelling of the seasonal wave climate of the Bunbury region from 1998-2007 by Met Ocean Solutions (2008) found:

- Greater mean significant wave height (H_S) during winter at inshore coastal Beacon 3 (July mean H_S=1.28 m) than summer months (February mean H_S=0.67 m).
- The locally and far-field generated seas have wave periods of 6-10 seconds and 12-18 seconds, respectively, with the largest wave events locally generated and approaching Beacon 3 from the northwest.
- On average wave heights near the Inner Harbour entrance are ~15% of those at inshore coastal Beacon 3 with the largest waves tending to occur during northwesterly storm conditions.

 9 am Bunbury (009965) 22 Nov 1995-30 Sep 2010	 9 am Bunbury Post Office (009519) 1 Jan 1965-11 Jun 1985	 9 am Busselton Aero (009603) 16 Oct 1997-30 Sep 2010	 9 am Cape Naturaliste (009519) 01 Jan 1957-30 Sep 2010
 3 pm Bunbury (009965) 22 Nov 1995-30 Sep 2010	 3 pm Bunbury Post Office (009519) 1 Jan 1965-11 Jun 1985	 3 pm Busselton Aero (009603) 16 Oct 1997-30 Sep 2010	 3 pm Cape Naturaliste (009519) 01 Jan 1957-30 Sep 2010

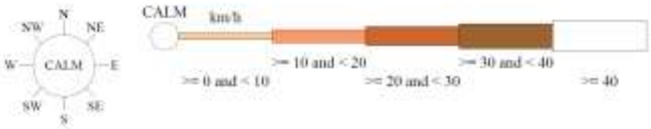


Figure 3 ***Annual wind roses from Bunbury, Busselton and Cape Naturaliste BoM stations***

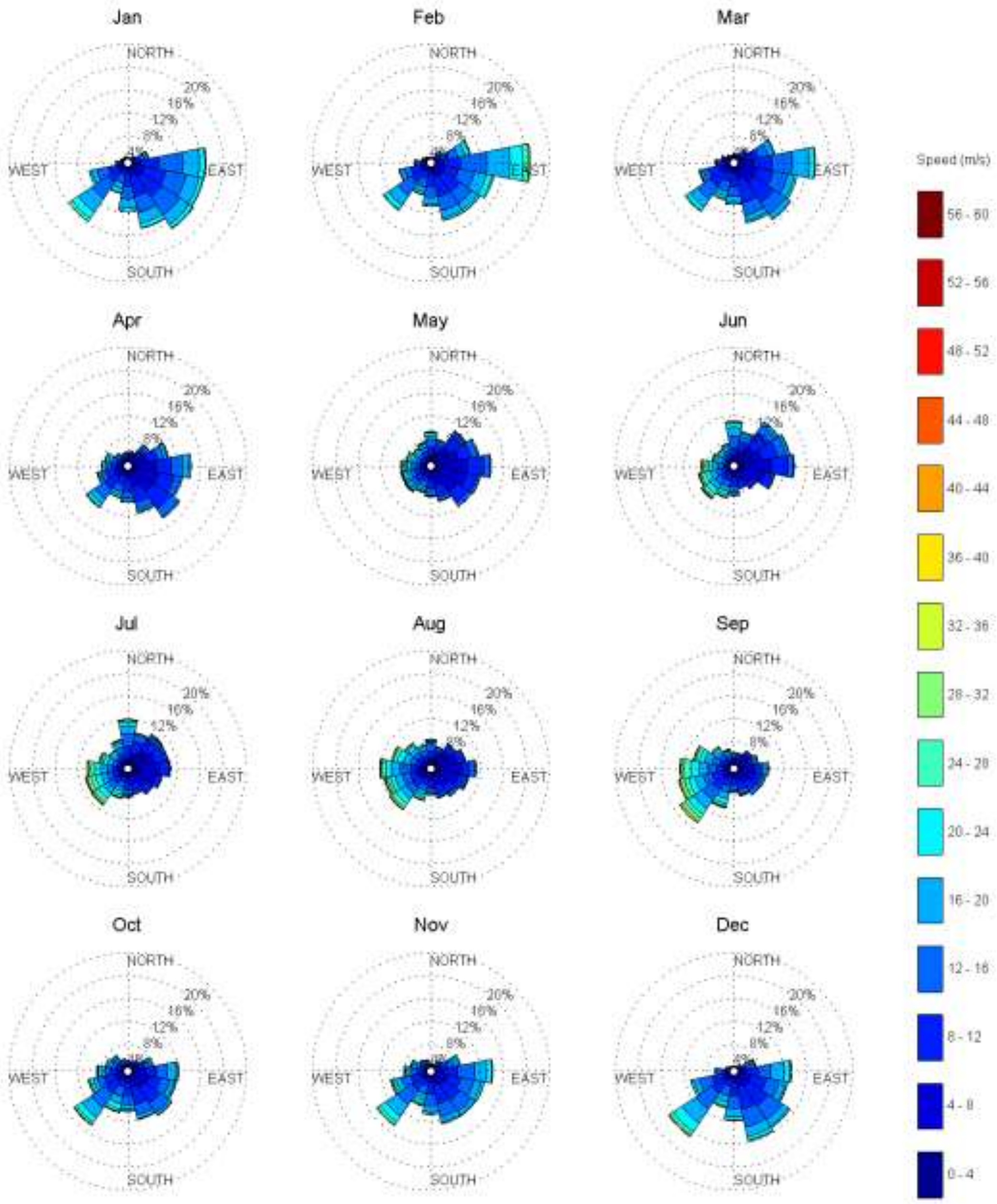


Figure 4 Monthly wind roses of Beacon 3 data from 2005-2013.

3.3 Koombana Bay hydrodynamics

3.3.1 Studies in the 1980s

Summer surveys during 1982-1983 (Hearn 1983, Hearn et al 1987) and associated numerical modelling (Hunter 1983, Hearn et al. 1987) characterised the following the circulation patterns of Koombana Bay:

- Field observations indicated that:
  - Typical patterns from drogue measurements (~2 m) of surface waters included:
    - Northeast currents across the bay to the northern coast.
    - Shallow water motion over most of the bay in an outward direction and to the northeast.
    - Virtually no water motion over the southwest portion of the bay.

  - A southward current over the navigation channel to the south of Point Casuarina.
- Mid-depth (5.5 m) current meter measurements between the Inner Harbour and The Cut exhibited uni-directional flows to the northeast (~3 cm/s) in agreement with daytime drogue measurements (~4 cm/s) in the same direction.
- Deep water (~9 m) drogue deployments in the navigation channel were transported toward the Inner Harbour (~6 cm/s).
- These measurements indicate that flushing of the Inner Harbour is enhanced through upwelling of Shipping Channel waters that replace the surface waters of southeastern Koombana Bay and the Inner Harbour. The displaced surface waters are transported to the north due the prevailing southerly winds.

– Two-dimensional vertically averaged modelling reproduced these general observations along with a weak clockwise topographic gyre in western Koombana Bay.

– Three-dimensional modelling reproduced southerly currents into Koombana Bay along the navigation channel and northeasterly surface currents across the bay in response to southerly wind forcing in agreement with observations.

Late winter measurements of the jet through The Cut during ebb tides in September 1984 by Leuketina and Imberger (1987) indicated a westerly penetration into northerneastern Koombana Bay of ~1-2 km. However, this relatively large penetration distance may, in part, be driven by the associated 'buoyant' jet of lower density estuarine waters (~5 psu lower than ambient seawater during end of winter). The radial jet front during ebb tides may be smaller during summer conditions when the salinity between Koombana Bay is similar to Leschenault Estuary.

3.3.2 Recent investigations

Hollingsworth (2006) performed six (6) drogue runs (each run with a set of 4 drogues) during 17-18 September 2006 where:

– Run 1 was released at the centre of Koombana Bay just to the east of the Shipping Channel, and travelled directly to the eastern shoreline at a rate of ~0.15 m/s (95% confidence interval [CI] of 0.001 m/s).

– Run 2 was released just to the southwest of the Outer Harbour entrance, and travelled in a southeasterly direction towards the centre of the bay at a rate of 0.12 m/s (95% CI of 0.001 m/s).

– Runs 3 to 6 were released in the southwest corner of Koombana Bay, and travelled in a northeasterly direction from 0.15-0.18 m/s (95% CI of 0.001-0.002 m/s).

Winds were generally from the west to northwest on September 17 (18 km/hour) and 18 (27-29 km/hr) representative of afternoon westerly conditions. Runs 1, 3 and 4 occurred during ebb tides and runs 2, 5 and 6 during slack tides. These drogue observations support the presence of a clockwise topographic gyre in the bay (Hearn 1983, Hearn et al 1987, Hunter 1983). Moreover, Hollingsworth's (2006) measurements indicated that westerly wind conditions generate substantive water currents that flush the southwestern portion of the bay. A lateral diffusion coefficient (K) of ~0.4 m^2/s (95% CI of 0.2) was estimated by Hollingsworth (2006).

Wave Solutions (2012a) carried out a drifter study during 11-21 June 2011 that included several deployments within Koombana Bay and found that:

– Deployments 1 and 4, released ~250 m to the east of the end of the Outer Harbour breakwater during brisk north-northeast winds of 20-30 knots, had trajectories towards shore that suggested a counter-clockwise gyre in the bay with speeds of 0.12-0.18 m/s.

– Deployment 3, released ~600 m northeast of the end of the Outer Harbour breakwater during brisk north-northeast winds of 20-30 knots, also had a trajectory towards shore that suggested a counter-clockwise gyre in the bay with a speed of 0.08 m/s.

– Deployments 5 and 6, released in similar locations as deployments 1 and 4 but with south to southwest winds of 10-15 knots, had easterly trajectories with speeds of 0.14-0.17 m/s.

Estimates of lateral dispersion coefficients ranged from 0.04-0.13 m^2/s, considerably less than those by Hollingsworth (2006) of 0.4 m^2/s. However, the current speeds of Hollingsworth (2006) of 0.12-0.18

m/s during predominately westerly winds were in reasonable agreement with those of Wave Solutions (2012a) of 0.08-0.18 m/s over a range of wind directions. Further, the wind directions seemingly have a strong effect on the current directions of western Koombana Bay with a northerly wind component transporting waters from the centre of Koombana Bay toward the southern shoreline, and conversely, southerly component transporting shallow waters to the northern bay deeper waters.

3.3.3 Casuarina Boat Harbour flushing

WorleyParsons (2017) applied a three-dimensional numerical model to simulate the e-folding flushing time scale (duration to exchange 63.2% of the harbour volume with the bay) of Casuarina Boat Harbour. The e-folding time of the initial volume of Casuarina Boat Harbour was predicted to be 1.5 days (winter for surface and bottom waters) to 1.9 days (autumn[2] for bottom waters) days with small variation between seasons.

MP Rogers (2016) carried out a rhodamine dye study during 8-18 March 2016 that spanned neap (9-11 March 2016) to spring (14-18 March 2016) tides with predominately westerly and south-southeasterly moderate winds of 5-20 knots. The e-folding flushing time at nine (9) sites throughout the Outer Harbour ranged from 1.9-2.5 days in reasonable agreement with the WorleyParsons (2017) modelling predictions. These e-folding flushing time scales are well below the recommended PIANC (2008) guideline of <10 days to maintain suitable harbour water quality.

[2] Low wind season.

4. Water quality

Water quality data was compared to relevant ANZG (2018) default guideline values for toxicants (DGVT) (i.e. metals/metalloids) and physical and chemical stressors (DGVPC). DGVPCs were based on the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 4.0) ecoregion of Leeuwin-Naturaliste in which Koombana Bay is located. If analytes had no ANZG (2018) DGVPC (e.g. TP, NH_4) or DGVT (e.g Al) then the ANZECC (2000) default trigger values for physical and chemical stressors of South West Australia (DTVPC) and recommended toxicant trigger values at the recommended level of species protection (95% or 99% level of species protection [LSP]) for slight-moderately disturbed ecosystems (TTV) were adopted, respectively. For aluminium (Al), antimony (Sb), arsenic (As), iron (Fe) and selenium (Se) the ANZECC (2000) low reliability trigger values (LRTV) were adopted.

4.1 Relevant past investigations

Table 4 provides a synopsis of relevant past water quality investigations of Koombana Bay.

