



Kendall Bay Sediment Remediation Project

ECOLOGICAL RISK ASSESSMENT

March 2018

**KENDALL BAY REMEDIATION PROJECT
ECOLOGICAL RISK ASSESSMENT
FINAL DRAFT**

Report for Jemena Ltd

By Synnot & Wilkinson Pty Ltd

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EXECUTIVE SUMMARY

The Project

In April 2015, Synnot & Wilkinson Pty Ltd (**S&W**) was commissioned by Jemena Ltd (**Jemena**) to investigate gasworks contamination in the sediments of Kendall Bay in the Parramatta River (an estuarine part of Sydney Harbour) due to data gaps and methodological issues with previous sediment investigations of the bay, as well as concerns that sediment disturbance, erosion and deposition may have rendered some of the older data unrepresentative.

The objectives of the investigation were to:

1. Review the available data on the sediments of Kendall Bay, identify data gaps, and design a sampling program to fill these gaps and define areas and depths of contamination both within the previously proposed remediation areas and, where necessary, outside them.
2. Review the existing Human Health and Ecological Risk Assessment (**HHERA**) for the 2014 proposed remediation areas and identify data gaps. Propose any further studies necessary for revision of the human health risk assessment (**HHRA**) and ecological risk assessment (**ERA**) and to determine remediation criteria.
3. Prepare a Sampling, Analysis and Quality Plan (**SAQP**) and carry out the necessary sampling and analysis according to the SAQP.
4. Provide reliable field and laboratory data to be used for input to a new HHRA and ERA, and Remediation Action Plan (**RAP**).
5. Distinguish gasworks contamination in Kendall Bay, and its effects, from background chemical contamination known to be present throughout the Parramatta River.
6. Provide reliable data to be used to derive remediation criteria, define remediation areas and specify the nature and extent of remediation that is recommended for each area.

EPA assessed the draft RAP in February 2017 and requested consideration of levels of chronic toxicity of sediments in Areas A and B in Kendall Bay, and also in bays upstream and downstream of Kendall Bay, outside of the Declared Area in the Parramatta River. This assessment was to consider the existing benthic communities, chemical status of the sediments, chronic toxicity of the sediments and also water quality at the sampling sites. The additional (post-RAP) investigations were carried out in October 2017.

Based on the pre-existing data, the study area was divided into five Investigation Areas, including two areas of Kendall Bay known to be contaminated with gasworks wastes, and three background areas:

- Southern Investigation Area – including the 2014 RAP's Area A plus surrounding areas;
- Northern Investigation Area – including 2014 RAP's Area B plus surrounding areas;
- those parts of Kendall Bay identified in the 2014 RAP as having background levels of PAHs;
- Southern Reference Area. Initially this was Exile Bay – a nearby bay not exposed to gasworks wastes. In the October 2017 sampling, Canada Bay was added; and
- Northern Reference Area. Initially this was Majors Bay – a nearby bay not exposed to gasworks wastes. In the October 2017 sampling, Brays Bay and Yaralla Bay were added.

The Problem

The sediments of parts of Kendall Bay are known to be heavily contaminated with gasworks wastes resulting from operations of the large Mortlake gasworks in Sydney between 1883 and 1986. The principal gasworks contaminants are polycyclic aromatic hydrocarbons (**PAHs**) and total recoverable hydrocarbons (**TRH**) at levels greatly exceeding Australian sediment quality guidelines for protection of aquatic organisms. Accordingly, an **ERA** was carried out in order to assess the risk from these contaminants to aquatic organisms in the bay and

the adjacent Parramatta River, develop site-specific remediation criteria for the gasworks-contaminated sediments and provide input to an updated **(RAP)**.

Many previous investigations have been carried out in Kendall Bay, however, a review of these in 2015 revealed a number of inadequacies and data gaps. Accordingly, a comprehensive program of investigations was carried out in 2015 and 2016 to obtain the necessary data.

This ERA has used data from the detailed sediment contamination studies, water quality monitoring, biological tissue monitoring, marine benthic community studies, and bioavailability and ecotoxicology studies to assess the risks to organisms exposed or potentially exposed to the gasworks-contaminated sediments of Kendall Bay.

The Data

Waters

The dissolved PAH levels in water from Kendall Bay were very low, mostly below the detection limits or in a few cases at or slightly above the detection limits. There are no Australian marine water quality guidelines for PAHs, due to insufficient data, however the very low PAH values found are considered unlikely to affect aquatic organisms.

The dissolved metal levels were also low and generally below the water quality guideline values except for copper, which consistently exceeded the guideline, and zinc, which occasionally exceeded the guideline. This indicates potential for adverse effects on some organisms, however the metal levels were no higher in the contaminated areas of Kendall Bay than at the background locations in and outside the bay, and therefore any toxic effects of metals cannot be attributed to the gasworks contamination.

Contaminants in Biological Tissue

There are no Australian assessment criteria for petroleum hydrocarbons in tissue. Samples from Kendall Bay did not show elevated levels of petroleum hydrocarbons compared to the background bays.

There are no Australian assessment criteria for PAHs in tissue. Samples from Kendall Bay did not show any significant difference in PAH levels compared to samples from the two background bays; the PAHs were all below or near detection limits.

Of the metals analysed, Australian assessment criteria are only available for cadmium, copper and zinc. Metals were not detected in mussels except for zinc, where the values were well below the generally expected levels (**GEL**). The zinc values showed no significant differences between Kendall Bay and the two background bays.

Only cadmium, copper and zinc were detected in the oyster samples. The cadmium values were well below the maximum residue limit (**MRL**). The copper values, however, were more than an order of magnitude higher than the GEL, and the zinc levels approximately an order of magnitude higher than the GEL. The copper values were comparable in Kendall Bay and the two background bays. The zinc and cadmium values were higher in Majors Bay oysters than in the oysters from Kendall and Exile Bays. Samples from Kendall Bay did not show elevated levels of metals compared to the background bays.

There is no evidence that the PAHs or TRHs in the contaminated gasworks sediments in Kendall Bay are being taken up by oysters or mussels.

Contaminants in Sediments

The sediment investigations showed that the gasworks contamination, commonly distinguished by black or dark grey oily sediments with a strong tar or hydrocarbon odour, was only present at the surface in the south-western corner of Kendall Bay, and in two small patches on the western side in the vicinity of the former coal wharf. Elsewhere, gasworks contamination, where present, was covered by a layer of estuarine mud deposited since the contamination entered the bay.

The sediment chemical data showed that the south-western and mid-western parts of the western areas of Kendall Bay (particularly in the vicinity of the former coal wharf) contained gasworks contaminants (PAHs and TRHs) greatly exceeding the sediment quality guideline values (**GVs**), indicating a risk to benthic organisms exposed to these sediments. These areas included parts of the 2014 Remediation Areas A and B, as well as parts of the bay adjacent to these areas.

The eastern and northern parts of the bay, more distant from the former gasworks, contained far lower levels of gasworks contaminants, generally comparable to the levels of PAHs and TRHs found elsewhere in the channel and bays of the Parramatta River.

The levels of heavy metals in Kendall Bay, though variable, were generally comparable to the levels found elsewhere in the channels and bays of the Parramatta River.

Bioavailability and Ecotoxicology Studies

Bioavailability studies carried out by CSIRO showed that the elevated mixed-metal burden in some Kendall Bay sediments was likely to cause chronic toxicity. However similar metal burdens are known to occur throughout the Parramatta River and its bays, beyond the influence of the gasworks, due to historic pollution from a large number of industrial and urban sources.

Total sediment PAH and porewater PAH data both indicated a potential for adverse effects on exposed organisms, although because of the high Black Carbon concentrations, the models provided poor predictions of toxicity from total PAH (normalised to 1% Total Organic Carbon (**TOC**)).

CSIRO carried out sediment toxicity studies on 47 samples. The majority of samples from the south-western and western parts of Kendall Bay, adjacent to the former gasworks site, exhibited chronic or acute toxicity to the test organisms. Some samples from the outer parts of Kendall Bay, as well as some samples from Reference Areas not exposed to gasworks contamination, also showed chronic toxicity.

All 14 sediment samples which CSIRO found to cause acute toxicity were oily or had an oily sheen, and were generally black, with a strong tar odour. Acute toxicity was attributed to high levels of PAHs and TRHs. These sediments only occurred at the surface in the south-western corner of Kendall Bay, and in two small patches on the western side in the vicinity of the former coal wharf. In some of these sediments, the acute toxicity was very high.

The sediments causing chronic toxicity (measured by effects on reproduction in amphipods and copepods) or no toxicity were typically grey or grey-brown, with either a 'marine' odour, no odour or, occasionally a slight hydrocarbon or tar odour. CSIRO attributed chronic toxicity to a combination of metals, plus PAHs and other contaminants of widespread distribution in the Parramatta River.

The incidence of high to very high chronic toxicity was frequent for sediments from within the Remediation Areas proposed in the 2017 RAP, compared to few instances of chronic toxicity and none with high or very high chronic toxicity in sediments tested from outer Kendall Bay (i.e., parts of the bay distant from the former gasworks).

The heads of other bays in this part of the Parramatta River, where stormwater contributes contaminants, particularly metals such as copper and zinc, also show high to very high chronic toxicity. Compared to sediments tested from outer Kendall Bay, the incidence of chronic effects to organism reproduction was higher for sediments from the heads of these other bays previously tested by CSIRO.

Some of the sediments from outer Kendall Bay showed low to moderate chronic toxicity but many did not. The same response was found in samples from the five bays in the Reference Areas. All but one these samples had elevated heavy metal burdens (sediment quality guideline quotient > 1) but all had low PAH burdens (sediment quality guideline quotient < 1), indicating that chronic toxicity, where present, was likely due to the heavy metals.

Benthic Community Studies

Throughout the majority of Kendall Bay, the layer of black oily gasworks-contaminated sediment was overlain by 50-300 mm of recent silt containing benthic infauna comparable to that found at other sites, distant from gasworks contamination, in the Parramatta River and its bays. The majority of samples, both Test Sites and Background Sites, supported marine benthic communities. The differences among sampling locations were typically small-scale differences in the number of animals rather than substantial differences in the number of taxa.

A small number of samples contained no fauna; these were generally in areas where gasworks contaminants were exposed at the surface and were (or were likely to be on the basis of the CSIRO criteria) acutely toxic.

Infaunal communities appear to show no clear patterns in the abundance and diversity across all bays and sites sampled, indicating that areas within Kendall Bay which are outside of the identified remediation areas are likely to be representative of infaunal communities within the nearby Reference Area embayments sampled in this study.

Conclusions and Recommendations

1. ERA has shown that two areas in Kendall Bay where oily gasworks sediments are present at or near the sediment surface, one area being on the south-western side and the other midway up the western side, are, or are likely to be, acutely toxic to benthic organisms due to levels of PAHs and TRHs greatly exceeding the chemical remediation criteria developed by CSIRO from toxicity testing of bay sediments. Those studies indicated that there would be a low risk of acute toxicity to benthic organisms for Kendall Bay sediments when:
 - Total PAH concentrations average <25 mg/kg (1% TOC) (representing effects thresholds) and maximum <55 mg/kg (1% TOC) (representing effects occurring frequently); and/or
 - TRH concentrations average <4400 mg/kg and maximum <6000 mg/kg.

Remediation that targets these acutely toxic sediments (i.e. intended to result in the remaining surface sediments having total PAHs and TRHs below the specified criteria) should eliminate acute toxicity and result in few instances of chronic toxicity to benthic organisms in Kendall Bay. It is recommended that these sediments be remediated.

2. In some areas of the bay the oily gasworks-contaminated sediments are overlain by recently accumulated mud containing benthic fauna comparable to that found outside the area of gasworks contamination. Remediation boundaries for ecological protection (acute toxicity) for these areas should be determined in the 2018 Remediation Action Plan using a weight-of-evidence assessment that considers the above CSIRO criteria, plus bioaccumulation and benthic ecology data, as well as the depth of recently accumulated silt covering the gasworks contamination.
3. The CSIRO results indicate that remediation targeting areas where chronic toxicity is observed may be ineffective at eliminating chronic toxicity of the sediments in the longer term because remediated areas within the bay will be expected to become re-contaminated as sediment from the surrounding environment is redeposited, and also from future stormwater inputs, particularly from the large stormwater drain at the southern end of Kendall Bay. It is not recommended that such areas be remediated.

Figure 1 shows that remediation of acutely toxic sediment in the proposed Remediation Areas (red-filled boxes) should significantly improve ecosystem health. Remediation of sediments with low-moderate chronic toxicity outside the proposed Remediation Areas, however (orange box) is not expected to significantly improve ecosystem health because this sediment is similar in composition to sediment from bays and sediments near Kendall Bay that are unaffected by gasworks contamination (red- and black-outlined boxes), and cleaner than the sediments in the heads of bays affected by stormwater contamination (black-filled circles – high chronic toxicity).

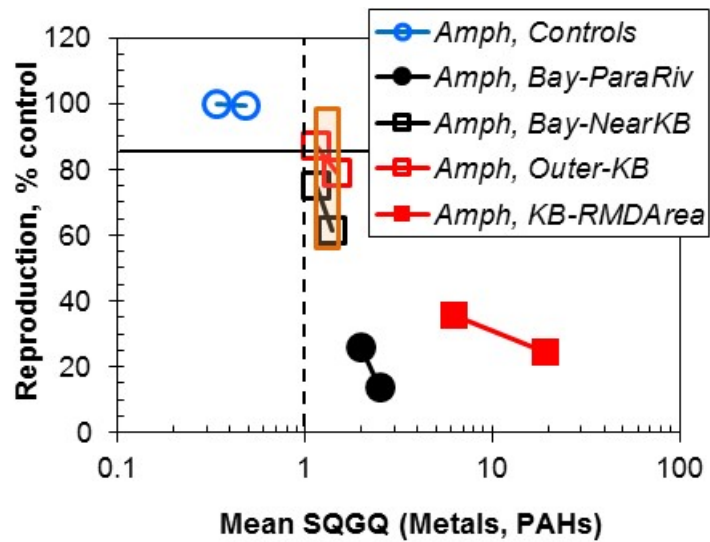


Figure 1. Comparison of the mean and 95% Upper Confidence Limits (95%UCL) of toxicity to reproduction of the amphipod versus the sediment quality guideline quotient (SQGQ for metals + total PAHs). The orange box indicates the inner Kendall Bay area that lie outside of the proposed remediation area, where SQGQ data exists without effects data. Descriptions of the SQGQs are provided in Appendix A to Simpson et al., 2016, 2018. The horizontal solid line indicates 85% reproduction. The vertical dashed line represents SQGQ = 1. Other lines join the mean and 95%UCL pairs (calculated using ProUCL 5.1).

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LIST OF ABBREVIATIONS AND UNITS

Abbreviations

AAS	Atomic absorption spectrometry
AEM	Dilute-acid extractable metals
ANZECC	Australia and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AVS:SEM	Acid-volatile sulphide and simultaneously extracted metals
BaP	Benzo(a)pyrene, a carcinogenic PAH
BC	Black Carbon
BDL	Below Detection Limit
BTEX	Benzene, toluene, ethylbenzene and xylene
COC	Chain-of-Custody
CoC	Contaminant of Concern
COPC	Contaminant of Potential Concern
Cr ⁶⁺	Hexavalent chromium
CRM	Certified Reference Material, i.e. a standard sample of certified composition
DNAPL	Dense non-aqueous phase liquids
DQO	Data quality objectives
CSM	Conceptual site model
EPA	NSW Environmental Protection Authority
ERA	Ecological risk assessment
HERA	Human health risk assessment
HHERA	Human health and ecological risk assessment
EILs	Environmental Investigation Levels
FID	Flame ionisation detector
FSANZ	Food Standards Australia New Zealand
GC	Gas chromatography
GCMS	Gas Chromatograph - Mass Spectrometer
GEL	Generally expected levels
GV	Guideline Value
HILs	Health Investigation Levels
HQ	Hazard quotient
ICP	Inductively coupled plasma
Jemena	Jemena Ltd
LOR	Limit of Reporting
MS	Mass spectrometry
MRL	Maximum residue limit
NATA	National Association of Testing Authorities
NC	No criterion
NEPM	National Environmental Protection (Assessment of Site Contamination) Measure, 1999 (2013 update)
OC	Organic carbon
OCP	Organochlorine Pesticides
OPP	Organophosphorus Pesticides
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
QA	Quality Assurance
QC	Quality Control
RAP	Remediation action plan
RPD	Relative Percentage Difference
RSD	Relative Standard Deviation
SAQP	Sampling, Analysis and Quality Plan
S&W	Synnot & Wilkinson

SKM	Sinclair Knight Merz
SOP	Standard Operating Procedure
SQG	Sediment Quality Guideline
SQGQ	Sediment quality guideline quotient
SQG-High	Sediment quality guideline high value
Investigation Areas	The areas that were studied in this investigation
TOC	Total organic carbon
TEQ	Toxic equivalence quotient
TPH/TRH	Total petroleum hydrocarbons, now called total recoverable hydrocarbons
TU	Toxic unit
UCL/95% UCL	Upper confidence limit/Upper 95% confidence limit
USEPA	United States Environmental Protection Agency
WOE	weight-of-evidence

Units

km	kilometre
m	metre
mm	millimetre
mg/kg	milligram per kilogram (ppm)
µg/kg	microgram per kilogram (ppb)
mg/L	milligram per litre
µg/L	microgram per litre
ppm	parts per million
ppb	part per billion

1 INTRODUCTION

1.1 Introduction and Scope of the Overall Investigations

Parts of Kendall Bay, a bay of the Parramatta River which is an estuarine part of Sydney Harbour, were declared a remediation site by the NSW Environmental Protection Authority (EPA) in 2004 (**Figure 1.1**). Jemena Ltd (**Jemena**) is currently undertaking the Kendall Bay Sediment Remediation Project, for which a Human Health and Ecological Risk Assessment (**HHERA**) and a Remediation Action Plan (**RAP**) were previously prepared by Sinclair Knight Merz (SKM 2014a, b). The 2014 RAP defined two remediation areas, Area A, at the southern end of the bay, and Area B, midway along the west side of the bay (**Figure 1.2**).

Figure 1.1 Location of Declared Area



Source: Figure 1, URS (November 2007)

Figure 1.2. Remediation Areas Proposed by SKM in 2014

Source: SKM, 2014b

Sediments in parts of the bay are contaminated principally by polycyclic aromatic hydrocarbons (**PAHs**) and coal tar-derived petroleum hydrocarbons, largely originating from the adjoining former AGL Mortlake gasworks site which operated as a gasworks between 1886 and 1971, closed in 1986, and was the largest gasworks in the Southern Hemisphere. The history of operation of the gasworks is detailed in SKM 2014a and b.

The site has been remediated and is now the residential suburb of Breakfast Point, however contamination of Kendall Bay has been documented in numerous reports prepared between 1989 and 2014, summarised in the 2014 RAP. The sediments of the whole Parramatta River, including Kendall Bay, are also known to contain elevated levels of heavy metals and other contaminants derived from many industrial and urban sources over the past two centuries.

In April 2015, Synnot & Wilkinson Pty Ltd (**S&W**) was commissioned by Jemena Ltd (**Jemena**) to investigate contamination in the sediments of Kendall Bay in the Parramatta River due to data gaps in previous sediment investigations of parts of the bay. Jemena commissioned S&W to review the previous studies and investigate the sediments in the mangroves and areas adjacent at the southern end of Kendall Bay Area A.

Subsequently S&W was commissioned to review the HHERA, identify any deficiencies and data gaps, and carry out the necessary investigations of surface and near-surface sediments to obtain suitable data for revision of the human health risk assessment (**HHRA**) and ecological risk assessment (**ERA**), and to determine remediation criteria and the extent of remediation works that were required, and prepare a revised RAP for Kendall Bay (Areas A and B). The studies were confined to Areas A and B within Kendall Bay (a section of the Declared Area) and to the definition of their boundaries. For comparative purposes, surface sediments were also to be sampled in similar bays to the north-west and south-east of Kendall Bay, outside the Declared Area, that had not been exposed to gasworks wastes.

S&W was also commissioned to carry out subsurface investigations at the above contaminated areas in Kendall Bay to determine the depth and extent of gasworks-derived contamination that posed an unacceptable risk to persons who used the beach and mangrove areas in the southern part of Kendall Bay, and that posed an unacceptable risk to benthic marine organisms that have populated parts of the bay. These investigations were carried out in stages between April 2015 and April 2016.

In January 2016 S&W was commissioned to commence a seasonal water quality monitoring program, and a program of shellfish collection and tissue analysis, to report on the data collected and carry out an assessment of the data against relevant criteria, suitable for use in the revised HHRA and ERA.

EPA assessed the draft RAP in February 2017 and requested consideration of levels of chronic toxicity of sediments in Kendall Bay, and also in bays upstream and downstream of Kendall Bay, outside of the Declared Area in the Parramatta River. Sampling for this assessment of chronic toxicity was carried out in October 2017 and considered the existing benthic communities, chemical status of the sediments, chronic toxicity of the sediments and also the water quality at the sampling sites.

This ERA report draws on the above reports, plus previously available information and reports by specialist subconsultants on sediment ecotoxicology and bioavailability, and benthic ecology.

1.2 Objectives

The objectives of the initial investigation were to:

- review existing data for Kendall Bay, and in particular the ERA sections of the SKM (2014a) HHERA, and identify the Contaminants of Potential Concern (**COPC**), appropriate ecological assessment criteria, and any data gaps relating to the sediments of the Study Area (the former Remediation Areas A and B and their immediate surroundings);
- review and assess the sediment chemistry, biological tissue chemistry and water quality data collected by S&W in 2015-2016, plus the data from specialist investigations including the ecotoxicity and bioavailability study and the marine benthic survey, and any other relevant data;
- design a sampling program to fill these data gaps, define areas and depths of contamination within the previously proposed Remediation Areas A and B and, where necessary, outside them to better define their boundaries and carry out the necessary sampling and analysis according to a sampling, analysis and quality plan (**SAQP**);
- provide reliable data to be used to derive remediation criteria, define remediation areas and specify the nature and extent of remediation that is recommended for each area.
- carry out an ERA of the contaminated sediments in Kendall Bay to assess the risk to aquatic organisms in the bay from gasworks contaminants; and
- provide input to the 2017 RAP.

The objectives of the additional (post-RAP) investigations were to:

- obtain the additional data requested by EPA on sediment chronic toxicity, plus associated chemistry and ecology data.

- distinguish gasworks contamination in Kendall Bay, and its effects, from background chemical contamination known to be present throughout the Parramatta River.
- provide reliable data to be used to derive remediation criteria, define remediation areas and specify the nature and extent of remediation that is recommended for each area.

1.3 Study Area

Kendall Bay is a shallow bay on the southern side of the Parramatta River, which forms the western estuarine section of the Sydney Harbour system (**Figure 1.3**). Kendall Bay, which is approximately 9 km west of the Sydney CBD, lies between the residential suburb of Breakfast Point (the remediated former gasworks site) to the west and south, and Cabarita Park to the east (SKM, 2014 a, b).

The overall study area is defined as that area centred on Kendall Bay and extending approximately two kilometres north-west to Brays Bay and 2.4 kilometres south south-east to Canada Bay, along the southern shoreline of the Parramatta River. The study area consists of the former Remediation Areas A and B and their immediate surroundings, called the Southern and Northern Investigation Areas, respectively (**Figures 3.2 and 3.3**), plus outer areas of the bay and other bays to the north-west and the south-west, which are termed Reference Areas.

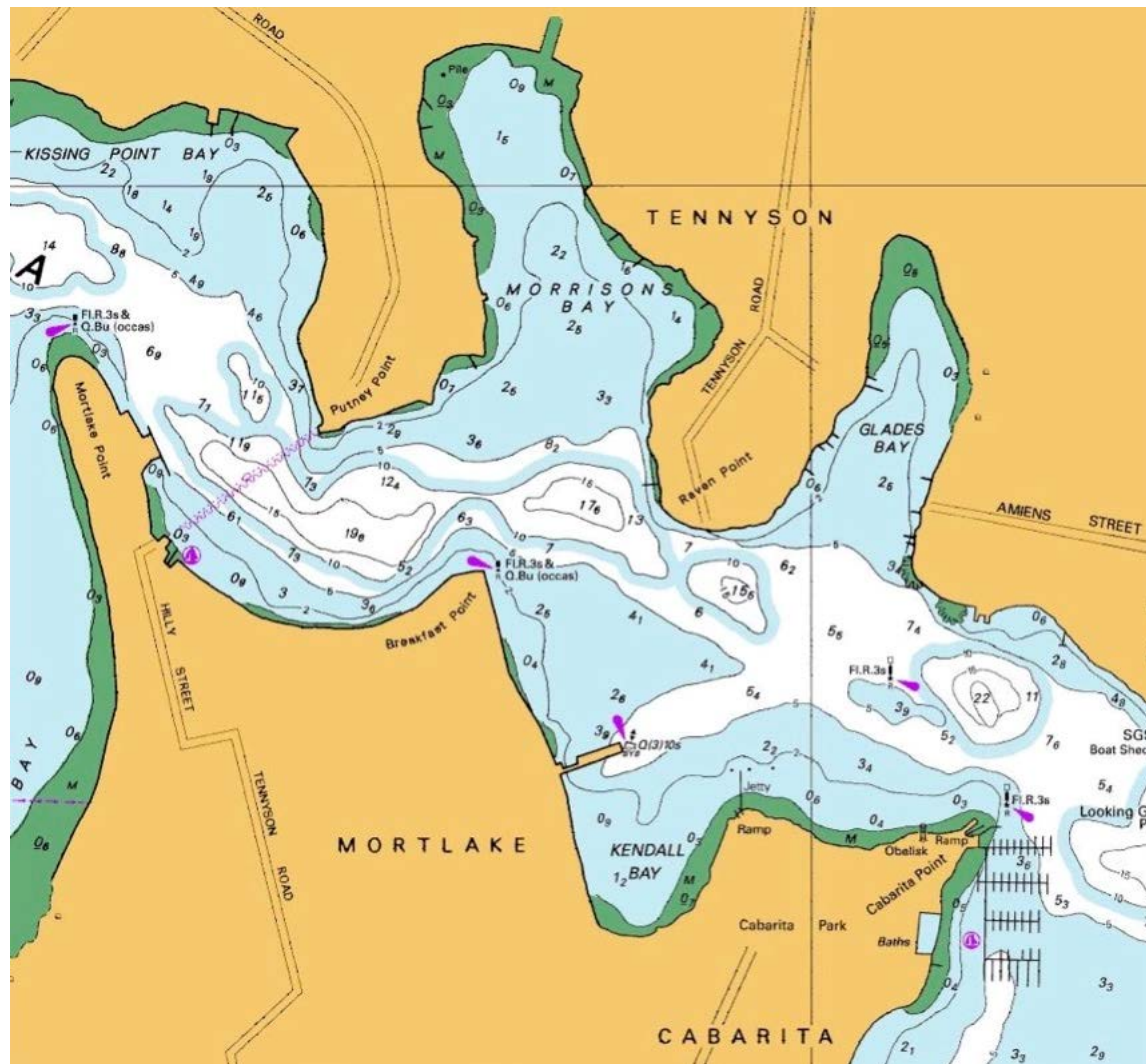
The outer part of Kendall Bay is open to the Parramatta River and has a maximum depth of 5 m. The bays extending off the Parramatta River are shallow but the main river channel is characterised by a succession of deep holes, up to 21 m deep, in this area. The bathymetry of parts of the area has changed significantly over the past decades – compare the Navy charts for 1992 (**Figure 1.4**) and 2010 (**Figure 1.5**). This is discussed in **Section 2.5**, below. The inner, semi-enclosed part of Kendall Bay has depths of less than 2 m except for a deeper channel dredged to the former gasworks coal wharf on the western side of the bay, and the berthing areas on either side of the wharf. The wharf was removed around 2006 however an elongated mound of shell-, coal- and coke-encrusted sediment marks its former position (see **Figure 1.6**).

Figure 1.3 Location of Kendall Bay

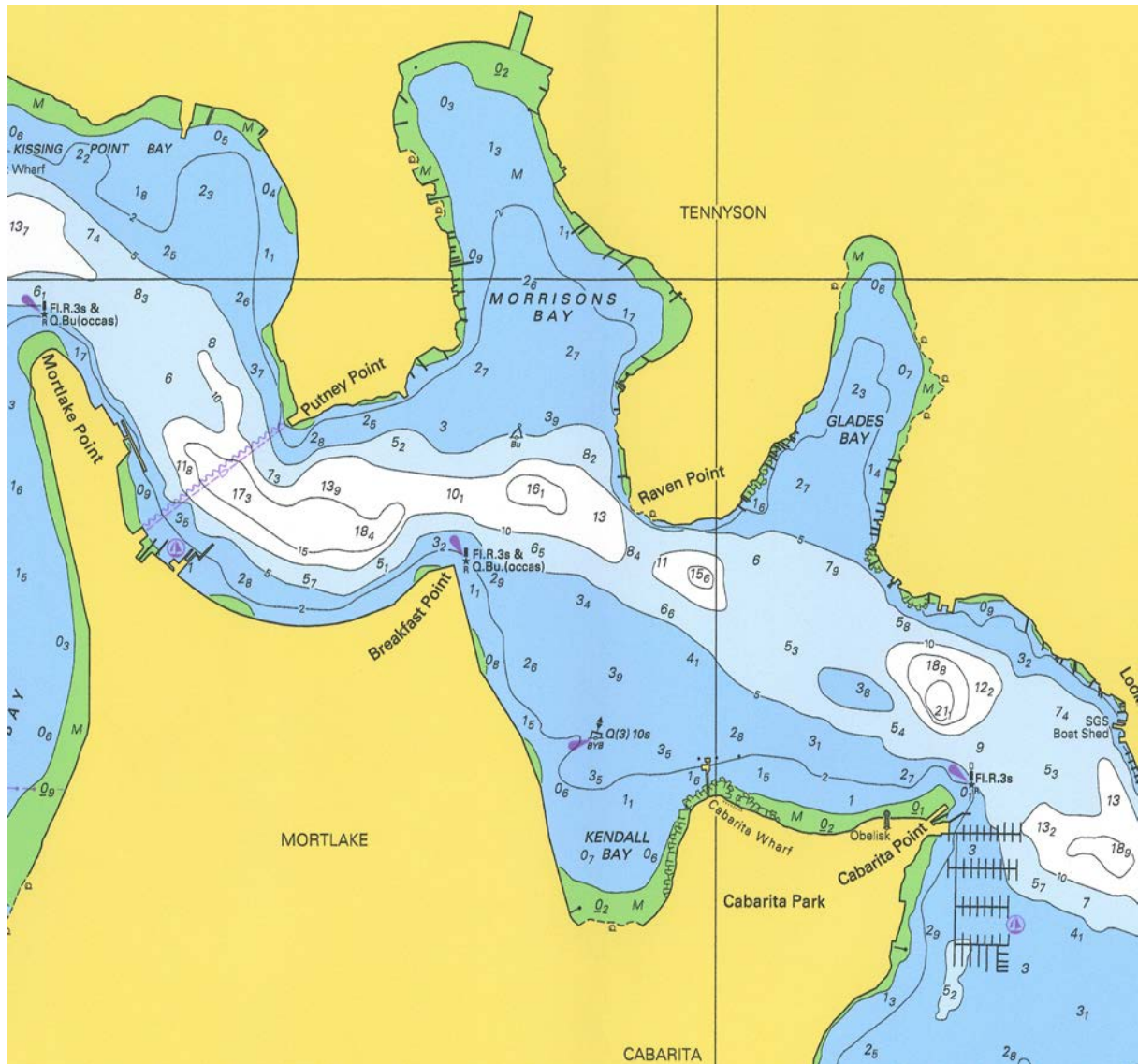


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Figure 1.4 Bathymetry of Parramatta River near Kendall Bay in 1992 (depths in metres)

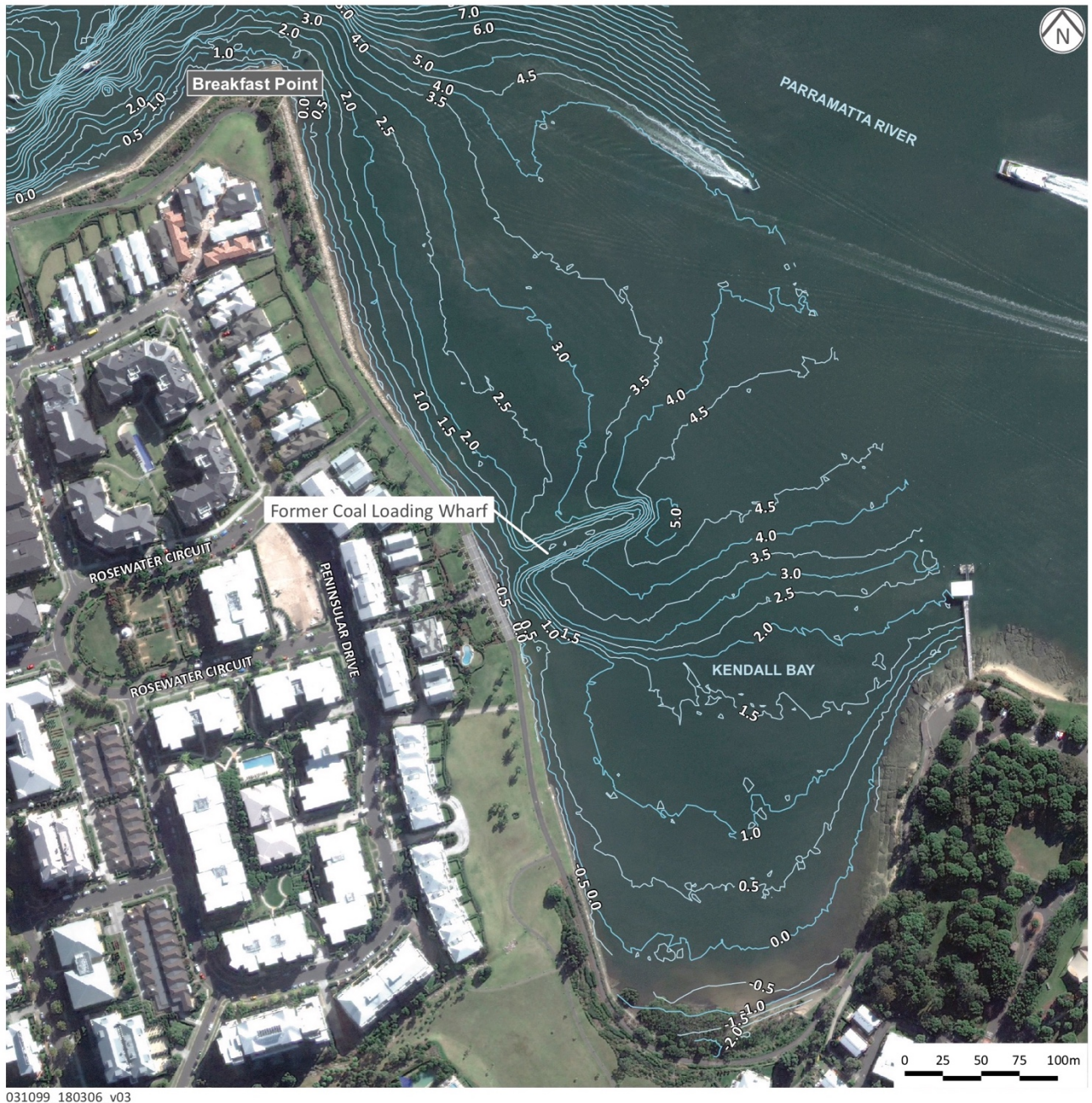


Source: Excerpt from Navy chart Aus 203, 1992.

Figure 1.5 Bathymetry of Parramatta River near Kendall Bay in 2010 (depths in metres)

Source: Excerpt from most recent update of Admiralty chart Aus 203, September 2010.

Figure 1.6 Bathymetry of Kendall Bay in 2014 (depths in metres). Note mound formed at location of former coal wharf, the partly infilled dredged channels to the north and south of the mound, and the stormwater delta north of the mangroves at the southern end of the bay.



Royal HaskoningDHV, 2016. Source, *Hydrographic & Cadastral Survey Pty Ltd, 2014*

Land areas to the south-east of Kendall Bay were previously industrial but have also been remediated and turned into residential areas. The southern and western shorelines of the bay were extensively reclaimed between the late 19th century and mid-twentieth century and are now enclosed by sea walls. Reclamation areas were partly filled with gasworks wastes, particularly the south-western end of the bay which, until the late 1930s, extended westwards into the gasworks site (the open land area to the west of the bay end in **Figure 1.2**).

2 BACKGROUND

2.1 Existing Environment

The existing environment of Kendall Bay and its environs is described in detail in the report, *Kendall Bay Sediment Remediation Project, Description of Existing Marine Environment* by Royal HaskoningDHV (2016a), and also in the 2017 RAP (S&W, 2017d). Key features of the environs of Kendall Bay are shown on **Figure 2.1**. Aspects of the existing environment that are directly relevant to this ERA are summarised below. **Figures 2.2 and 2.3** show views of southern Kendall Bay.

Figure 2.1. Key features of Kendall Bay in 2016. Note the stormwater delta, formed by discharge from a major stormwater outfall that discharges through the middle of the mangroves, the sediment visible in the shallow water north of the delta, the rocky eastern shore and the western shoreline, a seawall enclosing reclaimed foreshores. Kendall Bay formerly extended into the open land area to the south-west.



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Figure 2.2. View along western seawall of Kendall Bay looking south and showing the mangroves.



Figure 2.3. View from western seawall of Kendall Bay looking east and showing the mangroves and stormwater delta.



2.2 Contamination in the Parramatta River

Sydney Harbour is a drowned valley estuarine system and has deep channels, including the Parramatta River, but a shallow entrance, and only small streams flow into it. Consequently, the sediments upstream tend to be fine – silts and muds – and have acted as a pollution trap during more than two centuries of urbanisation and industrialisation.

The sediments of the Sydney Harbour system are contaminated with metals and organics from a wide range of historical industrial and urban sources (Irvine, 1980; Birch and Taylor, 2004). Contamination by metals extends to a depth of half a metre or more throughout much of the harbour, and much deeper in some places. Contamination is by a variety of heavy metals particularly mercury, copper, lead, zinc and chromium, which in many locations greatly exceed the ANZECC/ARMCANZ 2000 sediment quality guidelines as revised by Simpson et. al., 2013. The contamination tends to be highest in the ends of the many shallow bays off the main channel, particularly on the south side, where fine sediments accumulate, as well as near to long-term industrial pollution sources and stormwater inlets.

Other widespread contaminants in the Parramatta River, sometimes present at levels greatly exceeding the sediment quality guidelines, include organochlorine pesticides (**OCPs**), polychlorinated biphenyls (**PCBs**), polycyclic aromatic hydrocarbons (**PAHs**), total recoverable hydrocarbons (**TRH**) and dioxins. Due to stormwater flow and tidal action, these contaminants, which are largely attached to the fine fraction of the sediments, can be resuspended into the water column and transported both upstream and downstream of their original sources and points of deposition.

Previous work by Birch and others has also indicated that large areas of Parramatta River sediments show toxicity to aquatic organisms, however, attributing toxicity to any particular industry when there are so many potential sources, known and unknown, is extremely challenging (Birch et al, 2008).

Previous studies of contamination of marine tissues in Sydney Harbour have indicated significant levels of contaminants including heavy metals and organic chemicals (Hedge et. al., 2013). Widespread dioxin contamination in marine organisms from the harbour has led to restrictions on the consumption of seafood from locations west of the Sydney Harbour Bridge.

2.3 Previous Investigations of Kendall Bay and Data Gaps

2.3.1 Sediments

Numerous sediment studies of Kendall Bay and adjacent parts of the Parramatta River were carried out between 1989 and 2014. Investigations of Kendall Bay between 1989 and 2002 showed that the sediments are contaminated with gasworks wastes, metals and other pollutants (Jemena, 2014; SKM 2014a, b).

Between 2005 and 2007, investigations by URS (2006, 2007) delineated two areas of contaminated sediments that were stated to require remediation because they represented human health risks, principally due to the levels of carcinogenic PAHs. These areas included one at the southern end of the bay (then called Area A) and one midway along the western side of the bay (then called Area B). Area A did not include the mangroves (though potential human health impacts had been identified from the mangrove area).

Further investigations between 2009 and 2014 by SKM and others (SKM 2013, 2014a, b) obtained additional sediment data, refined the HHERA and enlarged the remediation areas. In particular, Remediation Area A was enlarged to include the mangroves (**Figure 1.2**).