Table 4 Synopsis of relevant past water quality investigations

Investigation	Findings
June 1976 to February 1985 Quarterly Sampling Quarterly sampling by the then Water and Rivers Commission at three (3) Leschenault Inlet stations.	The median of surface and bottom measurements of reduced inorganic nitrogen (NH_X), oxidised inorganic nitrogen (NO_X), filterable reactive phosphorus (FRP or phosphate [PO_4]) and total phosphorus (TP) during approximately quarterly surveys over a 10 year period from the mid-1970s to mid-1980s from three (3) stations (stations 6111018 [eastern Inlet], 611019 [middle Inlet] and 6111020 [western Inlet]) in Leschenault Inlet are included in the comparative assessment of water quality in Section 4.2.3 whereby: – NH_X ranged primarily from 10-70 ug/L, well above the ANZECC (2000) DTVPC for marine inshore marine waters of South West Australia of 5 ug/L. – NO_X ranged primarily from 10-20 ug/L, well above the seasonally varying ANZG (2018) DGVPC ranging from 2.6-6.2 ug/L. – TP ranged primarily from 30-75 ug/L, well above the ANZECC (2000) DTVPC of 20 ug/L. – FRP ranged primarily from 5-10 ug/L, equal to and just above the seasonally varying ANZG (2018) DGVPC between 4.7-5.5 ug/L.
1997 Maintenance Dredge Monitoring (Spoil Ground Benthic Habitat and Turbidity) SKM (2010a) reports on the 1997 pre- and post-maintenance dredging monitoring program in the vicinity of the spoil ground.	Dredge spoil disposal had a minimal impact on the surrounding benthic habitat as seagrass and macroalgae patches in the vicinity of the spoil ground were small but healthy. Many of the seagrass patches were elevated above the seabed, which suggests sediment loss may have undermined the beds. Continuous turbidity measurements at 1 m above the seabed in the vicinity of the spoil ground were slightly elevated (ca. 5%) relative to the reference site to the north. Elevated levels may have been in part due to turbid waters leaving the estuary via The Cut. Average turbidity was 29.0 and 30.5 NTU at the reference and spoil ground sites, respectively, from 25 July-23 August 1997.[3]
2001 Maintenance Dredge Monitoring (Spoil Ground Turbidity) SKM (2010a) reports on the 2001 maintenance dredging monitoring program in the vicinity of the spoil ground.	A summary of continuous turbidity measurements at 1 m above the seabed to the east of the spoil ground and at the reference site to the north from 22 February-30 April 2001 found that: – Turbidity was substantially greater during pre-disposal at both locations than the disposal and post-disposal periods. – Turbidity was greater adjacent to the spoil ground during pre- and post- disposal periods, but substantially lower during the disposal period. The influence of turbidity from The Cut and marked spatial variability in turbidity (i.e. poor observed water clarity at reference site versus spoil ground site) were attributed as factors. – The influence of turbid discharges from The Cut and wave-induced resuspension were likely to have a greater influence on turbidity than spoil disposal. Turbidity during the winter of 1997 (see above) was substantially greater than the summer/autumn of 2001 because of higher river-induced turbidity and a more energetic wave climate.
1995-2001 (October-April) Water Quality DoW (2007) carried out routine water quality	Cessation of water quality monitoring by the then Department of Water (DoW) of Leschenault Inlet was due to the consistency of physical and biological criteria at levels that did not present a significant risk to this water body's environment.

[3] Over the 90 day measurement record, biofouling on one of the sensors at the spoil grounds limited reliable comparisons over the first 30 days.

Investigation	Findings
monitoring on a bi-weekly basis of the Leschenault Inlet.	The water quality in Leschenault Inlet was regarded as good because of relatively low total nitrogen (TN) (mean 0.38 mg/L) and TP (mean 0.03 mg/L). These nutrient levels are slightly greater than natural levels, but reasonably expected due to developed nature of the catchment. No data was available from the WIN[4] database for this monitoring programme.
1998-2006 Water Quality Review SKM (2010a) undertook a compilation and review of existing surface and near-seabed water quality from sites in the Inner Harbour, Outer Harbour and spoil ground from 1998-2006 (SKM 1998, 2002, 2004, 2007a).	Averages of surface and bottom measurements of NH_X, NO_X, TN, TP and PO_4 during approximately biennial surveys (March 1998, March 2002, November 2004, March 2006) of Casuarina Boat/Outer Harbour, Inner Harbour and the spoil ground are included in the comparative assessment of water quality in Section 4.2.3 whereby: – NH_X was greater than the ANZECC (2000) DTVPC for the Inner Harbour, predominantly for Casuarina Boat/Outer Harbour and just below or above the criterion at the spoil ground. – NO_X had a similar pattern in relation to the seasonally varying ANZG (2018) DGVPC as NH_X. – TN was below the ANZECC (2000) DTVPC at the spoil ground, for three (3) of the four (4) surveys at Casuarina Boat/Outer Harbour and the Inner Harbour. – Similar to TN, PO_4 was generally below the ANZECC (2000) DTVPC at the spoil ground and Casuarina Boat/Outer, but generally was just above the criterion in the Inner Harbour. – In contrast, TP was generally above the ANZECC (2000) DTVPC at all three (3) locations, however as phosphorus limitation is unlikely in marine environments, the risk of algal blooms was considered low. – Chlorophyll-a (chl-a) was below or near the seasonally varying ANZG (2018) DGVPC at the spoil ground on three (3) of the four (4) surveys. However, Casuarina Boat/Outer Harbour were well above these guideline values for three (3) of the four (4) surveys. Nutrient levels in the Outer Harbour and the spoil ground indicated a wider spread source than from solely the Inner Harbour (SKM 2010). The Shipping Channel serves as a natural trap for decaying seagrass and macroalgae (i.e. wrack), which are dislodged by winter storms and transported into Koombana Bay. Sediments in the Shipping Channel contained up to 30% organic matter and high levels of nutrients (SKM 2010a). There is a potential risk of algal blooms from decomposition of organic material (e.g. wrack) because of increases in nitrogen concentrations (the likely limiting nutrient) (SKM 2010a). However, the high winter turbidity (see above) decreased the risk of algal blooms from decaying wrack because of light limitation. Generally, a gradient in nutrients and chl-a occurred with decreases from the Inner Harbour to the Outer Harbour and onto the spoil ground. Phytoplankton samples in 2002 (autumn), 2004 (spring) and 2006 (autumn) were generally dominated by diatoms (SKM 2010a).
2007-2008 Koombana Bay Baseline Study Oceanica (2008a) undertook four (4) seasonal water quality surveys at three (3) Outer Harbour sites, 12 Koombana Bay sites and three (3) Leuschenault Inlet sites from 9 July 2007 to 2 April 2008.	Averages of vertically integrated samples on a quarterly basis from July 2007 – April 2008 of NH_X, NO_X, TN, TP, PO_4 and chl-a during approximately biennial surveys (March 1998, March 2002, November 2004, March 2006) of Outer Harbour, Inner Harbour and the spoil ground are included in the comparative assessment of water quality in Section 4.2.3 whereby: – Generally, TN and NH_X exceeded ANZECC (2000) DTVPCs, and NO_X exceeded the relevant seasonally varying ANZG (2018) DGVPC during winter (July 2007) and spring (September 2007). In contrast, during summer (December 2007) all of these analytes met their respective guideline criteria. During autumn (April 2008) all three (3) locations were greater than their respective guideline criteria for NH_X, below for TN and only NO_X exceedances occurred only in the inlet. – PO_4 was below or just above the seasonally varying ANZG (2018) DGVPC at all three (3) locations over the four (4) surveys. Similarly, TP was below or just above the ANZECC (2000) DTVPC at all three (3) locations over the four (4) surveys. – Chl-a was well above by a factor of 3-10 of the seasonally varying ANZG (2018) DGVPC at all three (3) locations over the four (4) surveys. Generally, the data suggested increased nutrient levels in Koombana Bay were in response to rainfall-derived land-based inputs. Within Koombana Bay and the Outer Harbour the water temperature, salinity and turbidity were generally similar and co-varied seasonally. Phytoplankton densities within Koombana Bay and the Outer Harbour were seasonally elevated in summer with cell densities of potentially harmful species at a number of sites above WASQAP (2007) trigger levels. Enterococci and hydrocarbons were below the limit of reporting (LoR) on all sampling occasions at all stations.
May 2008, September 2009, February 2010 and May 2010 Dissolved Metals Monitoring SKM (2008, 2009, 2010a, 2010b) carried	Water quality measurements at two (2) to three (3) reference sites and Inner Harbour sites are summarised in Table 5 to Table 7 with comparisons to relevant guideline values. Key findings in the survey reports include: – During the surveys Al, Sb, cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), Fe, lead (Pb), mercury (Hg), nickel (Ni), Se, silver (Ag), vanadium (V) and zinc (Zn) were below LoRs

[4] Historical DoW (now Department of Water and Environmental Regulation [DWER]) database.

Investigation	Findings
out water sampling of the surface and bottom waters at two (2) to three (3) reference sites and a number of Inner Harbour sites during 26-28 May 2008, 29-30 September 2009, 3-4 February 2010 and 26-28 May 2010.	except at the Inner Harbour sites where aluminium (Al), iron (Fe) and vanadium (V) were above LoRs for at least one of the surveys. – Across the four (4) surveys silver (Ag) ranged from <0.1-1 µg/L at the reference location and <0.1-0.3 µg/L in the Inner Harbour. – Across the four (4) surveys arsenic (As) ranged from 1.5-2 µg/L at the reference location and 1.4-2.1 µg/L in the Inner Harbour. – Across the four (4) surveys manganese (Mn) ranged from <0.1-5.6 µg/L at the reference location and 1.4-2.1 µg/L in the Inner Harbour. – All 95% upper confidence limits (UCLs) of measured metals and metalloids were below relevant ANZG (2018) DGVTs, ANZECC (2000) TTVs and ANZECC (2000) LRTVs.
November 2010 and June 2011 Dissolved Metals Monitoring SKM (2011a, 2011b) carried out water sampling at three (3) Outer Harbour sites, three (3) reference and a number of Inner Harbour sites during spring (24-26 November 2010) and winter (8-10 June 2011) of the surface and bottom waters.	Dissolved metals measurements at three (3) Outer Harbour sites, three (3) reference sites and Inner Harbour sites are summarised in Table 8 and Table 9 with comparisons to relevant default guideline values. Key findings in the survey reports include: – During both surveys Al, Sb, Cd, Cr, Co, Cu, Fe, Hg, Ni, Se, Ag, V and Zn were below LoRs except at the Inner Harbour sites where Fe and Zn were above LoRs on one (1) of the two (2) surveys. – During the June 2012 survey Ag ranged from 0.2-0.5 µg/L in the Outer Harbour and 0.1-0.4 µg/L at the reference sites, whereas during the spring survey all concentrations were below LoR. The Inner Harbour 95% UCL was 0.7 µg/L and 0.1 µg/L during the winter and spring surveys, respectively. – As and Mn were the only analytes above LoR during both surveys at all sites, but below relevant ANZECC (2000) LRTV and ANZG (2018) DGVT, respectively.
2012 Chl-a and Total and Dissolved Metals Monitoring Wave Solutions (2012b) carried out water sampling on a six (6) (summer) to eight (8) (winter) weekly basis on six (6) occasions in 2012 including physico-chemical profiles and grab sampling (total and dissolved metals, chl-a and TSS) at five (5) sites in Koombana Bay, one (1) and (2) sites at the entrance and within the Inner Harbour, respectively.	Statistics of water quality measurements from eight (8) sites in Koombana Bay and the Inner Harbour are summarised in Table 11 with comparisons to relevant moderate and high reliability relevant guideline values. Further, the average of chl-a across the eight sites (3 in western Koombana Bay, 3 in eastern Koombana Bay, 2 in the Inner Harbour) over six (6) to eight (8) week sampling intervals from February to October 2012 are included in the comparative assessment of water quality in Section 4.2.3. Key findings in the report include: – Maximum chl-a generally exceeded the ANZECC (2000) DTVPC for each sampling round. However, mean chl-a for each sampling round was greater than the default guideline value on only one (1) occasion at the start of autumn, where the minimum of 0.5 µg/L, maximum of 4 µg/L, mean of 1.9 µg/L and standard deviation of 1.3 µg/L suggest many of the measurements were below the guideline value. – Total As only had one sampling date where the maximum concentration exceeded the ANZECC (2000) LRTV on the first summer winter sampling round. – Maximums and averages of total and filterable Cd were greater than ANZG (2018) DGVT for three (3) of the six (6) sampling rounds. – Total and filterable Cu were generally greater than the ANZG (2018) DGVT for five (5) and three (3) of the six (6) sampling rounds, respectively. – Total and dissolved Pb only had one (1) sampling date where the maximum concentrations exceeded the ANZG (2018) DGVT on the first summer sampling round. – Total Hg only had one (1) sampling date where the maximum, minimum and average concentrations exceeded the ANZG (2018) DGVT on the last winter sampling round. On the second sampling survey at the start of autumn only the maximum total Hg exceeded the DGVT. – All six (6) sampling dates had maximum and average total Zn levels above the ANZG (2018) DGVT, with the minimum concentrations below the trigger value for half the sampling surveys. For dissolved Zn five (5) of the six (6) sampling dates had maximum concentrations above the trigger value, one (1) survey had an average above the DGVT, and all the minimum concentrations were below the DGVT. – All other analytes (Al, Sb, Cr, Co, Fe, Mn, Ni, Se, V, Ag) had no exceedances of the relevant ANZG (2018) DGVTs, ANZECC (2000) TTVs and ANZECC (2000) LRTVs. – Physico-chemical profiling at the stations was characterised by weak stratification in temperature salinity, pH and dissolved oxygen.
Monthly Water Quality Monitoring of Koombana Bay and Casuarina Boat Harbour from September 2016 to September 2017 GHD (2023a) Monthly water quality monitoring of southern Koombana Bay and Casuarina Boat Harbour.	Findings reported in GHD (2023a). Averages of vertically integrated samples of metals and metalloids are included in the comparative assessment in Section 4.2.2. Averages of vertically integrated samples of NH_X, NO_X, TN, TP, FRP and chl-a included in the comparative assessment of water quality in Section 4.2.3.