It was noted that the sediments of both Area A and Area B often had an oily sheen and a strong tarry odour, and contained levels of PAHs and petroleum hydrocarbons greatly in excess of sediment quality guideline values. This highly contaminated sediment was found to be present to a maximum depth of more than 4 m in parts of Area B and a maximum of almost 8 m in parts of Area A (E3 Consult, 2011, SKM 2014a).

The gasworks contamination in Area A could have come from waste dumping, discharge or seepage down a bedrock valley (the former western end of the bay) which was partly reclaimed during the early history of the Mortlake gasworks and completely reclaimed by filling with industrial waste and other materials around the 1930s (SKM 2014b). A former large dam on the gasworks site subsequently became a repository for toxic wastes including tarry wastes from the 1940s on (Irvine, 1986, personal observation during site investigation). This waste dam lay on the reclaimed bedrock valley which would have formed a ready conduit to the bay sediments, and could have been a source of contamination to the bay until the former gasworks was remediated between 1999 and 2002.

Contamination in Area B could have come from loading and unloading operations at the former coal and coke wharves on the western side of the bay, including loading of tar barges from a tar pipeline which was reported to have overflowed into the bay on at least one occasion.

The bay sediments were also found to contain other contaminants, including metals and metalloids, though in general the levels were comparable to those found elsewhere in the Parramatta River and its bays.

Data Gaps

Methodological Issues

None of the sediment investigations carried out adjacent to the former gasworks site between 1989 and 2013 followed the Australian Standard (AS 4482–1, 2005) for sampling for volatiles and semi-volatiles, which requires collection of undisturbed samples. Therefore, the chemical analyses obtained from these samples cannot be proven to be reliable for these contaminants, which include low molecular weight TRH, BTEX and naphthalene.

Changes to Erosion and Sedimentation Patterns

Air photos and bathymetric charts show significant changes to sediment depths in the area over the past decades. For instance, comparing the 1992 and 2010 Navy charts (AUS 203, **Figures 1.4** and **1.5**) for the Parramatta River, some of the deeper sections of the river channel near Kendall Bay have shallowed by up to 1.5 m, and the ends of some bays (notably Kendall Bay) have seen further deposition from stormwater discharge as well as erosion (and presumable redeposition elsewhere) from wave action. The introduction of Rivercat and Harbourcat ferries to the Parramatta River has resulted in increased erosion in exposed shallow areas because their wave action is capable of transporting sand-sized (and finer) material alongshore in the shallow littoral zone. There are 25,000 such ferry passings of Kendall Bay every year (Royal Haskoning DHV, 2016). Where erosion or deposition has occurred, previously collected sediment chemical data may not be representative of current conditions.

Due to rapid growth of the Kendall Bay mangrove stand from the late 1990s to the present day and rapid sediment accumulation in the stormwater delta in the southern part of the bay, plus erosion in the south-western corner of the bay where wave energy is focused, chemical data for this area collected between 1989 and 2009 may not be representative of current conditions in this area.

Due to sediment disturbance when the former coal wharf was removed in 2006, the potential for erosion and slumping around the edges of the dredged channel to the wharf and the berths on its northern and southern sides, and preferential deposition in the channel and berth depressions, previously collected chemical data may not be representative of current conditions in this area.

Other parts of the bay may also have been exposed to erosion or deposition that is not apparent.

Sediment Coring Issues

For ERA and remediation planning it is vital to have data on the full depth of contamination in the sediments, and to understand the sediment chemistry, stratigraphy and geotechnical characteristics. The E3 Consulting study (2011), using a push-core rig, obtained valuable information on contamination at depth in the former Remediation Areas A and B, however due to the soft, oily nature of the heavily contaminated upper sediment layers, sediment was seldom recovered for the top 2 – 4 m of the profile. This is a critical data gap; much better data was needed for the upper 2-4 metres of sediments to adequately characterise them.

Inadequate Data or No Data for some Analytes

There were little data on the levels of other contaminants in bay sediments, such as the less commonly analysed metals, OCPs, PCBs and other organic substances.

Due to these uncertainties and data gaps, further data were needed to determine the extent and depth of contamination, and the nature of contamination, throughout the full depth of sediments in Kendall Bay.

2.3.2 Biological Tissues

There was little data on bioaccumulation of contaminants in organisms from Kendall Bay. Studies of PAH contamination of oysters in Kendall Bay and nearby reference bays were conducted by URS (2006):

Contaminant levels in oysters growing within the Declared Area were investigated by URS in January 2006. The investigation involved the collection of oysters from three locations (O1 – O3) that were situated along the northern shoreline in the Parramatta River (O1), near the boat ramp at the south-eastern end of Kendall Bay (O2), and near the former coal wharf in Kendall Bay (O3). Samples from two reference sites were also collected (R1 & R2), these being situated at Bedlam Point and Abbotsford Bay.

URS concluded that:

- *Both low and high molecular weight PAHs were detected in all samples, including the samples collected from the two reference sites;*
- *Oysters in the Declared Area had significantly higher PAH concentrations compared to the reference sites. Total PAH concentrations in the Declared Area were 0.907 - 8.146 mg/kg, which was 16 – 54 times higher than at the reference site (0.057 – 0.152 mg/kg);*
- *The maximum PAH concentrations were measured in sample O3 located along the shoreline near the former coal wharf in Kendall Bay; and*
- *There is a correlation between PAH concentrations in sediments and in oysters, which indicates that the main source of contamination in the oysters is contamination in the sediments.*

Data Gaps

No published data were found on the concentration of the contaminants of concern in mussels or other organisms in Kendall Bay. There were no published data addressing seasonal variation of the contaminants of concern in mussels and oysters, or any other organisms, in Kendall Bay.

Oyster tissue analyses carried out by URS in 2006 identified significant PAH contamination, however it was not clear from the methods used if the gills had been cleaned of suspended sediment. If not, this could have accounted for the elevated levels of PAHs. Additionally, the former coal wharf, which would have been a significant source of PAH contamination, has been removed since 2006, so these data may not be relevant to Kendall Bay at the present time. For these reasons, and to obtain data on an additional species, a new tissue sampling and analysis study was needed.

2.3.3 Water Quality

Water quality monitoring was carried out for the Kendall Bay area by URS in 2006, for TPH, PAHs, BTEX and cyanide. The results are summarised in Royal HaskoningDHV, 2016. URS found that concentrations of the contaminants analysed were all less than the relevant ANZECC/ARMCANZ (2000) 95% Trigger Values (Marine).

Water quality monitoring was also carried out for the Kendall Bay area (3 bay locations and two background locations) by Royal HaskoningDHV from August to October 2012 and from November 2013 to February 2014. At each location samples were taken from just below the surface and 0.5 m above the bay bed, and analysed for Total Suspended Solids (TSS), dissolved metals, Total Cyanide, Total Petroleum Hydrocarbons (TPH) (C₆-C₃₆), BTEX and PAHs. The results were documented in the report *Kendall Bay Sediment Remediation Project – Baseline Water Quality Report* (Royal HaskoningDHV, 2014) and summarised in Royal HaskoningDHV, 2016, and are summarised below.

Summary of Results – Chemical Contaminants/Toxicants

Results for chemical contaminants/toxicants were generally very low throughout the entire baseline monitoring period (i.e. Stages 1 and 2), with the majority of samples having contaminant concentrations below the relevant LOR values. Overall, the results for chemical contaminants/toxicants indicated that existing water quality conditions in Kendall Bay and Fairmile Cove are typically benign.

There were isolated instances where elevated concentrations were detected for arsenic, copper, zinc, total cyanide and PAHs, however such results were not consistently recorded. In addition, these elevated results were not confined to any particular monitoring location.

It is noted that a number of the elevated concentrations exceeded the relevant ANZECC trigger values, with several results up to around 10 times greater than the trigger value, most notably for copper, zinc and total cyanide. This indicated that Kendall Bay and Fairmile Cove may be occasionally characterised by poor water quality for these parameters under normal conditions.

Elevated PAH concentrations were recorded for three samples during the baseline monitoring period, with PAH values (sum of individual PAHs) varying between 3.3 µg/L and 49.2 µg/L. These samples contained a very high proportion of bed sediments, with TSS values of 346 mg/L and 1,420 mg/L recorded for these samples. These results indicated that the mobilisation of bed sediments can result in elevated PAH concentrations within Kendall Bay.

Summary of Results – Physical and Chemical Stressors

It was evident that water quality conditions in Kendall Bay and Fairmile Cove during the entire baseline monitoring period (i.e. Stages 1 and 2) were indicative of a typical estuary, and can be summarised as follows:

- **Dissolved Oxygen (DO):** DO values were typically in the order of 6 to 10 ppm throughout the water column at each monitoring location, and were generally within the default ANZECC trigger limits of 80 to 110%.
- **Electrical Conductivity (EC):** EC values were generally in the order of 40 to 52 mS/cm throughout the water column at each monitoring location, with lowest EC levels observed following rainfall events. These results indicate a relatively high degree of ocean water mixing due to tidal flows, with reductions in salinity associated with catchment runoff following rainfall events.
- **pH:** pH values were typically in the order of 7.1 to 8.2 throughout the water column at each monitoring location, while the average pH from depth-averaged results was around 7.8. pH results were therefore within the default ANZECC trigger limits of 7.0 to 8.513.
- **Turbidity:** Average turbidity values were lowest at the surface (4 to 6 NTU) and highest near the bed (8 to 32 NTU), while depth-averaged values were around 7 to 13 NTU. Turbidity results were therefore typically within the default ANZECC trigger limits of 0.5 to 10 NTU, except near the bed where turbidity measurements above 10 NTU were occasionally recorded. However, relatively elevated turbidity measurements would be expected near the bed under normal conditions, and these results were not considered to be indicative of poor water quality at the site.
- **Temperature:** Temperature values were strongly influenced by prevailing air temperatures due to the relatively shallow water at the site, with water temperatures ranging between 14 and 26°C during Stages 1 and 2.

In addition, it was evident that water quality conditions were relatively similar at each monitoring location, which indicated that the background monitoring locations were suitable reference locations for monitoring during the remediation project.

Data Gaps

Water quality in Kendall Bay is relatively well documented from the work of Royal HaskoningDHV and others reported above, although this is focused on the bay and the immediately adjacent Parramatta River. It would be useful to have water quality data from further upstream and downstream, since tidal movement of water

bodies will be a significant influence on water quality in the bay. There is also a need for water quality data on the main stormwater drain at the southern end of the bay, and other stormwater inputs nearby.

Elevated PAH and suspended sediment levels in bottom water samples may have been due to resuspension of the soft sediments by the weight that hangs below the water sampler. There is a need for water quality data on samples that can be demonstrated to be unaffected by disturbance of the bottom sediment.

2.3.4 Biological Investigations

Several ecological investigations have been carried out in Kendall Bay, including studies by The Ecology Lab (1989, 1996, 1999) and background studies for a proposed marina Cardno Ecology Lab (2009). The following summary draws on these reports.

Hard Surfaces

Fauna identified on hard surfaces in the bay included the Sydney Rock Oyster, Blue Mussel, several species of barnacles and gastropods, and a limpet. Other organisms included a finger sponge, an encrusting bryozoan and two species of crabs (Cardno Ecology Lab, 2009).

Soft Sediments

Benthic Infauna

Sediments in grab samples from the footprint of the proposed Inner West Marina (8 sites) – which was in the vicinity of the former (2007) Remediation Area B – contained 30 taxa (17 polychaete, 5 crustacean, 5 mollusc and 3 others), with mactrid bivalves, capitellid, nephtyid, sabellid, spionid and lumbrinerid polychaete worms being the most abundant. Sediments in grab samples from two sites in the southern part of the bay – in the vicinity of the former (2007) Remediation Area A – contained 17 taxa (8 polychaetes, 3 crustaceans, 4 molluscs and 2 others) and were dominated numerically by nephtyids and nemerteans (ribbon worms). The difference in numbers of taxa at these locations probably reflected a difference in sampling intensity, but did not appear to be linked with the concentrations of the major contaminants at the proposed marina location (Cardno Ecology Lab, 2009).

The mean number of taxa within samples from the proposed marina location was similar to that at both reference locations (elsewhere in the bay and outside in the Parramatta River, but the mean number of animals was similar to that at only one reference location. The overall structure of the assemblages at the proposed marina location, however, was significantly different from that at both reference locations. This suggested that the infaunal assemblages at the proposed marina location were not typical of that region of the estuary (Cardno Ecology Lab, 2009).

Benthic Epifauna

Benthic fish and mobile macroinvertebrates were sampled by beam trawling within and adjacent to the location of the proposed Inner West Marina – the vicinity of the former (2007) Remediation Area B. A total of 64 taxa (11 polychaete, 25 crustaceans, 16 molluscs, 6 fish and 6 other taxa) were collected at these sites with the mactrid bivalve *Spisula trigonella*, mysid *Haplostylis dakini*, amphipod *Corophium* sp. and shrimp *Philocherus* sp. being the most abundant. The mean numbers of taxa and animals, and overall structure of the epibenthic assemblages in Kendall Bay were similar to those at the reference locations combined. This suggested that the epibenthic assemblage at the location of the proposed Inner West Marina was typical of that region of the estuary (Cardno Ecology Lab, 2009).

The fish component of the epibenthic assemblages at Kendall Bay North and Kendall Bay South was significantly different from that at the Kendall Bay Mid and Kissing Point Bay locations. The exquisite goby (*Favonigobius exquiritus*) accounted for most of the dissimilarity in these assemblages and was more abundant on average at Kendall Bay Mid and Kissing Point Bay (Cardno Ecology Lab, 2009).

Mobile Fish and Invertebrates

Fish and mobile macroinvertebrates associated with nearshore soft sediments at the location of the proposed Inner West Marina, Sydney Rowing Club and Kissing Point Bay were sampled using a beach seine net. Fifteen taxa (1 jellyfish, 6 crustacean and 8 fish) were caught off the sandy beach near the location of the proposed Inner West Marina (in the vicinity of the former (2007) Remediation Area B), with the transparent goby *Gobiopterus semivestitus*, mysid *Haplostylis dakini* and glassy *Ambassis jacksoniensis* being the most abundant. Significantly fewer taxa were caught at the location of the proposed Inner West Marina than at either reference location. Intermediate numbers of taxa were caught at Kendall Bay South. There was some

indication of a difference in the structure of these assemblages among sites, with that at the proposed marina location being distinct from that at Kendall Bay South (Cardno Ecology Lab, 2009).

Aquatic Habitats, Flora and Fauna of Conservation Significance

Cardno Ecology Lab (2009) did not identify any critical habitats in Kendall Bay. No threatened marine invertebrate or algal species were listed in the area, and no critically endangered or endangered species have been recorded in the area. A vulnerable species, Black Cod, is known to occur in Sydney Harbour but has not been recorded within Kendall Bay. None of the threatened populations or threatened ecological communities listed as occurring in the Sydney Metro Area have been found in Kendall Bay or its immediate vicinity. Six threatened marine mammal species are known to occur within the Sydney Metro Area Marine Zone (Cardno Ecology Lab, 2009).

No protected fish have been reported in the Canada Bay Local Government Area (LGA). A Hairy Pipefish was reported at the southern end of Kendall Bay in 1988 (The Ecology Lab, 1988) but has not been reported since.

Protected wetlands (saltmarsh communities) are present at the southern end of Kendall Bay and to the east around Cabarita Wharf and Cabarita Point. None of these communities are affected by the proposed remediation activities.

There are 13 marine species and 15 migratory species listed under the *EPBC Act 1999* that occur within Canada Bay LGA, however, these are all birds (Cardno Ecology Lab, 2009).

Data Gaps

The above studies may not be representative of current conditions in the bay, and none of these studies were designed to investigate benthic communities as part of a Weight-of-Evidence (**WOE**) assessment of the gasworks- contaminated sediments in accordance with the ANZECC/ARMCANZ 2000 Sediment Quality Guidelines, as revised by Simpson *et al.* (2013). Accordingly, a new benthic ecology study was required.

2.3.5 Bioavailability and Ecotoxicology Data

No bioavailability or ecotoxicology data was found for Kendall Bay sediments.

2.3.6 Ecological Risk Assessment

The ERA sections of the 2014 HHERA contained much valuable data, however review of the document revealed a number of issues:

1. No bioavailability or toxicity testing was done. The 2014 HHERA states that 'A weight-of-evidence (**WOE**) framework that followed CSIRO (Simpson *et al.* 2010) recommendations was used to assess the ecological risks posed by contaminated sediments in the *Declared Area*.' However, the work done was not a scientifically robust WOE assessment because no data was collected on the bioavailability or toxicity of the sediments. The assessment largely relied on conclusions drawn from sediment ecology studies and old bioaccumulation data which could have had a number of causes.
2. The assessment process that should have been followed is set out in **Section 3.2** of the *Revision of the ANZECC/ARMCANZ 2000 Sediment Quality Guidelines* (Simpson *et al.*, 2013) and shown on **Figure 2.4** below:

'3.2 Application of the WOE Assessment Framework

If the conclusions from the evaluation of chemical and ecotoxicological evidence are ambivalent and further investigations are required, this will involve the application of the WOE assessment framework. The WOE investigation should combine assessments of:

- a) *sediment chemistry to measure contaminant concentrations, compare to Guideline Values (if available) and identify COPCs. These measurements may include chemistry-based bioavailability tests (e.g. pore water measurements, AVS, or biomimetic approaches for hydrophobic organic contaminants).*
- b) *toxicity testing (e.g. multiple species, varying exposure pathways, acute and chronic endpoints such as mortality, reproduction, development, growth, avoidance).*
- c) *bioaccumulation/biomagnification, and*
- d) *benthic community structure (e.g. ecological malfunction)*

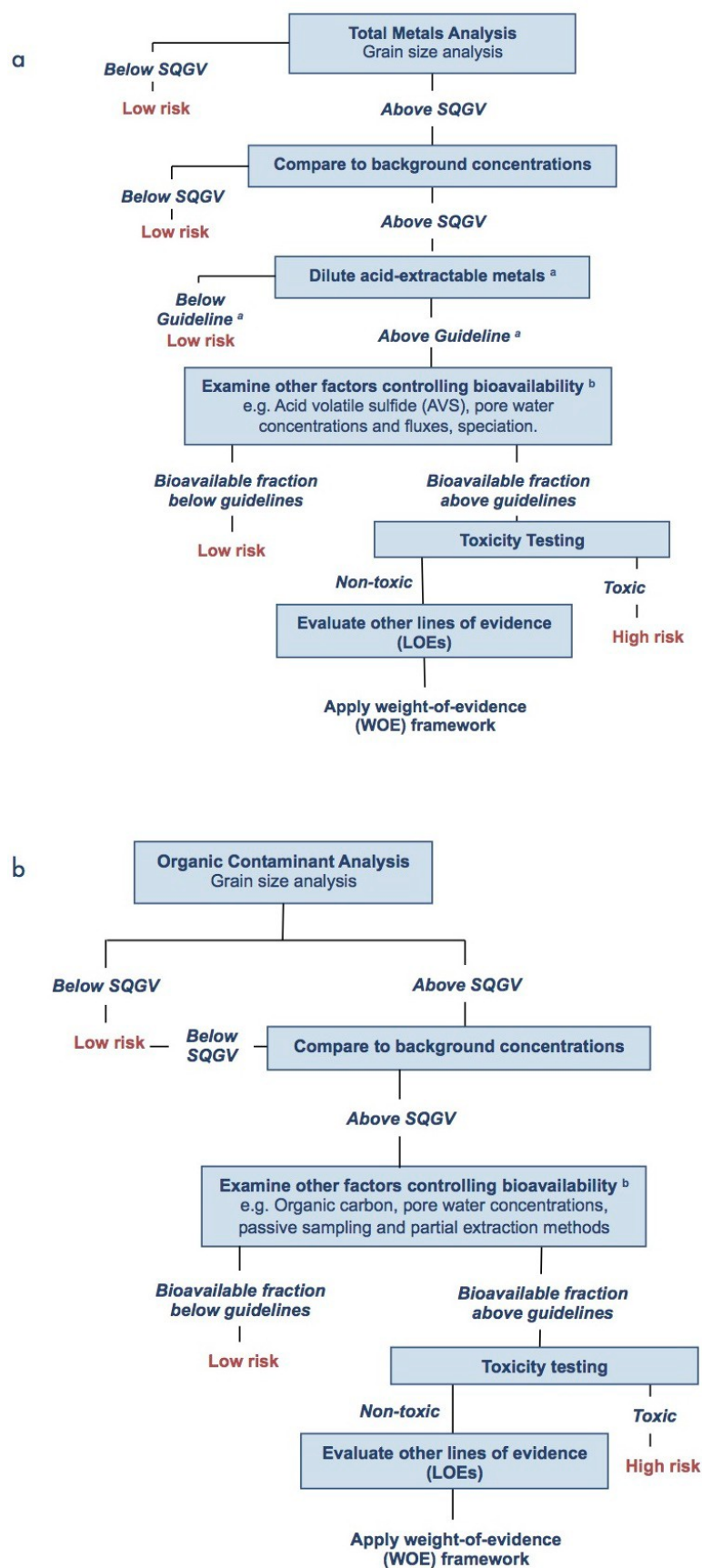
The WOE framework allows decisions to be reached when a single line of evidence (LOE) is insufficient for making decisions, e.g. if Guideline Values (GVs) do not exist for the contaminants, if there are no appropriate toxicity tests that are sensitive to the contaminants of concern.

The WOE approach tabulates and ranks the results of all individual Lines of Evidence (LOEs) used, such as sediment chemistry (e.g. exceedance of trigger values), elutriate and bioavailability testing (exceedance of the relevant criteria), toxicity testing (elevated toxicity compared to controls), bioaccumulation (significant differences compared to controls), and benthic community structure (reduced benthic diversity or abundance relative to controls)'.

3. The 2014 HHERA used the Simpson et al. (2013) Sediment Quality Guideline High (**SQG-High**) value of 50 mg/kg Total PAH (normalised to 1% Total Organic Carbon (**TOC**)) as a remediation criterion, however SQGs are expressly not remediation criteria as they do not take into account bioavailability, and exceedances of the SQGs require additional studies to identify whether identified chemical substances give rise to unacceptable impacts to biota.
4. Site-specific PAH remediation criteria need to be determined for Kendall Bay sediments, to identify whether an unacceptable risk is posed by the contaminants in the sediments, as they have been for other similar projects such as BHP's remediation of PAH-contaminated sediments in the Hunter River, Port of Newcastle.
5. Another issue in relation to normalisation of organics to 1% TOC is that the normalisation procedure was designed for typical marine sediments which typically contain TOC in the approximate range of 0.5 % to 5 %, and mainly of natural organic origin. The method was not designed for sediments containing extremely high levels of TOC much of which is Black Carbon of industrial origin. The issue of normalisation to forms of carbon needed further consideration.

For these reasons, and because of the data gaps identified in the preceding sections, an updated ERA was required.

Figure 2. 4. Australian Tiered Testing Framework for Assessment of Contaminated Sediments



Source: Simpson et al., 2013.

3 DESIGN OF ECOLOGICAL RISK ASSESSMENT

3.1 Australian and International ERA Guidelines

ERA is the method used to determine the risk posed by a contaminant or contaminants to the survival and health of ecosystems. Risk is defined as the probability that an adverse effect will occur as a result of exposure to a particular level of the contaminant or contaminants and is determined by assessing:

- the *consequences* (or effects) of an adverse event (i.e. toxicity); and
- the *probability* of the event occurring (i.e. exposure).

Risk is therefore the probability of an adverse event, or the likelihood of exposure, times the effects of that exposure.

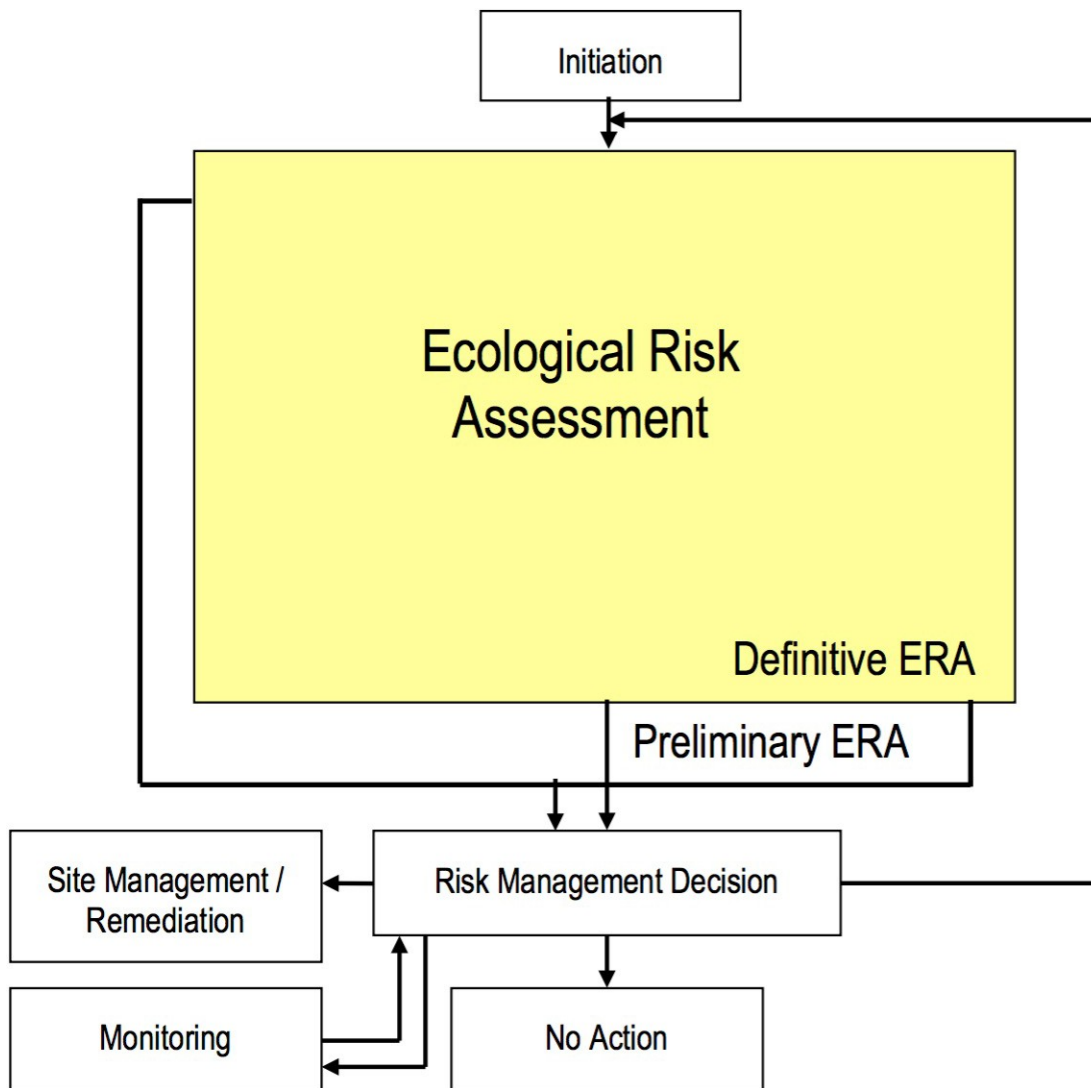
ERA is a set of formal scientific methods for defining and estimating the probabilities and magnitudes of adverse impacts on plants, animals and/or the ecology of a specified area posed by a particular stressor(s) and frequency of exposure to the stressor(s). Australian guidelines for ERA are set out in Schedule B5a, *Guideline on Ecological Risk Assessment*, of the National Environment Protection (Assessment of Site Contamination) Measure 1999, as updated in 2013 (NEPM, 2013), and these guidelines have been followed in the current study. The detailed US ERA guidance document (USEPA, 1998) has also been referred to, as Australian approaches have been largely derived from it.

It is noted, however, that the NEPM 2013 guidelines are general in nature and are designed to assess ‘the risk posed to terrestrial ecosystems (including soil processes, soil flora and fauna, and terrestrial invertebrates and vertebrates) from the adverse effects of chemical contaminants in soil.’ No guidance is provided for assessing risks to aquatic ecosystems from contaminated sediments – rather, reference is made to the ANZECC/ARMCANZ 2000 *Guidelines for Fresh and Marine Water Quality*. The *Revision of the ANZECC/ARMCANZ 2000 Sediment Quality Guidelines* (Simpson et al, 2013) updates the guidelines in respect of sediment quality assessment and sets out a WOE assessment approach. Additional guidance is provided in Simpson and Batley (2016), *Sediment Quality Assessment – A Practical Guide*.

There are no detailed Australian ERA guidelines for ecological risk assessment of contaminated marine sediments, nor have any general international marine ERA guidelines been identified, though the US Army Corps of Engineers (USACE, 1999) has produced ecological and human health risk assessment guidance for aquatic environments (relating to dredging of contaminated and uncontaminated sediments). Other relevant guidance includes: USEPA (2005), *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*; ITRC (2008), *Use of Risk Assessment in Management of Contaminated Sites*; USEPA (2009), *Evaluating Ecological Risk to Invertebrate Receptors from PAHs in Sediments at Hazardous Wastes Sites*; ITRC (2011), *Incorporating Bioavailability Considerations into the Evaluation of Contaminated Sediment Sites*; and Department of Ecology, State of Washington (2015), *Sediment Cleanup User’s Manual II*.

ERA is a process which ‘identifies the ecological receptors of concern, estimates the concentration that the ecological receptors are exposed to and, based on the magnitude of this concentration, determines whether the ecological receptors and ecological values may be at risk’ (NEPM, 2013).

The Australian ERA framework is an iterative process with two levels of assessment, a Preliminary ERA and a Definitive ERA. A Definitive ERA ‘is required only in a situation where the concentration of the contaminant(s) is sufficiently high that it may pose a risk. A Definitive ERA requires greater data collection, uses more complex and environmentally realistic methods and reduces the uncertainty in the outcome of the ERA compared to the Preliminary ERA’ (NEPM, 2013). The Framework for conducting ERA in Australia is set out in **Figure 3.1**.

Figure 3.1. Framework for Conducting Ecological Risk Assessments in Australia

Source: NEPM, 2013, Schedule B5a

Previous assessments (URS, 2006; SKM, 2014a) have established that the gasworks-contaminated sediments in parts of Kendall Bay greatly exceed sediment quality guidelines, in particular due to the high levels of PAHs, and therefore pose a risk to organisms living in the bay. For this reason, in preparing the current report a Definitive ERA has been carried out.

ERA consists of six basic and interrelated components:

- **Problem Formulation.** A scoping phase that establishes the objectives of the ERA and identifies the data required to achieve those objectives. Actions:
 - o establish the extent and degree of on-site contamination;
 - o identify the Contaminants of Potential Concern (**COPC**), i.e. those contaminants which have been identified in the site history or site sampling as presenting a potential risk to biota; and
 - o determine the most relevant Investigation Levels (i.e. sediment and water quality criteria or guidelines), as well as tissue levels.

- Receptor Identification. Focuses on those species ‘which may be at risk’ and ‘what do we want to protect?’
- Conceptual Model. To guide the overall risk assessment, a conceptual model is developed which describes the main contaminant sources, release and transport mechanisms to the study area, and the potential exposure routes and receptors.
- Exposure Assessment. Characterise the physical setting, identify potential exposure pathways and estimate exposure duration, concentrations and intakes.
- Toxicity Assessment. This involves estimating the concentration of contaminants at which species and ecological functions experience no harmful effects, and those at which toxic effects are caused. This data is in turn used to determine the concentration of contaminants that an ecosystem can be exposed to without adverse effect or with adverse effects of a certain magnitude.
- Risk Characterisation. This involves combining data and information from the exposure and toxicity assessments to determine the risk that ecosystems at the site face from the contaminants. This is usually done by comparing the measured contaminant concentrations with the assessment criteria.

The ERA process concludes by providing guidance for a risk management decision for the site. In a Definitive ERA, there are three possible outcomes:

- no action (although given that ecological risk has already been identified, no action would only occur in situations where contamination of the site was continuing);
- monitoring; or
- site management or remediation.

3.2 Problem Formulation

The objectives of the ERA are set out in **Section 1.2**, above.

3.2.1 Identification of Contaminants of Potential Concern

The COPCs were identified based on: an extensive review of the history of the Mortlake gasworks and its operations; review of the history of Kendall Bay and its surroundings, and the findings of extensive previous contamination investigations in the bay. The COPCs are listed in **Table 3.1**. The rationales in the table are based on the presence of elevated levels of key contaminants in Kendall Bay sediments, adjoining bays and the upper and lower reaches of the Parramatta River, particularly those contaminants that have principally come, or could have come, from the former gasworks.

3.2.2 Adopted Ecological Assessment Criteria

Sediments

The assessment criteria (i.e. sediment quality guideline values - **SQGs**) have been drawn from *Revision of the ANZECC/ARMCANZ 2000 Sediment Quality Guidelines*, Simpson et al, 2013, supplemented by other sources where necessary. The adopted SQGs are set out in Table 2.2. The lower value, the Guideline Value (**GV**), equates to the likely threshold of effects and is an investigation level. The high value (**SQG-High**) equates to a high probability of effects (assuming the contaminant is in a bioavailable form). No sediment quality guidelines were available for cyanides or phenolics.

Note that many organic contaminants, including PAHs (but not TRH), are normalised to the TOC content before comparison to the GV. Normalisation is carried out within the range of 0.5% TOC and 10% TOC. Where the TOC is lower or higher than these endpoints, either 0.5% or 10% is used, respectively. Normalisation is done by dividing the organic contaminant value (e.g. Total PAH) by the TOC value expressed as a percentage.

Table 3.1. Contaminants of Potential Concern in Kendall Bay

Contaminant of Potential Concern	Rationale
Total PAHs	Present at significantly elevated levels in some bay sediments, particularly along the south-western and western sides of Kendall Bay
TRH	Present at significantly elevated levels in some bay sediments, particularly along the south-western and western sides of Kendall Bay
Benzene, toluene, ethylbenzene and xylene (BTEX)	Present at significantly elevated levels in some bay sediments, particularly along the south-western and western sides of Kendall Bay
Naphthalene	Present at significantly elevated levels in some bay sediments, particularly along parts of the western side of Kendall Bay
Total PAHs	Present at significantly elevated levels in some bay sediments, particularly along the south-western and western sides of Kendall Bay
TRH	Present at significantly elevated levels in some bay sediments, particularly along the south-western and western sides of Kendall Bay
Benzene, toluene, ethylbenzene and xylene (BTEX)	Present at significantly elevated levels in some bay sediments, particularly along the south-western and western sides of Kendall Bay
Arsenic	Present at elevated levels in some bay sediments and Parramatta River
Cadmium	Present at elevated levels in some bay sediments and Parramatta River
Chromium	Present at elevated levels in some bay sediments and Parramatta River
Copper	Present at elevated levels in some bay sediments and Parramatta River
Lead	Present at elevated levels in some bay sediments and Parramatta River
Mercury	Present at elevated levels in some bay sediments and Parramatta River
Nickel	Present at elevated levels in some bay sediments and Parramatta River
Zinc	Present at elevated levels in some bay sediments and Parramatta River
Cyanides	Present at elevated levels in some gasworks wastes
Phenolics	Present at elevated levels in some gasworks wastes
OCPs and PCBs	Present at elevated levels in some Parramatta River sediments

The values in **Table 3.2** apply to benthic organisms exposed to sediments, i.e. organisms living within the sediments, or on or near the sediment surface, or feeding on the sediments. In many cases the sediment quality guidelines are lower than the human health guidelines, because organisms living in or on the sediment, or feeding on it, are continuously exposed to the contaminants, whereas humans will only have intermittent exposure to the contaminants.

Where the level of a contaminant lies below the GV, it is unlikely that there would be any significant effect on organisms from that contaminant. Where a contaminant is above the GV, effects on exposed organisms are possible. Effects become increasingly likely at or above the SQG-High, although both values are an imperfect guide to the extent of effects on organisms, because the toxicity of sediments is dependent on the bioavailability of the contaminants. If a contaminant is present in biologically unavailable forms, there may be no toxic effects on exposed organisms even when its level exceeds the SQG-High value.

Where the GV is exceeded for any contaminant, further testing is required in order to determine bioavailability and toxicity – and to make an assessment as to whether the contaminated sediments are in fact toxic. Without this information, the need for management or remediation for ecological protection cannot be determined.

Neither the GV or the SQG-High are remediation criteria. Also, as noted in Simpson et. al., 2013, some of these GVs are low quality (i.e. based in insufficient data), which makes it all the more important to carry out further investigation.

Table 3.2 Sediment Quality Investigation Criteria (Australian Sediment Quality Guidelines, mg/kg except where noted)

Contaminant	GV	SQG-High
Arsenic	20	70
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Silver	1.0	4.0
Zinc	200	410
Total PAHs *	10	50
TRH (= TPH)**	280	550

Sources: Except where noted otherwise, from Simpson, SL, Batley, GE and Chariton AA (2013). *Revision of the ANZECC/ARMCANZ 2000 sediment quality guidelines*. CSIRO Land and Water Report 8/07. Final Report for the Commonwealth Department of The Environment.

*Normalised to 1% TOC.

**Simpson et al., 2016, 2018, notes that the TRH guidelines are low quality.

Biological Tissue

There are no Australian ecological assessment criteria for contaminants in biological tissue. The adopted criteria for the assessment of levels of COPC in oysters and mussels collected from Kendall Bay and adjoining bays are based on the levels quoted in:

- *Australia New Zealand Food Standards Code* – Schedule 19 – Maximum levels of contaminants and natural toxicants 1991; and
- Generally Expected Levels (GELs) for Metal Contaminants - ADDITIONAL GUIDELINES to maximum levels in Standard 1.4.1 – Contaminants and Natural Toxicants, July 2001.

There are no Australian human health assessment criteria for petroleum hydrocarbons or PAHs in marine tissue, and of the metal COPCs the only criteria are for cadmium, copper and zinc. These values are included in the data tables in **Section 5**.

Waters

The adopted criteria for the assessment of water quality in Kendall Bay and adjoining bays (**Table 3.3**) are based on the Sydney Harbour and Parramatta River Water Quality Objectives (WQOs)(2006, <http://www.environment.nsw.gov.au/ieo/SydneyHarbour/report-02.htm>). The Upper Parramatta River is classified as Upper Estuary (**Figure 3.2**). In relation to toxicants, the ANZECC/ARMCANZ (2000) marine water quality guidelines for ecological protection apply.