Investigation	Findings
Semi-annual Water Quality Monitoring at Northern Leschenault Inlet Shoreline from May 2014 to November 2017 GHD (2018) carried out water quality monitoring on approximately a semi-annual basis at two (2) sites on the northern shoreline of the middle embayment.	Metals and metalloids measurements at the two (2) Leschenault Inlet sites near the northern shoreline of the middle embayment are summarised in Table 10. Averages of the two (2) samples from the two (2) shallow sites of NH_X, NO_X, TN, TP and chl-a are included in the comparative assessment of water quality in Section. Key findings from this dataset include: – DO was low in the range of 70-90% and often below the lower ANZECC (2000) DTVPC of 90%, likely due to sediment oxygen consumption and/or respiration in these shallow waters. – TSS was generally high often in the range between 10-60 NTU. Elevated levels are likely due to the effect of resuspension in the shallow waters in which sampling was undertaken. – When LoR was below relevant guideline values, Cu regularly exceeded the ANZG (2018) DGVT and As the ANZECC TTV on one (1) survey at both sites. However, LoRs were often greater than the ANZG (2018) DGVTs and ANZECC (2000) TTVs of metals and metalloids. – NH_X (30-200 ug/L), TN (200-750 ug/L) and TP (35-40 ug/L) were well above the ANZECC (2000) DGVPC of 5 ug/, 230 ug/L and 20 ug/L, respectively. These GHD (2018) nearshore data of nutrients are not used in the KBMS SPER technical assessment as they may not be representative of most past measurements with sites in open water locations.
Bunbury Ocean Outfall Monitoring (BOOM) from October 2005 to March 2016 Five (5) reference sites with surface and bottom water quarterly measurements provided by Water Corporation.	BOOM data serves as reference site data of the nearshore coastal waters. Averages of surface and bottom measurements across the five (5) reference sites of NH_X, NO_X, TN, TP, PO_4 and chl-a included in the comparative assessment of water quality in Section 4.2.3. Generally monitoring indicates that all analytes primarily meet the relevant ANZG (2018) DGVPCs and ANZECC (2000) DTVPCs.
Leschenault Inlet from January to August 2020 O2 Marine (2021) carried out water quality monitoring on a monthly that was comprised of continuous turbidity and PAR measurements, grab samples for nutrient and metals/metalloids analyses and sonde profiles at three (3) sites in the inlet.	Findings reported in O2 Marine (2021). Averages of vertically integrated samples of metals and metalloids are included in the comparative assessment in Section 4.2.2. Averages of vertically integrated samples of NH_X, NO_X, TN, TP, FRP and chl-a included in the comparative assessment of water quality in Section 4.2.3.

4.2 Assessment of water quality

4.2.1 Physico-chemical

Available physico-chemical measurements of monitoring during 2007-2008 (Oceanica 2008a), 2010 (Wave Solutions 2012b), 2010-2017 (GHD 2018), 2016-2017 (GHD 2023a) and 2020 (O2 Marine 2021) are shown in Figure 5 where:

– Temperatures ranged from ~15-25°C.

– Salinity ranged from ~34-36 psu.

– Dissolved oxygen (DO) saturation ranged from ~87-95% in 2007-2008 to ~95-105% in 2012 and 2016-2017 in Koombana Bay. Greater variability in DO saturation generally occurs in Leschenault Inlet than Koombana Bay.

– Total suspended solids (TSS) were generally 5-12 mg/L during 2007-2008 except for an elevated value of ~27 mg/L in Koombana Bay and Casuarina Boat Harbour in September 2007. Elevated levels of TSS with substantive variability was monitored at the northern Leschenault Inlet shoreline site from 2010-2014. TSS of Koombana Bay during 2016-2017 was somewhat lower than that of 2007-2008.

– The minimum turbidity generally followed a similar pattern as TSS, which indicates for the most part all three (3) water bodies.

Wave Solutions (2012b) deployed loggers that measured temperature, salinity, DO saturation and turbidity at two (2) locations in Koombana Bay on either side of the Harbour entrance in shallow water, which are reproduced in Figure 6. The temperature, salinity and DO saturation ranged from ~15-25°C, ~34-36 psu and ~85-110% in agreement with the spot measurements in Figure 5. Turbidity was generally less than 50 NTU to the west of the Inner Harbour entrance whereas it was greater through the winter at the site to the east. It is likely that biofouling of the turbidity sensor occurred and the data is suspect, or alternatively that riverine particles from the Cut lead to elevated turbidity in the bottom waters with the Shipping Channel acting as a barrier to turbidity intrusions into the western bay. Refer to GHD (2023a) for continuous measurements of depth, temperature, turbidity and PAR from September 2016 to September 2017 in Koombana Bay and O2 Marine (2021) for continuous measurements of turbidity and PAR in Leschenault Inlet from January to August 2020.

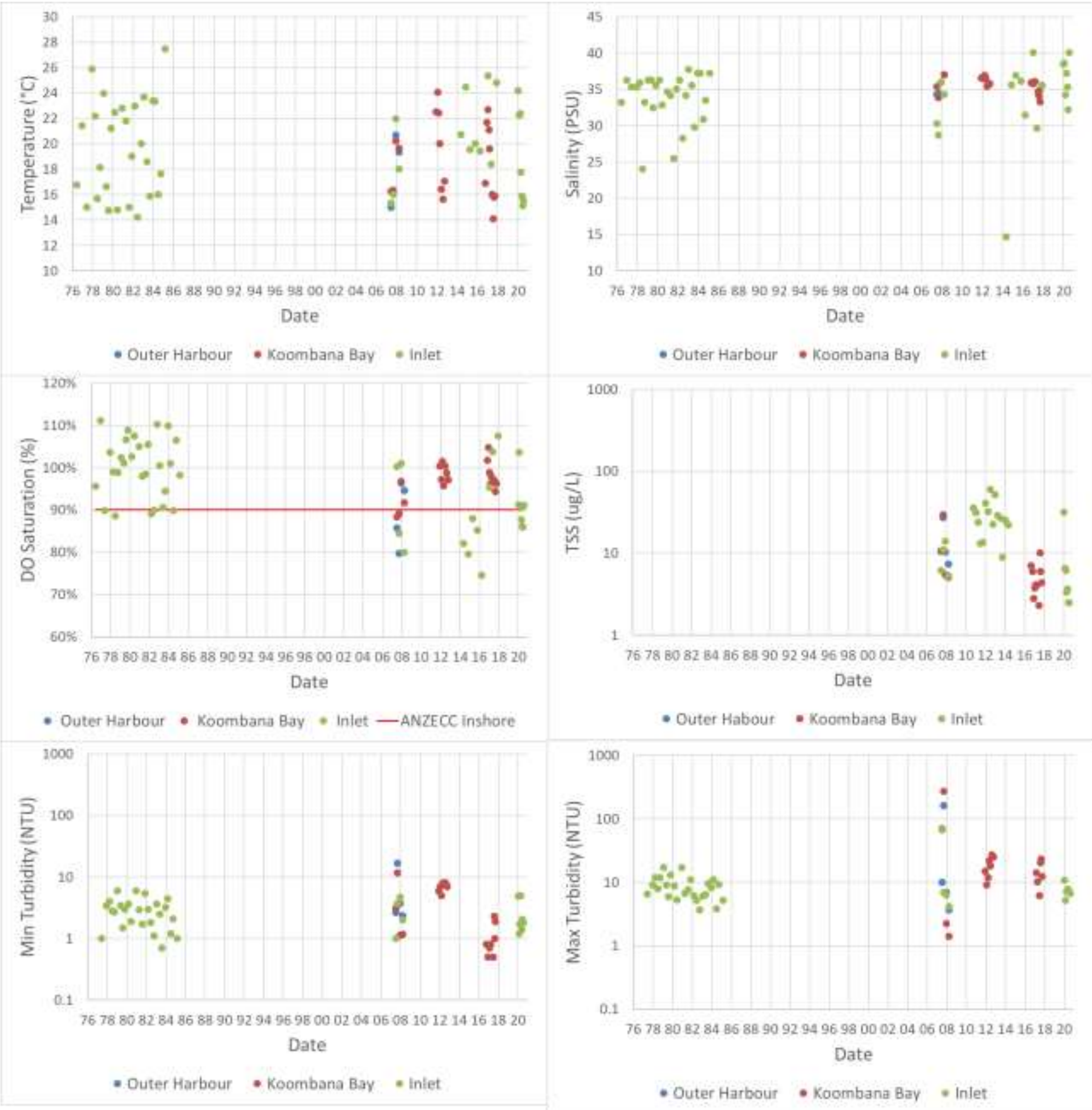


Figure 5 *Past water quality: physico-chemical*

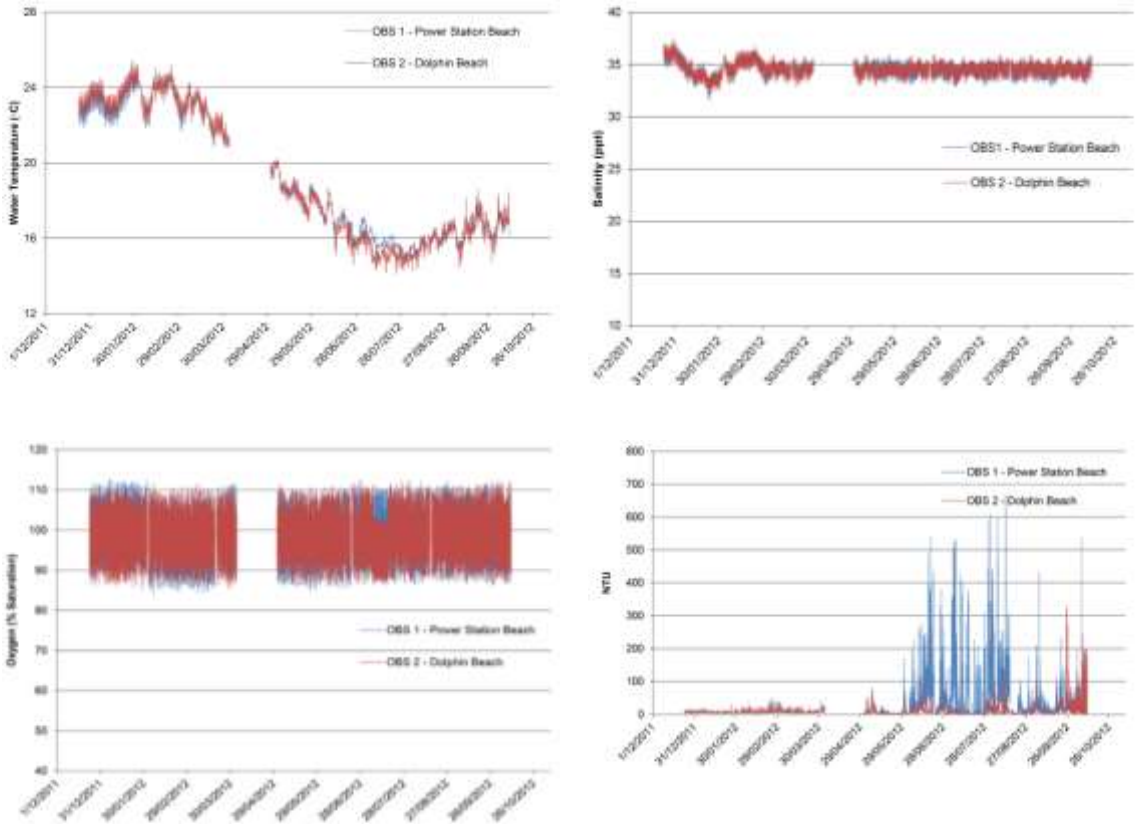


Figure 6 *Continuous logger measurements from December 2011-October 2012 (Wave Solutions 2012b)*