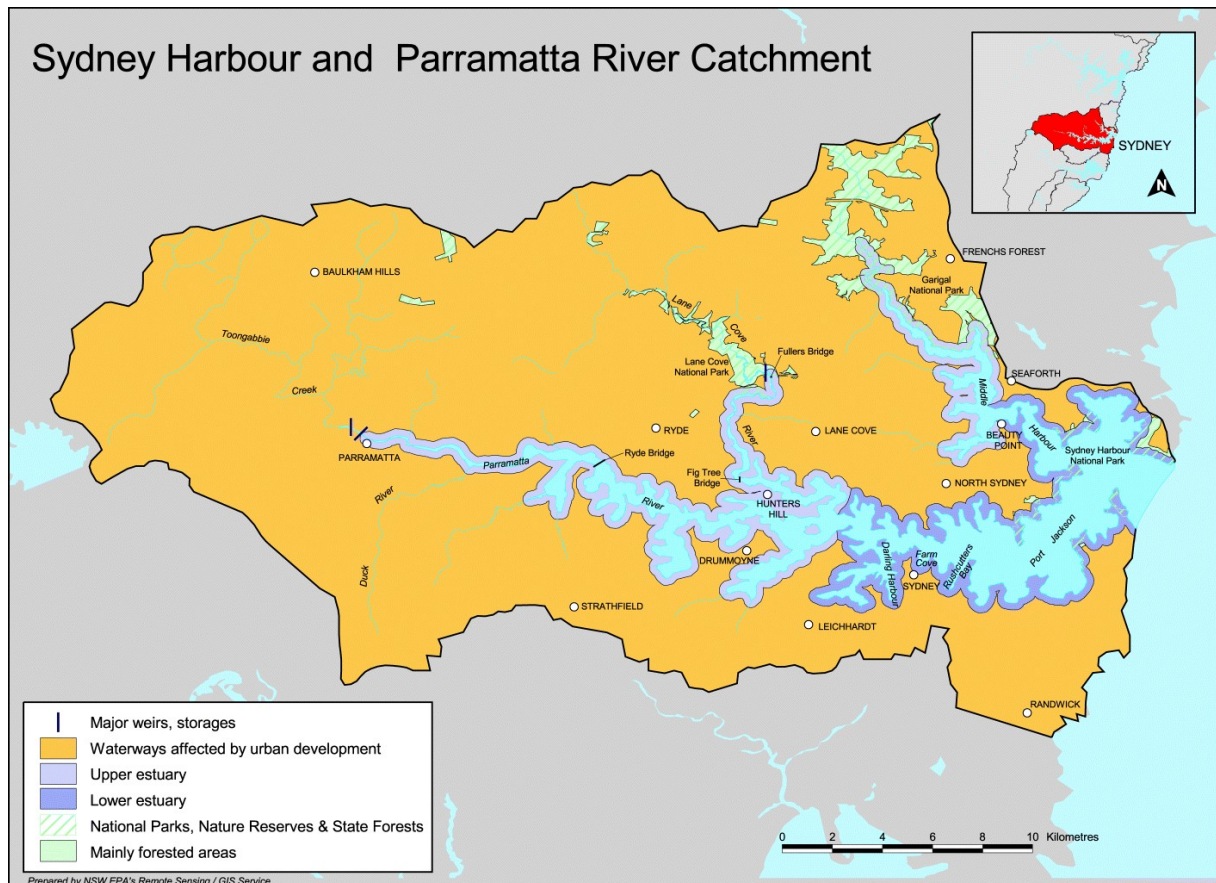
Table 3.3 Summary of Adopted Water Quality Criteria

Parameter	Parramatta River Upper Estuary WQOs (µg/L)	ANZECC/ARMCANZ (2000) Trigger Values for 95% Protection of Species (µg/L)	Assessment Criteria Adopted for this Study (µg/L) *
Toxicants			
Arsenic		2.3 (vol. 2 ANZECC)	2.3
Cadmium		0.7	0.7
Chromium		27 (Cr III)	27
Copper		1.3	1.3
Lead		4.4	4.4
Mercury		0.4	0.4
Nickel		70	70
Zinc		15	15
Benzene		500	500
Toluene		180	180
Ethylbenzene		5	5
m+p-Xylene		200	200
o-Xylene		75	75
Naphthalene		70	70
TRH		90-300 (WHO)	90-300 (WHO)
Total PAH		0.1	0.1
Ammonia (Total as Nitrogen, pH 8)		910	910
General Parameters			
pH	7.0-8.5		7.0 – 8.5
Dissolved Oxygen	80-110% saturation		80-110% saturation
Total Phosphorus	30 µg/L		30 µg/L
Total Nitrogen	300 µg/L		300 µg/L
NOx as N	15 µg/L		15 µg/L
Phosphate as P	30 µg/L		30 µg/L

* Total (unfiltered) metals

Where blank, no standard was specified

ID Insufficient Data

Figure 3.2. Sydney Harbour and Parramatta River Catchment Zoning

Source: Sydney Harbour and Parramatta River Water Quality Objectives (2006)

3.2.3 Investigation Program Overview

Because of the inadequacies and data gaps noted previously, Jemena commissioned S&W to carry out the necessary investigations of surface and subsurface sediments to:

- determine the depth and extent of gasworks-derived contamination that posed an unacceptable risk to:
 - o people who used the beach, mangrove areas and other foreshore areas of the bay; and/or
 - o marine organisms in the bay;
- obtain reliable data for revision of the HHRA and ERA;
- determine appropriate and scientifically justifiable remediation criteria;
- identify the extent of remediation works required; and
- identify the preferred and feasible remediation method/s.

Investigations to address these issues were carried out in stages between April 2015 and September 2016, with the results of each stage being used to refine the objectives and the sampling and analytical plans for later investigations. The work program was designed using the USEPA's seven-step Data Quality Objectives (DQO) process as set out in Appendix B of NEPC 2013, Schedule B2, *Guideline on Site Characterisation*. The process is described in the Sediment Investigation Data Report (S&W, 2017a).

The sediment investigations were carried out in four phases:

- Phase 1 – Investigation of the mangrove, beach and stormwater delta sediments at the southern end of Kendall Bay;

- Phase 2 – Investigation of the surface sediments throughout Kendall Bay, and suitable background areas, to obtain the data needed for:
 - o Revision of the HHRA;
 - o Preparation of an updated ERA using a WOE approach to assessment of the contaminated sediments in accordance with the latest revision of the ANZECC/ARMCANZ 2000 Sediment Quality Guidelines (Simpson *et al.* 2013). This included investigation of:
 - Sediment bulk chemistry and volatiles chemistry:
 - To measure contaminant concentrations, compare to sediment quality guideline values (SQGVs) where available, and identify COPCs;
 - Bioavailability testing including dilute acid extraction, AVS:SEM analysis, pore water and elutriate testing, analysis of Black Carbon content and evaluation of USEPA models; and
 - Specialised chemical analysis of volatiles;
 - Toxicity testing including multiple species, varying exposure pathways, and acute and chronic endpoints;
 - Bioaccumulation studies on oysters and mussels;
 - Assessment of benthic community structure; and
 - o Development of scientifically justifiable remediation criteria and strategies;
- Phase 3 – Investigation of the subsurface sediments of Kendall Bay to fill in data gaps, particularly for the soft oily clays in the top 2 – 4 m of the sediment column, which had previously proven difficult to sample, and to define the areas, depths and volumes of gasworks-contaminated sediments; and
- Phase 4 – a bulk dredging trial to:
 - o monitor water quality, air quality and odour release during a trial dredging of some of the most contaminated sediments; and
 - o obtain bulk samples for testing of sediment properties and for use in trials of various methods of *in-situ solidification* of the contaminated sediments, plus leachate testing of the stabilised materials.

The main sediment investigation work program, comprising 10 separate sampling episodes, was carried out between April 2015 and April 2016. Phases 2 and 3 overlapped. The bulk excavation trial was carried out in September 2016.

Water quality monitoring was carried out in February and April 2016, and oyster and mussel sampling in April 2016.

The Post-RAP sampling to address the issue of chronic toxicity was carried out in October 2017.

Investigation Areas

The Investigation Areas were progressively refined on the basis of data collected in the 10 sediment sampling episodes. Five Investigation Areas were defined (three of them being background areas):

- Southern Investigation Area – including the 2014 RAP Area A plus surrounding areas (**Figure 3.3**);
- Northern Investigation Area – including 2014 RAP Area B plus surrounding areas (**Figure 3.4**);
- the remainder of Kendall Bay – those parts of Kendall Bay identified in the 2014 RAP as having background levels of PAHs and metals (**Figure 3.5**);
- Southern Reference Areas including Exile Bay and Canada bay – nearby bays as background areas not impacted by gasworks waste (**Figure 3.6**); and
- Northern Reference Areas including Majors Bay, Yaralla Bay and Brays Bay – nearby bays as background areas not impacted by gasworks waste (**Figure 3.7**).

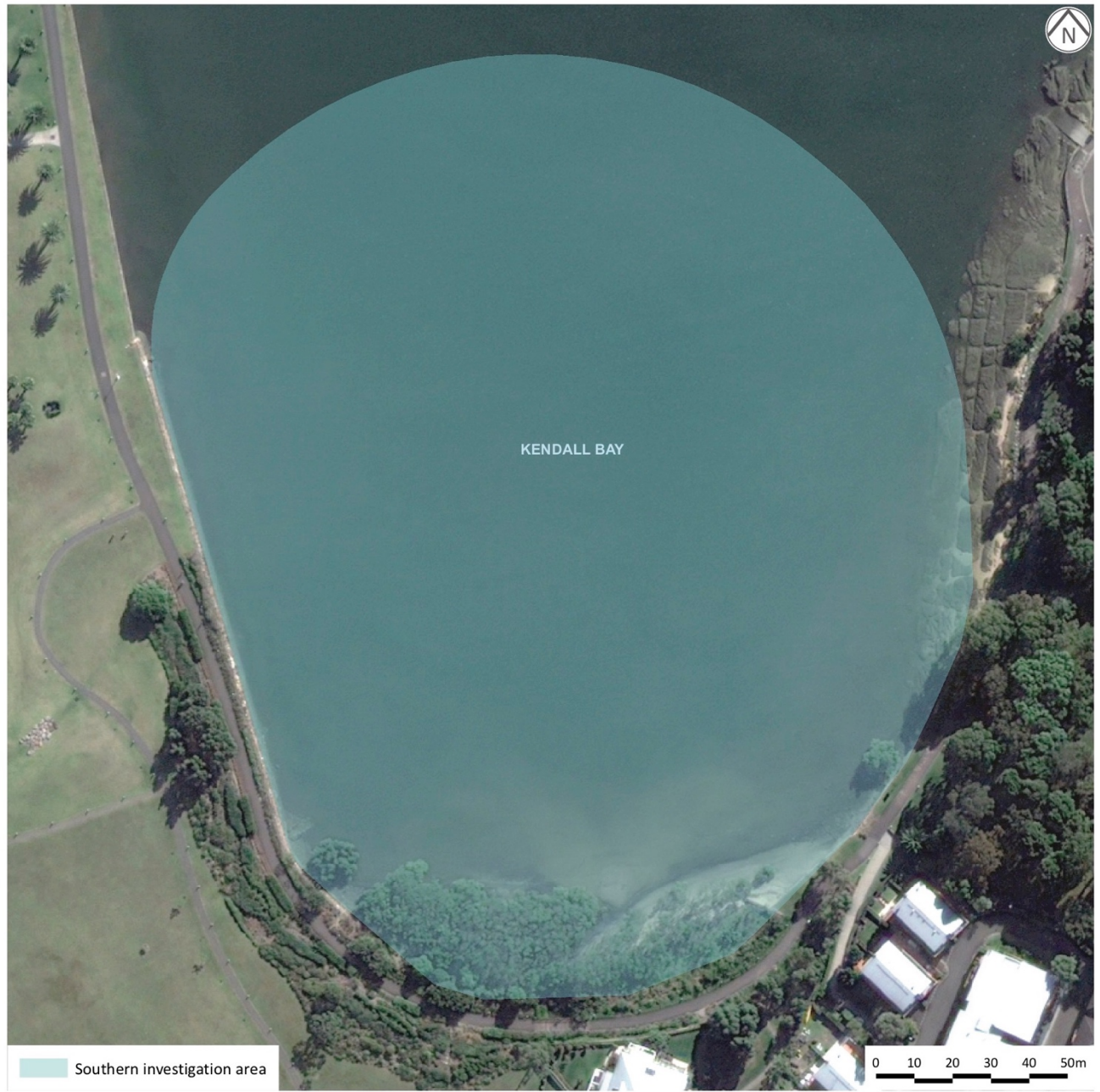
Figure 3.3. Southern Investigation Area

Figure 3.4. Northern Investigation Area.

Figure 3.5. Kendall Bay, Showing Areas with Background PAH Levels in Surface Sediments (2006-2013 data)



Source: SKM, 2014b

Figure 3.6. Southern Reference Area



Figure 3.7. Northern Reference Area



Studies Carried out to Obtain Data for the ERA

The specific investigations carried out to support this ERA are described in a series of reports by S&W, and consultants to S&W, as follows:

- surface and subsurface sediment sampling and analysis for COPCs and other parameters throughout Kendall Bay and in suitable reference areas (S&W, 2018a);
- water quality sampling and analysis for the COPCs and other parameters throughout Kendall Bay and in suitable reference areas (S&W, 2018b);
- oyster and mussel tissue sampling for key contaminants throughout Kendall Bay and in suitable reference areas (S&W, 2017c);
- surveys of marine benthic communities throughout Kendall Bay and in suitable reference areas, plus analysis of the sediments for the COPCs (Alison Hunt & Associates, 2016, 2018); and
- bioavailability and ecotoxicity studies of sediments from Kendall Bay and suitable reference areas by CSIRO, plus analysis of the sediments for the COPCs (Simpson et al., 2015; 2016; Simpson and Spadaro, 2018).

The reports tabulate the Data Quality Objectives (**DQOs**) to be met for these investigations, the sampling rationale, the quality assurance and quality control (**QA/QC**) measures adopted, the sampling and analysis programs carried out, the data obtained, and the data validations carried out to ensure that the data obtained met the DQOs and was, therefore, suitable for use in the ERA.

3.3 Receptor Identification

Ecological values and protection criteria are set out in **Section 3.2.2**.

The Conceptual Site Model (**CSM**) is described in **Section 3.4**, below.

For this assessment, it is assumed that the receptors are all biota of ecological value in the study area, including the biota described in **Section 2.2.4**.

Water Column Receptors

All biota inhabiting the water column of the study area are receptors.

Benthic Receptors

All biota living in or on, or exposed to the bottom sediments are receptors.

Uncertainties

The entire benthic community was chosen as the benthic receptor, and the water column community as the water column receptor, because insufficient data was available to select and assess individual species as benthic receptors. Therefore, receptor selection could only assess endpoints at the community level, not the level of individual species.

3.4 Conceptual Site Model

An important function of a Conceptual Site Model (**CSM**) is to identify a *complete* link between a contaminant source, contaminant release, contaminant transport pathway to sediment, presence of the contaminant in sediment, and exposure of the contaminant (above established risk levels) to receptors (Washington Dept. of Ecology, 2015).

An initial CSM was developed in the work program planning stage as a guide to the studies that would be required. The CSM and work program were developed using the USEPA's seven-step data quality objectives process as set out in Appendix B of NEPC 2013, Schedule B2, *Guideline on Site Characterisation*. The process is described in S&W, 2018a.

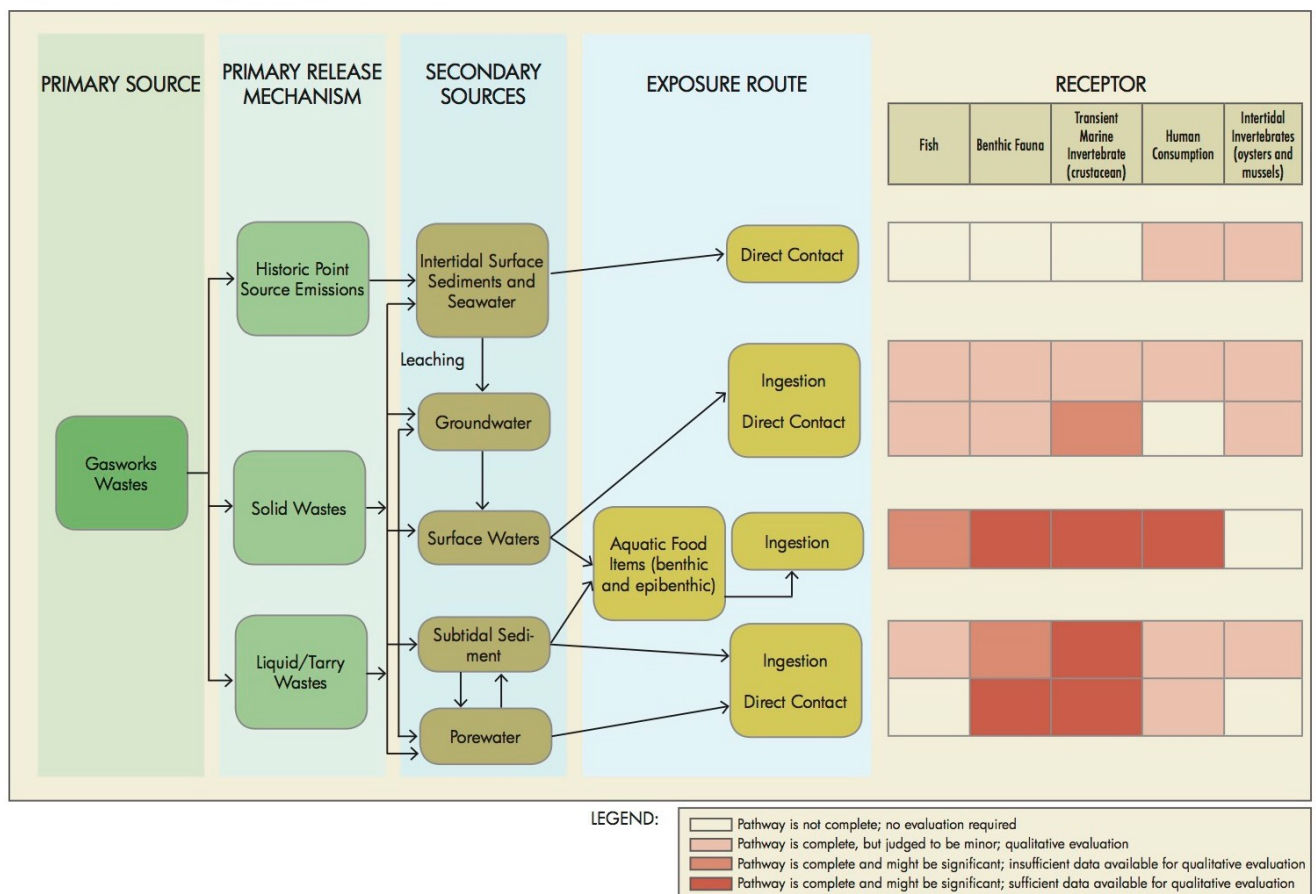
The CSM was progressively refined with the results of the individual investigations in 2015-2016. The purpose of the CSM was to:

- Identify the sources of contamination in the study area, the COPCs, and the areas contaminated by gasworks wastes and other pollutants;
- Show how contaminants already contained in the sediments of Kendall Bay, or released into the bay, might move in the aquatic environment;
- identify the potential human and ecological receptors that could be exposed to contaminants; and
- list the potential and complete exposure pathways (e.g. exposure to contaminated water, uptake from water, ingestion of contaminated sediment, direct contact with sediment, uptake from suspended sediment in water column) for each receptor.

The final conceptual model is shown in **Figure 3.8**. The primary contamination source was historic operations at the gasworks site between 1886 and the end of site remediation early this century. Current contamination sources to the bay include a number of stormwater outfalls, particularly the large stormwater outfall that discharges through the mangroves, resuspension and redeposition of contaminated sediment from the Parramatta River upstream and downstream of Kendall Bay, and groundwater movement from the former gasworks site and other remediated industrial sites in the area.

The principal exposure routes for organisms in the study area are ingestion of and direct contact with contaminated sediments, and ingestion of and direct contact with contaminated pore water and water overlying the contaminated sediments.

Figure 3.8. Conceptual Site Model



3.5 Contaminant Sources, Fate and Transport

3.5.1 Contaminant Sources

Historic Contamination Sources

Mortlake Gasworks

The principal source of the sediment contamination by gasworks wastes in the Declared Area was operations at the Mortlake gasworks site prior to its closure and remediation.

It is not known how the tarry oils, now present in some of the sediments of Kendall Bay, entered the bay. The Mortlake gasworks had multiple sources of tarry oils including tar wells and tanks, tar pipelines (one of which is reported to have extended along the former coke wharf into Kendall Bay), coke stockpiles (particularly large stockpiles on land reclaimed from the former bay end in the south-eastern part of the former gasworks site), waste piles such as oxide-revivifying areas and spent oxide dumps, also present in the south-eastern area and the large deep waste dam formed from the former water supply dam, which, sometime after the 1940s became a repository for tar and other wastes. Contamination from these sources could have entered the southern part of the bay down stormwater drains or by subsurface flow, and the mid-western side of the bay from tar pipeline releases and spilled coke. It is also possible that some wastes were dumped in the bay in early years of operation.

However, the gasworks contamination in the bay is considered to be historic rather than ongoing because the former gasworks site has been remediated and certified as being suitable for residential use and open space/parkland by the site auditor, all NSW EPA notices were removed more than a decade ago and the site has been redeveloped into the residential suburb of Breakfast Point.

Other Historic Sources

Other historic sources of contamination to Kendall Bay are likely to have included:

- the former Dulux paint factory at Cabarita, to the south-east of Kendall Bay, which operated from 1921 to the 1990s and produced white lead (lead oxide) and a range of paints (although wastewater discharge was to France Bay on Hen and Chicken Bay). This site was also remediated in the late 1990s and redeveloped for residential purposes;
- a number of stormwater outfalls, particularly the large stormwater outfall that discharges through the mangroves at the southern end of Kendall Bay;
- resuspension and redeposition of contaminated sediment from the Parramatta River upstream and downstream of Kendall Bay by tidal and wind currents;
- urban runoff and airborne fallout;
- groundwater movement; and
- vessels using the bay.

Current Contamination Sources

Current contamination sources to the bay include:

- resuspension of contaminated gasworks sediments exposed at the sediment surface and redeposition elsewhere in the bay;
- a number of stormwater outfalls, particularly the large stormwater outfall that discharges through the mangroves;
- resuspension and redeposition of contaminated sediment from the Parramatta River upstream and downstream of Kendall Bay by tidal and wind currents;
- urban runoff and airborne fallout;
- groundwater movement; and
- vessels using the bay.

3.5.2 Contaminant Fate and Transport Metals and Metalloids in Water

Metals and metalloids in seawater were measured in the dissolved form (i.e. after filtration through 0.45-micron filters) for comparison with the ANZECC/ARMCANZ (2000) marine water quality guidelines, as well as in the total (unfiltered) form. In dissolved form these contaminants would generally be regarded as being biologically available to exposed organisms, although it must be noted that trace elements exhibit a range of binding affinities and therefore can exchange between dissolved and particulate forms, or become complexed or precipitated, with changes in environmental conditions. Metals and metalloids do not degrade.

The majority of metals released into Kendall Bay waters from the contaminated sediments or other sources such as groundwater and stormwater (whether in dissolved form or attached to suspended matter) are liable to be redeposited in the bay, due to the generally weak tidal currents. Some suspended and dissolved contaminants would be transported out into the Parramatta River, from where they could be carried both upstream and downstream by tidal currents (see **Section 3.5.3**).

Nutrients in Water

Nutrients in seawater are readily altered from one form to another and can either remain in the water column, be lost into the atmosphere (in the form of nitrogen or ammonia), or be taken up by organisms or deposited in sediments. Some nutrients released into the bay would be transported into the Parramatta River, although a fraction would be taken up by organisms (e.g. the mangroves), or deposited (where attached to particulates) in low energy environments such as the mangroves and the shallow waters in the southern part of Kendall Bay. Nutrient cycling between the water column, sediments and organisms will occur readily.

PAHs in Water

Due to their generally low solubility in water, most PAHs are not expected to be present in dissolved form in significant quantities, exceptions being the low molecular weight PAHs such as naphthalene which have significantly higher solubility and volatility. Low molecular weight PAHs will be lost from water by volatilisation, microbial oxidation and sedimentation attached to particles. Higher molecular weight PAHs are largely removed from the water column by photo-oxidation and sedimentation (Moore and Ramamoorthy, 1984).

The majority of the PAHs are likely to be attached to suspended matter. Much of this is liable to be redeposited in the bay, although some could be transported out into the Parramatta River by tidal- and wind- induced currents.

Petroleum Hydrocarbons in Water

Petroleum hydrocarbons are mainly lost from water by volatilisation (the lighter aliphatic and aromatic fractions), sorption onto sediment particles followed by sedimentation, and microbial degradation.

The majority of the TRH in water is likely to be attached to suspended matter. Much of this is liable to be redeposited in the bay, although some could be transported out into the Parramatta River by tidal- and wind- induced currents.

Metals and Metalloids in Sediments

The majority of Kendall Bay is a depositional environment (see 3.5.3 below), and the bulk of the metals and metalloids in the sediments are therefore likely to be stable except during high energy events such as major storms. Parts of the bay, particularly along the south-western side, appear to be erosional due to focused wave energy in this area. Much of the resuspended sediment is likely to be redeposited in the bay, though some will be carried out into the Parramatta River. Some metals could be released from the sediments and pore water to the overlying water, though the majority of these are likely to be re-adsorbed onto particulates and redeposited.

The total levels of metals in sediments will not necessarily be directly related to toxicity, since metals can be present in sediments in many different forms, and can interchange between these forms, many of which are of low biological availability.

PAHs in Sediments

Most of the PAHs are relatively stable and, due to their low water solubility and high affinity for particulate matter, are expected to be bound to the sediments. PAHs in exposed sediments (i.e. at the sediment surface) can be removed by photolysis and volatilisation, particularly the low molecular weight PAHs such as

naphthalene which have significantly higher solubility and volatility. The gasworks-contaminated sediments in the bay also have very high levels of total organic carbon and pyrogenic Black Carbon, both of which act to bind PAHs and reduce their bioavailability.

PAHs in anoxic sediments that are not exposed (i.e. are below the sediment surface) are expected to be relatively stable to degradation processes, apart from the more soluble and volatile components which may be slowly released by upward migration of pore waters due to sediment consolidation. Microbial degradation is expected to be minor in anoxic sediments.

Petroleum Hydrocarbons in Sediments

TRHs in exposed sediments (i.e. at the sediment surface) can be removed by photolysis and volatilisation, particularly the low molecular weight aromatics and aliphatics. Microbial degradation will also be significant. TRHs in anoxic sediments that are not exposed (i.e. are below the sediment surface) are also subject to microbial degradation although it is likely to be a much slower process. The more soluble and volatile components may be slowly released by upward migration of pore waters due to sediment consolidation.

3.5.3 Sediment Transport, Erosion and Deposition in Kendall Bay

Sediment Transport

Kendall Bay is regularly subjected to boat wake waves made by Rivercat and Harbourcat movements and is also exposed to wind directions from the north-west to the east. Currents generated by this wave action are considered capable of mobilising the bed sediments (Royal HaskoningDHV, 2016). This is evidenced by the surface distribution of sediments in the bay – wave action at the shoreline margins has caused finer sediments to be winnowed out, carried offshore and deposited in the deeper, lower energy, environment, and leaving behind coarser sediments. Wave action, particularly from Rivercats and Harbourcats which is of longer period, is also capable of transporting sand-sized material alongshore in the shallow littoral zone.

Currents from tides and freshwater flooding are very low in magnitude and are not considered to have any significant influence on sediment transport within Kendall Bay (Royal HaskoningDHV, 2016).

The beach and stormwater delta at the head of the bay have formed since the south-western end of the bay was enclosed after the late 1930s (**Figure 3.9**). These sediments are likely to be a combination of coarser sandy marine sediments transported to the head of the bay by wind and boat wake wave action, and finer sediments from catchment sources delivered into the Bay by stormwater discharges.

The south-western corner of the bay contains coarse sediment including an area of cobbles in the intertidal zone. This area does not appear to support sediment deposition, probably due to the high wave energy and incident wave direction. The western shoreline is exposed to frequent ferry wake waves, which roll at an angle along the exposed face of the seawall and propagate into the south-western corner of the bay (Royal HaskoningDHV, 2016).

Figure 3.9: Aerial photographs of Kendall Bay in 1943 (left) and 2015 (right)

Source: Royal HaskoningDHV, 2016

Sedimentation and Erosion

Comparison of historical hydrographic surveys indicates that the maximum average rate of sedimentation between 1956 and 2014 within the central subtidal areas of the Bay was in the order of 10 mm to 14 mm per year. A plot of the depth differences between these surveys (Royal HaskoningDHV, 2016) (**Figure 3.10**), indicates that deposition over this period had generally occurred in the central portion of the Bay, whilst bed levels had become shallower along the eastern side of the Bay.

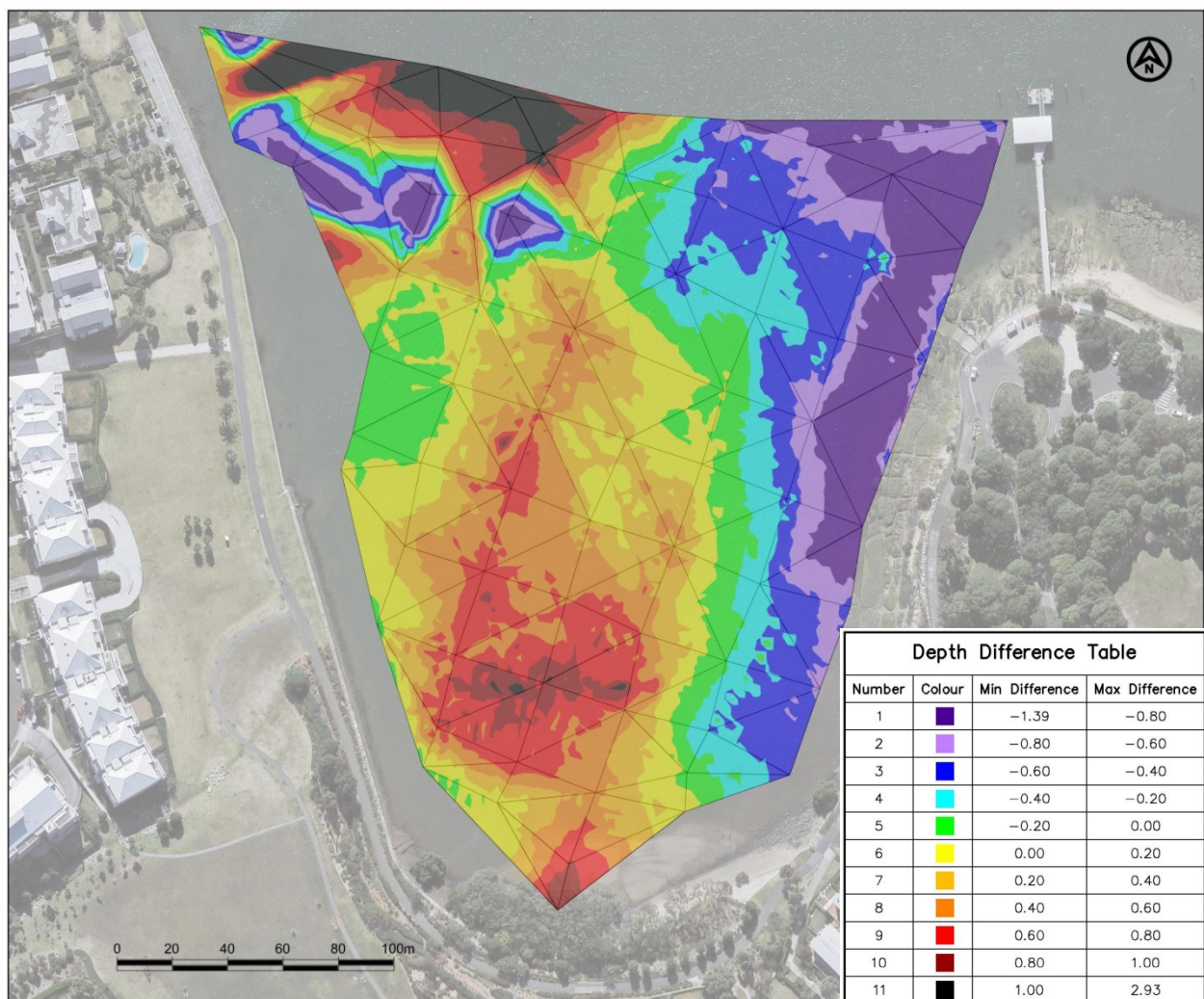
This map provides a broad indication of sedimentation patterns, however the estimated sedimentation rates determined from hydrographic survey comparison are indicative only. Factors such as the accuracy of historic survey techniques, dredging, wharf and jetty demolition, construction of seawalls and stormwater outlets, and introduction of Rivercats and Harbourcats on the Parramatta River are likely to confound sedimentation estimates and result in variable sedimentation rates over time. The available hydrographic survey data does not have sufficient time resolution to capture this variability. Furthermore, the '1956' survey data provided by Roads and Maritime Services was reported to comprise a compilation of several surveys completed pre-1995 (details of these surveys were not available).

The *Parramatta River Estuary Data Compilation and Review Study* (Cardno Lawson Treloar, 2008) reported that there was a paucity of information relating to sedimentation rates in the Parramatta River Estuary. Available data includes:

- Irvine, 1980. This study reported that the average distribution of the Holocene (i.e. since the end of the last Ice Age) estuarine deposit in Sydney Harbour was 7 m, and this had accumulated over the 9000 years since most of the harbour flooded as sea level rose. This gave an average sedimentation rate of 0.8 mm per year, though before dewatering and compaction the annual rate would be considerably higher, and the author noted that sedimentation rates would have been higher in upper river channels.

The thickness of Holocene sediments in Kendall Bay (i.e. those sediments occurring above the distinctive firm, red- and yellow-mottled sandy clay that marks the erosion surface when sea level was low in the last Ice Age), based on the push-coring done, typically ranged from 2.5 to 11.5 m in the Southern Investigation Area and averaged around 7 m, excluding foreshore areas where bedrock outcropped. Parts of the Northern Investigation Area were dredged for the coal wharf and possibly the coke wharf as well, so true depths of Holocene sediments cannot readily be determined.

Figure 3.10: Depth difference between ‘1956’ and 2014 hydrographic surveys. Positive depth difference and warmer colours indicates sedimentation, cooler colours indicate erosion.



Source: Royal HaskoningDHV 2016.

Taking an average of 7 m of sediment deposition in the bay since it filled, which would have been around 8000 years ago when sea level reached within a few metres of its current level (Couriel et al., 2014), implies a deposition rate of 0.9 mm/year, although recently deposited sediments have a very high water content and before dewatering and compaction the annual rate would be considerably higher, up to 5 mm/year.

- Irvine and Birch, 1998. This study inferred rates of sedimentation from analysis of sediment cores by identifying the depth of low heavy metal concentrations and assuming that this represented the thickness of sediment deposited from the start of anthropogenic impact 150-200 years ago. This approach determined that sedimentation rates within Sydney Harbour were between 1.5 and 3.5 mm/year. These rates would be higher than the long-term rates reported above, because dewatering and compaction would be much less.
- Other studies of sedimentation rates in Sydney Harbour have determined typical rates in the bays of 5 to 15 mm/year, and up to 25 mm/year near the mouth of stormwater canals entering bays (Dr Stuart Taylor 2016, pers. comm., 24 November 2016).

Having regard to the above, it is considered that the rates of sedimentation within subtidal areas of Kendall Bay, away from the immediate vicinity of stormwater outlets, are likely to be variable and lie in the range of 5 – 15 mm/year.

3.6 Exposure and Toxicity Assessment and Risk Characterisation

The data for these assessments was obtained from:

- Pre-existing studies, largely summarised in the SKM HHERA (SKM, 2014) for contaminant inputs to the bay, contamination in the sediments and waters of the bay, and background data for the adjacent Parramatta River. Additional water quality monitoring data was obtained from Royal HaskoningDHV, 2016.
- Investigations undertaken by S&W for the Kendall Bay Remediation Project:
 - o contamination investigations of surface and subsurface sediments carried out in 10 field sampling events between April 2015 and April 2016 (S&W, 2017a);
 - o water quality monitoring carried out in January and April 2016 and October 2017 (S&W, 2017b; 2018b);
 - o oyster and mussel tissue sampling and analysis carried out in April 2016 (S&W, 2017c); and
 - o surface sediment sampling carried out in October 2017 (S&W, 2018a).
- Investigations undertaken by other consultants to S&W for the project:
 - o toxicity and bioavailability testing by CSIRO Aquatic Contaminants Group, using samples collected by S&W in May and July 2015, February 2016 and October 2017 (Simpson et. al., 2016; 2018);
 - o benthic ecology surveys (Alison Hunt and Associates, 2016; 2018);
 - o marine environment report (Royal HaskoningDHV, 2016); and
 - o human health risk assessment for PAHs in sediments (EnRisks, 2017; 2018).

The sampling rationales, field and laboratory methods, results, quality assurance and quality control, and data validation of these studies are fully documented in the above reports. Relevant data is presented in **Sections 4 – 7** of this ERA.

The exposure assessments are presented in **Section 7** of this ERA.

Toxicity assessments are presented in **Section 8** of this ERA.

The risk characterisation is presented in **Section 9** of this ERA.

3.7 Selection of Assessment Endpoints

The assessment endpoints for the ecological risk assessment, i.e. the actual environmental values that are to be protected, are as follows.

- protection of benthic organisms from adverse effects on survival, abundance, growth and/or reproduction;
- protection of aquatic organisms from adverse effects on survival, abundance, growth and/or reproduction; and
- maintenance of seafood tissue levels below Australian standards.

3.8 Subdivisions of the Study Area

The study area was divided into five sub-areas, based on their different environmental and sediment characteristics, and proximity to contamination sources (**Table 3.4**).

Table 3.4 Subdivisions of the Study Area

Sub-Area	Name	Rationale
1	Southern Investigation Area	Known to contain levels of gasworks contaminants (particularly TRHs and PAHs) greatly exceeding sediment quality guideline values for ecological protection.
2	Northern Investigation Area	Known to contain levels of gasworks contaminants (particularly TRHs and PAHs) greatly exceeding sediment quality guideline values for ecological protection.
3.	Rest of Kendall Bay and adjacent Parramatta River	Known to generally have background levels of gasworks contaminants, but elevated levels of metals, metalloids and some other contaminants, typical of levels in the Parramatta River.
4.	Southern Reference Areas – background locations.	Has background levels of gasworks contaminants (TRHs and PAHs), but elevated levels of metals, metalloids and some other contaminants, typical of levels in the Parramatta River.
5.	Northern Reference Areas – background locations.	Has background levels of gasworks contaminants (TRH and PAH), but elevated levels of metals, metalloids and some other contaminants, typical of levels in the Parramatta River.

4 SEDIMENT CONTAMINATION

Full details of the sampling design, sampling and analytical methods, quality assurance and quality control, and data validation are provided in the Sediment Data Report (S&W 2017a).

4.1 Sampling Locations and Methods

The initial work program was carried out in three phases (mangroves, bay surface sediments and bay deeper sediments), comprising 10 sampling episodes, between April 2015 and April 2016. The Investigation Areas for the study (**Section 3.2.3**) were progressively refined on the basis of data collected in the 10 sampling episodes, as shown on **Figures 3.3 to 3.7** above.

The additional (Post-RAP) sampling program was carried out in October 2017.

4.1.1 Phase 1: Mangrove Area Sampling

Cores were collected by hand coring during low (spring) tides in April and May, 2015 using a toothed core tube, which was needed to cut through a thick mat of mangrove roots, and a Dormer corer for sloppy sediments near the stormwater outfall. Sample locations are shown on **Figure 4.1**. Where possible, cores were pushed or driven to a depth of 1.6 m or more. In the beach area and near the sea wall at the southern side of the mangroves, bedrock was shallower than this depth.

Background sediment sampling locations are shown on **Figures 4.3, 4.4 and 4.5**, below.

Immediately after core splitting, sampling was undertaken for volatile organic compounds in accordance with Australian Standard AS 4482.2–1999. Subsampling for chemical analysis of semi-volatile and non-volatile COPCs was also carried out. The details of sampling, subsampling, sample handling, preservation and decontamination, and QA/QC are described in S&W, 2016.

4.1.2 Phase 2: Sampling for HHRA, ERA and Development of Remediation Criteria

Toxicity and Bioavailability Testing

Bulk sampling for toxicity and chemical testing was carried out in three stages, in May 2015, July 2015 and February 2016. A total of 31 samples, each comprising 3–4 kg of sediment, were collected for toxicity testing at CSIRO, Lucas Heights. Samples from the May and July samplings were also subjected to bioavailability testing. Sample locations are shown on **Figures 4.2 to 4.4**.

Other aspects of sampling, subsampling, sample handling, preservation and decontamination are described in S&W, 2017a and Simpson et al., 2016.

Figure 4.1. Sediment Sampling Locations, Southern Investigation Area.



Figure 4.2. Locations of Ecotoxicology Samples, Kendall Bay.

031099_180308_v06

Figure 4.3. Locations of Ecotoxicology Samples, Southern Reference Area



Figure 4.4. Locations of Ecotoxicology Samples, Northern Reference Area.



Marine Macrobenthic Sampling

Forty-five locations were sampled in Kendall Bay in two stages, on January 20-21, 2016, and April 7, 2016. Approximately 5 kg of sediment was collected at each location using multiple casts of a Petite Ponar grab sampler which sampled the top 100 mm where the majority of the benthic fauna resides (USEPA 2015; Dr A Hunt, pers. comm. 2016). Separate samples (jars and volatiles vials) were collected for chemical analysis, plus bags for grainsize analysis.

Other aspects of sampling, subsampling, sample handling, preservation and decontamination are described in S&W, 2016 and Alison Hunt and Associates, 2016.

Sample locations are shown on **Figure 4.5**, below.

Figure 4.5. Marine Benthic Sampling Sites, Kendall Bay and Background Areas



4.1.3 Phase 3: Offshore Deep Sediment Sampling

Sampling to determine the depth and extent of gasworks contamination in Kendall Bay was carried out in six stages, in July 2015, September and October 2015 and February, March and April 2016. The sampling design took account of data obtained in a number of sediment coring investigations prior to 2015. All sampling except the April 2016 sampling was carried out using a GeoProbe push tube rig mounted on a barge.

In the Southern Investigation Area forty-nine locations (**Figure 4.1**) were sampled with the barge-mounted push core rig, in most cases pushing the cores to refusal on firm or stiff sediments. In parts of the Southern and Northern Investigation Areas, the soft black oily clays in the upper part of the sequence proved difficult to sample, as noted by E3 Consult in a previous investigation (E3 Consult, 2011). Accordingly, particular care was taken in sampling these materials, and in some locations the push cores were supplemented with hand cores to obtain better samples of the near-surface sediments. At three locations in the south-eastern corner of the bay only hand cores were taken as the depth was too shallow for the drilling barge.