4.2.2 Metals and metalloids

Available metals and metalloids data of Koombana Bay, the Casuarina Boat/Outer Harbour, coastal inshore reference sites and Leschenault Inlet are presented in Table 5 to Table 11. Key findings include:

- The 95th percentile upper confidence limit (UCL) of dissolved metals and metalloids (Al, Sb, As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, V, Zn) were below LoRs, and/or ANZG (2018) DGVTs and ANZECC (2000) TTVs:
  - At the reference sites for all five (5) SKM (2008, 2009, 2010b, 2011a, 2011b) surveys (May 2008, September 2009, February 2010, November 2010, June 2011).
  - During the November 2010 (SKM 2011a) and June 2011 (SKM 2011b) surveys of the Outer Harbour sites.
  - At the Inner Harbour sites for all five (5) SKM (2008, 2009, 2010b, 2011a, 2011b) surveys (May 2008, September 2009, February 2010, November 2010, June 2011).
- Though dissolved As did not exhibit any gradients between the Inner Harbour, Outer Harbour and reference sites, dissolved Pb and Ag exhibited a weak gradient, and dissolved Mn a stronger gradient of higher to lower values across the 2008-2011 SKM (2008, 2009, 2010b, 2011a, 2011b) surveys. In summary, the SKM (2008, 2009, S2010b, 2011a, 2011b) surveys indicate that eastern Koombana Bay levels of dissolved Zn, Cu and to a lesser degree Cd are influenced by the Inner Harbour.
- For the six (6) Wave Solutions (2012b) surveys during 2012 at eight (8) sites in Koombana Bay (three [3] in the middle of bay, three [3] near entrance to Inner Harbour) and the Inner Harbour (two [2] sites), the total and dissolved metals and metalloids were below the ANZG (2018) DGVTs and ANZECC (2000) TTVs for Sb, As, Cr, Co, Mn, Ni, Se, Ag and V. The ANZECC (2000) LRTV for Al could not be evaluated as the LoRs were too high. Exceedances of the appropriate ANZG (2018) DGVTs and ANZECC (2000) TTVs over the six (6) surveys (intervals of 6-8 weeks) included:

- Mean, maximum and minimum dissolved Al exceeded the ANZECC (2000) LRTV of 0.5 µg/L on all surveys. However, the applicability of this low reliability guideline value is considered uncertain.
- Mean and maximum dissolved Cd on three (3) surveys.
- Mean and minimum dissolved Cu on three (3) surveys, and maximum for four (4) surveys.
- Mean and maximum Fe on two (2) surveys, and minimum on one (1) survey. However, the applicability of this low reliability guideline value is considered uncertain.
- Maximum dissolved Pb for one (1) survey.
- Mean and minimum dissolved Hg was equal to the trigger value for three (3) surveys and the maximum on four (4) surveys.
- Mean and maximum dissolved Zn on the six (6) surveys, and the minimum on four (4) surveys.

– For the eight (8) GHD (2018) surveys from May 2014 to November 2017 at two (2) stations along the northern shoreline of the middle arm of the Leschenault Inlet, the dissolved metals and metalloids were below the ANZG (2018) DGVTs and ANZECC (2000) TTVs except for five (5) exceedances of Cu and one (1) exceedance of As. The exceedance of Cu is consistent with exceedances in the monitoring by Wave Solutions (2012b), which suggests that the Inlet and Bay have elevated levels of Cu.

– Over the baseline monitoring of Casuarina Boat Harbour and Koombana Bay from September 2016 to September 2017 (see GHD [2023a]) three (1) Cu exceedances in Koombana Bay, two (2) Zn exceedances in Koombana Bay, four (4) Pb exceedances and a number of As exceedances (but at or just above the guideline value) were recorded of individual samples. However, averages of all samples during each survey had no exceedances in contrast to Wave Solutions (2021b) noting that a number of these sites were within the Inner Harbour with poorer water quality than Koombana Bay, Leschenault Inlet, Casuarina Boat Harbour and the Outer Harbour.

Table 5 26-28 May 2008 dissolved metals & metalloids (SKM 2008)

Analyte	Guideline Value	Reference			Inner Harbour	Guideline Value Description
		R1	R2	95% UCL	95 % UCL	
Al	0.5 µg/L	<10	<10	<10	<10	ANZECC (2000) LRTV
Sb	10 µg/L	<0.5	<0.5	<0.5	<0.5	ANZECC (2000) LRTV
As	2.3 µg/L	2	1.6	2	1.6	ANZECC (2000) LRTV for AsIII
Cd	0.7 µg/L	<0.2	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 99% LSP
Cr	4.4 µg/L	<0.5	<0.5	<0.5	<0.5	ANZG (2018) DGVT at 95% LSP for CrIII,
Co	1 µg/L	<0.2	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 95% LSP
Cu	1.3 µg/L	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Fe	18 µg/L	<5	<5	<5	9.6	ANZECC (2000) LRTV
Pb	4.4 µg/L	<0.2	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 95% LSP
Mn	80 µg/L	<0.5	<0.5	<0.5	3.2	ANZG (2018) DGVT at unknown LSP
Hg	0.1 µg/L	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 99% LSP
Ni	7 µg/L	<0.5	<0.5	<0.5	<0.5	ANZG (2018) DGVT at 99% LSP
Se	3 µg/L	<2	<2	<2	<2	ANZECC (2000) LRTV
Ag	1.4 µg/L	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 95% LSP
V	100 µg/L	1.9	1.5	2	2.2	ANZG (2018) DGVT at 95% LSP
Zn	8 µg/L	<5	<5	<5	<5	ANZG (2018) DGVT at 95% LSP

Table 6 29-30 September 2009 dissolved metals & metalloids (SKM 2009)

Analyte	Trigger Value	Reference				Inner Harbour	Guideline Value Description
		R1	R2	Beacon 3	95% UCL	95% UCL	
Al	0.5 µg/L	<10	<10	<10	<10	14.5	ANZECC (2000) LRTV
Sb	10 µg/L	<0.8	<0.8	<0.8	<0.8	<0.8	ANZECC (2000) LRTV
As	2.3 µg/L	1.4	1.2	1.1	1.4	1.4	ANZECC (2000) LRTV for AsIII
Cd	0.7 µg/L	<0.6	<0.6	<0.6	<0.6	<0.6	ANZG (2018) DGVT at 99% LSP
Cr	4.4 µg/L	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP for CrIII,
Co	1 µg/L	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP
Cu	1.3 µg/L	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Fe	18 µg/L	<2	<2	<2	<2	<2	ANZECC (2000) LRTV
Pb	4.4 µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 95% LSP
Mn	80 µg/L	0.7	0.8	4	5.6	6.7	ANZG (2018) DGVT at unknown LSP
Hg	0.1 µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 99% LSP
Ni	7 µg/L	<4	<4	<4	<4	<4	ANZG (2018) DGVT at 99% LSP
Se	3 µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	ANZECC (2000) LRTV
Ag	1.4 µg/L	0.2	0.2	0.2	0.3	1	ANZG (2018) DGVT at 95% LSP
V	100 µg/L	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Zn	15 µg/L	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP

Table 7 3-4 February 2010 dissolved metals & metalloids (SKM 2010b)

Analyte	Trigger Value	Reference				Inner Harbour	Guideline Value Description
		R1	R2	Beacon 3	95% UCL	95% UCL	
Al	0.5 µg/L	<10	<10	<10	<10	<10	ANZECC (2000) LRTV
Sb	10 µg/L	<0.8	<0.8	<0.8	<0.8	<0.8	ANZECC (2000) LRTV
As	2.3 µg/L	1.5	1.5	1.5	1.5	2.1	ANZECC (2000) LRTV for AsIII
Cd	0.7 µg/L	<0.6	<0.6	<0.6	<0.6	<0.6	ANZG (2018) DGVT at 99% LSP
Cr	4.4 µg/L	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP for CrIII,
Co	1 µg/L	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP
Cu	1.3 µg/L	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Fe	18 µg/L	7.5	<2	<2	8.8	4.5	ANZECC (2000) LRTV
Pb	4.4 µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 95% LSP
Mn	80 µg/L	2.4	1.4	1.2	2.8	6.8	ANZG (2018) DGVT at unknown LSP
Hg	0.1 µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 99% LSP
Ni	7 µg/L	<4	<4	<4	<4	<4	ANZG (2018) DGVT at 99% LSP
Se	3 µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	ANZECC (2000) LRTV
Ag	1.4 µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 95% LSP
V	100 µg/L	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Zn	15 µg/L	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP

Table 8 Summary of 24-26 November 2010 dissolved metals & metalloids (SKM 2011a)

Analyte	Trigger Value	Outer Harbour				Reference				Inner Harbour	Guideline Value Description
		OH01	OH02	OH03	95% UCL	R1	R2	Beacon 3	95% UCL	95% UCL	
Al	0.5 µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	ANZECC (2000) LRTV

Analyte	Trigger Value	Outer Harbour				Reference				Inner Harbour	Guideline Value Description
		OH01	**OH02**	**OH03**	**95% UCL**	**R1**	**R2**	**Beacon 3**	**95% UCL**	**95% UCL**	
Sb	10 µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	ANZECC (2000) LRTV
As	2.3 µg/L	1.4	1.5	1.4	1.5	1.3	1.4	1.5	1.6	1.6	ANZECC (2000) LRTV for AsIII
Cd	0.7 µg/L	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	ANZG (2018) DGVT at 99% LSP
Cr	4.4 µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP for CrIII,
Co	1 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP
Cu	1.3 µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Fe	18 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	*2*	ANZECC (2000) LRTV
Pb	4.4 µg/L	0.4	<0.2	0.2	0.5	0.2	0.2	0.3	0.4	0.7	ANZG (2018) DGVT at 95% LSP
Mn	80 µg/L	2.6	2	2.2	2.7	0.8	0.9	1.6	1.9	5.4	ANZG (2018) DGVT at unknown LSP
Hg	0.1 µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 99% LSP
Ni	7 µg/L	<4	<4	<4	<4	<4	<4	<4	<4	<4	ANZG (2018) DGVT at 99% LSP
Se	3 µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	ANZECC (2000) LRTV
Ag	1.4 µg/L	0.5	0.2	0.4	0.6	0.2	0.1	0.4	0.5	0.7	ANZG (2018) DGVT at 95% LSP
V	100 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP
Zn	15 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP

Table 9 Summary of 8-10 June 2011 dissolved metals & metalloids (SKM 2011b)

Analyte	Trigger Value	Outer Harbour				Reference				Inner Harbour	ANZECC (2000)
		OH01	**OH02**	**95% UCL**	**95% UCL**	**R1**	**R2**	**Beacon 3**	**95% UCL**	**95% UCL**	
Al	0.5 µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	ANZECC (2000) LRTV
Sb	10 µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	ANZECC (2000) LRTV
As	2.3 µg/L	1.4	1.3	1.3	1.4	1.6	1.5	1.6	1.5	1.3	ANZECC (2000) LRTV for AsIII
Cd	0.7 µg/L	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	ANZG (2018) DGVT at 99% LSP
Cr	4.4 µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP for CrIII,
Co	1 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP
Cu	1.3 µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	ANZG (2018) DGVT at 95% LSP
Fe	18 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	ANZECC (2000) LRTV
Pb	4.4 µg/L	0.1	0.2	2.9	4.3	0.2	0.3	0.2	0.4	2.6	ANZG (2018) DGVT at 95% LSP
Mn	80 µg/L	2	2.1	2.1	2.1	0.8	0.7	0.6	0.9	3.6	ANZG (2018) DGVT at unknown LSP
Hg	0.1 µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	ANZG (2018) DGVT at 99% LSP
Ni	7 µg/L	<7	<7	<7	<7	<7	<7	<7	<7	<7	ANZG (2018) DGVT at 99% LSP
Se	3 µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	ANZECC (2000) LRTV
Ag	1.4 µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	ANZG (2018) DGVT at 95% LSP
V	100 µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	ANZG (2018) DGVT at 95% LSP
Zn	15 µg/L	2	<2	2	<2	2	<2	2	2	4.5	ANZG (2018) DGVT at 95% LSP

Table 10 Summary of May 2014 to November 2017 dissolved metals at Station PR09 and PR10 in Leschenault Inlet (GHD 2018) (µg/L). Exceedances of the guideline values denoted in bold red.

Analyte	Trigger Value	21-01-14	18-11-14	20-4-15	26-10-15	7-4-16	18-1-17	24-5-17	30-11-17	ANZECC (2000)
Station PR09										
As	2.3	<10	<10	<10	<5	<5	**2.4**	1.7	1.6	ANZECC (2000) LRTV for AsIII
Ba	-	15	15	12	16	15	15	15	14	None for marine waters
Co	1	<10	<10	<10	<5	<5	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 95% LSP
Cu	1.3	<10	<10	11	**9**	<5	**1.7**	**1.4**	**4**	ANZG (2018) DGVT at 95% LSP
Mn	80	22	27	15	16	18	14	12	18	ANZG (2018) DGVT at unknown LSP
Mo	-	-	14	11	12	14	14	13	11	None for marine waters
Ni	7	<10	<10	<10	<5	<5	<0.5	<0.5	<0.5	ANZG (2018) DGVT at 99% LSP
Zn	15	<50	<50	<50	<25	<25	<5	<5	7	ANZG (2018) DGVT at 95% LSP
Station PR10										
As	2.3	<5	<10	<10	<5	2	**2.3**	1.6	1.6	ANZECC (2000) LRTV for AsIII
Ba	-	39	19	13	16	22	16	12	16	None for marine waters
Co	1	<5	<10	<10	<5	<10	<0.2	<0.2	<0.2	ANZG (2018) DGVT at 95% LSP
Cu	1.3	<5	<10	<10	10	**3**	**2.3**	<1	**4**	ANZG (2018) DGVT at 95% LSP
Mn	80	33	40	18	14	18	17	10	16	ANZG (2018) DGVT at unknown LSP
Mo	-	-	12	11	12	11	13	11	11	None for marine waters
Ni	7	<5	<10	<10	5	<1	<0.5	0.8	<0.5	ANZG (2018) DGVT at 99% LSP
Zn	15	<25	<50	<50	<25	7	<5	<5	<5	ANZG (2018) DGVT at 95% LSP

Table 11 Summary statistics across 6 surveys of total and dissolved metals and metalloids, and chl-a, across 8 sites in Koombana Bay and the Inner Harbour during 2012 (Wave Solutions 2012b). Exceedance of dissolved metals over the guideline values denoted in bold red.

Analyte	Trigger Value	Statistic	Total Metals						Dissolved Metals						ANZECC (2000)
			2 2-12	20-3-12	30 4-12	22-6-12	16-8-12	11-11-12	2 2-12	20-3-12	30 4-12	22-6-12	16-8-12	11-11-12	
Al	0.5 µg/L	Mean	**4.6**	**6.1**	**16.6**	**53.3**	**41.1**	**48.6**	**2.5**	**2.8**	**2.5**	**3.3**	**16.6**	**8.5**	ANZECC (2000) LRTV
		SD	2.5	5.3	1.4	14	18.4	30	0	0.9	0	2.3	16.6	3.2	
		Min	**2.5**	**2.5**	**15**	**37**	**21**	**26**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**6**	
		Max	**9**	**17**	**19**	**80**	**76**	**120**	**2.5**	**5**	**2.5**	**9**	**55**	**15**	
Sb	10 µg/L	Mean	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	ANZECC (2000) LRTV
		SD	0	0	0	0	0	0	0	0	0	0	0	0	
		Min	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
		Max	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
As	2.3 µg/L	Mean	2.1	2	2	1.6	1.6	1.6	2	2	2	1	1.4	1.1	ANZECC (2000) LRTV for AsIII
		SD	0.4	0	0	0.5	0.5	0.5	0	0	0	0	0.5	0.4	
		Min	2	2	2	1	1	1	2	2	2	1	1	0.5	
		Max	3	2	2	2	2	2	2	2	2	1	2	2	
Cd	0.7 µg/L	Mean	0.5	1.1	0.8	1	0.5	0.5	0.5	**0.9**	**0.8**	**0.9**	0.5	0.5	ANZG (2018) DGVT at 99% LSP
		SD	0	0.4	0.3	0.4	0	0	0	0.4	0.3	0.4	0	0	
		Min	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
		Max	0.5	1.3	1.1	1.3	0.5	0.5	0.5	**1.3**	**1.1**	**1.3**	0.5	0.5	
Cr	4.4 µg/L	Mean	0.5	0.5	2.5	2.5	2.5	2.5	0.5	0.5	2.5	2.5	2.5	2.5	ANZG (2018) DGVT at 95% LSP for CrIII,
		SD	0	0	0	0	0	0	0	0	0	0	0	0	
		Min	0.5	0.5	2.5	2.5	2.5	2.5	0.5	0.5	2.5	2.5	2.5	2.5	
		Max	0.5	0.5	2.5	2.5	2.5	2.5	0.5	0.5	2.5	2.5	2.5	2.5	
Co	1 µg/L	Mean	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	ANZG (2018) DGVT at 95% LSP
		SD	0	0	0	0	0	0	0	0	0	0	0	0	
		Min	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
		Max	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Cu	1.3 µg/L	Mean	3.5	3.3	5.4	0.5	2.3	3.1	**2.8**	**2.7**	**2.1**	0.5	1.1	0.5	ANZG (2018) DGVT at 95% LSP
		SD	1.4	0.8	1	0	0.7	4.7	0.8	0.6	0.3	0	0.4	0	
		Min	2	2.5	3.9	0.5	1.3	0.5	**2**	**1.7**	**1.8**	0.5	0.5	0.5	
		Max	6.5	4.7	6.4	0.5	3.3	14	**4.3**	**3.8**	**2.7**	0.5	**1.7**	0.5	
Fe	18 µg/L	Mean	11	14.5	27	136.8	120.5	162	2.5	2.5	2.5	6.9	**46.5**	**27.1**	ANZECC (2000) LRTV
		SD	5	5.7	5.1	53.9	64.2	118.3	0	0	0	8	18.4	14.2	
		Min	6	11	21	86	52	80	2.5	2.5	2.5	2.5	**22**	17	
		Max	21	28	35	240	250	440	2.5	2.5	2.5	26	**76**	**60**	
Pb	4.4 µg/L	Mean	1.2	0.5	0.5	0.5	0.5	0.1	1.2	0.5	0.5	0.5	0.5	0.5	ANZG (2018) DGVT at 95% LSP
		SD	1.7	0	0	0	0	0	1.7	0	0	0	0	0	
		Min	0.5	0.5	0.5	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.5	0.5	
		Max	5.4	0.5	0.5	0.5	0.5	0.1	**5.4**	0.5	0.5	0.5	0.5	0.5	
Mn	80 µg/L	Mean	4.2	5.6	14.7	3.6	5.7	6.6	1.6	3.5	7.3	1.1	2.3	3.7	ANZG (2018) DGVT at unknown LSP
		SD	1	1.2	1.9	0.9	1.8	3.2	0.7	0.65	1.1	0.7	0.4	0.8	
		Min	3	4.2	11	2.2	3.4	4.2	0.5	2.7	6.1	0.5	1.5	2.7	
		Max	6	8.2	17	5.1	8	14	3	4.9	9.2	2.1	2.7	5.2	
Hg	0.1 µg/L	Mean	0.02	0.08	0.05	0.1	0.1	1.4	0.03	0.06	0.05	**0.1**	**0.1**	**0.1**	ANZG (2018) DGVT at 99% LSP
		SD	0	0.05	0	0	0	1.4	0	0.03	0	0	0	0	
		Min	0.02	0.05	0.05	0.1	0.1	0.5	0.03	0.03	0.05	**0.1**	**0.1**	**0.1**	
		Max	0.02	0.2	0.05	0.1	0.1	4.5	0.03	**0.1**	0.05	**0.1**	**0.1**	**0.1**	
Ni	7 µg/L	Mean	5	5	5	5	5	5	5	5	5	5	5	5	ANZG (2018) DGVT at 99% LSP
		SD	0	0	0	0	0	0	0	0	0	0	0	0	
		Min	5	5	5	5	5	5	5	5	5	5	5	5	
		Max	5	5	5	5	5	5	5	5	5	5	5	5	
Se	3 µg/L	Mean	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	ANZECC (2000) LRTV
		SD	0	0	0	0	0	0	0	0	0	0	0	0	
		Min	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
		Max	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Ag	1.4 µg/L	Mean	0.5	0.5	0.3	0.3	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3	ANZG (2018) DGVT at 95% LSP
		SD	0	0	0	0	0	0	0	0	0	0	0	0	
		Min	0.5	0.5	0.3	0.3	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3	
		Max	0.5	0.5	0.3	0.3	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3	
V	100 µg/L	Mean	1.9	2	2.5	2.2	2.6	2.1	1.8	1.65	2.3	1.7	1.7	1.6	ANZG (2018) DGVT at 95% LSP
		SD	0.3	0.2	0.3	0.3	0.6	0.3	0.4	0.26	0.26	0.2	0.2	0.2	
		Min	1.5	1.7	2	1.7	1.7	1.7	1.2	1.3	2	1.5	1.4	1.3	
		Max	2.5	2.3	3.2	2.5	3.7	2.6	2.5	2	2.7	1.9	1.9	1.8	
Zn	8 µg/L	Mean	17	27	19	19.6	21.6	18.5	**15**	**10**	**9.3**	**14.1**	**12.6**	**13.3**	ANZG (2018) DGVT at 95% LSP
		SD	5	5	2	9.3	18.2	7.7	6	3.3	2.4	6	2.4	2.5	
		Min	12	18	16	9	12	9	**9**	7	6	**8**	**10**	**11**	
		Max	28	35	22	38	66	31	**28**	**17**	**13**	**25**	**18**	**17**	

4.2.3 Nutrients and chl-a

Figure 7 illustrates the past measurements of nutrients and chl-a in the Koombana Bay region, which exhibit the following patterns:

- The averages of the five (5) Bunbury Ocean Outfall Monitoring program (BOOM) reference sites on each sampling date almost always meet the appropriate ANZECC (2000) DTVPCs or seasonally varying ANZG (2018) DGVPCs for all nutrients (TN, TP, NO_X, NH_X, FRP) and chl-a.
- Generally, TN in Casuarina Boat/Outer Harbour, Koombana Bay and Inner Harbour met the ANZECC (2000) DTVPC inshore marine waters of South West Australia, but it is exceeded in Leschenault Inlet.
- In contrast the NH_X ANZECC (2000) DTVPC and seasonally varying NO_X ANZG (2018) DGVPC were exceeded in all water bodies except the coastal waters outside of Koombana Bay. In particular NH_X is particularly elevated in Leshenault Inlet, but also in the Inner Harobur and Casuarina Boat/Outer Harbour. This demonstrate the greater bioavailability of nitrogen to primary producers in the harbours and bay than the BOOM reference site of the proximal coastal inshore waters..
- Generally, the Casuarina Boat Harbour, Koombana Bay and Inner Harbour locations exceed the TP ANZECC (2000) DGVPC and less frequently the seasonally varying FRP ANZG DGVPC. Exceedances of TP and FRP thresholds are more predominant and of greater magnitude in Leschenault Inlet.
- Though chl-a of the BOOM reference sites was approximately at the seasonally varying ANZG (2018) DGVPC, Koombana Bay and the other attached water bodies were generally much higher than this criteria.
- NH_X, NO_X and TP in Leschenault Inlet have been relatively similar during periods of monitoring from 1976-1985, 2007-2008 and 2020, which suggests consistent temporally and spatially patterns of water quality in this semi-enclosed water body.

Inputs from two relatively sizeable rivers (Preston and Collie), Bunbury Port activities and the surrounding urban area likely contribute nutrient loads. Given the reduced flushing of Koombana Bay and its attached water bodies relative to the open inshore coastal waters, this is likely a contributing factor of the greater chl-a levels relative to the inshore coastal waters to the north and south of the Koombana Bay region. However given the large range of flushing between Casuarina Boat Harbour (~2-3 days), Leschenault Inlet (~5-10 days) and Inner Harbour (~10-15 days) (see GHD 2023b), it is somewhat unexpected that larger variations in nutrients and chl-a do not occur between water bodies.

Monitoring by Oceanica (2008a) on a quarterly basis from July 2007–April 2008 was within the same range as those measured during this project’s baseline studies for NH_X, NO_X, TN, FRP, TP and chl-a within Koombana Bay and Casuarina Boat Harbour (GHD 2023a), and Leshenault Inlet (O2 Marine 2021). This suggests that the nutrient and chl-a climate of these water bodies has not changed over the past ~10 years. Further, measurements in Leschenault Inlet by DWER from 1976-1985 of NH_X, NO_X, TP and FRP indicate that the nutrient climate has been similar for the past ~35-45 years.

The BOOM reference site data has shown that NH_X, NO_X, TP, FRP and chl-a are substantially lower in the inshore coastal waters to the south of Bunbury. This suggests that the combination of river inputs and longer flushing time scales of Koombana Bay and the adjacent water bodies of interest relative to the typical non-sheltered inshore coastal waters are the likely primary mechanisms for higher concentrations.