In the Northern Investigation Area twenty-eight locations (**Figure 4.6**) were sampled with a barge-mounted push core rig, in many cases pushing the cores to refusal. In some locations, the push cores were supplemented with hand cores to obtain better samples of the near-surface sediments.

In all stages, the cores were subsampled over 300 mm intervals except in a few cases where the core was shorter than 300 mm. In the 2015 stages, cores were typically sampled at 1-1.5 m intervals from the near surface to refusal, although the sample intervals varied depending on the stratigraphy. Where stratigraphy was relatively uniform at depth the sample interval could be as much as 2 m. Samples showing significant visual indications of contamination, such as black, oily, odorous clays, oily seepage, presence of tar or DNAPL, and/or strong odour of tars, hydrocarbons or phenolics, were sampled more frequently.

In the 2016 investigations, all cores were subsampled at 0-300 mm, 300-600 mm and then 600-900 mm where depth permitted, then at 1-2 m intervals as described above. Due to dewatering, plastic flow of soft clays, and loss of some of the soft oily upper sediments, sediment depths measured in core tubes will differ from *in-situ* depths and must be interpreted with caution.

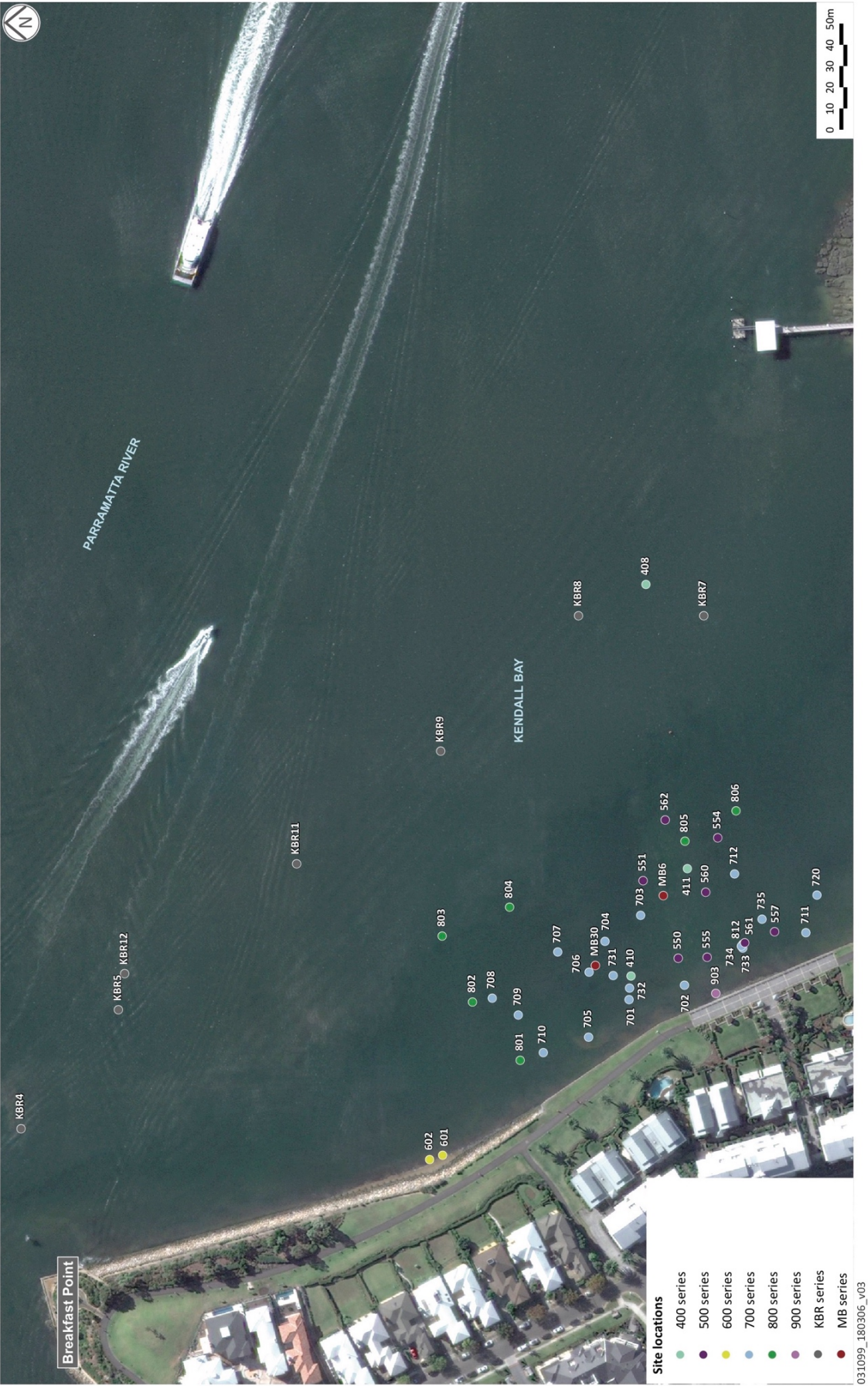
Other aspects of sampling, subsampling, sample handling, preservation and decontamination, and QA/QC are described in S&W, 2016.

Post-RAP sampling

Surface grab sampling for toxicity, bioavailability and chemical testing, was carried out in October 2017. The aim was to sample locations with background levels of gasworks contaminants and metals so as to provide additional data on chronic toxicity of the sediments. Sample locations were selected based on previously available data on the biology and toxicity status of the sediments. The same sampling, subsampling, handling and preservation procedures were used as for the previous samplings in 2015 and 2016. Sample locations are shown on **Figure 4.5**.

Twenty-three locations were sampled in October 2017 for marine macrobenthos. Sample locations were selected based on previously available data on the biology and contamination status of the sediments. Four samples were from test sites within the Northern and Southern Remediation Areas of Kendall Bay as proposed in the 2017 RAP. The remaining 19 samples, all background sites, were sampled from parts of Kendall Bay outside of the proposed remediation areas, as well as from the Northern and Southern Reference Areas. The specific procedures are described in Alison Hunt and Associates, 2018. Sample locations are shown on **Figure 4.5**.

Figure 4.6. Marine Sediment Sampling Locations, Northern Investigation Area.



4.2 Results

4.2.1 Field Observations

Observations made in the field are set out on the sediment core logs in S&W (2017a).

Southern Investigation Area

Intertidal area

Beach

Cores from the beach in the south-eastern corner of the bay were generally clean sands or silty sands containing little visible contamination apart from fine and coarse coal particles. The sediments sometimes had a slight hydrocarbon odour. The depth to refusal was generally less than 1 m and became less to the south, as would be expected given that bedrock outcrops nearby.

After a major rainfall event in early June 2016, a matted layer of wood fibres was present on the sediment surface through parts of the mangroves, beach and delta, apparently deposited by wave action.

Stormwater Drain Delta

The sediments of the eastern side of the delta were generally sands and silty sands to a depth of more than 1 m. They often had a slight hydrocarbon odour and were shelly and contained coal and coke particles.

In the central and western parts of the delta, the sediments were typically sands to a depth of 0.1-0.3 m, below which was fine silty or clayey sediment, dark grey or black, with an oily appearance and a strong tar odour, to a depth of greater than 1 m.

Mangroves

The sediments of the eastern section of the mangrove stand were typically sand with shell, coal and some coke, networked with dense mangrove roots, to a depth of 0.2-0.3 m. Below this, sediments sometimes had black, sticky or tarry layers with a tar odour.

In the central and western section of the mangrove stand, the sediments were typically firm at the surface, comprising sand, shell, coal and sometimes coke, and a dense network of mangrove rootlets. Below a depth of 0.1-0.25 m the sediment typically was a dark silty sand with a tarry odour. Below that, the sediment was typically a dark grey-black oily clay with a strong tar odour.

The sediments close to the sea wall immediately south of the mangroves generally showed little evidence of black or tarry contamination, but sometimes had a slight hydrocarbon odour.

South-western corner of bay, immediately north of the mangroves.

The sediments here were typically coarse at the surface, being silty sands or gravelly silty sands with shells, coal and coke and rock fragments, and often had a strong oily sheen and a hydrocarbon odour, to a depth of 0.2-0.3 m. Below this depth, the soft dark grey to black oily clay that has been observed elsewhere was typically found. It had a strong tar odour and visible Dense Non-Aqueous Phase Liquids (**DNAPLs**) and/or oily patches in places, and extended to a depth of 1 m or more.

Subtidal sediments

Surface sediments

Subtidal surface sediments in the south-western corner of the bay were often silty coarse sands or gravelly silty sands with grit-sized particles, shells, coal and coke and rock fragments, and sometimes clayey lumps. These sediments were often black with a strong oily sheen and a tar or hydrocarbon odour. In this area, black oily sediment often occurred at the surface though sometimes it was covered with a few centimetres of brown or grey sandy or gravelly mud. **Figure 4.7** shows the sample locations and locations where oily gasworks contamination was present at or near the sediment surface.

Figure 4.7. Gasworks Contamination Occurring at or Near Sediment Surface, Southern Investigation Area.



Surface sediments elsewhere in the defined Southern Investigation Area, away from the shoreline, were typically soft dark grey muds or slightly sandy muds with shell and sometimes coal fragments. The top few millimetres of sediment was often a pale brown floc although this was easily disturbed and not always observed in the samples.

Deeper sediments

Refusal depths were greatest in the south-western corner of the bay, being around or greater than 11 m. Refusal depths decreased rapidly to the south and more slowly to the north and east, and indicated that the former bedrock channel of the bay, before enclosure in the south-west by the sea wall in the 1930s, ran east-north-east through location 503, then locations 506, 507 and 510, then curved north through location 528.

The push cores showed an almost ubiquitous presence of the soft black oily and tarry clay that was found below the surface in the western mangroves, and offshore. This layer occurred at the surface or within a few centimetres of the surface in many of the cores from the south-western side of the bay. In the cores from the south-central and south-easterly parts of the bay, the black clay was generally covered by a recent mud deposit, typically 0.05-0.2 m thick.

Below the black clay, which had a thickness of 1.5-2 m or more in parts of the south-western section, the sediment was a dark clay or shelly clay, often with an oily sheen and dark veins or blobs of DNAPL and a moderate to strong tarry odour. This material could also be 1-2 m or more thick. The total thickness of the material considered to be contaminated, on the basis of visual observation and odour, was typically 4-6 m in the south-western part of the bay, but thinned to 1-2 m or less to the south, east and north. In several cores in the south-western corner of the bay (e.g. Cores 501 and 525), observable contamination was present throughout the cores, to a depth of approximately 8 m. The thickest contamination extended in a tongue east across the bay from Core 501, Core 525 and Core 25, and then north-east through Cores 508 and 509.

In the south-eastern corner of the bay the dark layer tended to be dark grey rather than black, and was thinner, often less than 1 m, with a less pronounced tar or hydrocarbon odour. Sediments in this area often contained copious wood fibres, similar in appearance to mats of wood fibres that were found on the beach and mangrove sediments after a major storm event. In the two easternmost cores, Cores 902 and 811, no significant visual contamination was observed.

The lowest sediment layer found, in which refusal typically occurred, was a mottled red/orange/yellow/grey sandy clay or clayey sand, sometimes semi-firm at the top but becoming firm then stiff with depth. This layer was mostly free of visual contamination although tar staining and tar or phenolic odours were noted in a few cores, for instance cores 501 and 533A.

Northern Investigation Area

Intertidal area

A narrow sandy beach has formed on stepped blocks of stone to the north of the Northern Investigation Area. The sediment was only 0.1-0.2 m deep and consisted of coarse brown sand with some sand-sized coal particles (Samples 601 and 602). There was no visual or olfactory evidence of contamination.

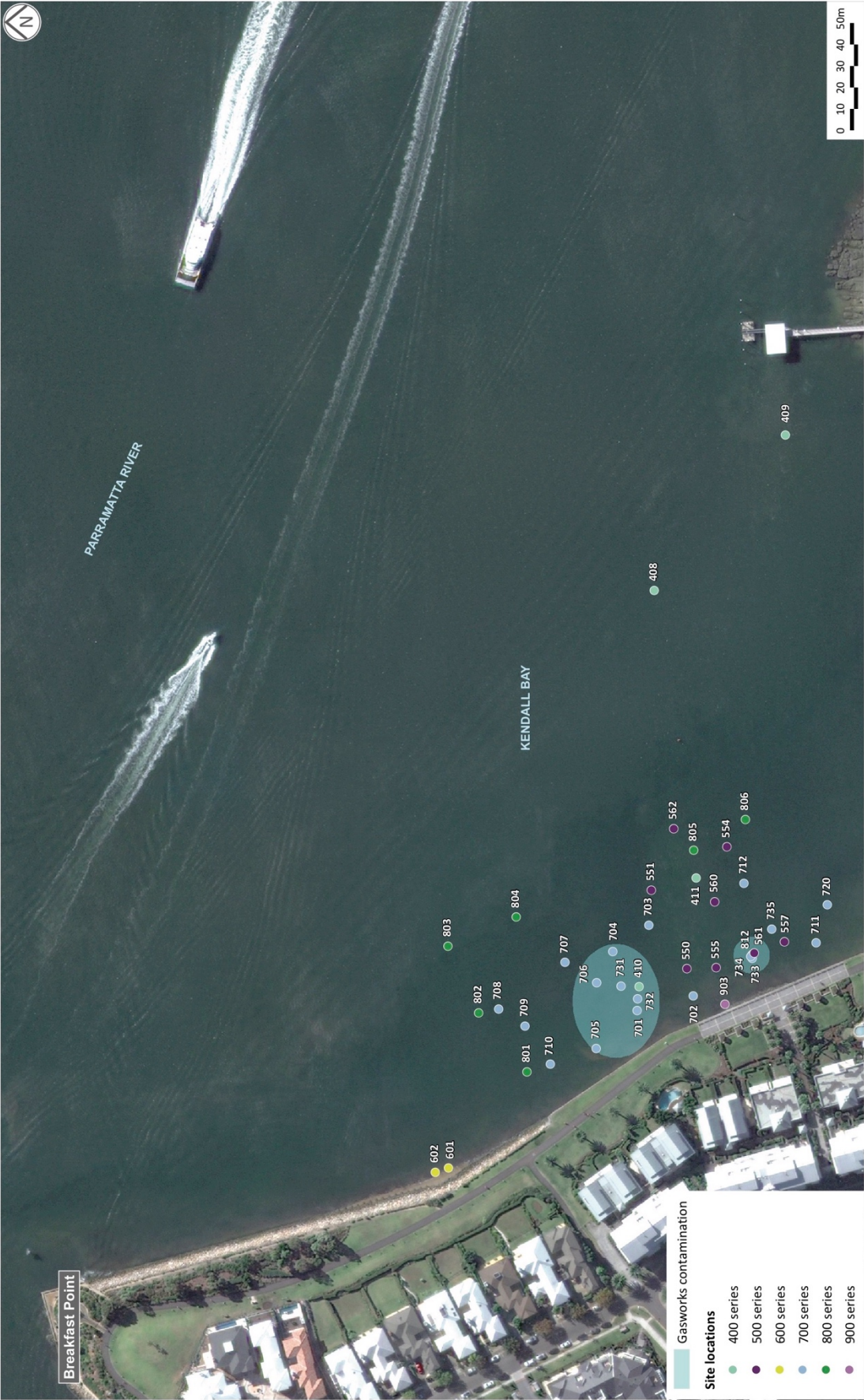
Sandy sediments were also found in intertidal sections of the Northern Investigation Area, although most of this area contained rock and rubble and could not be cored. Core 903 from this area sampled more than 0.7 m of silty sand with shell and gravel. This sand was visually clean to a depth of 0.46 m, below which it was black and gravelly and had a tar odour.

Subtidal sediments

Surface sediments

Some sediments in the inshore parts of the Northern Investigation Area contained a black, oily mud at the surface, and black oily mud was stirred up when small boats passed through the shallow water in this area (for instance around locations 561, 733 and 734). This mud was often gritty with fine gravel of coke and coal, and had a strong, unpleasant tar odour. At other places in this part of the Northern Investigation Area the black oily mud was overlain by up to 0.22 m of grey mud. **Figure 4.8** shows the sample locations and locations where oily gasworks contamination was present at or near the sediment surface.

Figure 4.8. Gasworks Contamination Occurring at or Near Sediment Surface, Northern Investigation Area.



Surface sediments throughout the remainder of the Northern Investigation Area were typically soft dark grey muds or slightly sandy muds with shell and some coal and coke fragments. The top few mm of sediment was often a pale brown floc although this was easily disturbed and not always observed in the grab or core samples.

Sediments near the shoreline were muddy sands or sandy muds, often containing shell and gravel of coal, coke and rock fragments.

Surface sediments on the mound formed below the former coal wharf frequently contained a relatively firm layer of shell, coal and coke in the top 0.15-0.2 m, presumably fallen from the wharf and from ship loading and unloading. This layer was often difficult to penetrate with the corer and appeared to form a cap over the contaminated sediments below.

Deeper sediments

Five locations were sampled along the mound that had formed under the former coal wharf (see **Figure 1.5** above). Most of the remaining cores were taken to the north of the mound, in deeper water where a shipping channel had been dredged, and further north. Several locations were cored to the south of the mound.

Refusal depths were typically in the range 2-6 m, being shallower near the western shore and to the north, typically 2-3.5 m, and deeper in the most easterly locations, typically 5-6 m. One location, 554, had a refusal depth of 8.3 m.

The push cores all showed the presence of a thick black, oily and tarry clay, often containing coal or coke pieces, that had a strong, unpleasant odour. In some places this layer began at the surface, while in other locations it was covered with a layer of mud or gravelly mud, 0.1-0.2 m or more in thickness. To the north of the Northern Investigation Area the black oily layer was still present but was covered by an increasing thickness of recently accumulated mud, typically 0.2-0.3 m in depth.

Due to poor recovery in many cores, the depths and thicknesses of the visually contaminated sediments in the Northern Investigation Area were sometimes indeterminate, however the thickness ranged from <1 m to 4.7 m, increasing from low values along the western shoreline where the sediment cover was thinnest.

The lowest layer, in which refusal typically occurred, was a mottled red/orange/yellow/grey sandy clay or clayey sand, or sometimes clay, semi-firm at the top but becoming firm then stiff with depth. This layer was mostly free of visual contamination although tar staining at the top was noted in a few cores.

Elsewhere in Kendall Bay and Nearby Parramatta River

Surface sediments throughout the northern and eastern parts of Kendall Bay, and in the adjacent Parramatta River, were typically soft olive grey to dark grey muds or slightly sandy muds with shell and sometimes coal fragments and soft clay lumps. Some samples had a faint hydrocarbon odour. The top few millimetres of sediment was often a pale brown floc although this was easily disturbed and not always observed in the samples. Sample KBR12, collected in October 2017 at the northern end of the bay, was distinctly different to the other Kendall Bay samples, being very shelly, and required many grab samples to collect sufficient material for the analyses.

Exile Bay

Most of the surface sediments sampled in Exile Bay were silty sands with a significantly higher proportion of sand (typically 80%) than the samples in Kendall Bay or Major's Bay. Unlike the other bays, these surface samples generally contained live seagrass (*Halophila ovalis*). Sample KBR17, however, sampled in October 2017 near the head of the bay, was a soft grey mud similar to the muds found in other shallow bays.

Canada Bay

The sediments sampled in Canada Bay were dark olive grey muds, soft and with a trace of sand and shell.

Majors Bay

The surface sediments sampled in Major's Bay were soft olive grey to dark grey muds, sometimes containing traces of broken shell and plant fibres. The top few millimetres of sediment was often a pale brown floc, easily disturbed.

Yaralla Bay

The surface sediments sampled were soft olive grey sandy muds containing traces of shell, and some plant fibres.

Bray's Bay

The surface sediments sampled in Brays Bay were soft dark olive grey muds with a trace of sand and shell.

4.2.2 Analytical Results

Initial Investigations (2015-2016)

The analytical data for the bulk sediments is reported in full in the Kendall Bay Sediment Remediation Project Sediment Data Report (S&W, 2018 a) and summarised in **Table 4.1** (Southern Investigation Area), **Table 4.2** (Northern Investigation Area) and **Table 4.3** (background samples collected elsewhere in Kendall Bay, in Exile Bay and in Majors Bay).

The analytical data for the volatiles samples taken from the sediments is summarised in **Table 4.4** (Southern Investigation Area), **Table 4.5** (Northern Investigation Area) and **Table 4.6** (the background samples collected elsewhere in Kendall Bay, in Exile Bay and in Majors Bay). The full data set is provided in the appendices to that report.

For the Southern and Northern Investigation Areas, the data are summarised for the depth intervals 0-300 mm below the sediment surface, 300-600 mm and for all depths below 600 mm. Samples which did not precisely match these intervals have been included in the depth range that they largely covered, for instance a sample from 100-400 mm would be included in the 0-300 mm range, whereas a sample from 200-500 mm would be included in the 300-600 mm range.

Grab samples, which covered the depth range 0-100 mm, were included in the 0-300 mm depth range although it should be noted that grab samples contain more sediment from the surface than from the bottom of the grab cut.

For the Kendall Bay, Exile Bay and Major's Bay background areas, the data are summarised for the 0-300 mm interval although most of the samples are grab samples sampling the top 0-100 mm, approximately.

4.2.2.1 Surface sediments (0-600 mm)

Southern Investigation Area

The analytical data for the sediments are summarised in **Table 4.1** and the volatiles vial data in **Table 4.4**.

Total PAHs

Total PAHs in the 0-300 mm samples ranged from 0.74 mg/kg to 3600 mg/kg (mean 411 mg/kg), and in the 300-600 mm samples from 0.12 mg/kg to 3300 mg/kg (mean 456 mg/kg). These values were comparable to or in some cases higher than those previously reported for the shallow sediments in this area in the 2014 HHERA.

Normalised PAH (normalised to 1% TOC) in the 0-300 mm samples ranged from 1.3 mg/kg to 2650 mg/kg (mean 80 mg/kg), and in the 300-600 mm samples from 0.2 mg/kg to 673 mg/kg (mean 68 mg/kg). The mean Total PAH values exceeded the GV by 7-8 times, and the maximum Total PAH values exceeded the GV by 265 times and 67 times, respectively.

The Total PAH values were comparable to or in some cases higher than those previously reported for the shallow sediments in this area in the 2014 HHERA. The highest values were significantly higher than the highest values previously reported. This could reflect the broader depth intervals of sampling and the higher density of sampling.

TRHs

TRH (C10-C40) in the 0-300 mm samples ranged from <250 mg/kg to 57,900 mg/kg (mean 6,402 mg/kg). In the 300-600 mm samples TRH (C10-C40) ranged from <250 mg/kg to 29,300 mg/kg (5,069 mg/kg). In each case the bulk of the TRH was in the >C16-C34 fraction. These values were comparable to or higher than those previously reported for the shallow sediments in this area in the 2014 HHERA.

The mean TRH (C10-C40) values exceeded the GV by approximately 23 times and 18 times, respectively, and the maximum TRH (C10-C40) values exceeded the GV by approximately 207 times and 105 times, respectively.

Metals

The key metals identified in the sediments were chromium, copper, lead, mercury, nickel and zinc. The levels found were generally comparable to or higher than those previously reported in the 2014 HHERA.

In the 0-300 mm samples, chromium ranged from 3-530 mg/kg (mean 145), and in the 300-600 mm samples from 3-570 mg/kg (mean 119 mg/kg). In each depth layer the mean value significantly exceeded the chromium GV of 80.

In the 0-300 mm samples, copper ranged from 2-143 mg/kg (mean 49), and in the 300-600 mm samples from 3-140 mg/kg (mean 49 mg/kg). In each depth layer the mean value was below the copper GV of 65.

In the 0-300 mm samples, lead ranged from 6.1-660 mg/kg (mean 110), and in the 300-600 mm samples from 6.6-1,590 mg/kg (mean 157 mg/kg). In each depth layer the mean value significantly exceeded the lead GV of 50.

In the 0-300 mm samples, mercury ranged from 0.01-8.5 mg/kg (mean 0.6), and in the 300-600 mm samples from 0.01-6.5 mg/kg (mean 0.8 mg/kg). In each depth layer the mean value significantly exceeded the mercury GV of 0.15.

In the 0-300 mm samples, nickel ranged from 1-230 mg/kg (mean 50), and in the 300-600 mm samples from 2-320 mg/kg (mean 38 mg/kg). In each depth layer the mean value significantly exceeded the nickel GV of 21.

In the 0-300 mm samples, zinc ranged from 10-820 mg/kg (mean 309), and in the 300-600 mm samples from 11-710 mg/kg (mean 101 mg/kg). In the 0-300 mm depth layer the mean value significantly exceeded the zinc GV of 200. However, in the 300-600 mm depth layer the zinc mean value was well below the GV.

TOC

The TOC values in the 0-300 mm samples ranged from 0.12 % to 57 % (mean 16 %), and in the 300-600 mm samples from 0.2 % to 61 % (mean 8.5%). As noted above, the sediments frequently contained high levels of coal, coke and tarry oils, referred to as 'Black Carbon', and these would represent the bulk of the TOC. These values were very much higher than typical for fine Parramatta River sediments but were comparable to or above the values previously found in the gasworks-contaminated sediments in Kendall Bay (HHERA, 2014). There is no Australian sediment GV for TOC.

BTEX and Naphthalene

Naphthalene was analysed in both the jar samples (with other PAHs) and in the methanol-containing volatiles vials.

In the 0-300 mm jar samples the naphthalene values ranged from <0.01 mg/kg to 860 mg/kg (mean 18 mg/kg). In the 300-600 mm samples, naphthalene ranged from <0.01 mg/kg to 500 mg/kg (mean 27 mg/kg).

In the 0-300 mm volatiles vial samples the naphthalene values ranged from <1 mg/kg to 220 mg/kg (mean 5.4 mg/kg). The levels of BTEX and other volatiles were generally below the LORs.

In the 300-600 mm volatiles vial samples, naphthalene ranged from <1 mg/kg to 400 mg/kg (mean 34 mg/kg). The levels of BTEX and other volatiles were often below the LORs, though the maximum values were significantly higher than in the 0-300 mm samples.

The jar naphthalene values were expected to be lower than the vial values due to volatilisation losses, although in a few cases the jar values were higher, and in the 0-300 mm depth range the average was higher. These data were reviewed carefully and it was concluded that, where higher values were found in the jars, they were attributable to presence of veins or blobs of tar oils in the jar samples (taken from 300 mm core lengths) that were not intersected in the much smaller (approximately 10 mm) vial samples. Because the veins and blobs were irregularly distributed and often separated by many centimetres, the 300 mm jar samples had a significantly greater chance of intersecting a vein or blob of tar oil, likely to contain a high naphthalene level, than did the small vial samples.

There is no Australian sediment GV for BTEX or naphthalene.

Other Analytes

The only other analyte frequently detected was total cyanide, which ranged from <0.5 mg/kg to 780 mg/kg in the 0-300 mm samples (mean 87mg/kg) and from <0.5 mg/kg to 1,191 mg/kg (mean 127 mg/kg) in the 300-600 mm samples. There is no Australian sediment GV for total cyanide.

Northern Investigation Area

The analytical data for the sediments is summarised in **Table 4.2** and the volatiles vial data in **Table 4.5**. **PAHs** Total PAHs in the 0-300 mm samples ranged from 2 mg/kg to 13 000 mg/kg (mean 720 mg/kg), and in the 300-600 mm samples from 6.1 mg/kg to 9,900 mg/kg (mean 909 mg/kg). These values were comparable to or in some cases significantly higher than those previously reported for the shallow sediments in this area in the 2014 HHERA.

Normalised PAH (1% TOC) in the 0-300 mm samples ranged from 0.3 mg/kg to 1,300 mg/kg (mean 82 mg/kg), and in the 300-600 mm samples from 2.8 mg/kg to 1,042 mg/kg (mean 153 mg/kg). The mean Total PAH values exceeded the GV by 8-15 times, respectively, and the maximum Total PAH values exceeded the GV by 130 times and 100 times, respectively.

The Total PAH values were comparable to or in some cases higher than those previously reported for the shallow sediments in this area in the 2014 HHERA. The highest values were significantly higher than the highest values previously reported. This could reflect the broader depth intervals of sampling and the higher density of sampling.

TRHs

TRH (C10-C40) in the 0-300 mm samples ranged from <250 mg/kg to 100,500 mg/kg (mean 9,475 mg/kg). In the 300-600 mm samples TRH (C10-C40) ranged from <250 mg/kg to 40,200 mg/kg (mean 7,201 mg/kg). In each case the bulk of the TRH was in the >C16-C34 fraction. These values were comparable to or higher than those previously reported for the shallow sediments in this area in the 2014 HHERA.

The mean TRH (C10-C40) values exceeded the GV by approximately 34 times and 26 times, respectively, and the maximum TRH (C10-C40) values exceeded the GV by approximately 359 times and 144 times, respectively.

Metals

The key metals were chromium, copper, lead, mercury, nickel and zinc. The levels found were generally comparable to or higher than those previously reported in the 2014 HHERA.

In the 0-300 mm samples, chromium ranged from 9-210 mg/kg (mean 89), and in the 300-600 mm samples from 11-170 mg/kg (mean 71 mg/kg). In the 0-300 mm layer the mean value exceeded the chromium GV of 80. In the 300-600 mm layer the mean value was below the GV.

In the 0-300 mm samples, copper ranged from 3-2800 mg/kg (mean 165), and in the 300-600 mm samples from 8.5-270 mg/kg (mean 82 mg/kg). In each depth layer the mean value significantly exceeded the copper GV of 65.

In the 0-300 mm samples, lead ranged from 8.4-860 mg/kg (mean 205), and in the 300-600 mm samples from 24-2300 mg/kg (mean 309 mg/kg). In each depth layer the mean value significantly exceeded the lead GV of 50.

In the 0-300 mm samples, mercury ranged from 0.02-3.2 mg/kg (mean 1.2), and in the 300-600 mm samples from 0.14-1.8 mg/kg (mean 0.9 mg/kg). In each depth layer the mean value significantly exceeded the mercury GV of 0.15.

In the 0-300 mm samples, nickel ranged from 4-40 mg/kg (mean 14), and in the 300-600 mm samples from 4-38 mg/kg (mean 13 mg/kg). In each depth layer the mean value was below the nickel GV of 21.

In the 0-300 mm samples, zinc ranged from 15-706 mg/kg (mean 375), and in the 300-600 mm samples from 39-670 mg/kg (mean 176 mg/kg). In the 0-300 mm depth layer the mean value significantly exceeded the zinc GV of 200. However, in the 300-600 mm depth layer the zinc mean value was below the GV.

TOC

The TOC values in the 0-300 mm samples ranged from 1.5% to 44% (mean 13%), and in the 300-600 mm samples from 0.95% to 34% (mean 9%). As noted above, the sediments frequently contain high levels of coal, coke and tarry oils and these would represent the bulk of the TOC. These values were very much higher than typical for fine Parramatta River sediments but were comparable to or above the values previously found in the gasworks-contaminated sediments in Kendall Bay (HHERA, 2014). There is no Australian sediment GV for TOC.

BTEX and Naphthalene

Naphthalene was analysed on both the jar samples (with other PAHs) and on the methanol-containing volatiles vials.

In the 0-300 mm jar samples the naphthalene values ranged from 0.07 mg/kg to 2800 mg/kg (mean 75 mg/kg). On the 300-600 mm samples, naphthalene ranged from 0.22 mg/kg to 3600 mg/kg (mean 209 mg/kg).

In the 0-300 mm volatiles vial samples the naphthalene values ranged from <1 mg/kg to 1000 mg/kg (mean 45 mg/kg). The levels of BTEX and other volatiles were lower, though the maximum values were significantly higher than in the Southern Investigation Area.

In the 300-600 mm volatiles vial samples, naphthalene ranged from <1 mg/kg to 1100 mg/kg (mean 165 mg/kg). The levels of BTEX and other volatiles were lower, though the maximum values were significantly higher than in the Southern Investigation Area and in the 0-300 mm samples from the Northern Investigation Area.

The jar naphthalene values were expected to be lower than the vial values due to volatilisation losses, although in a few cases the jar values were higher, and in both the 0-300 mm and 300-600 mm depth ranges the average was higher. These data were reviewed carefully and it was concluded that, where higher values were found in the jars, they were attributable to presence of veins or blobs of tar oils in the jar samples (taken from 300 mm core lengths) that were not intersected in the much smaller (approximately 10 mm) vial samples. Because the veins and blobs were irregularly distributed and often separated by many centimetres, the 300 mm jar samples had a significantly greater chance of intersecting a vein or blob of tar oil, likely to contain a high naphthalene level, than did the small vial samples.

There is no Australian sediment GV for BTEX or naphthalene.

Other Analytes

The only other analyte frequently detected was total cyanide, which ranged from <0.5 mg/kg to 510 mg/kg in the 0-300 mm samples (mean 17 mg/kg) and from <0.5 mg/kg to 10 mg/kg (mean 2 mg/kg) in the 300-600 mm samples. There is no Australian sediment GV for total cyanide.

Elsewhere in Kendall Bay and Nearby Parramatta River

The data for samples collected elsewhere in Kendall Bay are shown in **Table 4.3** and the volatiles vial data in **Table 4.6**.

The surface sediments of the Parramatta River and its bays, both upstream and downstream of Kendall Bay, are known to be contaminated with the common heavy metals (particularly copper, lead, zinc and chromium, and sometimes nickel, mercury and other metals) at levels above or considerably above the ANZECC/ARMCANZ 2000 sediment quality GVs, as revised by Simpson et al, 2013 (Birch et al, 2004; Birch et al, 2008).

Outside the Northern and Southern Investigation Areas, the sediments of Kendall Bay typically contained much lower levels of TRHs and PAHs (often more than an order of magnitude lower than the levels inside the Investigation Areas), as well as considerably lower TOC and Total Cyanide, the latter always being below the LOR. The TOC levels were typical of Parramatta River sediments unaffected by gasworks wastes. The levels of TRH and PAHs were comparable to those reported in the 2014 HHERA.

The levels of heavy metals were somewhat lower than the levels in the Kendall Bay Northern and Southern Investigation Areas, though often elevated above the GVs, and similar to the levels of metals known to occur elsewhere in the Parramatta River (Birch and Taylor, 2004) and those reported in the 2014 HHERA.

No Naphthalene, BTEX or other volatiles were detected in any of the volatiles vial samples.

Exile Bay

The sediments of Exile Bay typically contained much lower levels of TRHs (mean 219 mg/kg) and normalised PAHs (mean 4.2 mg/kg) than the levels inside the Investigation Areas, as well as considerably lower TOC and total cyanide, the latter always being below the LOR. The TOC levels were typical of Parramatta River sediments unaffected by gasworks wastes.

The levels of heavy metals were somewhat lower than the levels in the Investigation Areas, though often elevated above the GVs, and similar to the levels of metals known to occur elsewhere in the Parramatta River (Birch and Taylor, 2004) and those reported in the 2014 HHERA. The levels of metals in Exile Bay sediments were comparable to those in Kendall Bay outside the Investigation Areas.

No Naphthalene, BTEX or other volatiles were detected in any of the volatiles vial samples.

Majors Bay

The sediments of Majors Bay typically contained much lower levels of TRHs (mean 526 mg/kg) and normalised PAHs (mean 7.4 mg/kg) than the levels inside the Investigation Areas, as well as considerably lower TOC and Total Cyanide, the latter always being below the LOR. The TOC levels were typical of Parramatta River sediments unaffected by gasworks wastes.

The levels of heavy metals were somewhat lower than the levels in the Investigation Areas, though often elevated above the GVs, and similar to the levels of metals known to occur elsewhere in the Parramatta River (Birch and Taylor, 2004) and those reported in the 2014 HHERA. The levels of metals in Majors Bay sediments were comparable to or slightly higher than those in Kendall Bay outside the Investigation Areas. The levels of contaminants in Majors Bay sediments were consistently higher than in Exile Bay sediments, however this could be due to the Exile Bay sediments being much coarser – contaminants are generally preferentially associated with the fine fraction of a sediment.

No Naphthalene, BTEX or other volatiles were detected in any of the volatiles vial samples.

4.2.2.2 Deeper Sediments (>600 mm)

The analytical data for the deeper sediments is summarised in **Table 4.1** (Southern Investigation Area), **Table 4.2** (Northern Investigation Area), and the volatiles data in **Table 4.4** (Southern Investigation Area) and **Table 4.5** (Northern Investigation Area). The data is presented and discussed in S&W (2017a) but is not considered further in this ERA as the deeper sediments lie well below the depth to which aquatic organisms could be exposed.