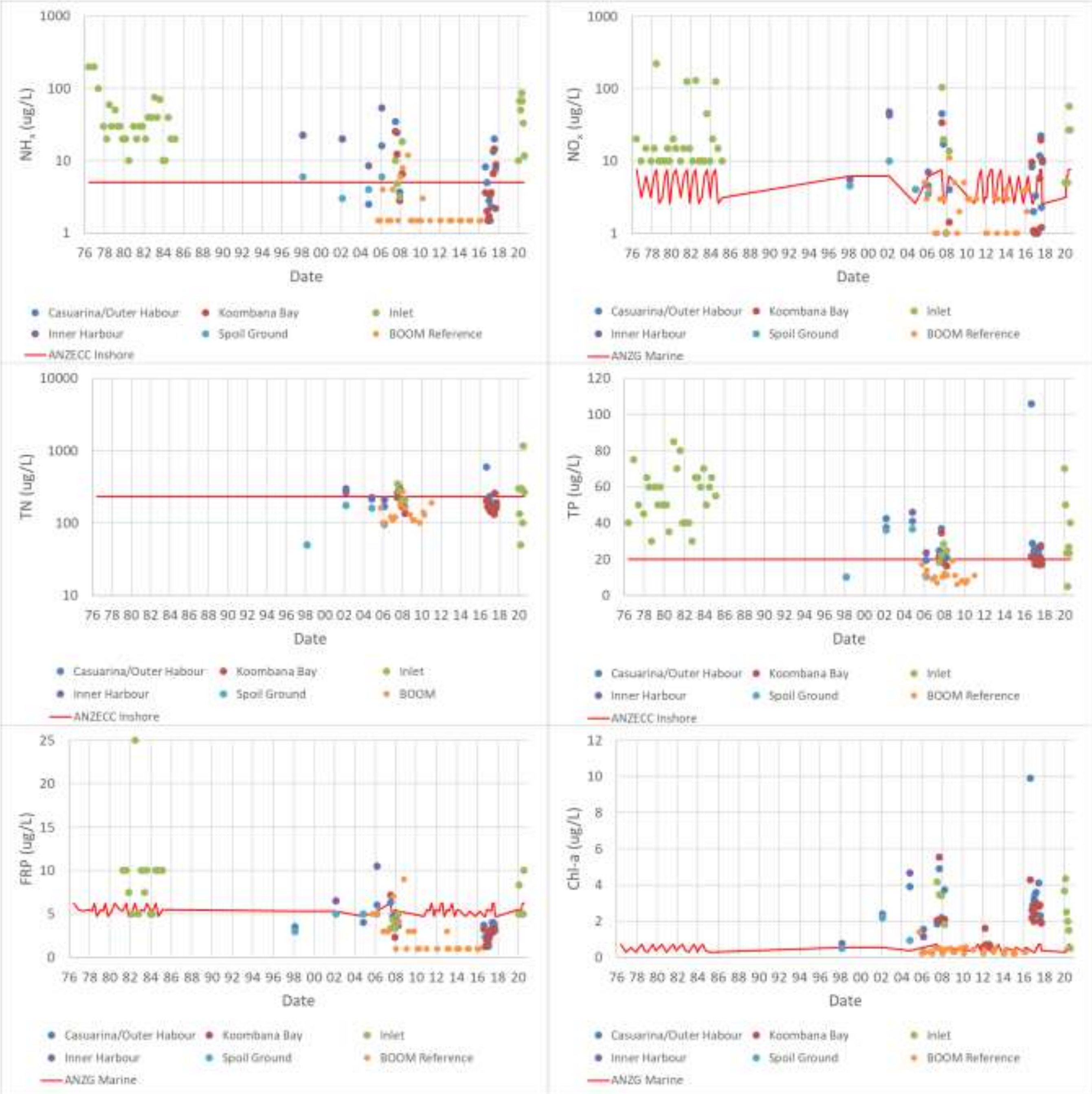


Figure 7 ***Past nutrients and chl-a in Koombana Bay region*** [5]

[5] Red lines represent relevant ANZG (2018) or ANZECC (2000) default guideline values for seasonally varying regional marine waters and inshore marine waters of South West Australia, respectively.

5. Sediment quality

Past sediment quality guidelines (ANZECC 2000, NOGDM 2002, NAGD 2009) are referenced in past reports and so too in Section 5.1.

In Section 5.2.2 and 5.2.3 sediment quality data was compared to ANZG (2018) toxicant default guideline values for sediment quality (DGVTS). If the DGVTS was exceeded then it was compared to the ANZG (2018) high toxicant default guideline values for sediment quality (DGVTS-High).

5.1 Relevant past investigations

Table 12 provides a synopsis of available past sediment quality investigations of Koombana Bay and its adjacent water bodies.

Table 12 Synopsis of available past sediment quality investigations

Study Description	Findings
2001 Sediment Origin Study SKM (2001) investigated the origin of material within the Shipping Channel to inform potential measures to reduce maintenance dredging frequency (every 2-3 years) with a focus on particle size distribution (PSD), loss on ignition (LOI), and metals and metalloid concentrations.	Sediments: – Shipping Channel consists predominately of fine silts (<26 um). – To the north and south of the port the sediments are generally much coarser (>250 um). – The Collie and Preston rivers have bimodal distributions in PSD with peaks in the 90-180 um and 250-500 um diameters. – Larger variations in and proximal to The Cut are consistent with known hydrodynamics whereby: • A mixture of coarse and fine material at the estuary opening (i.e. relatively moderate current speeds). • Coarser material several hundred meters to the west of the ocean opening (relatively high currents). • Predominately fine material to the south of The Cut in Koombana Bay (relatively low currents). LOI was higher in the Shipping Channel (28-35%) than sites in The Cut, eastern Koombana Bay, and northern and southern nearshore ocean waters (<5%), which suggests a composition that includes substantial quantities of decomposing plant material (i.e. seagrass wrack). As a result of this study, the port periodically uses a trawler to remove plant material within the Shipping Channel.
2001 Maintenance Dredge Monitoring (Spoil Ground Sediments) SKM (2010a) reports a required 2001 maintenance dredging monitoring program for tributylin (TBT)	TBT, dibutyltin (DBT) and monobutyltin (MBT) were above LoRs in the sediments at the spoil ground, Shipping Channel, Outer Harbour and Inner Harbour, but were only above NODGDM (2002) screening levels in the Inner Harbour. Further, the ratio of MBT to total butyltin was indicative of rapid breakdown (well oxygenated sediments) at all sites except for the Inner Harbour.
2004 Maintenance Dredge Monitoring (Spoil Ground Infauna and TBT) SKM (2010a) reports a 2004 maintenance dredging monitoring program for infauna recolonisation and success of capping TBT contaminated material of the spoil ground.	Disposal impacted both the spoil ground sites and a site 250 m to the north of the spoil ground, but probably did not impact the site 1,000 m to the north, and did not impact the site 2,000 m to the north. There was no indication of recovery at the three (3) impacted sites after 11 months where large temporal differences of unknown origin confounded the interpretation of infaunal recovery from disposal activities. Pre-disposal sampling had elevated TBT above the maximum guideline value at one (1) of five (5) locations in the spoil ground, which was likely localised contamination from a large paint flake remaining from previous dredging. Only one post-disposal TBT measurement exceeded the maximum guideline at depth (50 cm), whereas surface (2 cm) samples were below the maximum guideline value. The contaminated TBT sediment was deemed to be effectively capped and contained within the spoil ground with less contaminated dredged material.
2005 Leschenault Inlet Sampling DoW (2007) sampling at shallow, moderate and deep sites along two transects in Leschenault Inlet.	As, Cu and Hg were found to be just above the low ANZECC (2000) interim sediment quality guideline values (ISQG-low) at transects out from the southern shoreline.
2007 Maintenance Dredge Monitoring SKM (2007b) includes PSD, metals, organotins and porewater analyses.	The 95% UCL for metals and metalloids in three (3) dredge areas (Outer Harbour, Inner Harbour, Shipping Channel) were below the NODGDM (2002) screening levels. The 95% UCL for TBT in all two dredge areas (Outer Harbour, Shipping Channel) were below the NODGDM (2002) screening level.

Study Description	Findings
	Insufficient data provided to select appropriate Outer Harbour sites for this assessment, hence study not used in assessment of existing sediment quality.
2008 Maintenance Dredge Monitoring (Spoil Ground TBT) SKM (2010a) reports a 2008 maintenance dredging monitoring program for success of capping TBT contaminated material of the spoil ground with the following summary points.	The burial (capping) of TBT contaminated material at the spoil ground was successful with no TBT, DBT or MBT at monitoring sites outside the spoil ground, and only (1) one site within the spoil ground with measurable TBT (but below the screening level). There was a slight decrease in particle size to the north of the spoil ground likely from northerly currents distributing fine material during dumping.
2008 Koombana Bay Baseline Study Oceanica (2008b) sediment quality at seven (7) Casuarina Boat Harbour sites, 12 Koombana Bay sites, and 3 (3) Leschenault Inlet sites.	Sediments dominated by clay, mud and fine sand with relatively high organic content at some sites. The ANZECC (2000) ISQG-low for As was slightly exceeded at four (4) sites. The ANZECC (2000) ISQG-low for Cu was exceeded at one (1) Outer Harbour site. TBT was recorded in all samples with highest values in the Outer Harbour, though the ANZECC (2000) ISQG-low was not exceeded at any sites, Polycyclic aromatic hydrocarbons (PAHs) were below ANZECC (2000) ISQG-low. No organohosphate pesticides (OP) recorded for any samples. Two organochlorine pesticides (OC) (DDE and DDD) were recorded. Generally sediments in the Koombana Bay region were found to be uncontaminated.
1999-2010 Sediment Quality Review SKM (2010a) evaluated the most recent measurements of radionuclides (1999), metals and metalloids (2010), TBT (2010), OCs-PCBs (2003) and PAHs-TPH (2010).	Radionuclide (uranium [U], thorium [Th], potassium [K]) from 4 March 1999 sediment samples in the Outer Harbour were more than a 100-fold less that the guideline value of 35 Bq/g. Organochlorines (OCs) and polychlorinated biphenyls (PCBs) from 2003 were consistently below LoRs. PAHs during 2003 in the Shipping Channel, Inner Harbour and Outer Harbour sediments were below detection levels; and total petroleum hydrocarbons (TPH) in the Outer Harbour and the Shipping Channel were at detectable levels, but below NAGD (2009) screening level. Sediments in the Shipping Channel, Inner Harbour and Outer Harbour between 2006 and 2010 were below NAGD (2009) screening levels. Normalised TBT in dredged sediments of the Inner Harbour between 1999 and 2006 indicated increasing levels that attained levels above the NAGD (2009) screening level. No measurement was reported in 2010 for Inner Harbour sediments in SKM (2010). The spoil ground also had values above the NAGD (2009) screening level, but this value in 2010 decreased below the screening level. The Outer Harbour and the Approach Channel were below the NAGD (2009) screening levels on all occasions.
2010 Alcoa Port Screening Study Oceanica (2011) evaluated three (3) reference sites for mussels (metals, organotins) and sediments (PSA, metals, organotins) in Nov. 2010	Sediments of the reference sites outside of Koombana Bay consisted mainly of coarse and very coarse sand, whereas Inner Harbour sediments were mainly silt, clay and very fine sand. All metal and metalloid concentrations were below ANZECC (2000) ISQG-low values at the reference locations with the exception of As at one (1) reference site. Cu was above the ANZECC (2000) ISQG-low but below the ANZECC (2000) ISQG-high values at several Inner Harbour sites.
May 2008, September 2009, February 2010 and May 2010 Sediment Metals Monitoring SKM (2008, 2009, 2010b, 2010c) carried out sediment sampling at two (2) to three (3) reference sites and a 11 to 12 Inner Harbour sites during 26-28 May 2008, 29-30 September 2009, 3-4 February 2010 and 26-28 May 2010.	SKM (2008, 2009, 2010a, 2010b) carried out sediment measurements at two (2) to three (3) reference sites and 11 to 12 Inner Harbour sites of Al (no NAGD (2009) screening level [SL]), Sb, As, Cd, Cr, Co (no SL), Cu, Fe (no SL), Pb, Mn (no SL), Hg, Ni, Se (no SL), Ag, V (no SL), Zn and TBT (normalised to 1% TOC). The key findings in regards to comparisons with NAGD (2009) screening levels were: – The 95% UCL of the two (2) (May 2008) and three (3) (September 2009) reference sites, and 80th percentile of three (3) (February 2010, May 2010) reference sites were below the relevant NAGD (2009) screening levels. – The 95% UCL of the 11 (only May 2008) to 12 sites in the Inner Harbour were below the relevant NAGD (2009) screening levels, except for TBT during the February 2010 survey.
November 2010 and June 2011 Sediment Metals Monitoring SKM (2011a, 2011b) carried out sediment sampling at three (3) Outer Harbour sites, three (3) reference and 20 Inner Harbour sites during spring (24-26 November 2010) and winter (8-10 June 2011).	SKM (2011a, 2011b) carried out sediment quality measurements at three (3) reference sites, three (3) Outer Harbour sites and 20 Inner Harbour sites of Al (no Screening Level [SL]), Sb, As, Cd, Cr, Co (no SL), Cu, Fe (no SL), Pb, Mn (no SL), Hg, Ni, Se (no SL), Ag, V (no SL), Zn and TBT (normalised to 1% TOC). The key findings in regards to comparisons with NAGD (2009) screening levels are: – The 80th percentile of the three (3) reference sites were below the relevant NAGD (2009) screening levels, except for As on both surveys and Ag during the November 2010 survey. – The 95% UCL of the three (3) Outer Harbour sites were below the relevant NAGD (2009) screening levels, except for Sb, As and Ag above the screening levels for the November 2010 survey.