Table 4.1. Sediment Chemical Data Summary, Southern Investigation Area Kendall Bay (mg/kg except where noted otherwise)

Southern Investigation Area Sites – 0 to 300 mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
Samples	94	94	94	94	94	92	88	90	94	94	94	94	94	94	94	94	72
Mean	658	4949	795	6402	18	411	16	80	17	0.4	145	49	110	0.6	50	309	87
Min	<50	<100	<100	<250	<0.01	0.12	0.06	1.3	2	<0.1	3	2	6.1	0.01	1	10	<0.5
Max	8000	46000	6800	57900	860	3600	57	2650	54	1.2	530	143	660	8.5	230	820	780
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–
300 to 600 mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
Samples	60	60	60	60	60	56	59	59	60	60	60	60	60	60	60	60	58
Mean	769	3752	548	5069	27	456	8.5	68	25	0.4	119	49	157	0.8	38	256	127
Min	<50	<100	<100	<250	<0.01	0.74	0.2	0.2	3	<0.1	3	3	6.7	0.01	2	11	<0.5
Max	5100	22000	3100	29300	500	3300	61	673	64	2.1	570	140	1590	6.5	320	710	1191
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–
600 + mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	235	235	235	235	235	229	232	213	235	235	235	235	235	235	235	235	212
Mean	406	1264	188	1857	68	260	2.8	192	18	0.3	38	20	52	0.3	12	101	13
Min	<50	<100	<100	<250	<0.01	<0.1	0.02	0.1	0.25	<0.1	3	0.7	2	<0.01	0.8	1	<0.5
Max	4800	15000	2500	19200	1100	3100	49	4407	62	1.4	450	130	290	1.9	200	1400	430
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–

Table 4.2. Sediment Chemical Data Summary, Northern Investigation Area Kendall Bay (mg/kg except where noted otherwise)

Northern Investigation Area Sites – 0 to 300 mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC%	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	52	52	52	53	52	52	51	51	54	54	54	54	54	54	54	54	32
Mean	1457	7107	1093	9475	75	720	13	82	17	0.4	89	165	205	1.2	14	375	17
Min	<50	<100	<100	<250	0.07	2	1.5	0.3	5.6	<0.1	9	3	8.4	0.02	4	15	<0.5
Max	22000	71000	7500	100500	2800	13000	44	1300	32.5	1.2	210	2800	860	3.2	40	706	510
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–
300 to 600 mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	29	29	29	29	29	29	27	27	29	29	29	29	29	29	29	29	28
Mean	1637	4906	659	7201	209	909	9.0	153	21	0.5	71	82	309	0.9	13	314	2
Min	<50	<100	<100	<250	0.22	6.1	0.95	2.8	11	<0.1	11	8.5	24	0.14	4	39	<0.5
Max	14000	24000	2200	40200	3600	9900	34	1042	40.1	1.0	170	270	2300	1.8	38	670	10
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–
600 + mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	73	73	73	73	73	72	71	71	74	74	74	74	74	74	74	74	73
Mean	900	2632	357	3888	84	444	5.7	296	16	0.3	55	40	87	0.5	9.5	176	41
Min	<50	<100	<100	<250	<0.01	0.44	0.03	0.1	0.5	<0.1	4	1	4	<0.01	0.7	3	<0.5
Max	8300	26000	2500	36800	1100	4200	57	4500	36	1.4	320	220	300	2.0	64	1070	1269
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–

Table 4.3. Sediment Chemical Data Summary, Background Areas (mg/kg except where noted otherwise)

Kendall Bay Background Sites – 0 to 300 mm																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	4
Mean	27	437	130	594	0.5	22	4.8	3.3	13	0.2	66	63	122	0.7	10	253	<0.5
Min	<50	<100	<100	<250	<0.01	0.2	0.08	0.64	4	<0.1	6.9	6.7	22	0.01	4	50	<0.5
Max	130	1800	390	2320	3.7	130	15	13	22	0.5	130	130	240	1.4	17	570	<0.5
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–
Exile Bay Sites – 0 to 300																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	2
Mean	25	127	67	219	0.1	7.3	1.5	4.2	14	0.4	53	82	115	0.4	6.5	250	<0.5
Min	<50	<100	<100	<250	0.01	1.2	0.6	1.9	4.0	<0.1	10	30	30	0.06	1.0	50	<0.5
Max	25	560	200	785	0.2	21	2.9	7.2	29	1.1	120	260	300	1.2	14	580	<0.5
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–
Majors Bay Sites – 0 to 300																	
Analyte	TRH >C10- C16	TRH >C16- C34	TRH >C34- C40	Sum C10 - C40	Naphthalene	Total +ve PAH's	TOC %	PAH Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Total Cyanide
No Samples	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	1
Mean	25	355	145	526	0.1	10	2.9	7.4	17	1.1	124	91	182	0.6	13	426	
Min	<50	<100	<100	<250	0.01	1.3	0.44	1.02	6.9	<0.1	15	19	41	0.1	2	70	<0.5
Max	25	860	330	1215	0.17	22	6.3	49.5	23	2.0	230	140	250	0.84	24	760	<0.5
GV	–	–	–	280	–	–	–	10	20	1.5	80	65	50	0.15	21	200	–

Table 4.4. Southern Investigation Area Volatiles Data Summary (mg/kg)

0 – 300 mm Depth										
Analyte	TRH C₆ - C₉	TRH C₆ - C₁₀	vTPH C₆ - C₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	85	85	85	85	85	85	85	85	85	85
Mean	11.9	13.2	13.1	0.1	0.3	0.6	1.0	0.5	5.4	86
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	65
Max	12.5	49	45	0.5	1	3	1	2	220	105
300 – 600 Depth										
Analyte	TRH C₆ - C₉	TRH C₆ - C₁₀	vTPH C₆ - C₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	34	34	34	34	34	34	34	34	34	34
Mean	11.1	17.5	19.3	0.2	0.4	1.1	1.6	1.0	34	83
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	65
Max	59	140	99	2	4	7	16	10	400	104
>600										
Analyte	TRH C₆ - C₉	TRH C₆ - C₁₀	vTPH C₆ - C₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	240	240	240	240	240	240	240	240	240	240
Mean	9.4	21.3	25.1	0.8	0.7	1.2	2.5	1.7	72.7	84.8
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	61
Max	140	460	1,100	87	25	54	96	110	5,900	109

Table 4.5. Northern Investigation Area Volatiles Summary

0 – 300 mm Depth										
Analyte	TRH C ₆ - C ₉	TRH C ₆ - C ₁₀	vTPH C ₆ - C ₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	47	47	47	47	47	47	47	47	47	47
Mean	18	31	26	0.3	0.5	1.4	2.8	1.5	45	85
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	72
Max	160	430	330	6	8	13	55	26	1,000	108
300 – 600 mm Depth										
Analyte	TRH C ₆ - C ₉	TRH C ₆ - C ₁₀	vTPH C ₆ - C ₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	12	12	12	12	12	12	12	12	12	12
Mean	43.5	102	77	0.5	0.9	11.1	5.9	8.0	165	87
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	65
Max	260	670	480	4	5	96	31	59	1,100	96
>600 mm Depth										
Analyte	TRH C ₆ - C ₉	TRH C ₆ - C ₁₀	vTPH C ₆ - C ₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	82	82	82	82	82	82	82	82	82	82
Mean	33	61	47	1	1	3	7	4	125	89
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	61
Max	400	790	500	40	19	62	130	76	1,600	109

Table 4.6. Background Areas Volatiles Summary

Kendall Bay – Outside Investigation Areas (0-300)										
Analyte	TRH C ₆ - C ₉	TRH C ₆ - C ₁₀	vTPH C ₆ - C ₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	14	14	14	14	14	14	14	14	14	14
Mean	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	90
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	68
Max	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	111
Exile Bay (0-300)										
Analyte	TRH C ₆ - C ₉	TRH C ₆ - C ₁₀	vTPH C ₆ - C ₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	4	4	4	4	4	4	4	4	4	4
Mean	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	111
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	107
Max	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	121
Majors Bay (0-300)										
Analyte	TRH C ₆ - C ₉	TRH C ₆ - C ₁₀	vTPH C ₆ - C ₁₀ less BTEX (F1)	Benzene	Toluene	Ethylbenzene	m+p-Xylene	o-Xylene	Naphthalene	Surrogate
No Samples	10	10	10	10	10	10	10	10	10	10
Mean	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	90
Min	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	74
Max	<25	<25	<25	<0.2	<0.5	<1	<2	<1	<1	105

Post-RAP Investigations (October 2017)

These samples were collected from eastern and northern parts of Kendall Bay, where previous data (see above and Figure 3.4) indicated that the sediments generally contained background levels of gasworks contaminants (TRH and PAH) typical of the Parramatta River in the vicinity of Kendall Bay, and from bays in the Northern and Southern Reference Areas. The sample locations are shown on **Figures 4.1 to 4.6 and 4.8** and the key analytical data in **Table 4.7**, below.

Jar Samples

The data show that the TRH levels were generally low, often at or slightly above the Practical Quantification Limit (PQL) and, apart from one replicate sample in the southern part of Kendall Bay (KBR4C), closer to the Remediation Areas, not significantly different from the levels found in the five bays in the Reference Areas.

The levels of Total PAH, normalised to 1% TOC, were, with one exception, low and well below the ANZECC sediment quality Screening Level of 10 mg/kg. The levels found in Kendall Bay were comparable to the levels in the five bays in the Reference Areas. The one exception was sample KBR12, from the northern part of Kendall Bay. This sample, as noted above, was very shelly and had an unusually low TOC level, which raised the PAH level via the normalisation process.

Of the metals and metalloid, the arsenic, chromium, nickel and zinc levels in Kendall Bay were comparable to the levels in the Reference Bays. The levels of cadmium tended to be higher outside Kendall Bay. The levels of copper in Kendall Bay were comparable to the levels in the bays of the Northern Reference Area but lower than the levels in the Southern Reference Area. The levels of lead in the Southern Reference Area showed a tendency to be higher than in the other locations. The levels of mercury in Kendall Bay showed a slight tendency to be higher than outside it.

Overall, the metal levels in the Southern Reference Area (Exile and Canada Bays), considered as sediment quality quotients, were significantly higher than in Kendall Bay or the Northern Reference bays. This is not surprising – the bays of Hen and Chicken Bay are known to contain high levels of metals, particularly copper.

Volatiles Vials

No volatiles were detected in any of the vial samples. This was not unexpected; in the previous samplings, volatiles were only found in surface samples collected from areas where oily gasworks contamination was exposed at the sediment surface.

4.3 Timing of the Gasworks Contamination to the Sediments

The sedimentological and chemical data strongly suggest that the majority of the gasworks contamination entered Kendall Bay via surface disposal, release or discharge of tar or tarry wastes many decades ago, and that heavy tarry oils and DNAPL subsequently migrated downwards into the sediments. Supporting data for this conclusion includes:

- throughout the majority of the Declared Area, where gasworks-contaminated sediments are present, they are overlain by 0.05 – 0.3 m of recently deposited mud characterised by significantly lower levels of the COCs, and containing benthic infauna;
- the recent mud depth measurements are considerable underestimates of the true in-situ depth because:
 - a) the soft surface layer was sometimes lost by impact of the push corer with the sediment surface; and
 - b) significant dewatering of these soft loose muds occurs on and after sampling. The true in-situ depth of recent mud would be significantly greater, implying a maximum recent silt accumulation of up to 400 mm. Estimated sedimentation within the central subtidal areas of the bay is 5-15 mm per year (**Section 3.5.3**). This indicates that many decades have passed since input of gasworks wastes ceased;
- the sandy sediments in the mangrove area and the stormwater delta immediately north of the mangroves, which from air photos of the bay were largely deposited since the 1970s and also immediately overlie the black oily clays, support this time estimate; and
- although gasworks-contaminated sediments are found at the surface in parts of the Southern and Northern Investigation Areas (**Section 4.2.1, Figures 4.7 and 4.8**), the presence of contaminated sediments at the surface in those locations appears to be due to either erosion from high wave energy (**Section 3.5.3**), erosion on the edges of past dredged channels, or disturbance during removal of the former coal and coke wharves.

Table 4.7. Key Sediment Analysis Data, Chronic Toxicity Study, October 2017.

Sample Site No.	Site Location	Sum C10 - C40	Total +ve PAH's	PAHs, Norm 1%	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	TOC	Fines <0.063mm
Units		mg/kg	mg/kg		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	%
PQL			0.05		4	0.4	1	1	1	0.1	1	1		1
KBR1	Brays Bay	125	2.5	1.8	17	<0.4	76	74	110	0.5	10	270	1.4	78
KBR2A	Brays Bay	125	1.8	1.3	15	<0.4	69	72	100	0.5	9	250	1.4	61
KBR2B	Brays Bay	195	2.5	2.1	16	<0.4	65	70	97	0.5	8	230	1.2	60
KBR3	Majors Bay	125	7.8	2.4	15	0.8	84	81	110	0.5	10	310	3.2	64
KBR4A	Kendall Bay	385	24	3.0	14	<0.4	62	88	100	0.8	8	230	7.9	54
KBR4B	Kendall Bay	745	42	5.5	17	<0.4	89	120	140	1.1	12	340	7.6	52
KBR4C	Kendall Bay	1510	37	4.1	18	<0.5	92	100	150	1.1	14	440	9	
KBR5A	Kendall Bay	125	9.2	2.0	21	<0.4	100	130	160	1.2	13	380	4.5	63
KBR5B	Kendall Bay	355	20	3.4	20	<0.4	89	110	140	1.1	12	340	5.8	33
KBR6	Kendall Bay	355	16	3.4	24	<0.4	110	140	180	1.3	16	420	4.7	80
KBR7	Kendall Bay	235	9.2	3.4	21	<0.4	130	170	200	1.4	17	480	2.7	95
KBR8A	Kendall Bay	125	5.2	1.8	15	<0.4	93	130	150	1	12	350	2.9	98
KBR8B	Kendall Bay	840	5.1	1.6	25	<0.5	160	190	270	1.5	23	740	3.1	
KBR9	Kendall Bay	365	18	6.9	24	<0.4	100	140	170	1.5	13	380	2.6	75
KBR10A	Yaralla Bay	125	2.9	1.0	17	1	100	110	140	0.6	12	400	2.8	83
KBR10C	Yaralla Bay	610	0	0.0	19	1.4	120	110	160	0.68	15	570	3.3	
KBR11	Kendall Bay	295	16	5.7	22	<0.4	120	150	180	1.4	15	440	2.8	89
KBR12	Kendall Bay	385	20	30.8	20	<0.4	87	110	140	1.2	12	340	0.65	13
KBR13	Yaralla Bay	125	0.97	0.5	8	<0.4	23	27	41	0.2	3	94	1.8	61
KBR14	Majors Bay	125	2.7	1.1	16	<0.4	93	100	130	0.6	11	310	2.5	100
KBR15	Canada Bay	245	5.3	1.7	23	0.4	150	540	280	0.9	15	580	3.2	97
KBR16	Canada Bay	125	5.4	2.3	18	<0.4	100	330	180	0.8	11	400	2.3	96
KBR16B	Canada Bay	770	6.4	2.1	28	<0.5	150	370	260	0.93	18	680	3	
KBR17	Exile Bay	185	6.4	2.8	26	0.7	130	380	290	1.3	16	570	2.3	95
KBRMB18	Majors Bay	125	2.4	1.0	17	0.7	160	150	190	0.8	16	470	2.5	95

It is not possible to tell whether contamination was due to a single pollution discharge or release, or to a number of such events at one location in Kendall Bay or in a number of locations. However, it is known that in the early 1930s the gasworks began dumping of “non-specification coal tar, CWG tar-water emulsions and other toxic and inert gas manufacturing residuals and wastes, at a site on the foreshores of Homebush Bay” (Hathaway, 2010). Release of similar wastes into Kendall Bay could also have occurred at that time.

4.4 Conclusions

The results presented above are in generally good agreement with the results of previous investigations in Kendall Bay, and provide considerably more information on the distribution of contamination by area and depth throughout the bay, particularly in relation to volatile contaminants where the previous data was scanty. The results also fill in critical data gaps for the sediments in relation to:

- Kendall Bay to the north of the 2014 remediation Area A, where there was insufficient surface and subsurface data;
- Kendall Bay to the north and east of the 2014 remediation Area B, where there was insufficient surface and subsurface data; and
- the top 2-4 m of sediments in the Southern and Northern Investigation Areas. Push coring had previously failed to recover samples of the soft oily gasworks-contaminated sediment from this interval.

The results demonstrate that the bulk of gasworks contamination is confined to the south-west corner of the bay and an area on the western side of the bay in the vicinity of the former coal and coke wharves. The principal gasworks contaminants were PAHs and TRHs.

In the Southern Area the mean Total PAH (normalised to TOC) values exceeded the Australian sediment quality Guideline Value (GV) by 7-8 times, and the maximum Total PAH values exceeded the GV by 265 times in the 0-300 mm samples and 67 times in the 300-600 mm samples, respectively. The mean TRH (C10-C40) values exceeded the GV by approximately 23 times in the 0-300 mm samples and 18 times in the 300-600 mm samples, respectively, and the maximum TRH (C10-C40) values exceeded the GV by approximately 207 times in the 0-300 mm samples and 105 times in the 300-600 mm samples, respectively. The heavy metal levels in the sediments, while often elevated above the GVs, were generally comparable to levels found elsewhere in the Parramatta River.

In the Northern Area the mean Total PAH (normalised to TOC) values exceeded the GV by 8-15 times, respectively, and the maximum Total PAH values exceeded the GV by 130 times in the 0-300 mm samples and 100 times in the 300-600 mm samples, respectively. The mean TRH (C10-C40) values exceeded the GV by approximately 34 times and 26 times, respectively, and the maximum TRH (C10-C40) values exceeded the GV by approximately 359 times and 144 times, respectively. The heavy metal levels in the sediments, while often elevated above the GVs, were generally comparable to levels found elsewhere in the Parramatta River.

These results confirm the conclusions of previous investigations that high levels of gasworks contaminants are likely to cause adverse effects on organisms exposed to these sediments.

5 TISSUE CONTAMINATION

Full details of sampling and analytical methods, quality assurance and quality control, and data validation are provided in the Biological Tissue Report (S&W 2017c).

5.1 Sampling Locations and Methods

Oysters, *Saccostrea glomerata*, and mussels, *Mytilus edulis*, were collected from three suitable locations, one on the western side of Kendall Bay, one in Exile Bay near the sediment collection area, and one near the entrance of Majors Bay. Selection of sampling sites depended on the availability of suitable substrates for oysters and mussels. Mussels were sparse in distribution and those found were generally extremely small with little flesh inside; in some cases, only a small part of a jar of tissue was obtained. Oysters were also generally small.

The samples for biological tissues are listed in **Table 5.1** and the locations shown on **Figure 5.1**.

Table 5.1 Mussel and Oyster Sample Codes and Locations

Sample Code	Location
KBM	Kendall Bay Mussels
EBM	Exile Bay Mussels
MBM	Majors Bay Mussels
KBO	Kendall Bay Oysters
EBO	Exile Bay Oysters
MBO	Majors Bay Oysters

5.2 Results

The data obtained from analysis of oyster and mussel tissue samples is shown in **Table 5.2** for hydrocarbons, **Table 5.3** for PAHs and **Table 5.4** for metals.

Hydrocarbons

There are no Australian assessment criteria for hydrocarbons in tissue. The data show that light fraction hydrocarbons (TRH >C10-C16) were below detection limit (practical quantitation limit, PQL) in all samples. Higher fraction hydrocarbons (TRH >C16-C34 and TRH >C34-C40) were present in all samples however the levels were similar in all samples and locations. Samples from Kendall Bay did not show elevated levels of hydrocarbons compared to the background bays.

No data has been found for tissue concentrations of TRH in the vicinity of Kendall Bay.

Figure 5.1 Mussel and Oyster Sampling Locations



Table 5.2 Hydrocarbons in Oyster and Mussel Tissue, Kendall Bay and Background Areas

Sample Description	TRH C10 - C14	TRH C15 - C28	TRH C29 - C36	TRH >C10-C16	TRH >C16-C34	TRH >C34-C40
Assessment Criteria	NC	NC	NC	NC	NC	NC
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
PQL	50	100	100	50	100	100
KBM Kendall Bay Mussels	<50	220	270	<50	460	140
EBM Exile Bay Mussels	<50	180	310	<50	450	200
MBM Majors Bay Mussels	<50	220	250	<50	430	170
KBO Kendall Oysters	<50	210	360	<50	530	210
EBO Exile Bay Oysters	<50	290	470	<50	680	280
MBO Majors Bay Oysters	<50	130	290	<50	340	240

NC – No criteria

PAHs

There are no Australian assessment criteria for PAHs in tissue. PAHs were not detected in any mussel samples from Kendall Bay or the two background bays. With one exception, PAHs were not detected in any oyster samples from Kendall Bay or the two background bays. The exception was the individual PAH benzo(a)pyrene which was detected in the Kendall Bay oyster sample at slightly above the PQL, however precision is low for values close to the PQL and this result may not be meaningful.

The URS analysis of PAHs in oysters (URS 2003) indicated that Total PAH concentrations varied between 1.03 and 8.14 mg/kg in Kendall Bay and between 0.15 to 0.06 mg/kg at nearby reference sites. The highest value in Kendall Bay (8.14 mg/kg) was derived from samples near the old coal loading wharf. These values are considerably higher than values obtained in this study where Total PAHs in Kendall Bay oysters were recorded at 0.06 mg/kg slightly south of the location of the old coal loading wharf.

The significantly lower values found in the current study are considered to reflect the lower PAH inputs to the bay since remediation of the former gasworks site was completed, as well as removal of the coal wharf which was likely to have been a significant contamination source, as tar spills are believed to have occurred from a tar pipeline along the wharf.

Metals

Australian assessment criteria are only available for cadmium, copper and zinc. Metals were not detected in mussels except for zinc, where the values were well below the generally expected levels (GEL). The zinc values showed no significant differences between Kendall Bay and the two background bays.

Only cadmium, copper and zinc were detected in the oyster samples. The cadmium values were well below the maximum residue limit (MRL). The copper values, however, were more than an order of magnitude higher than the GEL, and the zinc levels approximately an order of magnitude higher than the GEL. The copper values were comparable in the three bays. The zinc and cadmium values were higher in Major's Bay oysters than in the oysters from Kendall and Exile Bays. Samples from Kendall Bay did not show elevated levels of metals compared to the background bays.

No previous data has been found for levels of metals in mussels and oysters in Kendall Bay.

5.3 Conclusion

From the data presented above, there is no evidence that the PAHs or TRHs in the contaminated gasworks sediments in the bay are being taken up by oysters or mussels. Metals in oysters and mussels were comparable in all areas and there is no evidence of greater uptake from the gasworks-contaminated areas.

Table 5.3 PAHs in Oyster and Mussel Tissue, Kendall Bay and Background Areas

	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b,j,k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Benzo(a)pyrene TEQ calc (zero)	Benzo(a)pyrene TEQ calc(half)	Benzo(a)pyrene TEQ calc(PQL)	Total Positive PAHs
Sample Description	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Assessment Criteria	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
PQL	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.05	0.1	0.1	0.1	0.5	0.5	0.5	
KBM Kendall Bay Mussels	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.05	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	NIL (+)VE
EBM Exile Bay Mussels	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.05	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	NIL (+)VE
MBM Majors Bay Mussels	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.05	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	NIL (+)VE
KBO Kendall Oysters	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	0.06	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	0.06
EBO Exile Bay Oysters	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.05	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	NIL (+)VE
MBO Majors Bay Oysters	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.05	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	NIL (+)VE

NC: No Criteria

Table 5.4 Metals in Oyster and Mussel Tissue, Kendall Bay and Background Areas (coloured values exceed the assessment criteria)

	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Sample Description	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
PQL	2	0.2	1	1	1	0.1	1	1
Assessment Criteria	NC	MRL 2.0	NC	GEL 5 Median 30 90% UCL	NC	NC	NC	GEL 130 Median 290 90% UCL
KBM Kendall Bay Mussels	<2	<0.2	<1	<1	<1	<0.1	<1	17
EBM Exile Bay Mussels	<2	<0.2	<1	<1	<1	<0.1	<1	14
MBM Majors Bay Mussels	<2	<0.2	<1	<1	<1	<0.1	<1	18
KBO Kendall Oysters	<2	0.7	<1	180	<1	<0.1	<1	1100
EBO Exile Bay Oysters	<2	0.6	<1	190	<1	<0.1	<1	1000
MBO Majors Bay Oysters	<2	1	<1	170	<1	<0.1	<1	1900

Notes:

GEL – Generally Expected Levels MRL – Maximum Residue Limit

Results that exceed the Assessment Criteria are in bold and shaded. NC – No Criteria

UCL – Upper Confidence Limit

6 WATER QUALITY MONITORING

Full details of sampling and analytical methods, quality assurance and quality control, and data validation are provided in the Seawater Monitoring Reports (S&W 2017b and S&W, 2018b).

6.1 Sampling Locations and Methods

Sampling locations were selected to align with the locations of the marine benthic monitoring sites (S&W 2016b), because these sites had been chosen to be representative of the range of gasworks-contaminated sediments in Kendall Bay (ranging from sediments that showed acute toxicity in CSIRO testing to sediments that were chronically toxic (Simpson et. al., 2016), plus sediments that were known to contain levels of contaminants comparable to background levels previously found in this part of the Parramatta River (SKM 2014a, b; S&W, 2017a). Water samples were also taken at or near the marine benthic background sampling sites in Exile Bay and Majors Bay.

As seawater quality varies seasonally, the sampling program focussed on defining the variability of the levels of the COPCs. Samplings have been carried out in January and April 2016, and October 2017.

Seawater samples were collected using a decontaminated and de-ionised water-washed Teflon Niskin Bottle lowered into the water on a stainless-steel cable. Particular care was taken to ensure that the weight hanging below the water sampler did not make contact with the underlying sediments, as this would have resulted in very high levels of suspended sediment in the sampled water, not representative of natural conditions.

In situ water quality monitoring was undertaken using a TPS model 90-FLT water quality meter which included a water quality logger in a single portable unit. The meter combines measurements of Dissolved Oxygen, Conductivity, TDS, pH, mV, Turbidity and Temperature. The meter was calibrated prior to each use using the proprietary methods provided in the TPS manual and using certified reagents. The sample locations are shown on Figures 6.1 to 6.3.

Figure 6.1 Water Quality Sampling Locations, Kendall Bay and Parramatta River



Figure 6.2 Water Quality Sampling Locations, Northern Reference Area



Figure 6.3 Water Quality Sampling Locations, Southern Reference Area



6.2 Results

The data obtained from analysis of water samples is summarised in **Tables 6.1 and 6.2** for PAHs, **Tables 6.3 and 6.4** for metals, and **Tables 6.5 and 6.6** for nutrients and other parameters. The complete data sets are provided in Appendix 2 of the Seawater Monitoring Report (S&W, 2017b).

Hydrocarbons, BTEX and Naphthalene

January 2016

Petroleum hydrocarbons and naphthalene were below or at the detection for all samples.

The only BTEX identified was toluene, which was often present at low levels, up to 4 µg/L (4 times the PQL). The levels tended to be higher in the background areas than in Areas A and B.

April 2016

Petroleum hydrocarbons, naphthalene and BTEX were below detection limits in all samples from all locations.

October 2017

Petroleum hydrocarbons, naphthalene and BTEX were below detection limits in all samples from all locations.

PAHs

January 2016

The levels of PAHs in water were very low, generally below detection or not far above detection limits, and bearing in mind the low precision where values are close to the detection limit, there was little difference between the values found in the Investigation Areas compared to the background locations (**Table 6.1**). The lowest levels of PAHs were found in the Northern Investigation Area and Majors Bay, and the highest levels in the Southern Investigation Area. This is not surprising as a major stormwater outfall discharges into this area.

April 2016

The PQL of PAHs in water was raised due to interference from analytes (other than those being tested).

The levels of PAHs in water were very low, generally below detection or not far above detection limits, and bearing in mind the low precision where values are close to the detection limit, there was little difference between the values found in the Investigation Areas compared to the background locations (**Table 6.2**). Again, the lowest levels of PAHs were found in the Northern Investigation Area and Majors Bay, and the highest levels in the Southern Investigation Area. This is not surprising as a major stormwater outfall discharges into this area.

October 2017

The levels of dissolved PAHs in water were almost all below detection levels. Two samples (one from south-east Kendall Bay and one from south-west Kendall Bay) had dissolved PAHs marginally above PQLs.

Levels of total PAHs in surface waters were slightly above detection levels in a number of locations in this sampling. These included:

- Majors Bay (one site);
- Exile Bay (two sites);
- Parramatta River upstream of Kendall Bay; and
- Sites in the mid, south, east and west of Kendall Bay.

Table 6.1 Range of Total PAHs in Water, Kendall Bay and Background Areas, January 2016

Location	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b,j,k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Total Positive PAHs
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Assessment Criteria	70	NA	NA	NA	2	0.4	1.4	NA	NA	NA	NA	0.2	NA	NA	NA	NA
PQL	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	
Kendall Bay Area B	<0.02-0.09	<0.01	<0.01	<0.01	<0.02-0.03	<0.01	<0.01-0.03	<0.01-0.02	<0.01	<0.01	<0.02	<0.01-0.01	<0.01	<0.01	<0.01	NIL – 0.14
Kendall Bay Area A	<0.02-0.02	<0.01-0.02	<0.01	<0.01	<0.02-0.06	<0.01	<0.01-0.14	<0.01-0.15	<0.01-0.07	<0.01-0.1	<0.02-0.2	<0.01-0.12	<0.01-0.02	<0.01-0.09	<0.01-0.09	NIL – 1.1
Kendall Bay Background	<0.02-0.09	<0.01-0.02	<0.01	<0.01	<0.02	<0.01	<0.01-0.02	<0.01-0.05	<0.01-0.01	<0.01-0.02	<0.02-0.06	<0.01-0.04	<0.01	<0.01-0.02	<0.01-0.02	NIL – 0.26
Exile Bay Background	<0.02	<0.02-0.03	0.01-0.02	<0.01	<0.02-0.03	<0.01	<0.05-0.09	<0.08-0.11	<0.01-0.02	0.2	0.06	0.04	<0.01	0.02	0.02	NIL - 0.43
Majors Bay Background	<0.02	<0.01	<0.01	<0.01-0.02	<0.02-0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	NIL – 0.06

NA: No criteria available

Table 6.2 Range of Total PAHs in Water, Kendall Bay and Background Areas, April 2016

Location	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b,j,k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Total Positive PAHs
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Assessment Criteria	70	NA	NA	NA	2	0.4	1.4	NA	NA	NA	NA	0.2	NA	NA	NA	NA
PQL	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	
Kendall Bay Area B	<0.02	<0.01	<0.01	<0.01	<0.03- <0.3	<0.01	<0.01- 0.01	<0.01- 0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	NIL – 0.02
Kendall Bay Area A	<0.02	<0.01	<0.01	<0.01	<0.03- <0.05	<0.01	<0.01- 0.12	<0.01- 0.23	<0.01- 0.07	<0.01- 0.06	<0.02- 0.22	<0.01- 0.16	<0.01- 0.02	<0.01- 0.07	<0.01- 0.07	NIL – 1.2
Kendall Bay Background	<0.02	<0.01	<0.01	<0.01	<0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	NIL
Exile Bay Background	<0.02	<0.01	0.01	<0.01	<0.03- <0.3	<0.01	0.02	<0.02	<0.01- 0.02	<0.01- 0.01	0.02- 0.03	0.02	<0.01	0.01	0.01- 0.02	0.11- 0.14
Majors Bay Background	<0.02	<0.01	<0.01	<0.01	<0.03	<0.01	0.01	0.01- 0.02	<0.01	<0.01	<0.02- 0.03	<0.01- 0.02	<0.01	<0.01- 0.01	<0.01- 0.02	0.02- 0.14

NA: No criteria available

Organochlorine Pesticides

January 2016

No organochlorine pesticides were found in any sample.

April 2016

No organochlorine pesticides were found in any sample.

October 2017

No organochlorine pesticides were found in any sample.

Metals

January 2016

The dissolved metal levels were typical of those found in urbanised estuaries and in the Parramatta River. As is commonly found, copper was typically several times higher than the ANZECC/ARMCANZ 2000 marine water quality criterion (95% protection) in all areas (**Table 6.3**). There was no elevation of heavy metals in the Investigation Areas compared to the background areas, and in fact the highest levels of metals were found in Majors Bay.

April 2016

The dissolved metal levels were typical of those found in urbanised estuaries and in the Parramatta River. As is commonly found, copper was typically several times higher than the ANZECC/ARMCANZ 2000 marine water quality criterion (95% protection) in all areas (**Table 6.4**). There was no elevation of heavy metals in the Investigation Areas compared to the background areas.

October 2017

All dissolved metals in the study areas were below the assessment criteria (**Table 5.7**), except for copper which exceeded the criteria in the Parramatta River and in every bay sampled on the southern side of the River, around and including Kendall Bay.

Other Chemical and Physical Parameters

January 2016

The total suspended solids (TSS), pH and conductivity were typical of Parramatta River estuarine waters (**Table 6.7**). The Total Phosphorus and Total Nitrogen levels were below or close to the detection limits, as were the phosphate and forms of nitrogen levels, and there was no clear difference between the waters at the Investigation Areas and the background areas.

April 2016

The total suspended solids (TSS), pH and conductivity were typical of Parramatta River estuarine waters (**Table 6.8**). Due to a lab issue the Total Phosphorus and Total Nitrogen PQLs had to be raised, and therefore all values were below PQLs, and could not be compared to the January values. The phosphate levels exceeded the assessment criteria in Kendall Bay, including background areas, and were slightly lower in Exile and Majors Bays. This could be due to the stormwater outfall at the end of Kendall Bay. Forms of nitrogen were also slightly higher in Kendall Bay, including background areas, though all levels were close to the PQLs.

October 2017

The total suspended solids (TSS), pH and conductivity were typical of Parramatta River estuarine waters (**Table 6.9**). Levels of Total Nitrogen exceeded the assessment criteria in Majors and Exile Bays, as did the levels of Total Phosphorous. This presumably represents anthropogenic inputs to these bays.

Table 6.3 Total PAHs in Water, Kendall Bay and Background Areas, October 2017

	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b,j,k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Total Positive PAHs
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Assessment Criteria	70	NA	NA	NA	2	0.4	1.4	NA	NA	NA	NA	0.2	NA	NA	NA	NA
PQL	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	
Brays Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Yaralla Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Majors Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Majors Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 4	<0.0 1	0.04	0.04	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.08
Canada Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 3	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Exile Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 3	<0.0 1	0.02	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.02
Exile Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	0.01	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.01
Parramatta River D/S Kendall Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 3	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Parramatta River U/S Kendall Bay	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	0.04	0.04	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.08
Kendall Bay SW Side	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 4	<0.0 1	0.05	0.05	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.1
Kendall Bay South Mid	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 5	<0.0 1	0.04	0.04	<0.0 1	<0.0 1	0.03	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.11
Kendall Bay South East Side	<0.0 2	0.02	<0.0 1	0.06	0.1	0.02	0.08	0.08	<0.0 1	<0.0 1	0.06	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.46
Kendall Bay Centre West Side	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 4	<0.0 1	0.01	0.01	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.02
Kendall Bay Centre Mid	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 3	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Kendall Bay Centre East Side	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Kendall Bay North West Side	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 4	<0.0 1	0.03	0.03	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	0.06
Kendall Bay North Mid	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE
Kendall Bay North East Side	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 1	<0.0 2	<0.0 1	<0.0 1	<0.0 1	<0.0 1	NIL (+)VE

Table 6.4 Range of Dissolved Metals in Water, Kendall Bay and Background Areas, January 2016

	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
PQL	1	0.1	1	1	1	0.05	1	1
Assessment Criteria	2.3	0.7	27	1.3	4.4	0.1	7	15
Kendall Bay Area B	2	<0.1	<1	2	<1	<0.05	<1	<1-2
Kendall Bay Area A	2	<0.1	<1	2-3	<1	<0.05	<1	<1-1
Kendall Bay Background	2	<0.1	<1	2-3	<1	<0.05	<1	<1-1
Exile Bay Background	2	<0.1	<1	2-3	<1	<0.05	<1	<1
Majors Bay Background	2-3	<0.1	<1-5	2-6	<1-7	<0.05-0.08	1-2	<1-16

Note: Results that exceed the Assessment Criteria are in bold.

Table 6.5 Range of Dissolved Metals in Water, Kendall Bay and Background Areas, April 2016

	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
PQL	1	0.1	1	1	1	0.05	1	1
Assessment Criteria	2.3	0.7	27	1.3	4.4	0.1	7	15
Kendall Bay Area B	2	<0.1	<1	2-5	<1-2	<0.05	<1-2	6-17
Kendall Bay Area A	2	<0.1	<1	2-6	<1	<0.05	<1-2	6-11
Kendall Bay Background	2	<0.1	<1	5-11	<1	<0.05	1	7-8
Exile Bay Background	2	<0.1	<1	3-8	<1	<0.05	<1-2	6-8
Majors Bay Background	2	<0.1	<1	1-2	<1	<0.05	<1	6

Note: Results that exceed the Assessment Criteria are in bold.

Table 6.6 Dissolved Metals in Water, Kendall Bay and Background Areas, October 2017

Location	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
PQL	1	0.1	1	1	1	0.05	1	1
Assessment Criteria	2.3	0.7	27	1.3	4.4	0.1	7	15
Brays Bay	1	<0.1	<1	4	<1	<0.05	<1	10
Brays Bay	1	<0.1	<1	4	<1	[NT]	<1	10
Yaralla Bay	1	<0.1	<1	2	<1	<0.05	1	11
Majors Bay	1	<0.1	<1	3	<1	<0.05	<1	9
Majors Bay	<1	0.1	<1	4	<1	<0.05	1	11
Canada Bay	1	<0.1	<1	4	<1	<0.05	1	11
Exile Bay	1	<0.1	<1	4	<1	<0.05	2	9
Exile Bay	1	<0.1	<1	5	<1	<0.05	2	8
Parramatta River D/S Kendall Bay	1	<0.1	<1	4	<1	<0.05	1	7
Parramatta River U/S Kendall Bay	1	<0.1	<1	5	<1	<0.05	2	11
Kendall Bay SW Side	1	<0.1	<1	3	<1	<0.05	<1	9
Kendall Bay South Mid	1	<0.1	<1	5	<1	<0.05	4	13
Kendall Bay South Mid	<1	<0.1	<1	5	<1	[NT]	4	11
Kendall Bay South East Side	1	<0.1	<1	3	<1	<0.05	1	9
Kendall Bay Centre West Side	1	<0.1	<1	3	<1	<0.05	<1	9
Kendall Bay Centre Mid	1	<0.1	<1	3	<1	<0.05	2	9
Kendall Bay Centre East Side	1	<0.1	<1	4	<1	<0.05	2	9
Kendall Bay North West Side	1	<0.1	<1	2	<1	<0.05	<1	7
Kendall Bay North Mid	1	<0.1	<1	2	<1	<0.05	<1	8
Kendall Bay North East Side	1	<0.1	<1	3	<1	<0.05	2	10

NT - Not tested

Table 6.7 Range of Nutrients and Other Parameters in Water, Kendall Bay and Background Areas, January 2016

	TSS	pH	Conductivity	Total P	Phosphate P	Total N	NOx as N	Ammonia as N
Units	mg/L	pH units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L
PQL	0.05	0.1	1	0.05	0.005	0.1	0.005	0.005
Assessment Criteria	-	7-8.5	-	0.03	0.03	0.3	0.015	0.9
Kendall Bay Area B	8-14	8-8.2	43,000-47,000	<0.05	0.007-0.009	<0.1	<0.005-0.007	<0.005
Kendall Bay Area A	9-11	8.2	43,000-44,000	<0.05-0.05	0.008-0.01	<0.1	<0.005	<0.005
Kendall Bay Background	<5-19	8.1-8.2	42,000-44,000	<0.05	0.006-0.007	<0.1	<0.005	<0.005
Exile Bay Background	6-9	8.2	44,000-45,000	<0.05	<0.005-0.008	<0.1	<0.005	<0.005
Majors Bay Background	10-92	8.2-8.3	40,000-41,000	<0.05-0.06	0.009-0.017	<0.1	<0.005	<0.005

TSS: Total suspended solids

Note: Results that exceed the Assessment Criteria are in bold.

Table 6.8 Range of Nutrients and Other Parameters in Water, Kendall Bay and Background Areas, April 2016

	TSS	pH	Conductivity	Total P	Phosphate P	Total N	Nitrate as N	Nitrite as N	Ammonia as N
Units	mg/L	pH units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
PQL	0.05	0.1	1	0.05-0.25	0.005	0.1-2	0.005	0.005	0.005
Assessment Criteria	-	7-8.5	-	0.03	0.03	0.3	0.015	0.015	0.9
Kendall Bay Area B	<5-14	NT	40,000-42,000	<0.25	0.034-0.038	<2	<0.02-0.04	<0.005-0.005	<0.054-0.074
Kendall Bay Area A	10-22	NT	40,000-42,900	<0.25	0.035-0.036	<2	<0.02-0.05	<0.005-0.007	<0.047-0.09
Kendall Bay Background	5-14	NT	40,000	<0.25	0.033-0.037	<2	<0.02-0.03	<0.005	<0.032-0.049
Exile Bay Background	14-21	NT	41,000	<0.25	<0.02-0.021	<2	<0.009-0.01	<0.005	<0.005
Majors Bay Background	24-63	NT	40,000	<0.25	0.028- 0.03	<2	<0.006-0.01	<0.005	<0.005-0.005

TSS: Total suspended solids

NT: Not tested

Note: Results that exceed the Assessment Criteria are in bold.

Table 6.9 Nutrients and Other Parameters in Water, Kendall Bay and Background Areas, October 2017

Location	TSS	pH	Conductivity	Total P	Phosphate P	Total N	Nitrate	Nitrite	Ammonia	TDS	Turbidity
Units	mg/L	pH units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	NTU
PQL	5	0.1	1	0.05	0.05	0.1	0.005	0.005	0.005	5	0.1
Assessment Criteria	-	7-8.5	-	0.03	0.03	0.3	0.015	0.015	0.9		
Brays Bay	15	7.54	53200	<0.05	0.027	0.3	0.01	<0.005	0.055	34000	9.5
Brays Bay	13	7.68	53400	0.06	0.031	0.3	0.01	<0.005	0.059	34000	9.6
Yaralla Bay	64	7.71	53700	<0.05	0.022	0.3	0.007	<0.005	0.036	36000	9.4
Majors Bay	10	7.82	53400	0.05	0.021	0.3	0.006	<0.005	0.023	40000	8.8
Majors Bay	52	7.51	53100	0.09	0.019	0.4	0.009	<0.005	0.033	39000	33
Canada Bay	16	7.94	53300	<0.05	0.014	0.3	<0.005	<0.005	0.01	34000	12
Exile Bay	17	7.95	53100	<0.05	0.016	0.3	<0.005	<0.005	0.009	34000	8.8
Exile Bay	9	7.95	53000	<0.05	0.016	0.2	<0.005	<0.005	0.005	39000	5.6
Parramatta River D/S Kendall Bay	10	7.99	52900	<0.05	0.018	0.2	<0.005	<0.005	0.015	39000	3.8
Parramatta River U/S Kendall Bay	6	7.94	52900	<0.05	0.019	0.3	0.007	<0.005	0.018	39000	4.4
Kendall Bay SW Side	6	7.91	52100	<0.05	0.018	0.3	0.03	<0.005	0.073	40000	4.3
Kendall Bay South Mid	8	7.92	52300	<0.05	0.019	0.2	0.01	<0.005	0.03	38000	4.6
Kendall Bay South Mid	<5	7.94	52500	<0.05	0.022	0.3	0.01	<0.005	0.03	36000	4.5
Kendall Bay South East Side	10	7.96	52500	<0.05	0.019	0.3	<0.005	<0.005	0.013	37000	4.6
Kendall Bay Centre West Side	<5	7.99	52600	<0.05	0.018	0.3	<0.005	<0.005	0.013	39000	3.2
Kendall Bay Centre Mid	9	8.02	52300	<0.05	0.019	0.3	<0.005	<0.005	0.013	40000	3.6
Kendall Bay Centre East Side	8	7.65	52700	<0.05	0.021	0.2	0.008	<0.005	0.024	40000	3.5
Kendall Bay Centre East Side	<10	7.77	52800		0.025	0.2	0.005	<0.005	0.023	40000	4
Kendall Bay North West Side	5	7.87	52600	<0.05	0.021	0.2	0.007	<0.005	0.023	40000	2.7
Kendall Bay North Mid	7	7.91	52500	<0.05	0.02	0.3	<0.005	<0.005	0.017	42000	3
Kendall Bay North East Side	6	7.92	52500	<0.05	0.02	0.2	0.005	<0.005	0.015	41000	1.2

Microbiology

January 2016

Sampling for bacteria was not carried out in the January sampling.

April 2016

In the April sampling, samples were tested for Total Coliforms and Enterococci. The Total Coliform counts ranged from 1-30 Colony Forming Units (CFU)/100 mL, well below the Primary Contact Recreational Guideline of 150 CFU/100 mL on median of five samples, and were comparable between the contaminated areas of Kendall Bay and the background areas. Several values were flagged NBO, meaning that the presence of competing background organisms in the sample may have reduced the count. Some other values were flagged 'A', meaning an approximation.

The Enterococci counts ranged from <1 to 32 CFU/100 mL, though most values were low. These values were well below the Primary Contact Recreational Guideline of 35 CFU/100 mL on median of five samples, and were comparable between the Investigation Areas of Kendall Bay and the background areas.

October 2017

In October 2017, the Total Coliform counts ranged from 1 to 55 Colony Forming Units (CFU)/100 mL, well below the Primary Contact Recreational Guideline of 150 CFU/100 mL on median of five samples. Enterococci values ranged from <1 to 10. These values were well below the Primary Contact Recreational Guideline of 35 CFU/100 mL on median of five samples, and were comparable between the gasworks-contaminated areas of Kendall Bay and the background areas.

6.3 Comparison to Previous Water Quality Data

Water quality monitoring was carried out for the Kendall Bay area by URS in 2006, for TPH, PAHs, BTEX and cyanide, and is summarised in Royal HaskoningDHV, 2016. URS found that concentrations of the contaminants analysed were all less than the relevant ANZECC/ARMCANZ (2000) 95% Trigger Values (Marine).

Water quality monitoring was also carried out for the Kendall Bay area (3 bay locations and two background locations) by Royal HaskoningDHV from August to October 2012 and November 2013 to February 2014. At each location samples were taken from just below the surface and 0.5 m above the bay bed, and analysed for TSS, dissolved metals, Total Cyanide, TPH (C₆-C₃₆), BTEX and PAHs. The results were documented in the report *Kendall Bay Sediment Remediation Project – Baseline Water Quality Report* (Royal HaskoningDHV, 2014) and are summarised in Royal HaskoningDHV, 2016, and above in **Section 2.2.3**.

The results of the S&W January and April 2016 and October 2017 sampling events are consistent with the results previously reported by URS and Royal HaskoningDHV, with the exception that no high PAH values (as were sometimes found by Royal HaskoningDHV) were reported in the 2016 or 2017 sampling events. However, it is apparent that the high PAH values sometimes reported by Royal HaskoningDHV were associated with high levels of suspended sediments in the samples, and all the 2016 and 2017 water samples had relatively low levels of suspended sediments.

6.4 Conclusion

The water quality data did not show any significant difference between the levels of contaminants in the areas of Kendall Bay contaminated by gasworks wastes and other parts of Kendall Bay, or the background locations outside the bay.

7 EXPOSURE ASSESSMENT

The exposure assessment summarises existing knowledge of the extent of contamination at the site and the measured or assumed uptake of contaminants by the ecological receptors.

7.1 Sources, Fate, Transport and Distribution of Contaminants in Kendall Bay

The sources, environmental fate and transport of contaminants in Kendall Bay have been described

In **Section 3.5** of this ERA.

Further information on contamination sources and distribution in bay sediments is presented in

Sections 4.2 and 4.3.

7.2 Receptor Identification

Receptors are identified in **Section 3.3** of this ERA, based on surveys summarised in **Section 2.3.4.**

7.3 Exposure Assessment

The sediment, water and tissue chemical data used to estimate exposure has been summarised in **Sections 4, 5 and 6**, respectively. The full data set, including the data validations, can be found in S&W 2018a, b and c, respectively.

Exposure pathways are identified in **Section 3.4** and on the accompanying Conceptual Site Model (**Figure 3.8**).

7.3.1 Water Column Biota Receptors of Concern

The receptors of concern include all aquatic organisms in the study area.

Contaminants of Potential Concern

The COPCs are the gasworks contaminants analysed in the water quality monitoring, i.e. TRHs and PAHs.

Exposure Point Concentrations

The exposure points are the Southern and Northern Investigation Areas of the Kendall Bay sediments, parts of which are heavily contaminated with gasworks wastes. The exposure point concentrations are normally the means (estimated via the upper 95% confidence limit of the mean (95% UCL)) of the concentrations of each contaminant of concern in water samples from each area. However, in view of the limited water quality data available, for conservatism the maximum value for each COPC has been used.

It has been assumed that all aquatic biota is exposed to contaminants in the water via dermal contact or ingestion, and for conservatism the maximum concentration in the water has been compared to the adopted water quality guidelines. Conservative assumptions include that ecological receptors are present within contaminated areas 100% of the time, contaminants are 100% available to biota, the most sensitive life stages of the organisms are exposed to contaminants and the organisms feed on, live in and/or are exposed 100% of the time to the most contaminated waters.

The data shows that the dissolved PAH levels were very low, mostly below the detection limits or in a few cases at or slightly above the detection limits. There are no Australian marine water quality guidelines for PAHs, due to insufficient data, however the low values found indicate that exposure of water column organisms to PAHs in Kendall Bay is likely to be minimal.

The levels of petroleum hydrocarbons, BTEX and naphthalene were below or at the detection limits in all samples except for toluene, which was detected at low levels in some samples in the January 2016 sampling, however the levels tended to be higher in the background locations. Based on this data, exposure of water column organisms to hydrocarbons derived from the gasworks-contaminated sites is likely to be minimal.

The dissolved metal levels were also low and generally below the water quality guideline values except for copper, which consistently exceeded the guideline, and zinc, which occasionally did. This indicates potential for adverse effects on some organisms, however the metal levels in the contaminated areas of Kendall Bay were comparable to the levels at the background locations in and outside the bay, and exposure to metals would largely be due to the regional heavy metal burden rather than to the gasworks contamination.

7.3.2 Bioaccumulation in Oyster and Mussel Tissue

This exposure assessment summarises existing knowledge of the extent of contamination of oysters and mussels by the COPCs, i.e. PAHs, TRHs and metals. The TRHs and PAHs are present at high levels in sediments of the Northern and Southern Investigation Areas but at background levels typical of the Parramatta River in the other areas. Metals are present at elevated levels in both the Northern and Southern Investigation Areas, and the background areas.

For conservatism, due to the limited data available on tissue concentrations in the vicinity of Kendall Bay, the maximum contaminant concentrations in oysters and mussels have been compared to the Australian Maximum Residue Limits (MRLs).

There are no Australian assessment criteria for PAHs in tissue. PAHs were not detected in any mussel samples from Kendall Bay or the two background bays. With one exception, PAHs were not detected in any oyster samples from Kendall Bay or the two background bays. The exception was the individual PAH benzo(a)pyrene which was detected in the Kendall Bay oyster sample at slightly above the PQL, however precision is low for values close to the PQL and this result may not be meaningful.

There are no Australian assessment criteria for hydrocarbons in tissue. The data show that light fraction hydrocarbons (TRH >C10-C16) were below detection limit (practical quantitation limit, PQL) in all samples. Higher fraction hydrocarbons (TRH >C16-C34 and TRH >C34-C40) were present in all samples however the levels were similar in all samples and locations. Samples from Kendall Bay did not show elevated levels of hydrocarbons compared to the background bays.

Australian assessment criteria are only available for cadmium, copper and zinc. Metals were not detected in mussels except for zinc, where the values were well below the generally expected levels (GEL). The zinc values showed no significant differences between Kendall Bay and the two background bays.

Only cadmium, copper and zinc were detected in the oyster samples. The cadmium values were well below the maximum residue limit (MRL). The copper values, however, were more than an order of magnitude higher than the GEL, and the zinc levels approximately an order of magnitude higher than the GEL. The copper values were comparable in the three bays. The zinc and cadmium values were higher in Major's Bay oysters than in the oysters from Kendall and Exile Bays. Samples from Kendall Bay did not show elevated levels of metals compared to the background bays.

From the data presented above, there is no evidence that the PAHs or TRHs in the contaminated gasworks sediments in the bay are being taken up by oysters or mussels.

Exposure to receptors (i.e. aquatic organisms eating other contaminated organisms) could not be calculated due to a lack of data.

7.3.3 Benthic Biota

Receptors of Concern

The receptors of concern include all benthic organisms in the study area.

Contaminants of Potential Concern

The COPCs are TRHs, PAHs and metals and metalloids.

Exposure Point Concentrations

The exposure points are the Southern and Northern Investigation Areas of Kendall Bay, parts of which are heavily contaminated with gasworks wastes. The exposure point concentrations are the means (estimated via the upper 95% confidence limit of the mean (**95% UCL**)) of the concentrations of each contaminant of concern in each area.

Initially it was assumed that all benthic biota were exposed to the contaminants in the sediment via dermal contact or ingestion, and for conservatism the maximum concentration in the sediment was compared to the adopted sediment quality guidelines. Conservative assumptions include that ecological receptors are present within contaminated areas 100% of the time, contaminants are 100% available to biota, the most sensitive life stages of the organisms are exposed to contaminants and the organisms feed on, live in and/or are exposed 100% of the time to the most contaminated sediments.

From the data presented in **Section 4.2**, it is clear that benthic biota in the Northern and Southern Investigation Areas are exposed to the key gasworks-derived contaminants in the sediments (TRHs and PAHs) at levels exceeding or greatly exceeding the sediment quality GVs. There is a significant risk of toxic effects on benthic biota, which is assessed in **Section 8**.

7.4 Uncertainties

Nature and Extent of Contamination

The analysis of environmental samples can be affected by high salt levels, complicated chemical matrices, sample preparation, intrinsically inhomogeneous samples or samples that cannot be perfectly homogenised, and analytical differences between laboratories, and therefore the results may be less precise than desired.

The levels of contaminants in environmental media vary from location to location, with depth in water, sediments and tissues, and over time as well, and few investigation programs can be large enough and prolonged enough to fully characterise the spatial and temporal variation in all these media. The sediment investigations carried out by S&W in 2015-2016 were comprehensive, and the results were generally in agreement with extensive sampling programs previously carried out by other consultants, as summarised in SKM (2014a). For this reason, it is considered that the sediment data obtained is representative of the distribution of contaminant values in the study area. The water quality and tissue concentration data are more limited both in time and space and only representative of contaminant values at the time of sampling, and therefore there is greater uncertainty as to the representativeness of this data.

Exposure Pathways

The exposure assessment has not considered all possible exposure pathways for all ecological receptors, and therefore the exposure could be underestimated. For example, sediment quality guidelines do not specifically take into account ingestion of contaminated particles by benthic organisms.

Undetected Contaminants

The list of COPCs analysed was based on the known key contaminants from the former gasworks, supplemented by other contaminants known to be present in the Parramatta River, however not all contaminants that could conceivably be present in Kendall Bay have been analysed for.

Study Area Concentrations

In exposure calculations, the desired input value is the true mean of the concentration of a contaminant within the area of exposure, which is usually approximated by the 95% UCL of the mean. This will slightly overestimate the true concentration where the data set is large and the variance small, but may greatly overestimate the true concentration where the dataset is small and the variance high. Where the maximum value has been used, this may considerably overestimate the true concentration of the contaminant.

Wildlife Exposure Factors

In this study, it was assumed that organisms had 100% exposure to contaminants and spent all of their time within the study area. These assumptions may be realistic for sedentary organisms (e.g. oysters) and

small benthic infauna. For aquatic organisms that swim or move with the currents, and benthic organisms that range over a wide area (such as fish, prawns and crabs), these assumptions are likely to considerably overestimate exposure to contaminants.

Absorption from Ingested Doses and Direct Contact

The toxicity of an ingested contaminant depends on the proportion that is absorbed from the stomach, however this varies from organism to organism, and also according to the chemical forms of each contaminant; and is generally not known. The same applies to absorption of contaminants through the skin or gills. Exposure estimates that assume 100% bioavailability of all contaminants in all media may be realistic for dissolved contaminants in water and prey, but are liable to considerably overestimate exposure from contaminants such as PAHs that are mainly found in suspended sediment or bed sediment, either from contact or ingestion of particulates, because of the low solubility of many contaminants adsorbed to sediments.

Overall Assessment

The above uncertainties include those that could lead to under-estimates and over-estimates of exposure, however because many of the assumptions are conservative, it is believed that the data is more likely to over-estimate exposure.

8 TOXICITY ASSESSMENT

8.1 Water Column Organisms

The ANZECC/ARMCANZ 2000 guidelines for protection of aquatic organisms (95% protection) apply in the Parramatta River and are the adopted water quality guidelines set out in **Section 3.2.3** and **Table 3.3**.

Based on the water quality data collected in 2016 and 2017 (**Table 8.1**), and the low values of TRH and PAHs found, exposure of water column organisms to TRH and PAHs from the gasworks contaminated sediments is likely to be minimal, and the levels below the water quality guideline values. Dissolved PAHs were almost always below the PQLs. Toxic effects are, therefore, unlikely. Note that TRHs are not included in the table as they were not detected in any sample. Dissolved metals were below the relevant guideline values on almost all occasions and locations, except for copper which was above the marine water quality guideline value on all occasions in all samples.

Table 8.1. Key Contaminants in Water, Kendall Bay and Background Areas

January 2016	Total PAH	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Assessment Criteria	NA	0.7	27	1.3	4.4	0.1	7	15
Kendall Bay Northern Investigation Area	NIL – 0.14	<0.1	<1	2	<1	<0.05	<1	<1-2
Kendall Bay Southern Investigation Area	NIL – 1.1	<0.1	<1	2-3	<1	<0.05	<1	<1-1
Kendall Bay Background	NIL – 0.26	<0.1	<1	2-3	<1	<0.05	<1	<1-1
Exile Bay Background	NIL -0.43	<0.1	<1	2-3	<1	<0.05	<1	<1
Majors Bay Background	NIL – 0.06	<0.1	<1-5	2-6	<1-7	<0.05-0.08	1-2	<1- 16
April 2016	Total PAH	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Kendall Bay Northern Investigation Area	NIL – 0.02	<0.1	<1	2-5	<1-2	<0.05	<1-2	6-17
Kendall Bay Southern Investigation Area	NIL – 1.2	<0.1	<1	2-6	<1	<0.05	<1-2	6-11
Kendall Bay Background	NIL	<0.1	<1	5-11	<1	<0.05	1	7-8
Exile Bay Background	0.11-0.14	<0.1	<1	3-8	<1	<0.05	<1-2	6-8
Majors Bay Background	0.02-0.14	<0.1	<1	1-2	<1	<0.05	<1	6
October 2017	Total PAH	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Kendall Bay Northern Investigation Area	NIL-0.02	<0.1	<1	3-4	<1	<0.05	<1-2	9
Kendall Bay Southern Investigation Area	0.1-0.46	<0.1	<1	3-5	<1	<0.05	<1-4	9-13
Kendall Bay Background	NIL-0.08	<0.1	<1	2-5	<1	<0.05	<1-2	7-11
Southern Reference Area	NIL-0.02	<0.1	<1	4-5	<1	<0.05	1-2	8-11
Northern Reference Area	NIL	<0.1-0.1	<1	2-4	<1	<0.05	<1-1	9-11

Note: Results that exceed the Assessment Criteria are in bold.

Oyster and Mussel Bioaccumulation

Based on the bioaccumulation data collected in 2016 (**Table 8.2**), which showed that TRH and PAHs were below or at detection limits in all samples, there is no evidence that the PAHs or TRHs in the contaminated gasworks sediments in the bay are being taken up by oysters or mussels.

Copper and zinc were significantly elevated in all the oyster tissue samples; however, the Kendall Bay levels were comparable to or lower than the background area levels, indicating that bioaccumulation of these metals was due to the elevated regional heavy metal background.

Table 8.2. Key Contaminants in Oyster and Mussel Tissue, Kendall Bay and Background Areas (mg/kg)

	Total PAH	TRH C10-C40	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
	mg/kg	Mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
PQL	NA	250	0.2	1	1	1	0.1	1	1
Assessment Criteria	NC	NC	MRL 2.0 mg/kg	NC	GEL 5 mg/kg Median 30 mg/kg 90% UCL	NC	NC	NC	GEL 130 mg/kg Median 290 mg/kg 90% UCL
KBM Kendall Bay Mussels	NIL (+)VE	625	<0.2	<1	<1	<1	<0.1	<1	17
EBM Exile Bay Mussels	NIL (+)VE	675	<0.2	<1	<1	<1	<0.1	<1	14
MBM Majors Bay Mussels	NIL (+)VE	625	<0.2	<1	<1	<1	<0.1	<1	18
KBO Kendall Oysters	0.06	765	0.7	<1	180	<1	<0.1	<1	1100
EBO Exile Bay Oysters	NIL (+)VE	985	0.6	<1	190	<1	<0.1	<1	1000
MBO Majors Bay Oysters	NIL (+)VE	605	1	<1	170	<1	<0.1	<1	1900

Notes:

GEL – Generally Expected Levels

MRL – Maximum Residue Limit

Results that exceed the Assessment Criteria are in bold and shaded.

NC – No Criteria

UCL – Upper Confidence Limit

8.2 Benthic Organisms

8.2.1 Preliminary Assessment

An initial assessment was done by comparing the degree of exposure of the ecological receptors to the COPCs (i.e. the maximum values found in the Northern and Southern Investigation Areas), to the dose associated with adverse effects. Ecological risk can be estimated numerically using the USEPA's Hazard Quotient (HQ) approach, where the HQ is the ratio of the maximum value in each area to the GVs set out in **Section 3.2.2** and **Table 3.2**. Where the HQ is greater than 1, harmful effects on organisms may occur. Note that the degree by which the HQ exceeds 1 is not relevant, only the exceedance itself.

The mean and maximum sediment values of each contaminant of concern were compared to the GVs for the Northern and Southern Investigation Areas (**Table 8.3**). Where the maximum value for a COPC exceeded the relevant guideline (marked in bold) the hazard quotient is greater than 1, and harmful effects on some organisms are likely to occur, assuming the contaminants are bioavailable.

Table 8.3. Key Sediment Chemical Data Summary, 0-300 mm (mg/kg except where noted otherwise)

Southern Investigation Area Sites – 0 to 300 mm										
Analyte	Sum C10-C40	Total PAH	TOC %	PAH Norm 1%	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Samples	94	92	88	90	94	94	94	94	94	94
Mean	6402	411	16	80	145	49	110	0.6	50	309
Min	<250	0.12	0.06	1.3	3	2	6.1	0.01	1	10
Max	57900	3600	57	2650	530	143	660	8.5	230	820
GV	280	–	–	10	80	65	50	0.15	21	200
Northern Investigation Area Sites – 0 to 300 mm										
Analyte	Sum C10-C40	Total PAH	TOC%	PAH Norm 1%	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Samples	53	52	51	51	54	54	54	54	54	54
Mean	9475	720	13	82	89	165	205	1.2	14	375
Min	<250	2	1.5	0.3	9	3	8.4	0.02	4	15
Max	100500	13000	44	1300	210	2800	860	3.2	40	706
Kendall Bay Background Sites – 0 to 300 mm										
Analyte	Sum C10-C40	Total PAH	TOC %	PAH Norm 1%	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Samples	16	16	16	16	16	16	16	16	16	16
Mean	594	22	4.8	3.3	66	63	122	0.7	10	253
Min	<250	0.2	0.08	0.64	6.9	6.7	22	0.01	4	50
Max	2320	130	15	13	130	130	240	1.4	17	570
Exile Bay Background Sites – 0 to 300										
Analyte	Sum C10-C40	Total PAH	TOC %	PAH Norm 1%	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Samples	6	6	6	6	6	6	6	6	6	6
Mean	219	7.3	1.5	4.2	53	82	115	0.4	6.5	250
Min	<250	1.2	0.6	1.9	10	30	30	0.06	1.0	50
Max	785	21	2.9	7.2	120	260	300	1.2	14	580
Majors Bay Background Sites – 0 to 300										
Analyte	Sum C10-C40	Total PAH	TOC %	PAH Norm 1%	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Samples	11	11	11	11	11	11	11	11	11	11
Mean	526	10	2.9	7.4	124	91	182	0.6	13	426
Min	<250	1.3	0.44	1.02	15	19	41	0.1	2	70
Max	1215	22	6.3	49.5	230	140	250	0.84	24	760

GV: ANZECC Sediment Quality Guideline Value (Simpson et al., 2013)

On this basis the sediments from the Northern and Southern Investigation Areas are considered to be potentially toxic to benthic organisms due to high levels of TRHs and PAHs. These sediments could also be toxic due to elevated levels of metals, particularly chromium, copper, lead, mercury, nickel and zinc, although as discussed in **Section 4.2** and shown in **Table 4.3**, the levels of these and other metals in the gasworks-contaminated areas of Kendall Bay are comparable to the levels found elsewhere in the Parramatta River. Therefore, toxicity due to elevated metal levels is attributable to the regional heavy metal background rather than to gasworks contamination.

8.2.2 Detailed Assessment

Because the preliminary assessment indicated that gasworks-contaminated sediments were likely to be toxic, a more detailed investigation was carried out. This included a weight-of-evidence (**WOE**) assessment (Simpson et al, 2013) (**Section 2.3.6**, point 2, above and **Figure 2.4**).

The WOE procedure combines assessments of:

- a) sediment chemistry to measure contaminant concentrations, compare to GVs (if available) and identify COPCs. These measurements may include chemistry-based bioavailability tests;
- b) toxicity testing (e.g. multiple species, varying exposure pathways, and acute and chronic endpoints such as mortality, reproduction, development, growth, avoidance);
- c) bioaccumulation/biomagnification; and
- d) benthic community structure (e.g. ecological malfunction).

The sediment chemistry and bioaccumulation studies have previously been discussed. New investigations included bioavailability and toxicity testing, and benthic community studies. The results of these studies are described below.

8.2.2.1 Toxicity and Bioavailability Testing

CSIRO's Aquatic Contaminants Group was engaged to investigate the chemical bioavailability and toxicity of contaminants within the sediments at Kendall Bay and to provide advice on the development of appropriate chemical remediation targets. The work is summarised below and reported in Simpson and Spadaro, 2015, and Simpson et al., 2016, and Simpson et. al 2018.

Methods

Bulk sampling for toxicity and chemical testing was carried out in four phases, in May 2015, July 2015 and February 2016, and October 2017. A total of 47 samples, each comprising 3-4 kg of sediment, were collected for toxicity testing at CSIRO, Lucas Heights. Sample locations were shown on **Figures 4.2 to 4.4**, previously.

The 21 sample locations selected in Phases 1 and 2 were intended to represent the full range of gasworks-contaminated sediments in Kendall Bay, from locations distant from the gasworks as well as locations where visible tars and oils were present, plus background locations beyond the influence of the gasworks.

The 10 sample locations in Phase 3 were chosen to provide further information on sediments that could cause acute toxicity to benthic organisms, and therefore samples were collected from areas where gasworks contamination was known to be present at the sediment surface.

In October 2017 a further 16 locations were sampled and tested. This testing was carried out to obtain further information on chronic toxicity of sediments in Kendall Bay as well as sediments from bays outside Kendall Bay which have background levels of metals, TRHs and PAHs but are not exposed to gasworks contamination. Accordingly, samples were collected from the eastern and northern sides of Kendall Bay, away from the areas of heavy gasworks contamination sampled previously, as well as from Brays, Yaralla and Majors Bays to the north-west, and Canada and Exile Bays to the south-east.

Analysis of total concentrations of major contaminants in the sediments was done by external NATA-accredited laboratories Envirolab and NMI, and the results provided to CSIRO. The major contaminants included metals and metalloids, PAHs and TPHs. Analyses for BTEX and naphthalene were carried out on all samples. Selected samples were analysed for OC and OP pesticides, and PCBs. Porewater analyses were undertaken on selected samples (extracted by centrifugation under nitrogen).

Bioavailability and toxicity testing were carried out at CSIRO's Aquatic Contaminants Group, Lucas Heights, using standard methods as described in Simpson and Spadaro, 2015 and Simpson et al, 2016. Other aspects of sampling, subsampling, sample handling, preservation and decontamination are described in S&W, 2017a.

Results

Bioavailability Testing

Bioavailability testing was carried out on samples from the Phase 1 and 2 sampling events. Testing included analysis of porewaters and elutriates for PAHs and TRHs, and analysis for dilute-acid extractable metals, acid-volatile sulfides and simultaneously available metals (**AVS:SEM**). Equilibrium partitioning models were also considered for the organics and metals. Key data on the sediments is summarised in **Table 8.4**. Key data on the sediments sampled in the chronic investigation, October 2017, is summarised in **Table 8.5**.

Metals

Dilute-acid extractable metal (**AEM**) analyses showed that lead and zinc should be considered metals of potential concern in most sediments, and copper for some sediments. Based on extensive studies of the ecotoxicological effects of these metals to benthic organisms, it is likely that the mixed metal contamination would result in chronic toxicity for some of these sediments (Simpson et al., 2011; 2013; 2014a, b).

The AVS concentrations of the Kendall Bay sediments ranged from 0.1 to 43 $\mu\text{mol/g}$. The AVS-SEM analyses indicated that many sediments had a small to moderate excess of potentially bioavailable metals (Cd, Cu, Ni, Pb and Zn). The Kendall Bay sediments are unique owing to the large portion of organic carbon in the form of coal tar and coal particles. Because of this, the application of the extended form of the AVS-SEM model that includes metal-binding to OC may not be appropriate. In the extended model, sediments with $(\text{SEM-AVS})/\text{foc} < 130 \mu\text{mol/gOC}$ (where foc = fraction of OC in the sediments) are predicted to pose a low risk of adverse biological effects. When applied to Kendall Bay, the extended model predicts only a few sediments contain SEM at concentrations and forms that may pose a risk to benthic organisms.

Organics

The bioavailability of hydrophobic organic contaminants, such as PAHs, is influenced by the concentration of TOC in sediments. Both natural sedimentary organic carbon, which includes diagenetic organic carbon such as plant material, and also forms of pyrogenic or Black Carbon (**BC**) (e.g. soot, coal tars and coal and coke particles) and residues of incomplete combustion (e.g. charcoal), may exist in aquatic sediments. BC may typically constitute 10% of TOC in ordinary sediments (Middelburg et al., 1999). In sediments impacted by fossil-fuel related residues of historic industrial activity, the contribution of BC may exceed 50% of the TOC. The sorption of PAHs to BC is typically 10-1,000 times stronger than the sorption to naturally occurring TOC (Koelmans et al., 2006; Maruya et al., 2010; USEPA, 2012).

All of the Kendall Bay sediments displayed a high proportion of BC (54 to 100% of TOC), with 8 of 14 sediments from Area A having greater than 10% BC (>100,000 mg BC/kg dry weight). These observations were consistent with the presence of a large amount of coal tar and coal and coke particles present in many sediments, as noted in **Section 4.2**. The risk of toxicity posed by PAHs in sediments is predicted to be considerably less for sediments that contain high BC concentrations, however, the existing models appear to provide poor predictions for Kendall Bay sediments.

Table 8.4. Summary of major sediment contaminants, Phase 1, 2 and 3 testing

SEDIMENT LOCATION	TOTAL PAHs, mg/kg		TPHs, mg/kg	TOTAL METALS, mg/kg			DILUTE-ACID EXTRACTABLE METALS, mg/kg		
	(raw)	normalised to 1% TOC		Cu	Pb	Zn	Cu	Pb	Zn
Kendall Bay (Phase 1)									
100 (Area A*)	25	10	285	27	49	120	4	27	62
101 (Area A)	8	25	125	8	15	41	10	10	27
102 (Area A)	63	6.3	745	10	16	79	4	22	118
103 (Area A)	93	9.3	1310	47	95	610	4	44	386
104 (Area A)	67	6.7	1060	42	110	620	4	69	455
108 (Area A)	100	10	1740	100	140	390	28	117	348
109 (Area A)	630	63	11100	50	91	420	15	71	382
110 (>Area A)	170	17	3190	120	150	420	44	156	439
Kendall Bay (Phase 2)									
402 (Area A)	110	12	1610	20	63	150	4	25	118
403 (Area A)	1750	175	33150	38	95	225	1	48	143
405 (Area A)	135	14	4700	74	150	370	33	119	298
406 (Area A)	555	56	8815	59	130	340	27	84	235
407 (Area A)	160	16	2540	57	130	500	11	69	392
410 (Area B*)	620	62	16600	99	190	440	38	164	400
411 (Area B)	38	10	748	160	260	610	75	250	541
408 (NE side)	13	4.3	538	130	240	570	78	258	552
409 (NE side)	25	5.2	468	96	200	450	63	181	392
Exile Bay (Phase 2)									
404	1	1.9	138	53	115	325	16	85	242
412	21	7.2	798	30	30	50	7	21	33
Majors Bay (Part 2)									
401	8	4.0	138	260	300	580	121	302	576
413	11	3.6	718	120	250	600	59	239	562
Phase 3									
KB731	480	48	9070	86	160	360	NA	NA	NA
KB732	3150	320	51100	70	190	410	NA	NA	NA
KB733	13000	1300	101000	52	250	660	NA	NA	NA
KB734	850	85	15900	64	110	270	NA	NA	NA
KB735	28	9	990	86	160	340	NA	NA	NA
KB736	390	39	7740	42	98	460	NA	NA	NA
KB737	480	48	8440	49	120	360	NA	NA	NA
KB738	240	24	4120	39	91	220	NA	NA	NA
KB739	370	37	5290	48	100	240	NA	NA	NA
KB740	250	25	4260	45	660	300	NA	NA	NA
Guideline value		10	280	65	50	200			

TPHs = total recoverable petroleum hydrocarbons (also referred to as TRHs). PAHs, TPHs and total metal concentration data analysed by Envirolab Services. Dilute-acid extractable metal analyses made by CSIRO The GV's are from ANZECC/ARMCANZ (2000), as per the proposed revision of Simpson et al. (2013). Average value shown where replicate sample analyses undertaken.

* Area A is equivalent to the Southern Investigation Area, Area B = the Northern Investigation Area.

Table 8.5. Summary of major sediment properties and contaminants, October 2017 Sampling

SEDIMENT LOCATION	TOTAL PAHs, mg/kg		TPHs	TOTAL RECOVERABLE METALS, mg/kg							
	(raw)	normalised to 1% TOC	mg/kg	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Kendall Bay											
KBR4	33	4.3	565	16	<0.4	76	104	0.95	10	120	285
KBR5	15	2.7	240	21	<0.4	95	120	1.2	13	150	360
KBR6	16	3.4	355	24	<0.4	110	140	1.3	16	180	420
KBR7	9.2	3.4	235	21	<0.4	130	170	1.4	17	200	480
KBR8	5.2	1.8	125	15	<0.4	93	130	1.0	12	150	350
KBR9	18	6.9	365	24	<0.4	100	140	1.5	13	170	380
KBR11	16	5.7	295	22	<0.4	120	150	1.4	15	180	440
KBR12	20	31	385	20	<0.4	87	110	1.2	12	140	340
Brays Bay											
KBR1	1.9	1.3	125	17	<0.4	77	75	0.5	10	110	270
KBR2	2.2	1.7	160	16	<0.4	67	71	0.5	8.5	99	240
Majors Bay											
KBR3	7.8	2.4	125	15	0.8	84	81	0.5	10	110	310
MB18	3.9	1.6	125	17	0.7	160	150	0.8	17	190	475
KBR14 (entrance)	2.7	1.1	125	16	<0.4	93	100	0.6	11	130	310
Exile Bay											
KBR17	6.4	2.8	185	26	0.7	130	380	1.3	16	290	570
Canada Bay											
KRB16	5.4	2.3	125	18	<0.4	100	330	0.8	11	180	400
KBR15	5.3	1.7	245	23	0.4	150	540	0.9	15	280	580
Guideline value (SQGV)		10	280	20	1.5	80	65	0.15	21	50	200
SQG-High		50	550	70	10	370	270	1	52	220	410

PAHs = polycyclic aromatic hydrocarbons. TPHs = total recoverable petroleum hydrocarbons (also referred to as TRHs). PAHs, TPHs and total metal concentration data provided by Synnot and Wilkinson Pty Ltd (analysed by Envirolab Services). The GVs are from ANZECC/ARMCANZ (2000), as per the proposed revision by Simpson et al. (2013). Average values are shown where replicate sample analyses were undertaken.

Porewater was able to be extracted from some of the sediments. The data are presented in **Table 8.6** for PAHs and **Table 8.7** for TRHs.

Australia's current water quality guidelines for PAHs are considered to be of low reliability (ANZECC/ARMCANZ, 2000). For naphthalene in marine waters, the 95% species protection concentration is 70 µg/L. To express the potential risk posed by the PAHs in the pore waters and elutriates, a form of toxic unit (TU) was calculated (**Table 8.6**). The TU was based on final chronic values for individual PAHs as described in USEPA (2012). If the TUs are greater than one, then benthic organisms may not be protected and adverse effects may result. For each of the pore waters extracted from bay sediments collected from the Southern Investigation Area, the TUs were between 1.2 and 5.0 (Sediments 108, 109, 110, 402, 403, and 406), indicating potential for adverse effects from PAHs.

For the sediment elutriates prepared from samples collected in the mangroves (101 to 104), the TUs for the dissolved PAHs concentrations ranged from 0.19 to 0.25. This indicates that PAHs released from those sediments by a disturbance would likely be re-adsorbed or diluted by surrounding waters to levels that would not be predicted to cause adverse effects.

Table 8.6. Porewater concentrations of PAHs

PAH SEDIMENT	CONCENTRATIONS OF INDIVIDUAL PAHS (µg/L)									
	KENDALL BAY (Phase 1)			KENDALL BAY (Phase 2)					EXILE BAY	
	108	109	110	402	403	406	408	410	404	412
Naphthalene	0.01	0.04	0.01	0.77	0.10	0.04	0.02	0.03	0.02	0.02
Acenaphthylene	0.16	0.36	0.12	4.8	0.59	0.18	0.06	0.11	0.04	0.02
Acenaphthene	0.01	0.04	0.01	17	0.72	0.44	0.05	0.01	0.78	0.05
Fluorene	0.02	0.06	0.01	1.1	0.40	0.10	0.01	0.05	0.03	0.03
Phenanthrene	0.02	0.09	0.02	3.6	0.74	0.14	0.19	0.18	0.21	0.35
Anthracene	0.04	0.12	0.03	0.81	0.49	0.07	0.04	0.03	0.04	0.08
Fluoranthene	0.09	0.33	0.07	1.9	4.45	0.69	0.17	0.22	0.34	0.43
Pyrene	0.34	0.90	0.25	2.3	3.7	0.97	0.26	0.37	0.34	0.44
Benz(a)anthracene	0.06	0.17	0.04	0.09	0.06	0.07	0.03	0.03	0.01	0.01
Chrysene	0.10	0.28	0.07	0.08	0.06	0.06	0.03	0.03	0.01	0.01
Benzo(b)&(k)fluoranthene	0.44	0.88	0.39	0.07	0.03	0.10	0.06	0.10	0.02	0.02
Benzo(a)pyrene	0.33	0.68	0.29	0.04	0.02	0.09	0.05	0.07	0.01	0.01
Indeno(1,2,3-cd) pyrene	0.14	0.26	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Dibenz(ah)anthracene	0.04	0.08	0.03	0.02	0.01	0.05	0.02	0.04	0.01	0.01
Benzo(ghi)perylene	0.16	0.30	0.14	0.02	0.01	0.05	0.03	0.05	0.01	0.01
Porewater toxic unit	2.4	5.0	2.0	3.8	2.2	1.2	0.57	0.82	0.40	0.47

The toxic unit (TU) was calculated based on final chronic values for individual PAHs as described in Appendix A. Where concentrations were below the limit or reporting (LOR), the LOR values (0.01 or 0.02 µg/L) are shown.

Table 8.7. Porewater concentrations of TRHs

TPH FRACTION SEDIMENT	CONCENTRATIONS of TRH (C-fraction) (µg/L)						
	KENDALL BAY (Phase 2)					EXILE BAY	
	402	403	406	408	410	404	412
C10 - C14	170	60	110	240	140	61	130
C15 - C28	400	240	520	280	230	<100	140
C29 - C36	<100	<100	<100	<100	<100	<100	<100
>C10 - C16	300	100	210	310	180	71	160
>C16 - C34	260	180	440	200	180	<100	110
>C34 - C40	<100	<100	<100	<100	<100	<100	<100

Toxicity Testing

Initial Assessment (2015 and 2016)

Assessment of sediment toxicity to benthic organisms was undertaken using an amphipod survival and reproduction test (*Melita plumulosa*) and a harpacticoid copepod reproduction test (*Nitocra spinipes*) (Tables 8.8 and 8.9), with survival added as an endpoint for the copepod in Phase 3 (Table 8.9). The tables include sediment quality guideline quotients (SQGQ), which provide a perspective on the results. An SQGQ is the concentration of a contaminant divided by its SQGV.

Table 8.8. Phase 1 and 2 summary: toxicity and sediment quality guideline quotients for metals and organics

Sediment location	Toxicity	AMPHPOD % of Mean Survival	Copepod % of Mean Survival Category	Toxicity	Reproduction	SQG Metals	Total PAHs	2 Classes Metals+ PAHs
100 (Area A*)	No Acute-Chronic(M)	94 (3)	53 (7)	Chronic(M)	53 (12)	0.5	1.1	0.8
101 (Area A)	No Acute-Chronic(L)	94 (3)	67 (5)	Chronic(M)	30 (3)	0.2	2.5	1.4
102 (Area A)	No toxicity	96 (6)	75 (12)	No Toxicity	91 (14)	0.2	0.6	0.4
103 (Area A)	No Acute-Chronic(H)	83 (3)	19 (5)	Chronic(M)	31 (4)	1.5	0.9	1.2
104 (Area A)	No Acute-Chronic(H)	85 (7)	28 (2)	Chronic(H)	20 (4)	1.6	0.7	1.1
108 (Area A)	No Acute-Chronic(L)	98 (5)	75 (6)	Chronic(H)	17 (4)	1.6	1.0	1.3
109 (Area A)	No Acute-Chronic(L)	89 (8)	70 (11)	Chronic(M)	46 (5)	1.3	6.3	3.8
110 (~Area A)	No Acute-Chronic(M)	98 (4)	63 (4)	Chronic(M)	45 (5)	1.7	1.7	1.7
Kendall Bay (Phase 2)								
402 (Area A)	Acute(vH)	0 (0)	0 (0)	Chronic(H)	4 (2)	0.8	1.2	1.0
403 (Area A)	Acute(H)-Chronic(H)	19 (9)	0 (0)	Chronic(H)	3 (2)	2.8	18	10
405 (Area A)	No Acute-Chronic(M)	93 (5)	48 (9)	Chronic(H)	27 (30)	1.5	1.4	1.4
406 (Area A)	Acute(L)-Chronic(H)	63 (10)	17 (9)	Chronic(H)	9 (3)	1.5	5.6	3.5
407 (Area A)	No Acute-Chronic(M)	92 (6)	57 (8)	No Toxicity	75 (8)	2.0	1.6	1.8
410 (Area B*)	Acute(M)-Chronic(M)	57 (14)	62 (11)	Chronic(H)	12 (3)	1.7	6.2	4.0
411 (Area B)	No Acute-Chronic(M)	87 (4)	55 (5)	No Toxicity	83 (6)	2.4	1.0	1.7
408 (NE side)	No Acute-Chronic(L)	89 (2)	84 (3)	Chronic(L)	66 (8)	2.1	0.4	1.3
409 (NE side)	No Acute-Chronic(L)	102 (2)	71 (3)	Chronic(L)	60 (4)	1.7	0.5	1.1
Exile Bay (Phase2)								
404	No Acute-Chronic(M)	88 (4)	60 (10)	Chronic(L)	62 (6)	1.2	0.4	0.8
412	No toxicity	100 (3)	90 (7)	No Toxicity	85 (3)	0.3	0.2	0.2
Majors Bay (Phase 2)								
401	No Acute-Chronic(L)	104 (0)	79 (16)	Chronic(M)	56 (6)	2.8	0.7	1.8
413	No toxicity	98 (4)	102 (16)	Chronic M)	48 (4)	2.3	0.4	1.3

L = low, M = moderate H = high, and vH = High indicate the degree of acute or chronic toxicity.