Study Description	Findings
	– The 95% UCL of the 20 Inner Harbour sites were below the relevant NAGD (2009) screening levels, except for Cu above the screening level on the June 2011 survey, and Ag above the screening level on the November 2010 survey.
August 2011 Sediment Quality of Inner Harbour Sediments Wave Solutions (2012c) characterised PSD and sediment quality of surficial sediments of four (4) samples from three (3) sediment cores in the dredge footprint within the Inner Harbour, collated 27 PSD samples from previous studies within their Lanco Inner Harbour Project Area, and collected 10 surficial sediments from the offshore disposal area.	Fine particle fractions <30 µm accounted for approximately 30% of the sediment profile through the dredge footprint. Surficial sediments at the proposed offshore spoil ground was primarily comprised (>77%) of coarse sediment with diameters >500 µm and <5% <250 µm. The 95% UCLs of all metals and metalloids (Sb, As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Ag, Z) of samples in the Inner Harbour and at the offshore spoil ground were below the respective NAGD (2009) screening levels. TN, NH_X, NO_X, FRP and TP in the Lanco footprint within the Inner Harbour were 1,500±1,200 mg/kg, 4.6±3.5 mg/kg, 0.7±0.7 mg/kg, 35.3±27.1 mg/kg and 336±199 mg/kg, respectively. The 95% UCL for TBT (28.5 µg/kg) exceeded the NAGD (2009) screening level of 9 µg/kg. However, the 95% UCLs for total PAH (<20 µg/kg) and the pesticides of DDE (0.3 µg/kg) and DDD (0.6 µg/kg) were below their respective NAGD (2009) screening levels of 10,000 µg/kg, 2.2 µg/kg and 2 µg/kg, respectively.
2015 Koombana Bay Sediment Quality MAFRL (2015) collected sediments from three (3) sites in Casuarina Boat Harbour, seven (7) sites in Koombana Bay and three (3) reference sites to evaluate metals and metalloids, TBT, organochlorine pesticides, TPH and PAH.	All 95% UCLs for total metals and metalloids were below NAGD (2009) screening levels except Zn. One high Zn level in Koombana Bay of 660 mg/kg resulted in the 95% UCL (220 mg/kg) just exceeding the NAGD (2009) screening level of 200 mg/kg. Generally, highest concentrations occurred closest to the Casuarina Boat Harbour slipway and the lowest at sites closest to the Leschenault Inlet. Normalised TBT was below the NAGD (2009) screening level at all sites. Organochlorine pesticides were below LoRs at three (3) sites sampled. TPH and PAH were below the NAGD (2009) screening levels at three (3) sites sampled
Semi-annual from May 2014 to November 2017 (As, Co, Cu, Mn, Mo, Zn) and May 2014 (Sb, Ba, Be, Cd, Cr, Pb, Hg, Ni, Sn, V) Sediment Quality Monitoring at Northern Leschenault Inlet Shoreline at 2 Sites GHD (2018) carried out sediment monitoring on approximately a semi-annual basis for a partial list of analytes and once in May 2014 on a more complete list of analytes.	All metals and metalloids analytes were well below the ANZECC & ARMCANZ (2000) low ISQG-low (equivalent to the NAGD (2009) screening value). TRH, BTEX and Naphthalene were below LoR. .
Sediment PSD of Koombana Bay and Casuarina Boat Harbour on September 2016 GHD (2023a) PSD analyses of eight (8) surficial sediment samples in Casuarina Boat Harbour.	Refer to GHD (2023a). The 50^{th} percentile diameter is ~50 µm (coarse silt) with <7% comprised of clay to very fine silt. The organic content as loss on ignition at 500°C was 10-20%.
Sediment Quality of Casuarina Boat Harbour on October 2017 RPS (2017) PSD and sediment quality analyses of cores collected from 19 sites in Casuarina Boat Harbour with 26 samples analysed, and an additional 14 samples for elutriate analysis.	Refer to RPS (2017) and GHD (2023a). The average particle size distribution was ~12% clay (0-4 µm), ~15% silt (4-63 µm) and ~71% sand (63-2000 µm). Hg was the only metal/metalloid that exceeded ANZG (2018) DGVTS for 5 of the 26 samples though the mean, median and 95% UCL concentrations of mercury were below the ANZG (2018) DGVTS. Six (6) samples exceeded the TBT ANZG (2018) DGVTS (9 µgSn/kg) of which two (2) exceeded the ANZG (2018) DGVTS-high of 70 µgSn/kg of the 16 samples analysed. The maximum concentration of 287 µgSn/kg was adjacent to the boat maintenance facility, and the other sampling sites that exceeded the default guideline value were along the western boundary of the dredge area. The mean and 95% UCL concentrations of TBT exceeded with the ANZG (2018) DGVTS though the median was lower. Total PAH and total recoverable hydrocarbons (TRH) were below the ANZG (2018 DGVTS (note TRH compared to TPH guideline value) for all samples. Though dieldrin and endrin LoRs are marginally above the sediment guideline value, no samples were above LoR. DDT wer above the ANZG (2018) DGVTS in one (1) sample, however no other pesticides were detected above relevant guideline values. DDD and DDE were above LoR in one (1) and two (2) samples, respectively. Elutriate analyses of metals/metalloids were below the ANZG (2018) DGVTS . Mean FRP and ammonia concentrations of 0.084 mg/L and 1.83 mg/L, respectively, are substantially greater than ANZECC (2000) DTVPC of 0.005 mg/L for ammonia and the seasonally varying ANZG (2018) DGVPC of 0.005-0.006 mg/L for FRP. Hence, there is likely to be some degree of nutrient stimulation, particularly nitrogen, during dredging activities in this semi-enclosed water body.

Study Description	Findings
Sediment Quality of Leschenault Inlet on January 2020 O2 Marine (2021) PSD and sediment quality analyses of three (3) surficial sediment samples in Leschenault Inlet.	Refer to O2 Marine (2021) and GHD (2023a). TBT and metals/metalloids (Sb, As, Cd, Cu, Cr, Pb, Hg, Ni, Ag, Zn) were below their respective ANZG (2018) DGVTS. Additionally, organochlorin and organophosphate pesticides were all below LoR. Nutrient levels in the sediments ranged from 1,200-1,400 mg/kg, 10-20 mg/kg, <1 mg/kg, 63-96 mg/kg and <1 mg/kg for TN, NH_X, NO_X, TP and FRP, respectively.
Sediment Quality of KBSC footprint on April 2021 Cardno (2021) PSD and sediment quality analyses of ten (10) sites from 1 m cores over the KBSC marina footprint.	Refer to Cardno (2021) and GHD (2023a). The sediment quality of the proposed KBSC footprint presents limited risk in terms of toxicity to the marine environment during dredging activities.
PSD of Surficial Sediments over the Proposed Casuarina Boat Harbour northern breakwater on June 2020 O2 Marine (2020) PSD analyses of seven (7) surficial sediment samples over the proposed Casuarina Boat Harbour northern breakwater dredge footprint.	Refer to O2 Marine (2020) and GHD (2023a). On average silt comprises 62% of the sediments, sand 31% and clay 6%. Approximately 60% of the material is comprised of medium silt to very fine sand (16-125 µm diameter).

5.2 Assessment of sediment quality

Past datasets that were collated to characterise the sediment quality are summarised in Table 13.

Table 13 Data and statistics used in sediment quality assessment

Reference and Sampling Date	Statistics used in Assessment
SKM (2007b) *November 2006*	95% UCLs of Outer Harbour (22 sites), Inner Harbour (22 sites) and spoil ground (17 sites).
Oceanica (2008b) *December 2007*	80^{th} percentiles of Casuarina Boat Harbour (7 sites) and Koombana Bay (11 sites)
SKM (2008) *May 2008*	95% UCLs of Inner Harbour (11 sites) and reference locations (2 sites).
SKM (2009) *September 2009*	95% UCLs of Inner Harbour (11 sites) and reference locations (3 sites).
SKM (2010b *February 2010*	95% UCLs of Inner Harbour (12 sites) and 80^{th} percentiles of reference locations (3 sites).
SKM (2010c) *May 2010*	95% UCLs of Inner Harbour (12 sites) and 80^{th} percentiles of reference locations (3 sites).
Oceanica (2011) *November 2010*	80^{th} percentiles of Inner Harbour (6 sites) and reference locations (3 sites).
SKM (2011a) *November 2010*	95% UCLs of Inner Harbour (20 sites) and Outer Harbour (3 sites), and 80^{th} percentiles of reference locations (3 sites).
SKM (2011b) *June 2011*	95% UCLs of Inner Harbour (20 sites) and Outer Harbour (3 sites), and 80^{th} percentiles of reference locations (3 sites).
Wave Solutions (2012c) *June 2011*	80^{th} percentiles of spoil grounds (10 sites).
MAFRL (2015) *January 2015*	80^{th} percentiles of Outer Harbour (3 sites), Koombana Bay (7 sites) and reference locations (3 sites).
RPS (2017) *October 2017*	95% UCLs of Casuarina Boat Harbour (19 sites).

5.2.1 Particle size distribution

On the basis of sediment PSD measured in November 2006 (SKM 2007b, Figure 8) and July 2011 (Wave Solution 2012c, Figure 9), the following is noted:

– In November 2006 coarser sediments occurred in the coastal waters relative to the protected Koombana Bay waters. The median particle size was:
  - Coarse silt (38-63 µm) in the Shipping Channel.
  - Very fine sand (63-90 µm) in the Inner Harbour and Outer Harbour.
  - Medium sand (250-500 µm) at the spoil ground.

– In July 2011 good coverage of western Koombana Bay was sampled of the surficial whereby PSD had median particle sizes ranging from medium sand (250-500 µm) to coarse silt (38-63 µm) with the overall median between very fine sand (63-90 µm) to fine sand (90-125 µm).

Generally, in terms of the proposed dredging areas of the KBMS SPER, the PSD analyses indicate the following:

– A high content of silt-clay in excess of 60% characterises the sediments to be dredged below the proposed phase 1 Casuarina Boat Harbour northern breakwater dredging footprint (O2 Marine 2020).
– A moderate clay-silt content of ~27% characterises the phase 2 dredging of the Casuarina Boat Harbour sediments (RPS 2017).
– A low clay-silt content of ~13% characterises the KBSC marina footprint sediments (Cardno 2021).