* Area A is equivalent to the Southern Investigation Area, Area B = the Northern Investigation Area. See full test results in Appendix C of Simpson. *et al*, 2016, for more detailed descriptions. Descriptions of the SQG Quotients are provided in Appendix A of Simpson. *et al*, 2016.

Table 8.9. Phase 3 summary: toxicity and sediment quality guideline quotients (SQGQ) for metals and organics

SEDIMENT LOCATION		AMPHIPOD % CONTROL MEAN (SE)		COPEPOD % CONTROL MEAN (SE)		SQG-QUOTIENTS		
						METALS	TOTAL PAHs	2 CLASSES METALS + PAHs
Phase 3	Category	Survival	Reproduction	Survival	Reproduction			
KB731	Acute(H) - Amphipod No toxicity - Copepod	2 (2)	0 (0)	94 (6)	61 (8)	1.5	4.8	3.2
KB732	Acute(vH) Acute(vH)	0 (0)	-	0 (0)	-	1.7	32	17
KB733	Acute(vH) Acute(vH)	0 (0)	-	0 (0)	-	2.4	130	66
KB734	Acute(H) Acute(M)-Chronic(H)	19 (13)	5 (3)	39 (7)	0 (0)	1.1	8.5	4.8
KB735	No toxicity Acute(L)-Chronic(M)	98 (4)	96 (14)	80 (5)	41 (10)	1.4	0.90	1.1
KB736	Acute(vH) Acute(H)-Chronic(H)	0 (0)	-	14 (5)	0 (0)	1.3	3.9	2.6
KB737	Acute(vH) Acute(vH)-Chronic(H)	0 (0)	-	0 (0)	0 (0)	2.6	4.8	3.7
KB738	Acute(M)-Chronic(H) Acute(L)-Chronic(H)	53 (4)	26 (6)	67 (5)	21 (5)	1.3	2.4	1.9
KB739	Acute(L)-Chronic(H) Chronic(H)	65 (5)	26 (4)	69 (15)	9 (5)	1.5	3.7	2.6
KB740	Acute(L)-Chronic(M) Acute(H)-Chronic(H)	78 (4)	64 (3)	14 (7)	0 (0)	3.7	2.5	3.1

Categories of toxicity (amphipod row 1, copepod row 2): low, M = moderate H = high, and vH = High indicate the degree of acute or chronic toxicity. See full test results in Appendix C of Simpson. *et al*, 2016, for more detailed descriptions. Descriptions of the SQG-Quotients are provided in Appendix A of Simpson. *et al*, 2016.

Toxicity to amphipod and copepod reproduction was observed in all Kendall Bay sediments, except sample 102 from the mangroves. For sample 102, the chemical analyses had indicated a low risk of adverse biological effects. Despite the lower concentrations of PAHs and TPHs, the two sediments from the north-eastern side of Kendall Bay (samples 408 and 409), that were intended to represent background sites largely unimpacted by the gasworks operations, showed moderate levels of chronic toxicity (<50% effect).

Of the four sediments collected from the neighbouring bays (Exile and Majors Bays), one from each bay showed moderate levels of chronic toxicity. The two sediments that exhibited no toxicity had TPH concentrations of 720 and 800 mg/kg, and had moderate to low concentrations of BC (0.5 and 5.1%) compared to the Kendall Bay sediments.

Four of the fifteen Kendall Bay sediments from Phase 1 and 2 (**Table 8.8**), and nine of ten sediments from Phase 3 resulted in acute toxicity to the amphipod (**Table 8.9**). Of the Phase 3 sediments, the one sediment that did not cause acute toxicity to the amphipod did cause a low degree of acute toxicity to the copepod.

Of the Phase 2 sediments, the four that caused acute toxicity, 402, 403, 406 and 410, had the highest concentrations of more volatile PAHs (e.g. naphthalene and acenaphthylene) and also had the highest TRH concentrations (1610 – 33150 mg/kg, respectively). Sediments 103 and 104 from Phase 1 had a naphthalene-like odour but did not cause acute toxicity. The least toxic of the Phase 3 sediments was KB735 and this had by far the lowest concentration of total PAHs and TRHs of those ten sediments. The two sediments (KB732 and KB733) that caused very high acute toxicity to both species had the highest concentrations of total PAHs and TPHs of those ten sediments. The results for KB731 appeared unusual due to no toxicity being observed

for the copepod, but high acute toxicity to the amphipod that was consistent with the high concentrations of total PAHs and TPHs.

Chronic Toxicity Assessment, October 2017

The data for the chronic toxicity testing carried out in October 2017 is shown in **Tables 8.5** (above) and **8.10**.

Concentrations of total PAHs were below the SQGV of 10 mg/kg (1% TOC), except for one of the outermost sites of Kendall Bay (KBR12) where a value of 31 mg/kg (1% TOC) was measured. The concentrations of TPHs (C10-C40) were higher in most sediments from outer Kendall Bay compared to sediments from the other bays, with the highest concentration of 565 mg/kg being measured at the outermost point (KBR4). The guidelines for TPHs are considered to be of low reliability, and a SQGV of 280 mg/kg has been recently recommended as part of the proposed revision of the Australian and New Zealand sediment quality guidelines (Simpson et al., 2013).

The levels of metal contamination were similar to those observed in the past studies and similar to that observed throughout much of the western Parramatta River where the highest concentrations typically occur within the inner parts of embayments closer to stormwater sources (Birch and Taylor, 2004). When comparing the outer Kendall Bay sites to the other embayments, the major metal contaminants were Cu, Pb and Zn, with overlap of the ranges in concentrations. The concentration of mercury (Hg) exceeded the SQG-High value in many of the outer Kendall Bay sediments. However, as noted in Simpson et al. (2016), a recent critical review of effects and guidelines for mercury indicated that sediments with <3 mg Hg/kg should pose a low risk of adverse effects to benthic organisms (Condor et al., 2015).

Typical of many estuarine sediments, exceedances of SQGVs were also observed for arsenic and nickel, which is largely consistent with background concentrations in finer particle size materials. This may also be the case for chromium, although significant sources of chromium may also exist in the urban environment. Analyses of dilute-acid extractable metals indicated that the majority of the lead and zinc, but a lesser portion of copper, were present in potential bioavailable forms. Sediment quality guideline quotients (SQGQs), relating to the magnitude by which contaminants exceed the guidelines, were calculated and are shown in **Table 8.10**. As expected, these indicate that the metals Cu, Pb and Zn (Cd and Ni were also included in quotient, but not Hg) were the dominant COPCs, with SQGQs >1 for all sediments, compared to SQGQs for total PAHs being generally <0.5, except for three sediments from outer Kendall Bay.

The assessment of the toxicity of the sediments to benthic organisms was undertaken using an amphipod survival and reproduction test (*Melita plumulosa*) (Table 5). The additional testing of sixteen sediments from outer Kendall Bay and other nearby embayments provided a useful addition to the data gathered in previous studies (Simpson and Spadaro, 2015; Simpson et al., 2016), however, higher levels of both metal contamination and toxicity were initially expected. No sediments exhibited toxicity to survival of the amphipod (described as 'acute toxicity'), and this was consistent with none of the sediments having concentrations of total PAHs greater than 60 mg/kg (1% TOC) or TRHs greater than 5500 mg/kg (Simpson et al., 2016). The sediments exhibiting the greatest toxicity were the two from Canada Bay and one from Majors Bay, with the sediment from Exile Bay (KBR17) having similarly higher metal concentrations but not causing any toxicity.

Concentration-response relationships between ecotoxicity and sediment contaminants

For the Kendall Bay sediments, the earlier studies (Simpson et al., 2016) found that the concentrations of total PAHs provided the strongest relationship with the observed acute toxicity (e.g. organism survival), and the concentrations of metals and total PAHs expressed in the form of a SQGQ provided the strongest relationship with the observed chronic toxicity (e.g. organisms reproduction) (Figures 8.1 and 8.2).

Figure 8.1. Relationship between toxicity to amphipod and copepod reproduction and exceedances of sediment quality guideline values (SQGVs) for metals and total PAHs (1% TOC), as represented by mean sediment quality guideline quotient (SQGQ) values. The filled symbols represent the data for Kendall Bay (red), Sydney Harbour (Parramatta River, blue), and open symbols for other sediments in NSW or Tasmania using these tests.

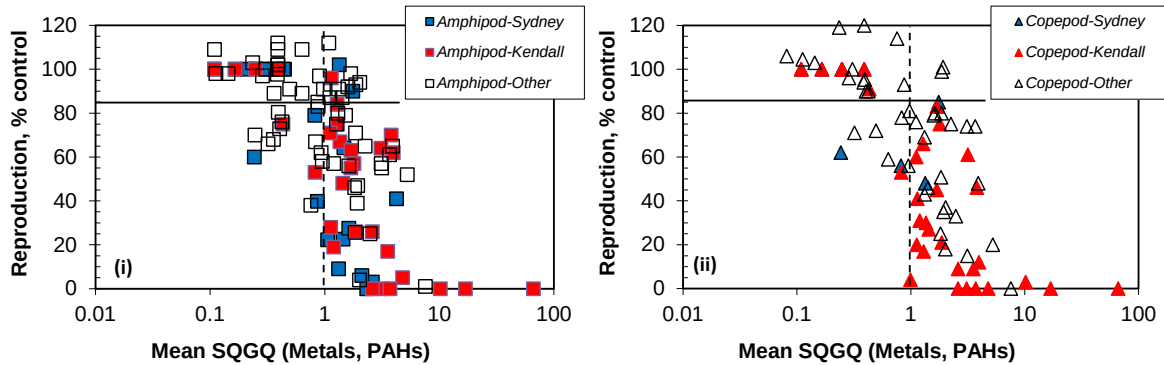
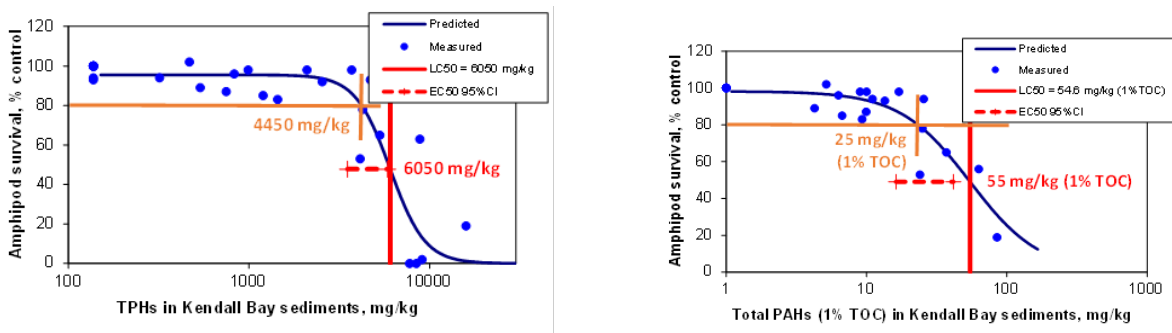


Figure 8.2. Relationship between toxicity to survival of the amphipod *M. plumulosa* and the concentrations in the Kendall Bay sediments of TPHs and total PAHs (1% TOC).



Those studies indicated that there would be a low risk of acute toxicity to benthic organisms for Kendall Bay sediments when:

- total PAH concentrations: average <25 mg/kg (1% TOC) (representing effects thresholds) and maximum <55 mg/kg (1% TOC) (representing effects occurring frequently); and
- TRH concentrations: average <4400 mg/kg and maximum <6000 mg/kg.

Based on the data available for those studies, in combination with data sets (chemistry and ecotoxicology) from other studies of sediments in the Parramatta River area within approximately 5 km of Kendall Bay, it was considered likely that the significant level of ‘background contamination’ that exists within the region would continue to result in some level of ‘background toxicity’ in the form of moderate levels of chronic toxicity (e.g. sublethal effects to organism reproduction). The strongest relationships between COPCs are the observed chronic toxicity.

From the present study, the testing of an additional 16 sediments strengthens our understanding of background concentrations or COPCs and chronic toxicity within areas surrounding the proposed Kendall Bay remediation area. The following analysis utilised paired chemistry-ecotoxicity data, comprising 19 points (data sets) for Controls, 10 for inner bays of 2-4 km east of Kendall Bay (Kings Bay, Five Dock Bay, Iron Cove), 11 for bays 1-2 km from Kendall Bay (Bays Bay, Exile Bay, Majors Bay, Canada Bay), 10 for outer Kendall Bay (outside proposed remediation areas), and 22 data sets for sites within the proposed remediation areas. Data sets from sites further away or for very sandy sediments (e.g. <25% silt) were not included, but some were in the data analysis undertaken by Simpson et al. (2016).

Table 8.10. Chronic Toxicity Sampling, October 2017. Toxicity and sediment quality guideline quotients (SQGQ) for metals and organics

SEDIMENT		AMPHIPOD % OF CONTROL MEAN (SE)		SQG QUOTIENTS		
				METALS	TOTAL PAHs	2 CLASSES METALS + PAHs
LOCATION	Category	Survival	Reproduction			
Kendall Bay						
KBR4	No toxicity	94 (5)	99 (10)	1.26	0.43	0.84
KBR5	No toxicity	99 (4)	85 (14)	1.53	0.27	0.90
KBR6	No toxicity	94 (3)	94 (9)	1.80	0.34	1.07
KBR7	No toxicity	101 (2)	85 (7)	2.04	0.34	1.19
KBR8	No toxicity	90 (4)	109 (8)	1.54	0.18	0.86
KBR9	No toxicity	103 (0)	102 (3)	1.69	0.69	1.19
KBR11	No Acute-Chronic(M)	94 (9)	61 (6)	1.84	0.57	1.21
KBR12	No toxicity	94 (5)	83 (9)	1.43	3.08	2.25
Brays Bay						
KBR1	No toxicity	97 (6)	87 (9)	1.12	0.13	0.62
KBR2	No toxicity	99 (2)	94 (6)	1.01	0.17	0.59
Majors Bay						
KBR3	No toxicity	96 (4)	80 (9)	1.25	0.24	0.75
MB18	No Acute-Chronic(M)	92 (4)	32 (3)	1.99	0.16	1.08
KBR14 (entrance)	No toxicity	99 (2)	93 (10)	1.32	0.11	0.72
Exile Bay						
KBR17	No toxicity	90 (6)	89 (18)	3.19	0.28	1.73
Canada Bay						
KRB16	No Acute-Chronic(M)	94 (3)	43 (6)	2.32	0.23	1.28
KBR15	No Acute-Chronic(M)	86 (7)	37 (4)	3.58	0.17	1.88

Acute toxicity determined for the amphipod, but not the copepod in Phase 1 and 2 testing.

L = low, M = moderate H = high, and vH = High indicate the degree of acute or chronic toxicity.

Descriptions of the SQGQ (Quotients) are provided in Appendix A. See full test results in Appendix B for more detailed descriptions.

The analysis of the effects data based on SQGQs that include metals (Cd, Cu, Ni, Pb and Zn) and total PAHs as the main contaminants of concern (COCs) indicated the following (**Figure 8.3**):

- Organism survival (**1S, 2S and 3S**) is adversely affected only for sediments from sites within the proposed remediation area and from sites in the inner bays 2-4 km east of Kendall Bay (Key: Bay-ParaRiv). The frequent very high acute toxicity of the Kendall Bay sediments proposed for remediation (**1S**) is clearly demonstrated when they are removed in **2S** (KBRMDArea removed). The absence of acute toxicity of sediments in the outer Kendall Bay area (outside proposed remediation areas) and also those from bays near Kendall Bay (Key: Bay-NearKB) is demonstrated in **3S**.

Note, inner bay sites, such as those indicated by 'Bay-ParaRiv', are where sources of stormwater continue to impact the bays through inputs of contaminants, particularly metals such as copper and zinc.

- Organism reproduction (**1R, 2R, 3R**) is adversely affected in sediments from all areas, except for Controls (**1R**). Compared to sediments tested from outer Kendall Bay, the incidence of chronic effects to organism reproduction is higher for sediments from other inner bay sites (e.g. **2R**: high to very high chronic toxicity for 'Bay-ParaRiv') and similar or higher for bays near Kendall Bay (e.g. **3R**: low to high chronic toxicity for 'Bay-NearKB').
- The incidence of high to very high chronic toxicity is frequent for sediments from within the proposed remediation area, compared to few instances of chronic toxicity and none with high or very high chronic toxicity

in sediments tested from Outer Kendall Bay. The best visualisation of the impact of the proposed remediation is provided by comparing **4R** and **5R**.

Reducing the risk of toxicity to benthic organisms from gasworks contamination.

A strong contaminant effects data set has been generated for chronic effects (amphipod and copepod), however, due to the joint contributions of metals and PAHs to the observed toxicity. It is not considered possible to use these data to effectively develop separate remediation targets. However, it is considered useful to use the available data for surface sediments to calculate and compare mean and 95% Upper Confidence Limits (95%UCL of the mean) for SQGQs and chronic effects to the amphipod (Figure 3, Appendix B of Simpson et. al, 2018).

The predictive ability of these values must be considered in relation to the relative small size of the data sets, and also the selection of sites for testing, but they do provide another perspective how the proposed remediation will considerably reduce the likelihood of adverse effects to benthic organisms. In addition to the analysis of the effects data, we calculated a mean and 95%UCL of the SQGQ of 1.4 and 1.6, respectively, for surface sediments within inner Kendall Bay that lie outside of the proposed remediation area. We don't have effects data specifically for this inner Kendall Bay area, but based on the effects relationships for the other areas and the calculated SQGQs we have indicated where we expect this area to lie in **Figure 8.4**.

Overall, the results are consistent with the earlier studies, and indicate that significant improvements in ecosystem health may be expected to be achieved by removal or isolation of sediments that caused acute toxicity to benthic organisms. The results continue to indicate that remediation targeting areas where chronic toxicity is observed may be ineffective at eliminating chronic toxicity of the sediments in the longer term as remediated areas within the bay will be expected to become re-contaminated as sediment from the surrounding environment is redeposited, and also from future stormwater inputs.

Remediation that targets the acute toxicity of the Kendall Bay sediments that exists within the proposed remediation areas (i.e. intended to result in the remaining surface sediments having total PAHs with mean <25 mg/kg (1% TOC) and none with >55 mg/kg (1% TOC)) should eliminate acute toxicity and result in few instances of chronic toxicity to benthic organisms in Kendall Bay.

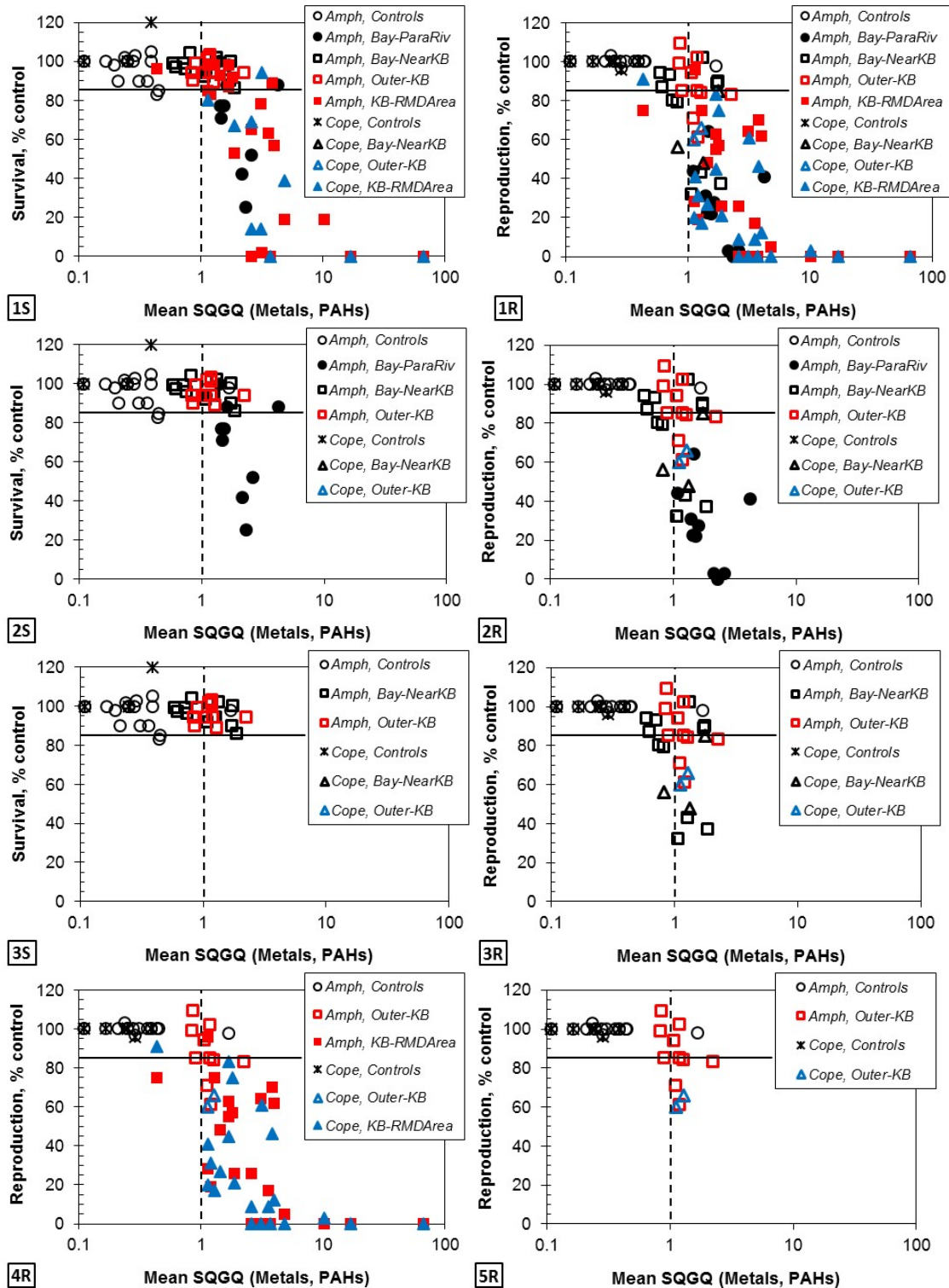


Figure 8.3. Comparison of toxicity (survival on left and reproduction on right) to mean sediment quality guideline quotient (SQGQ) values derived using GVs and SQGQs based on the concentrations of total metals and total PAHs (1% TOC): 1S,1R = All data, 2S,2R = removed data within the proposed remediation area, and 3S,3R = removed data within the proposed remediation and sites 2-4 km away from Kendall Bay. 4R,5R = comparison of data for Kendall Bay only. Descriptions of the SQGQs are provided in Appendix A (Simpson et al. 2016, 2018). The horizontal solid line indicates 85%. The vertical dashed line represents SQGQ = 1.

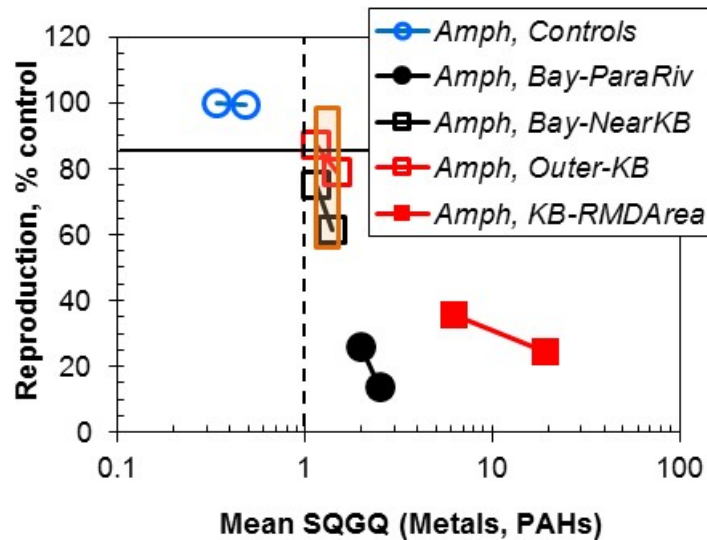


Figure 8.4. Comparison of the mean and 95% Upper Confidence Limits (95%UCL) of toxicity to reproduction of the amphipod versus the sediment quality guideline quotient (SQGQ for metals + total PAHs). The orange box indicates the inner Kendall Bay area that lie outside of the proposed remediation area, where SQGQ data exists without effects data. Descriptions of the SQGQs are provided in Appendix A (Simpson et al. 2016, 2018). The horizontal solid line indicates 85% reproduction. The vertical dashed line represents SQGQ = 1. Other lines join the mean and 95%UCL pairs (calculated using ProUCL 5.1).

The toxicity status of all the tested sediments is shown on **Figure 8.5**, and details for the Southern and Northern Areas respectively on **Figures 8.6 and 8.7**. **Table 8.11** summarises the chemistry and toxicity of all 47 samples tested. This table shows that Acute and High-Chronic toxicity is largely due to gasworks contaminants, is essentially confined to the proposed Remediation Areas and will be removed by remediation, and that Low-Moderate toxicity is largely due to background levels of metals and is found in some samples elsewhere in Kendall Bay as well as throughout the Parramatta River.

Table 8.11. Sediment Toxicity and Chemistry Summary

Sample No/Location	Toxicity (highest found)		Sediment Quality Guideline Quotients (SQGQ)		TRH (mg/kg)
	Acute	Chronic	Metals	Total PAHs	
Southern Remediation Area					
100 (S beach – sand)	No	Moderate	0.5	1.1	285
101 (S beach – sand)	No	Moderate	0.2	2.5	125
102 (edge mangroves – sand)	No	No	0.2	0.6	745
103 (in mangroves)	No	High	1.5	0.9	1,310
104 (in mangroves)	No	High	1.6	0.7	1,060
108 (near boundary of RA)	No	High	1.6	1.0	1,740
109	No	Moderate	1.3	6.3	11,100
110	No	Moderate	1.7	1.7	3,190
402 (coarse: sandy & gravelly)	Very High	High	0.8	1.2	1,610
403	High	High	2.8	18	33,150
405	No	High	1.5	1.4	4,700
406	Low	High	1.5	5.6	8,815
407	No	Moderate	2.0	1.6	2,540
KB736	Very High	High	1.3	3.9	7,740
KB737	Very High	High	2.6	4.8	8,440
KB738	Moderate	High	1.3	2.4	4,120
KB739	Low	High	1.5	3.7	5,290
KB740	High	High	3.7	2.5	4,260
Northern Remediation Area					
410	Moderate	High	1.7	6.2	16,600
KB731	High	High	1.5	4.8	9,070
KB732	Very High	No data (no survival)	1.7	32	51,100
KB733	Very High	No data (no survival)	2.4	130	101,000
KB734	High	High	1.1	8.5	15,900
KB735	Low	Moderate	1.4	0.9	990
Elsewhere in Kendall Bay					
408	No	Low	2.1	0.4	538
409	No	Low	1.7	0.5	468
411	No	Moderate	2.4	1.0	748
KBR4	No	No	1.3	0.4	565
KBR5	No	No	1.5	0.3	240
KBR6	No	No	1.0	0.3	355
KBR7	No	No	2.0	0.3	235
KBR8	No	No	1.5	0.2	125
KBR9	No	No	1.7	1.2	365
KBR11	No	Moderate	1.8	0.6	295
KBR12	No	No	1.4	3.1	385
Northern Reference Area					
401 (Majors Bay, edge mangrove)	No	Moderate	2.8	0.7	138
413 (Majors Bay)	No	Moderate	2.3	0.4	718
KBR3 (Majors Bay)	No	No	1.3	0.2	125
MB18 (Majors Bay)	No	Moderate	2.0	0.2	125
KBR14 (Yaralla Bay)	No	No	1.3	0.1	125
KBR1 (Brays Bay)	No	No	1.1	0.1	125
KBR2 (Brays Bay)	No	No	1.0	0.2	160
Southern Reference Area					
404 (Exile Bay, edge mangrove, sand)	No	Moderate	1.2	0.4	138
412 (Exile Bay – sandy)	No	No	0.3	0.2	798
KBR17 (Exile Bay)	No	No	3.2	0.3	185
KBR16 (Canada Bay)	No	Moderate	2.3	0.2	125
KBR15 (Canada Bay)	No	Moderate	3.6	0.2	245

Source Data: Simpson et al., 2016; Simpson and Spadaro, 2018; Synnot & Wilkinson, 2018e.

Acutely toxic or highly chronically toxic.

Exceeds ANZECC SQGQ for metals/PAH, SQG-High for TRH (Simpson et al., 2013).

Exceeds CSIRO PAH remediation criterion (max. 55 mg/kg).

Exceeds CSIRO TRH remediation criterion (max. 6000 mg/kg).

RA: Remediation Area.

Figure 8.5. Toxicity of Sediments from Reference Areas

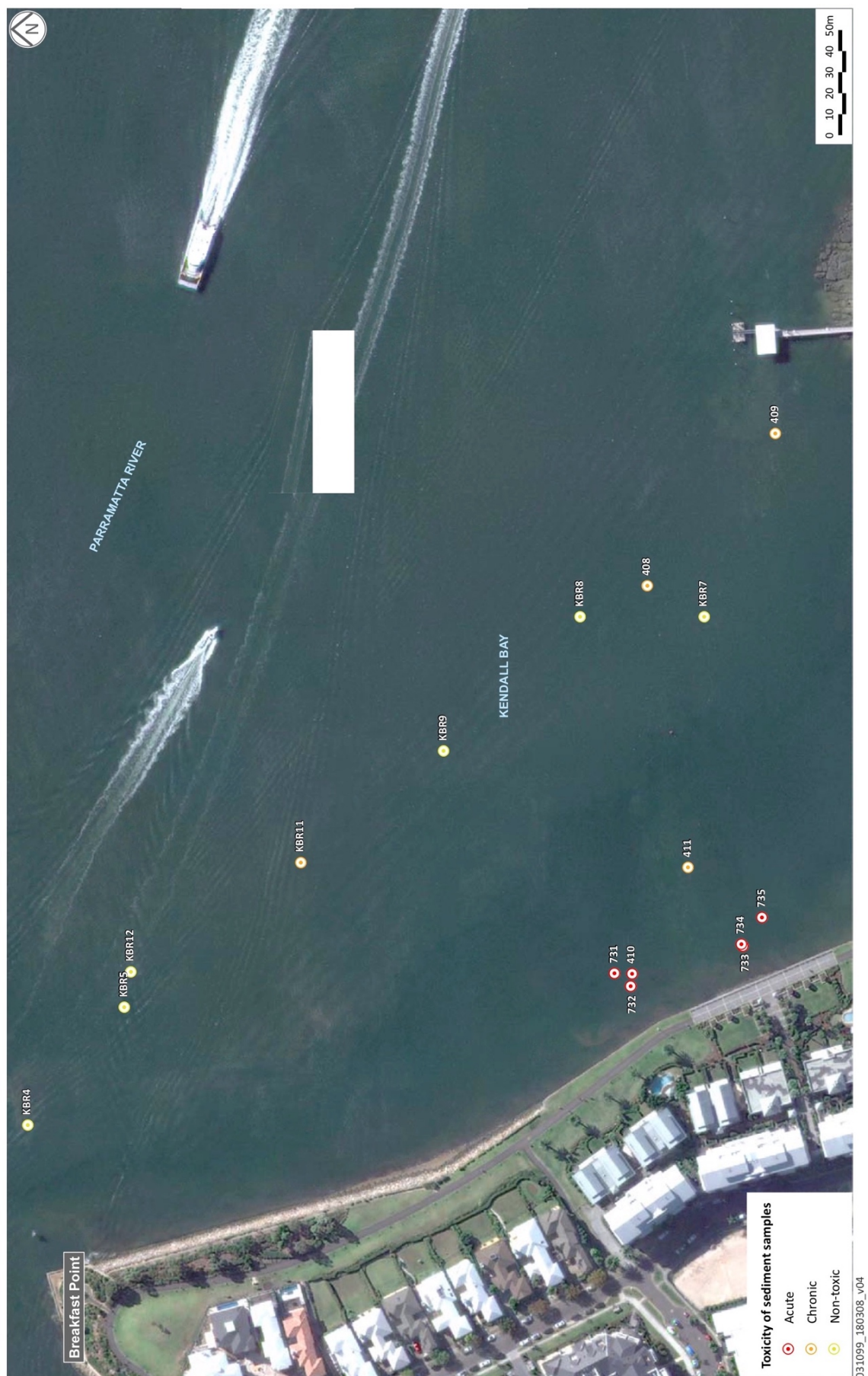


Figure 8.6. Toxicity of Sediment Samples, Southern Investigation Area (acute, chronic or non-toxic).



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Figure 8.7. Toxicity of Sediment Samples, Northern Investigation Area (acute, chronic or non-toxic).



Conclusions of the chronic toxicity study

This study was undertaken to provide additional information to address concerns raised by the NSW EPA in relation to the level of residual chronic toxicity of the sediments that will remain in Kendall Bay if the proposed remediation was to occur.

The position taken in the RAP (2017) was that ‘high background concentrations of metal contamination exist in the surrounding regions of the Parramatta River, and also within the middle and eastern side of Kendall Bay that are less impacted by hydrocarbons. Without remediation of the broader contamination beyond Kendall Bay, remediation targeting areas where chronic toxicity is observed in Kendall Bay may be ineffective at eliminating chronic toxicity of the sediments in the longer term because remediated areas within the bay would likely become re-contaminated with sediment from the surrounding environment.’

The concerns raised by the NSW EPA were for the level of residual chronic toxicity of the sediments that will remain in Kendall Bay after remediation of the acutely toxic gasworks wastes. This concern included whether insufficient tests were undertaken to demonstrate that re-contaminating silt with elevated metals would likely result in chronic toxicity, and also that a lower level of chronic toxicity due to background metals rather than due to hydrocarbon contamination due to the gasworks, leading to residual chronic toxicity being significantly greater than just metals.

The results continue to indicate that:

- significant improvements in ecosystem health may be expected to be achieved by removal or isolation of sediments that caused acute toxicity to benthic organisms; and
- remediation targeting areas where chronic toxicity is observed may be ineffective at eliminating chronic toxicity of the sediments in the longer term as remediated areas within the bay will be expected to become re-contaminated as sediment from the surrounding environment is redeposited, together with deposition from future stormwater inputs.

The inner areas of most embayments within this region of the Parramatta River have a significant legacy of metal contamination and stormwater continues to impact the bays through ongoing inputs of contaminants, particularly metals such as copper and zinc that contribute significantly to what is referred to in this report and the past report (Simpson et al., 2016) as ‘background toxicity’.

The silty materials in the outer region of Kendall Bay were found to result in few instances of chronic toxicity to the amphipod. It is expected that these materials will continue to move around within this region, e.g. through resuspension by river-cat (ferry) movements, and may be representative of the surface sediments that will remain in Kendall Bay following remediation.

8.2.2.2 Marine Benthic Infaunal Assemblages

Initial Investigations

Alison Hunt & Associates Pty Ltd (AH Ecology) carried out an assessment of marine benthic infauna for the Project. Forty-five locations were sampled in Kendall Bay in two stages, the first on 20-21 January 2016, and the second on 7 April 2016. Sampling locations are shown on **Figure 4.5**, above. The findings of the study are detailed in the *Marine Benthic Infauna Assemblages* report (Alison Hunt & Associates Pty Ltd 2016). Other aspects of sampling, subsampling, sample handling, preservation and decontamination for the chemical analyses are described in S&W (2017a). Conclusions are summarised below.

NSW EPA advised in their *2007 Remediation Order* that contamination in the Declared Area (which includes the Northern and Southern Investigation Areas) had resulted in environmental harm in that there was a ‘lack of benthic biota’ in the area and that although ‘cause and effect’ had not been established it

was reasonable to assume based on the scientific literature that the nature and degree of the contaminants resulted in the lack of benthic biota. EPA's broad statement has been shown to be inconsistent with the findings of this current study, and studies by The Ecology Lab (1988, 1996) and Cardno Ecology Lab (2009).

The majority of sediment samples (both Test and Background) collected for marine benthic infauna assessment continue to support a range of benthic taxa. In effect, samples of marine benthic infauna collected from within the investigation areas were not consistently significantly different from the background locations in adjoining bays unaffected by gasworks contaminants, in terms of numbers, diversity or relationships among abiotic factors and benthic infauna. Instead, this study found that the differences amongst the test sites and background sites were typically small-scale differences in the number of animals rather than substantial differences in the number of taxa.

Only four sites were identified (three with the Northern Investigation Area and one within the Southern Investigation Area) from the 28 samples collected from the Northern and Southern Investigation Areas (test sites) that lacked identifiable benthic biota, and one of these sites from the Northern Area lay well to the east of the gasworks contaminated area. The remaining 24 samples from the Test Sites and 17 samples from the background sites, except Exile Bay, all contained similar arrays of infauna taxa and abundance of these taxa, although Exile Bay sites did contain more animals and taxa than any of the sampling sites. This may be related to the sandy sediments of Exile Bay.

The criteria used to recommend areas for remediation were developed using multiple lines-of-evidence (LOE) including ecotoxicity testing, sediment chemistry and marine benthic communities. When these multiple LOE were considered, four marine benthic sites were recommended for remediation (i.e. Northern Area: MB1, MB3 and Southern Area; MB14, MB20) as these sites supported low numbers of marine benthic infauna as well as gasworks contamination at levels considered to be acutely toxic to marine benthos. These locations are shown on **Figures 8.8 and 8.9**.

Follow-up Investigation, October 2017

NSW EPA raised concerns around the level of residual chronic toxicity of the sediments that would remain in Areas A and B in Kendall Bay after remediation and whether the residual toxicity of sediments is similar to the toxicity in the surrounding bays outside of the area of influence of the AGL Gasworks and also about the sufficiency of testing to adequately characterise the background concentrations/toxicity within areas surrounding the proposed Kendall Bay Remediation Area. The investigation and results are reported in Alison Hunt and Associates, 2018.

To address these issues, additional sediment sampling was undertaken 9 – 12 October 2017, to better understand and quantify the levels of background chronic toxicity that exist in areas outside of the proposed remediation areas in Kendall Bay and in nearby embayments in the Parramatta River (**Figures 4.4, 8.6 & 8.7**). The benthic macroinvertebrate communities within these sediment samples were identified and analysed to characterise the benthic infauna communities in these areas in order to compare these communities to infauna communities in the Declared Areas within Kendall Bay. Additional sampling provided an opportunity to further address the potential level of differentiation in infauna communities across small spatial scales and also in time. Hence, six previously sampled sites were also resampled for this Study, and these were compared to samples taken in 2016.

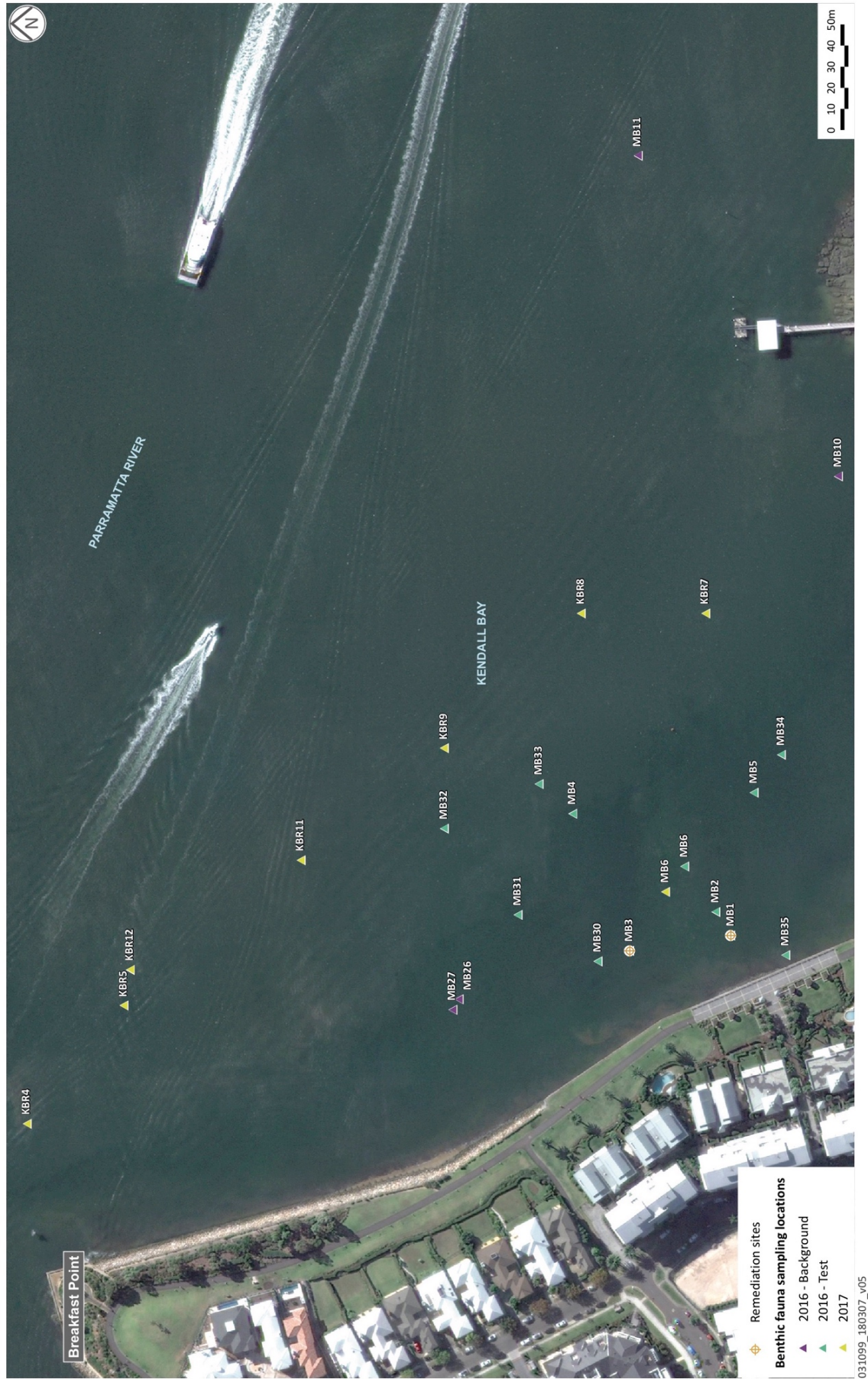
The findings of this study support the findings from the sampling program during 2016 (Alison Hunt & Associates Pty Ltd 2017) and show that:

- chronic toxicity of sediments appears widespread within this section of the Parramatta River (S&W 2018);
- even given this widespread chronic toxicity, these sediments support a heterogeneous array of infaunal communities; and
- infaunal communities appear to show no clear patterns in the abundance and diversity across all bays and sites sampled, indicating that areas within Kendall Bay which are outside of the identified remediation areas are likely to be representative of infaunal communities within the nearby embayments sampled in this study.