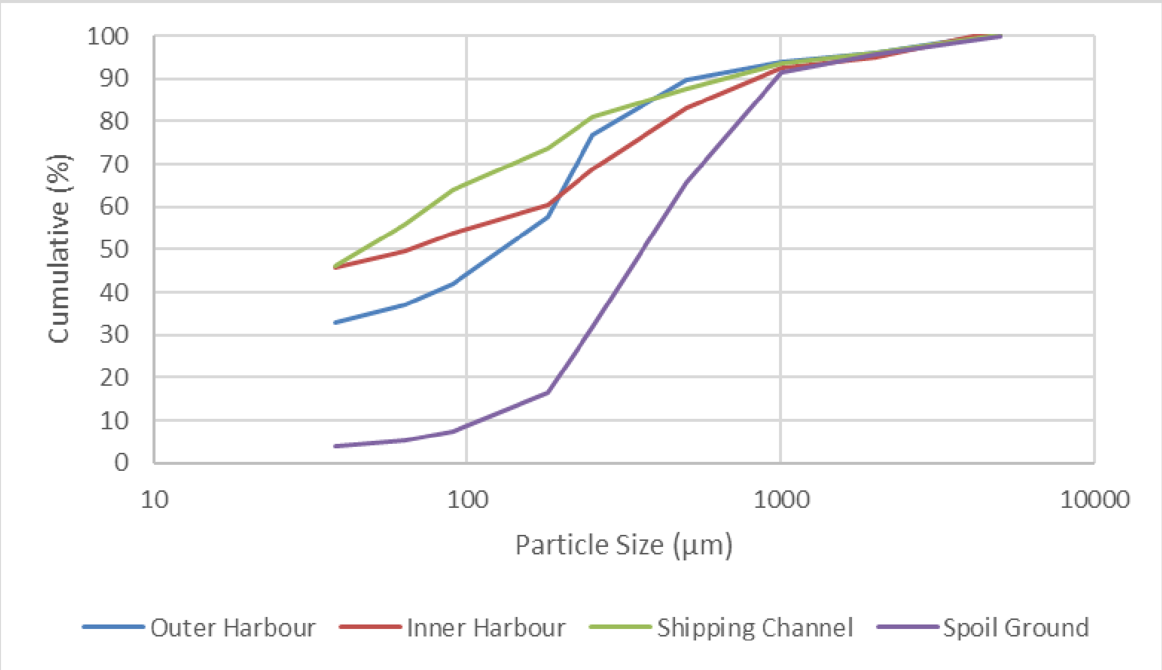


Figure 8 ***PSD in November 2006 (SKM 2007b)***

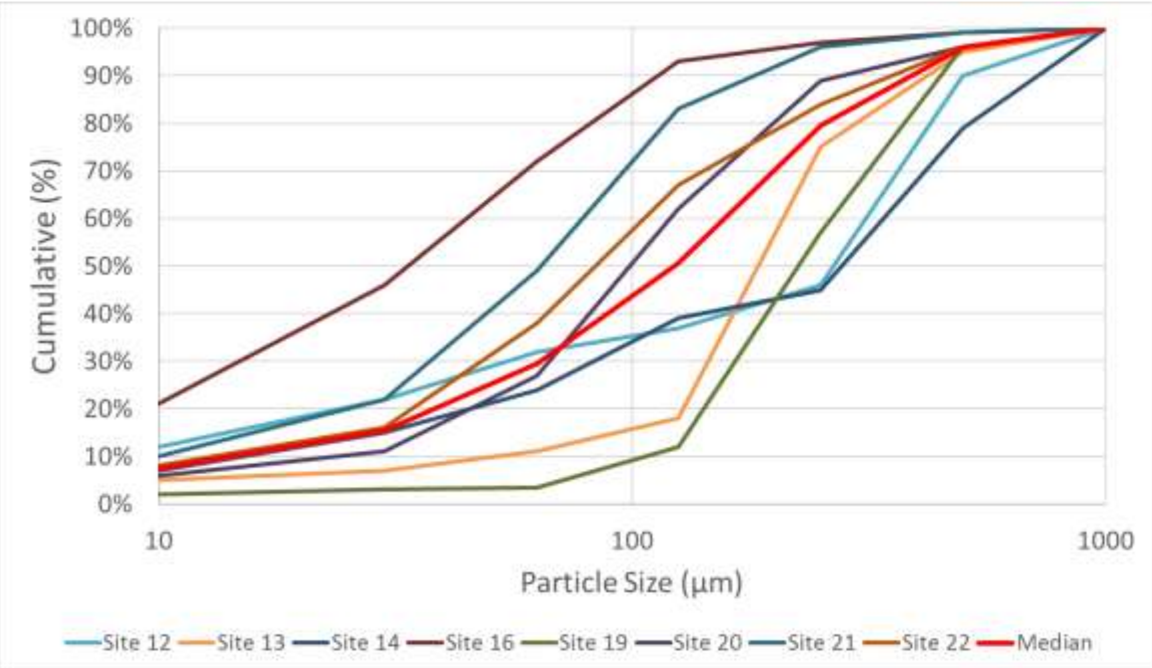


Figure 9 ***PSD in July 2011 of sites in western Koombana Bay (Wave Solutions 2012c)***

5.2.2 Metals and metalloids, and TBT

A summary of metals and metalloids, and TBT levels in the marine sediments of Koombana Bay, Casuarina Boat /Outer Harbour, the Inner Harbour and proximal open coastal inshore reference sites on the basis of past investigations is summarised in Figure 10 and Figure 11. Key points of the collated sediment quality data include:

- Al, Co, Cr, Ni, Pb, Hg, Zn and TOC in the sediments of the Inner Harbour, Casuarina Boat/Outer Harbour and Koombana Bay were generally greater than at the reference and spoil ground sites of the coastal inshore waters. In contrast, As and Fe in the sediments were generally greater at the reference sites than the other sites. Se did not exhibit any marked gradients or patterns between locations.
- Metal and metalloid exceedances included:
  - Cr, Ni, Cd, Pb, Hg and Zn were always below the ANZG (2018) DGVTS on all surveys at all sites.
  - As generally exceeded the ANZG (2018) DGVTS at reference sites of the coastal waters, but not the DGVTS-high. The Casuarina Boat/Outer Harbour and Koombana Bay sites also tended to be greater than the Inner Harbour, which suggests naturally occurring elevated levels.
  - Sb exceeded the ANZG (2018) DGVTS at Casuarina Boat/Outer Harbour on one (1) survey in November 2010, but was well below the DGVTS-high of 25 mg/kg.
  - Ag was at the ANZG (2018) DGVTS at Casuarina Boat/Outer Harbour on one (1) survey in November 2010, but was well below the DGVTS-high of 4 mg/kg.
- Total organic carbon (TOC) was substantially lower in the sediments of the reference sites than those at other sites in Koombana Bay and the adjacent water bodies.
- TBT exceeded the ANZG (2018) DGVTS at the dredge spoil ground in November 2006, the Inner Harbour in November 2006 and February 2010, and most recently in the sediments of Casuarina Boat Harbour in October 2017. However, there were no exceedances of the DGVTS-high of 70 µg/kg.

In summary, the recent sediment quality surveys indicate that potential contaminants of concern in Casuarina Boat/Outer Harbour and Koombana Bay are Sb, As, Ag and TBT. However, though these exceedances are above the ANZG (2018) DGVTS, they do not approach the DGVTS-high.

Figure 10 ***Sediment quality of Al, Sb, As, Cd, Cr, Co, Fe, Mn, NI and Pb***[6]

[6] Dashed orange and red dotted lines on plots denote ANZG (2018) toxicant default guideline value and high guideline value, respectively.

Figure 11 Sediment quality of Hg, Se, Ag, Zn, TBT, V and TOC[7]

[7] Dashed orange dotted lines on plots denote NAGD (2009) screening levels.

5.2.3 Other sediment quality findings

Other relevant sediment quality findings from past investigations include:

- Total PAH, organophosphate pesticides and organochlorine pesticides were below the NAGD (2009) screening levels in Casuarina boat harbour, Koombana Bay and Leschenault Inlet (Oceanica 2008b).
- Total PAH and TPH levels were below the NAGD (2009) screening levels at reference, Outer Harbour and Inner Harbour sites (SKM 2011a,b).
- In the proposed dredged Lanco footprint of the Inner Harbour, Wave Solutions (2012c) found that:
  - Total PAH, TPH and organophosphate pesticides were all below the LoR of 20 µg/kg (and NAGD (2009) screening level of 10,000 µg/kg).
  - With the exception of DDD and DDE, all organochlorine pesticides were below the LoR (<1 ug/kg).
  - The 95% UCLs of TN, NH_4, NO_3, FRP, TP and total cyanide to be 1,900, 5.6, 0.9, 43.2, 394 and <0.5 mg/kg.
- Total PAH, TPH and organochlorine pesticides were below the NAGD (2009) screening levels in Koombana Bay, Casuarina boat harbour and the nearshore reference sites (MAFRL 2015).
- In Leschenault Inlet:
  - Sediment quality findings along the southern shoreline on November 2005 by DoW (2007) indicate that sediment contaminant levels for As, Cu and Hg can be greater than NAGD (2009) screening levels, presumably from urban sources transported by drains and/or groundwater.
  - However, GHD (2018) sediment quality findings along the northern shoreline from May 2014-November 2017 indicates metals and metalloids, TRH, BTEX and naphthalene are all below NAGD (2009) screening levels. Further, O2 Marine (2021) found no exceedances of the ANZG (2018) DGVTS for any metals and metalloids, as well as TBT.

6. Mussels

Table 14 summarises the metals and metalloids in blue mussels along with comparisons to the EPA (2017) environmental quality guidelines (EQG) or standards (EQS) over six surveys from May 2008-June 2011 in the Inner Harbour, Outer Harbour and reference sites. Generally, EQG or EQS exceedances (and concentrations) co-occur across the three regions, which suggests that levels in biota respond to natural or anthropogenic contaminant loads on a regional scale.

Table 14 ***Metals and metalloids in blue mussels (mg/kg) in the Inner Harbour, Casuarina Boat/Outer Harbour and reference sites from 2008-2011***

Date and Source	Analyte	Inner Harbour		Casuarina Boat /Outer Harbour		Reference		EPA (2017)	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	EQG	EQS
26-28 May 2008 (SKM 2008)[8]	Inorg As[9]	1.6	0.1			2.3	0.2		1
29-30 Sep 2009 (SKM 2009)		0.1	0.0			0.2	0.0		
3-4 Feb 2010 (SKM 2010b)		1.4	0.1			1.8	0.0		
24-26 Nov 2010 (SKM 2011a)		1.3	0.1	2.1	0.6	1.6	0.0		
18-26 Nov 2011 (Oceanica 2011)		0.2	0.0			0.1	0.0		
8-10 June 2011 (SKM 2011b)		1.7	0.2	2.7	0.5	2.3	0.2		
26-28 May 2008 (SKM 2008)	Cd	0.6	0.3			1.9	0.3		2
29-30 Sep 2009 (SKM 2009)		1.2	0.5			4.5	0.5		
3-4 Feb 2010 (SKM 2010b)		0.5	0.2			1.95	0.1		
24-26 Nov 2010 (SKM 2011a)		0.5	0.1	1.0	0.5	1.3	0.2		
18-26 Nov 2011 (Oceanica 2011)		0.1	0.1			0.1	0.0		
8-10 June 2011 (SKM 2011b)		0.5	0.1	1.3	0.2	1.6	0.0		
26-28 May 2008 (SKM 2008)	Cu	162	122			5	1		2
29-30 Sep 2009 (SKM 2009)		5	2			5	0		
3-4 Feb 2010 (SKM 2010b)		73	51			3	0		
24-26 Nov 2010 (SKM 2011a)		10	2	48.8	26.1	6	0		
18-26 Nov 2011 (Oceanica 2011)		2	0			1	0		
8-10 June 2011 (SKM 2011b)		52	34	89.5	40.8	41	27		
26-28 May 2008 (SKM 2008)	Pb	0.5	0.0			0.5	0.0	30	
29-30 Sep 2009 (SKM 2009)		0.5	0.0			0.5	0.0		
3-4 Feb 2010 (SKM 2010b)		6.7	4.5			0.5	0.0		
24-26 Nov 2010 (SKM 2011a)		0.6	0.2	1.8	0.5	0.5	0.0		
18-26 Nov 2011 (Oceanica 2011)		0.1	0.0			0.0	0.0		
8-10 June 2011 (SKM 2011b)		1.9	1.4	3.8	1.7	1.5	0.7		
26-28 May 2008 (SKM 2008)	Hg	0.02	0.00			0.02	0.00	0.5	
29-30 Sep 2009 (SKM 2009)		0.23	0.38			0.05	0.01		
3-4 Feb 2010 (SKM 2010b)		0.05	0.02			0.07	0.00		
24-26 Nov 2010 (SKM 2011a)		0.04	0.02	0.06	0.03	0.03	0.00		
18-26 Nov 2011 (Oceanica 2011)		Not Measured							
8-10 June 2011 (SKM 2011b)		0.04	0.02	0.06	0.01	0.03	0.00		

[8] Mud oysters collected at Berth 4 for this survey only.

[9] Estimated as 10% total As. EFSA (2009) suggests that, in general, the organic component of arsenic only accounts for 5 to 10% (as a highly conservative estimate) of the total arsenic concentration in tissues.

Date and Source	Analyte	Inner Harbour		Casuarina Boat /Outer Harbour		Reference		EPA (2017)	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	EQG	EQS
26-28 May 2008 (SKM 2008)	Se	4.0	0.9			6.0	0.0	1	
29-30 Sep 2009 (SKM 2009)		1.3	0.4			1.4	0.2		
3-4 Feb 2010 (SKM 2010b)		4.2	0.4			4.5	0.7		
24-26 Nov 2010 (SKM 2011a)		5.0	0.0	6.0	0.0	5.0	0.0		
18-26 Nov 2011 (Oceanica 2011)		0.7	0.1			0.7	0.0		
8-10 June 2011 (SKM 2011b)		5.7	0.8	7.0	0.0	6.0	0.0		
26-28 May 2008 (SKM 2008)	Zn	2,993	2,245			205	21	290	
29-30 Sep 2009 (SKM 2009)		492	196			290	28		
3-4 Feb 2010 (SKM 2010b)		260	189			175	7		
24-26 Nov 2010 (SKM 2011a)		243	78	278	107	125	21		
18-26 Nov 2011 (Oceanica 2011)		37	10			16	3		
8-10 June 2011 (SKM 2011b)		214	68	283	56	170	28		

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