Figure 8.8. Benthic fauna locations in the Southern Investigation Area recommended for remediation.



Figure 8.9. Benthic fauna locations in the Northern Investigation Area recommended for remediation.



8.3 Uncertainties

Nature and Extent of Contamination

The analysis of environmental samples can be affected by high salt levels, complicated chemical matrices, sample preparation, intrinsically inhomogeneous samples or samples that cannot be perfectly homogenised, and analytical differences between laboratories, and therefore the results may be less precise than desired.

The levels of contaminants in environmental media vary from location to location, with depth in water, sediments and tissues, and over time as well, and few investigation programs can be large enough and prolonged enough to fully characterise the spatial and temporal variation in all these media. The sediment investigations carried out by S&W in 2015-2016 were comprehensive, and the results were generally in agreement with extensive sampling programs previously carried out by other consultants, as summarised in SKM (2014a). For this reason, it is considered that the sediment data obtained is representative of the distribution of contaminant values in the study area.

The water quality and tissue concentration data is more limited both in time and space and only representative of contaminant values at the time of sampling, and therefore there is greater uncertainty as to the representativeness of this data.

Undetected Contaminants

The list of COPCs analysed was based on the known key contaminants from the former gasworks, supplemented by other contaminants known to be present in the Parramatta River, however not all contaminants that could conceivably be present in Kendall Bay have been analysed for.

Absorption from Ingested Doses and Direct Contact

The toxicity of an ingested contaminant depends on the proportion that is absorbed from the stomach, however this varies from organism to organism, and also according to the chemical forms of each contaminant, and is generally not known. The same applies to absorption of contaminants through the skin or gills. Exposure estimates that assume 100% bioavailability of all contaminants in all media may be realistic for dissolved contaminants in water and prey, but are liable to considerably overestimate exposure from contaminants such as PAHs that are mainly found in suspended sediment or bed sediment, either from contact or ingestion of particulates, because of the low solubility of many contaminants adsorbed to sediments.

Toxicity Testing

The toxicity test results are only based on two species. While these test species are considered to be sensitive, they cannot represent all the benthic organisms that may be present in Kendall Bay, nor all the potential routes of exposure. The toxicity data may therefore underestimate or overestimate the true effects of the gasworks contaminants in the sediments.

Bioavailability Testing

The bioavailability testing is subject to a number of uncertainties. A limited number of samples were tested and these may not have been representative of all sediment chemical and physical states. Normalisation to TOC is affected by the very high levels of BC present and uncertainty as to the degree to which BC affected partitioning of PAHs. Where porewater could not be obtained, elutriate testing was used instead however this only provides an estimate of likely porewater concentrations.

Bioaccumulation Data

Bioaccumulation data for oysters and mussels is unlikely to apply to benthic organisms, which have far greater exposure. The bioaccumulation data is therefore likely to underestimate the bioaccumulation risk to benthic organisms and organisms that feed on them.

Overall Assessment

The above uncertainties include those that could lead to under-estimates and over-estimates of toxicity, however because many of the assumptions are conservative, and because the dose-response curves are based on a large amount of good quality data that is supported by data from other areas, it is believed that the toxicity assessments are realistic.

9 RISK CHARACTERISATION

9.1 Water Column Organisms

Contaminants in Water

Risk characterisation has been carried out by comparing the degree of exposure of ecological receptors to the contaminants of concern (i.e. the maximum values found in waters in the Northern and Southern Investigation Areas), to the dose associated with adverse effects (i.e. the water quality criteria). Ecological risk is estimated numerically using the USEPA's Hazard Quotient (**HQ**) approach, where the HQ is the ratio of the maximum value in each sub-area to the relevant water quality criterion. Where the HQ is greater than 1, harmful effects on organisms may occur. Note that the degree by which the HQ exceeds 1 is not relevant to the assessment, only the exceedance itself.

The maximum water values of each contaminant of concern have been compared to the adopted water quality guidelines for toxicants (**Tables 6.1 to 6.4**). Where a maximum value exceeds the relevant guideline (marked in bold) the HQ is greater than 1 and harmful effects on some organisms are likely to occur, assuming the contaminants are bioavailable. If so, the waters from that area are considered potentially toxic.

The data shows that the dissolved PAH levels were very low, mostly below the detection limits or in a few cases at or slightly above the detection limits. There are no Australian marine water quality guidelines for PAHs, due to insufficient data, however the low PAH values found are considered unlikely to affect aquatic organisms.

The metal levels were also low and generally below the water quality guideline values except for copper, which consistently exceeded the guideline, and zinc, which occasionally did. This indicates potential for adverse effects on some organisms, however the metal levels in the contaminated areas of Kendall Bay were comparable to the levels at the background locations in and outside the bay, and therefore any toxic effects of metals cannot be attributed to the gasworks contamination.

Bioaccumulation in Oysters and Mussels

The data (**Tables 5.1 to 5.4**) show that light fraction hydrocarbons (TRH >C10-C16) were below detection limit in all oyster and mussel tissue samples. Higher fraction hydrocarbons (TRH >C16-C34 and TRH >C34-C40) were present in all samples however the levels were similar in all samples and locations. Samples from Kendall Bay did not show elevated levels of hydrocarbons compared to the background bays.

PAHs were not detected in any mussel samples from Kendall Bay or the two background bays. With one exception, PAHs were not detected in any oyster samples from Kendall Bay or the two background bays. The exception was the individual PAH benzo(a)pyrene which was detected in the Kendall Bay oyster sample at slightly above the PQL, however precision is low for values close to the PQL and this result may not be meaningful.

Metals were not detected in mussels except for zinc, where the values were well below the generally expected levels (GEL). The zinc values showed no significant differences between Kendall Bay and the two background bays.

Only cadmium, copper and zinc were detected in the oyster samples. The cadmium values were well below the MRL. The copper values were more than an order of magnitude higher than the GEL, and the zinc levels approximately an order of magnitude higher than the GEL. The copper values were comparable in the three bays. The zinc and cadmium values were higher in Majors Bay oysters than in the oysters from Kendall and Exile Bays. Samples from Kendall Bay did not show elevated levels of metals compared to the background bays, and for this reason it does not appear that the gasworks-contaminated sediments in the Southern and Northern areas are significantly contributing to the levels of metals in oysters or mussels.

From the data presented above, there is no evidence that the PAHs or TRHs in the contaminated gasworks sediments in the bay are being taken up by oysters or mussels.

9.2 Benthic Organisms

The potential for adverse effects of the COPCs on benthic organisms was assessed using comparison of COPC levels in surface sediments (0-300 mm) with sediment quality GVs, site-specific sediment toxicity tests and by a benthic community assessment. The results showed:

- Sediments in parts of the Southern and Northern Investigation Areas exceeded or greatly exceeded the Australian sediment quality GVs for TRHs and PAHs (**Table 8.11**), indicating a significant risk to benthic organisms.
- Sediments throughout Kendall Bay, including areas known to be unaffected by gasworks contamination, plus sediments in the Northern and Southern Reference Areas, commonly exceeded the Australian sediment quality GVs for a number of common metals, indicating a risk to benthic organisms.
- Some of the sediments throughout Kendall Bay, including areas known to be unaffected by gasworks contamination, and some of the sediments from the Northern and Southern Reference Areas, exhibited chronic toxicity to test organisms. This was attributed to broad-scale sediment contamination in the Parramatta River, particularly by metals.
- Sediments in two areas of Kendall Bay, one in the Southern Investigation Area and one in the Northern Investigation Area, were acutely toxic to test organisms. These sediments also commonly showed high chronic toxicity. Both Acute and High-Chronic toxicity was attributed to high levels of TRHs and PAHs and was associated with areas where oily gasworks-contaminated were present at or near the sediment surface. Site-specific effects criteria for TRHs and PAHs were developed from dose-response curves derived from the toxicity testing, and compared to the levels in surface sediments (**Figures 9.1 – 9.4**). On this basis, areas of Kendall Bay where the sediments were, or were predicted to be, acutely toxic to benthic organisms were identified. These areas can be further refined in the RAP using surface PAH and TRH data from the 2014 HHERA.
- Four samples collected from the investigation areas (3 samples from the Northern Investigation Area and one from the Southern Investigation Area) lacked identifiable benthic biota.
- In the remainder of the Investigation Areas, gasworks contamination was overlain by 0.05 – 0.3 m (as measured in cores) of estuarine mud deposited subsequently to the contamination entering the bay. Samples of marine benthic infauna collected from within the investigation areas were not consistently significantly different from the background locations in adjoining bays unaffected by gasworks contaminants, in terms of numbers, diversity or relationships among abiotic factors and benthic infauna.

Figure 9.1. Surface samples exceeding the CSIRO Acute Toxicity criteria for PAHs, Southern Investigation Area.



Figure 9.2. Surface samples exceeding the CSIRO Acute Toxicity criteria for PAHs, Northern Investigation Area.

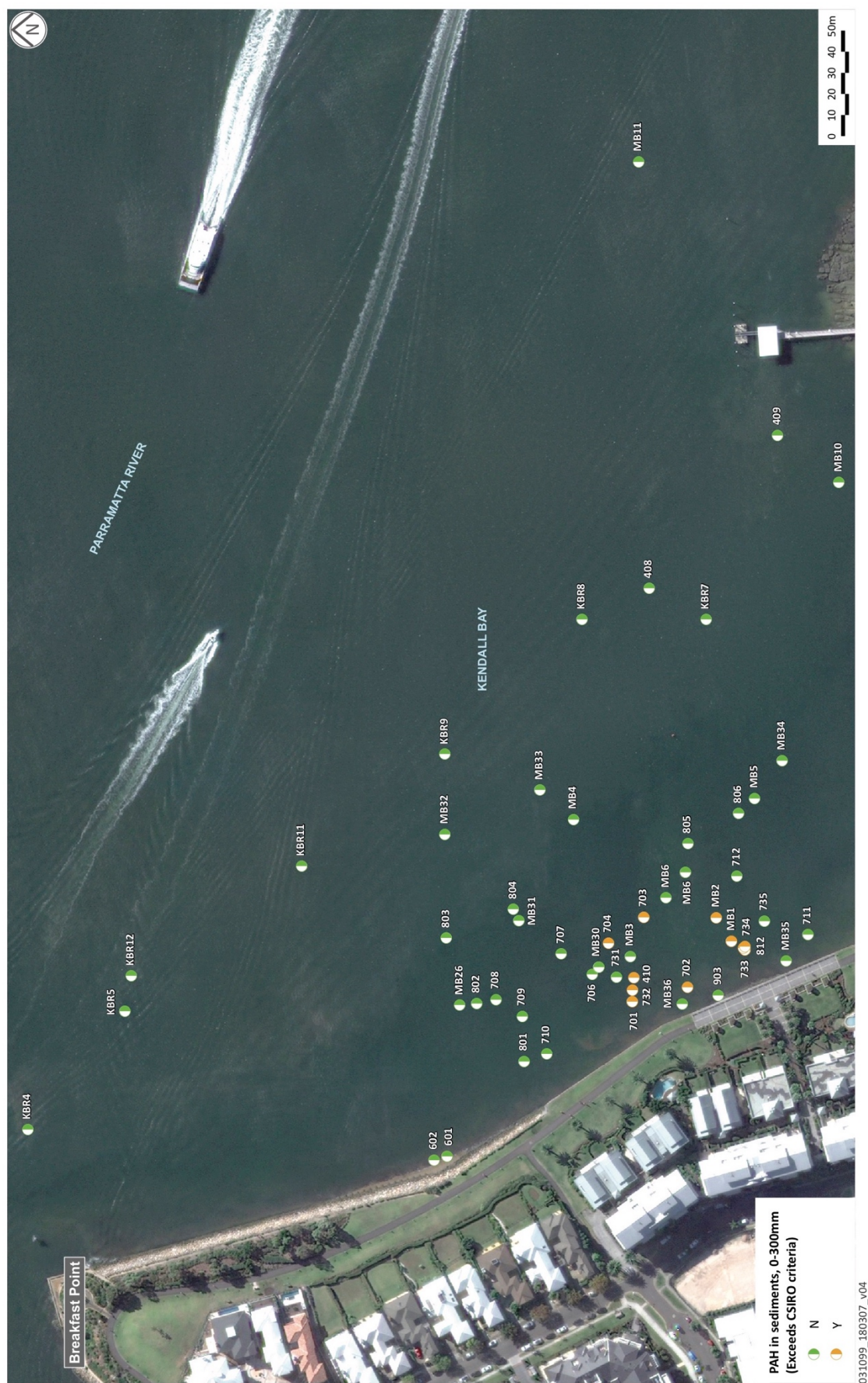
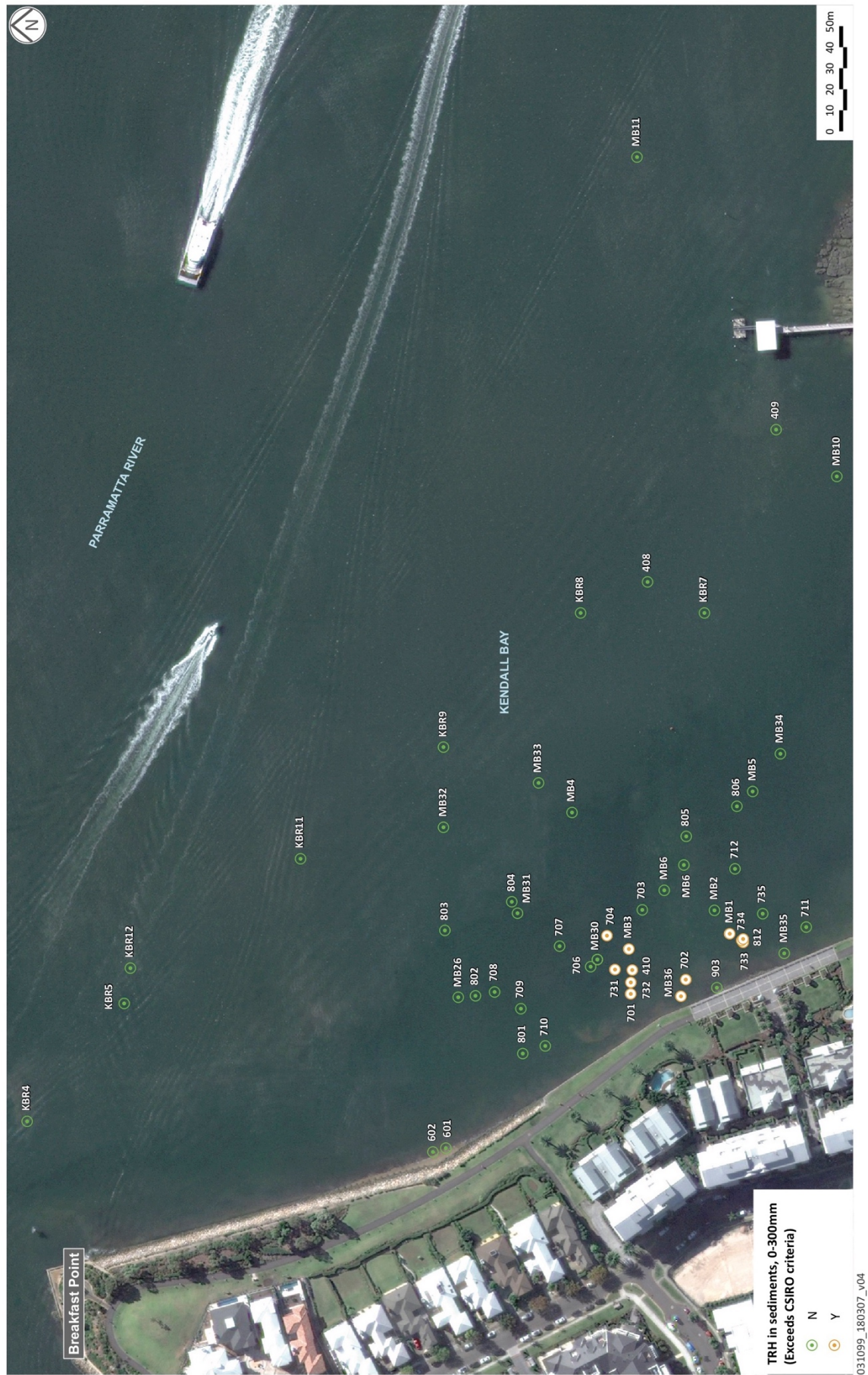


Figure 9.3. Surface samples exceeding the CSIRO Acute Toxicity criteria for TRHs, Southern Investigation Area.



Figure 9.4. Surface samples exceeding the CSIRO Acute Toxicity criteria for TRHs, Northern Investigation Area.



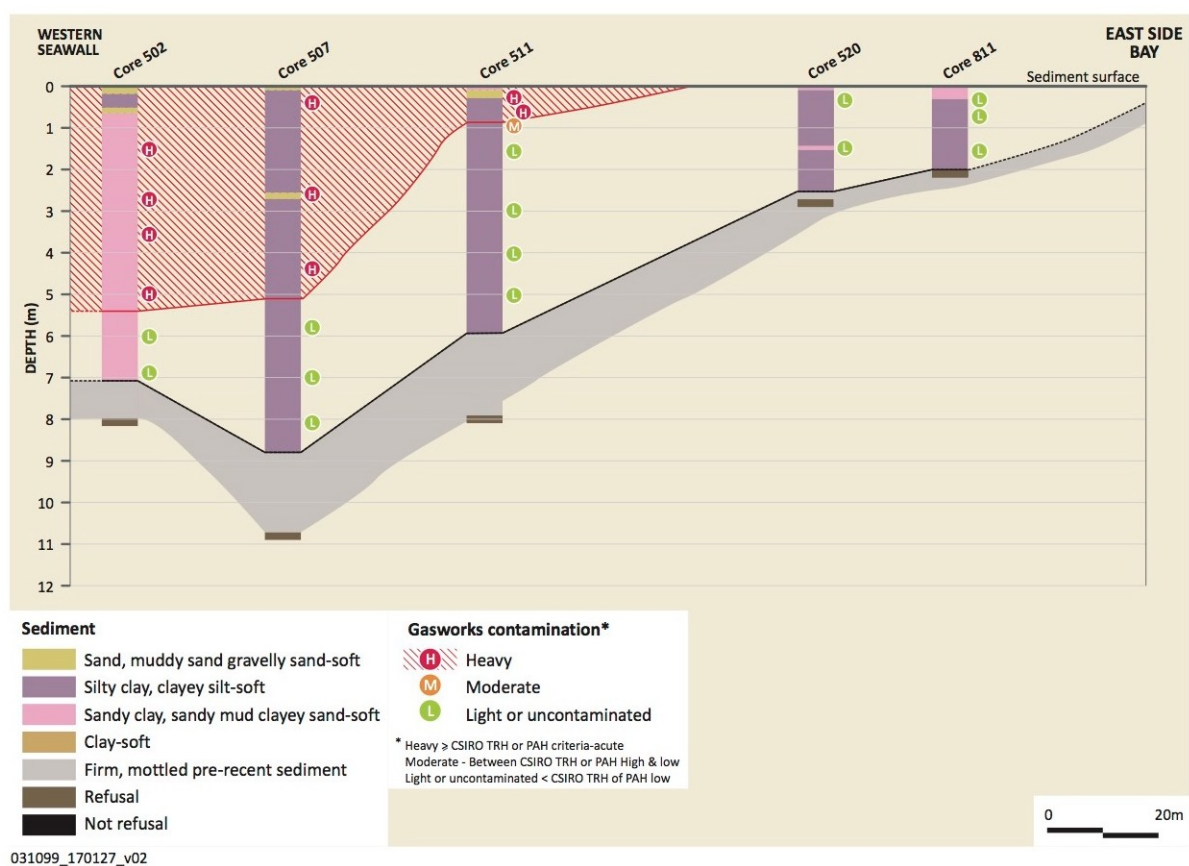
9.3 Conceptual Model of Gasworks Contamination in Kendall Bay

9.3.1 Gasworks Contamination in the Sediments

A conceptual model of gasworks contamination was developed for the bay. The model was based on the sedimentology observed in core logs as well as the chemical data obtained during the investigations, and observations made in relevant previous studies of the sediments. The model shows the distribution with depth of gasworks contamination in the bay, as well as the depth of recent silt overlying the contamination, and the depth at which firm sediments occur below the contamination.

Figures 9.5 and 9.6 are cross-sections through the sediments of the Southern and Northern Investigation Areas, respectively. Note that due to dewatering, compaction and plastic flow during coring, depths shown on the figures are approximate.

Figure 9.5. East-West Cross-section through the Sediments, Southern Investigation Area

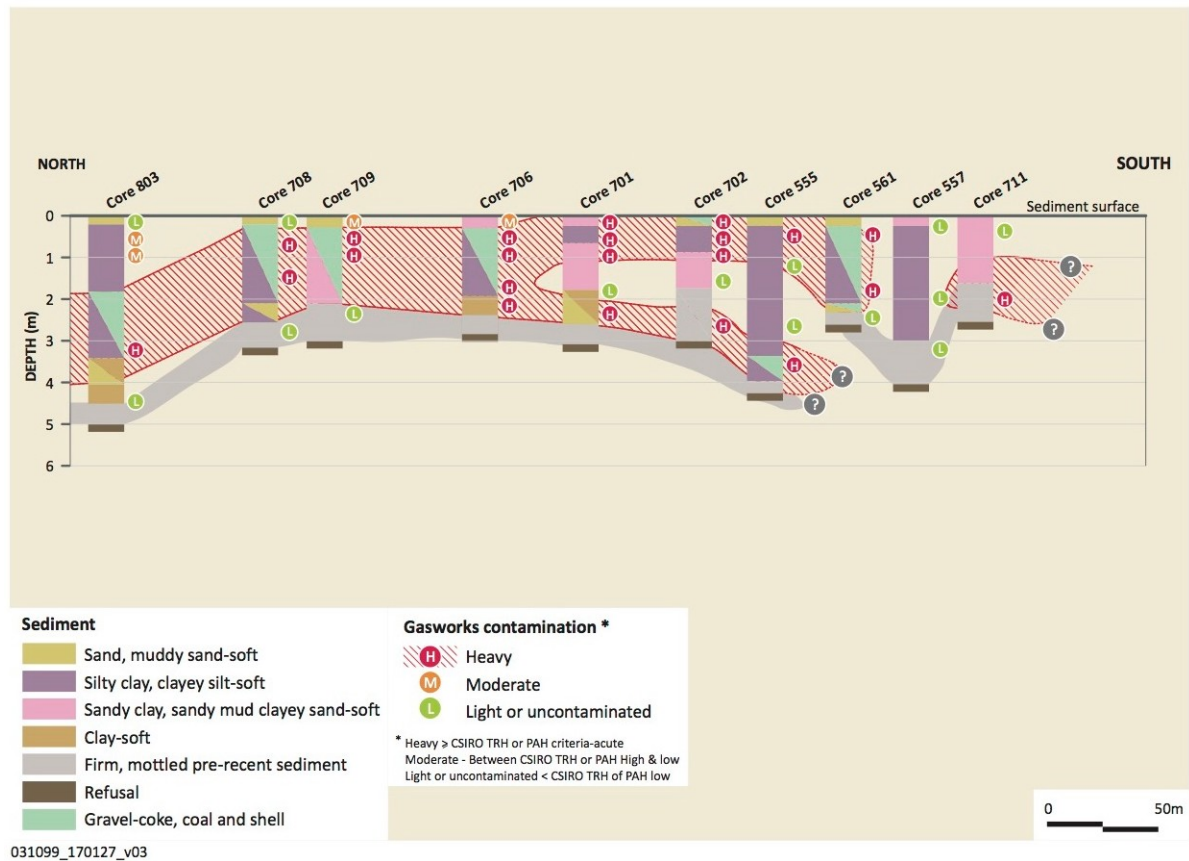


In the Southern Investigation Area, typically a thin layer of recent estuarine mud (0.05-0.25 m thick) overlies a layer of black or dark grey soft oily gasworks-contaminated sediment, commonly around 1 m in thickness, occasionally 2 m or more thick, sometimes containing gravel or coal or coke. In the south-western corner, however, the dark oily sediment occurs at the surface. Below is a layer of soft silty clay, typically 2 to 5 m thick, which can contain veins and blobs of black oil or DNAPL. The lowest layer encountered was a firm sandy clay or clayey sand, mottled orange and yellow, which was uncontaminated in most cores, though several cores on the south-western side of the bay did contain contamination in this layer.

Based on the chemical data, the typical thickness of heavy gasworks contamination (defined as exceeding the CSIRO Acute criteria for TRH or normalized PAH) in the south-western corner of the bay was 5 m

(maximum 8 m), though to the north and east the contaminated layer thinned rapidly and was absent in some cores on the eastern side of the bay.

Figure 9.6. North-South Cross-section through the Sediments, Northern Remediation Area



In the Northern Investigation Area, typically a thin layer of recent estuarine mud (0.05-0.3 m thick) overlies a layer of black or dark grey soft oily gasworks-contaminated sediment, commonly around 1 m in thickness, occasionally 3 m or more thick, often containing gravel of coke or coal. In two areas, near and north of the former coal wharf mound, the dark oily sediment occurs at the surface. Below it is a layer of soft silty clay, sometimes gravelly, typically around 1 m thick, which was sometimes oily or contained veins and blobs of DNAPL. The lowest layer encountered was a firm sandy clay or clay, mottled orange and yellow, which was sometimes contaminated.

Based on the chemical data, the typical thickness of heavy gasworks contamination (defined as exceeding the CSIRO Acute Criteria for TRH or normalized PAH) in the Northern Investigation Area was 2-4 m. In cores near and north of the former coal wharf, two heavily contaminated layers were often present, separated by sediment that was relatively clean. This pattern may be due to removal of the former coke and coal wharves, dredging, and/or sediment slumping into dredged channels.

9.4 Uncertainties

Problem Formulation

The entire benthic community was chosen as the benthic receptor, and the water column community as the water column receptor, because insufficient data was available to select and assess individual species as benthic receptors. Therefore, receptor selection could only assess endpoints at the community level, not the level of individual species.

Nature and Extent of Contamination

The analysis of environmental samples can be affected by high salt levels, complicated chemical matrices, sample preparation, intrinsically inhomogeneous samples or samples that cannot be perfectly homogenised, and analytical differences between laboratories, and therefore the results may be less precise than desired.

The levels of contaminants in environmental media vary from location to location, with depth in water, sediments and tissues, and over time as well, and few investigation programs can be large enough and prolonged enough to fully characterise the spatial and temporal variation in all these media. The sediment investigations carried out by S&W in 2015-2016 were comprehensive, and the results were generally in agreement with extensive sampling programs previously carried out by other consultants, as summarised in SKM (2014a). For this reason, it is considered that the sediment data obtained is representative of the distribution of contaminant values in the study area. The water quality and tissue concentration data is more limited both in time and space and only representative of contaminant values at the time of sampling, and therefore there is greater uncertainty as to the representativeness of this data.

Representativeness of Receptors

The risk characterisation was based on national and international standards, criteria and guidelines for a generalised set of aquatic species, which may or may not occur within the study area. Where hazard quotients above 1 were found, these may reflect risks to species not present at the site. The risks to the species actually present within the study area may be higher or lower than the assessed risks.

Absence of Toxicity Data for Some Potential Contaminants

The generic criteria, guidelines and standards used in the assessment may not have been developed from all of the contaminants potentially present in the study area, and therefore the risk may be underestimated.

Extrapolation of Toxicity Data

The toxicity data used to develop the criteria, guidelines or standards used may not be fully applicable to the field situation at the site. Risks may either be overestimated or underestimated. This is a problem for sediment quality guidelines in particular, as the generalised guidelines have largely been developed from overseas (North American) data. This could lead to an overestimate or underestimate of risk for the study area. Furthermore, sediment quality guidelines do not take bioavailability into account and therefore are liable to overestimate the risk of the contaminants to organisms.

Chemical Interactions

Most criteria and guidelines have been developed from single toxicant studies, however in the environment there are almost invariably multiple contaminants, which, in combination, may have additive, synergistic or antagonistic effects on organisms. Assessing the combined effects of all the contaminants present is extremely complex and was beyond the scope of this investigation. The effects could therefore be overestimated or underestimated, although the former is more likely. The toxicity testing carried out will, however, reduce this uncertainty.

Population-Level Impacts

The assessment endpoints for the receptors at this site are based on population-level effects, however, the estimation of such effects on the population is fraught, and the precise risks that will lead to population-level adverse effects will vary from one receptor to another.

Definition of Sediment Contamination/Toxicity Boundaries

The boundaries of the areas where sediment has been assessed as being acutely toxic are subject to uncertainty as these areas have been estimated by interpolation from individual sediment sampling points having varying spacings.

Overall Assessment

The above uncertainties include those that could lead to under-estimates and over-estimates of ecological risk, however because many of the assumptions are conservative, and because the assessment based on a large amount of good quality data, including previously collected data that is generally consistent with the data collected for this ERA, it is believed that the risk assessment is realistic.

9.5 Catastrophic Exposure Scenario

The ERA presented above, and its findings, applies to the study area in its present state. In the event of a catastrophic event, e.g. a major (unprecedented) storm event that eroded contaminated sediments present in the shallow south-western and western parts of Kendall Bay, large quantities of toxic sediments could be redistributed throughout the bay and the Parramatta River. However, the extent of any such catastrophic exposure cannot be predicted in advance.

10 SUMMARY OF UNCERTAINTIES

The uncertainties in this ERA have been discussed in the individual report sections and are summarised in **Table 10.1**, which also assesses the magnitude of errors for each component of the ERA. Many potential errors have been identified, some of which could lead to underestimates of risk and others to overestimates of risk. However in relation to the gasworks-contaminated sediments, in view of the large amount of generally consistent data available from many investigations, and the risk assessment which has followed the latest Australian procedures including a weight-of-evidence assessment considering the four branches of sediment quality assessment, namely sediment chemistry, toxicity, bioaccumulation and benthic community assessment, it is believed that the ecological risk from the sediments has been adequately assessed.

Table 10.1 Summary of Uncertainties for the ERA

Assessment Component	Aspect of Uncertainty	Direction of Error	Magnitude of Error
Nature and extent of contamination	Sampling may not be representative of variability in space, time or depth.	Unknown	Probably small for sediments, possibly moderate for water quality, tissue levels and benthic biota surveys
	Lack of analytical precision.	Unknown	Probably small
Exposure Assessment	Not all exposure pathways considered.	Risk underestimated	Unknown, probably small
	Not all contaminants present analysed for.	Risk underestimated	Probably small
	Use of maximum value to represent true concentration.	Risk overestimated	Significant for sediments, small for tissues
	Exposure estimates of 100% unrealistic for some organisms.	Risk overestimated	May be significant for non-sessile/small ranging organisms
	Bioaccumulation data for oysters and mussels unlikely to apply to benthic organisms, which have far greater exposure.	Risk underestimated	May be significant
	Absorption estimates may be unrealistic for sediment exposures, due to uncertainty as to bioavailability.	Risk over-estimated	May be significant for sediment exposures, but mitigated by toxicity testing
Toxicity Assessment	Generic aquatic test organisms may not have same risk as study area organisms.	Risk over- or under-estimated	Probably small
	Criteria used may not apply to all contaminants present in study area.	Risk underestimated	Probably small
	Toxicity data used to develop criteria may not be fully applicable to study area.	Risk over- or under-estimated	Could be significant, but mitigated by toxicity testing
	Bioavailability testing is subject to a number of uncertainties.	Risk may be under- or over-estimated	Could be significant, but mitigated by toxicity testing
	Organisms used for toxicity testing do not represent all study area habitats, exposure pathways and organisms	Risk may be under- or over-estimated	Could be significant, but partly mitigated by weight-of-evidence assessment
Risk Characterisation	Chemical interactions not taken into account.	More likely to underestimate	Probably small, but mitigated by toxicity testing
	Estimation of population-level effects difficult.	Unknown	Probably small
	Definition of toxic sediment boundaries is approximate, due to interpolation between sampling points	Risk may be under- or over-estimated	Probably small; accuracy can be improved by incorporation of data from the 2014 HHERA into the boundary delineations in the 2017 RAP.

11 CONCLUSIONS

The ecological risk assessment used data from the sediment contamination studies, water quality monitoring, biological tissue monitoring, marine benthic community studies, and the bioavailability and ecotoxicology studies to assess the risks to organisms exposed or potentially exposed to the gasworks-contaminated sediments of Kendall Bay.

Waters

The dissolved PAH levels in water from Kendall Bay were very low, mostly below the detection limits or in a few cases at or slightly above the detection limits. There are no Australian marine water quality guidelines for PAHs, due to insufficient data, however the very low PAH values found are considered unlikely to affect aquatic organisms.

The metal levels were also low and generally below the water quality guideline values except for copper, which consistently exceeded the guideline, and zinc, which occasionally exceeded the guideline. This indicates potential for adverse effects on some organisms, however the metal levels were no higher in the contaminated areas of Kendall Bay than at the background locations in and outside the bay, and therefore any toxic effects of metals cannot be attributed to the gasworks contamination.

Contaminants in Biological Tissue

There are no Australian assessment criteria for petroleum hydrocarbons in tissue. Samples from Kendall Bay did not show elevated levels of petroleum hydrocarbons compared to the background bays.

There are no Australian assessment criteria for PAHs in tissue. Samples from Kendall Bay did not show any significant difference in PAH levels compared to samples from the two background bays; the PAHs were all below or near detection limits.

Of the metals analysed, Australian assessment criteria are only available for cadmium, copper and zinc. Metals were not detected in mussels except for zinc, where the values were well below the generally expected levels (GEL). The zinc values showed no significant differences between Kendall Bay and the two background bays.

Only cadmium, copper and zinc were detected in the oyster samples. The cadmium values were well below the maximum residue limit (MRL). The copper values, however, were more than an order of magnitude higher than the GEL, and the zinc levels approximately an order of magnitude higher than the GEL. The copper values were comparable in Kendall Bay and the two background bays. The zinc and cadmium values were higher in Majors Bay oysters than in the oysters from Kendall and Exile Bays. Samples from Kendall Bay did not show elevated levels of metals compared to the background bays.

There is no evidence that the PAHs or TRHs in the contaminated gasworks sediments in Kendall Bay are being taken up by oysters or mussels.

Contaminants in Sediments

The sediment investigations showed that the gasworks contamination, commonly distinguished by black or dark grey oily sediments with a strong tar or hydrocarbon odour, was only present at the surface in the south-western corner of Kendall Bay, and in two small patches on the western side in the vicinity of the former coal wharf.

Elsewhere, gasworks contamination, where present, was covered by a layer of estuarine mud deposited since the contamination entered the bay.

The sediment chemical data showed that the south-western and parts of the western areas of Kendall Bay (particularly in the vicinity of the former coal wharf) contained gasworks contaminants (PAHs and TRHs) greatly exceeding the GVs, and indicative of a risk to benthic organisms exposed to these sediments. These areas included parts of the 2014 Remediation Areas A and B, as well as parts of the bay adjacent to these areas.

The eastern and northern parts of the bay, more distant from the gasworks, contained far lower levels of gasworks contaminants, generally comparable to the levels of PAHs and TRHs found elsewhere in the channel and bays of the Parramatta River.

The levels of heavy metals in Kendall Bay, though variable, were generally comparable to the levels found elsewhere in the channels and bays of the Parramatta River.

Sediment Bioavailability and Toxicity

The CSIRO bioavailability studies indicated that the elevated mixed-metal burden in some Kendall Bay sediments was likely to cause chronic toxicity, although similar metal burdens occur throughout the Parramatta River and its bays, beyond the influence of the gasworks.

Total PAH and porewater PAH data both indicated a potential for adverse effects on exposed organisms, although because of the high BC concentrations, the models provided poor predictions of toxicity from total PAH (normalised to 1% TOC).

All 14 sediment samples which CSIRO found to cause acute toxicity were oily or had an oily sheen, and were generally black, with a tar odour. These sediments only occurred at the surface in the south-western corner of Kendall Bay, and in two small patches on the western side in the vicinity of the former coal wharf. In some of these sediments, the acute toxicity was very high.

The sediments causing chronic toxicity (measured by effects on reproduction in amphipods and copepods) or no toxicity were distinctly different, typically grey or grey brown, with a 'marine' odour, no odour or, occasionally a slight hydrocarbon or slight tar odour.

The incidence of high to very high chronic toxicity was frequent for sediments from within the proposed remediation area, compared to few instances of chronic toxicity and none with high or very high chronic toxicity in sediments tested from outer Kendall Bay (i.e., parts of the bay distant from the former gasworks). The best visualisation of the impact of the proposed remediation is provided by comparing 4R and 5R on **Figure 8.1**.

The heads of other bays in this part of the Parramatta River, where stormwater inputs contaminants, particularly metals such as copper and zinc, also show high to very high chronic toxicity. Compared to sediments tested from outer Kendall Bay, the incidence of chronic effects to organism reproduction was higher for sediments from the heads of other bays (called inner bay sites) previously tested by CSIRO (see **Figure 8.1**, e.g. 2R: high to very high chronic toxicity for 'Bay-ParaRiv') and similar or higher for bays near Kendall Bay (e.g. 3R: low to high chronic toxicity for 'Bay-NearKB').

Some of the sediments from Outer Kendall Bay showed low to moderate chronic toxicity but many did not. The same response was found in samples from the five bays in the Reference Areas. These samples had elevated heavy metal burdens (sediment quality guideline quotient > 1) but low PAH burdens (sediment quality guideline quotient < 1), indicating that chronic toxicity, where present, was likely due to the heavy metals.

Remediation

The CSIRO studies indicated that significant improvements in ecosystem health may be expected to be achieved by removal or isolation of sediments that caused acute toxicity to benthic organisms. Those studies indicated that there would be a low risk of acute toxicity to benthic organisms for Kendall Bay sediments when:

- Total PAH concentrations: average <25 mg/kg (1% TOC) (representing effects thresholds) and maximum <55 mg/kg (1% TOC) (representing effects occurring frequently); and
- TRH concentrations: average <4400 mg/kg and maximum <6000 mg/kg.

Remediation that targets the acute toxicity of the Kendall Bay sediments that exists within the proposed remediation areas (i.e. intended to result in the remaining surface sediments having total PAHs with mean <25 mg/kg (1% TOC) and none with >55 mg/kg (1% TOC)) should eliminate acute toxicity and high-chronic toxicity, and result in few instances of chronic toxicity to benthic organisms in Kendall Bay (see **Figure 8.2**).

This figure shows that remediation of acutely toxic sediment in the proposed Remediation Areas (red-filled boxes) should significantly improve ecosystem health. Remediation of sediments with chronic toxicity outside the proposed Remediation Areas, however (orange box) is not expected to significantly improve ecosystem health because this sediment is similar in composition to sediment from bays and sediments near Kendall Bay that are unaffected by gasworks contamination (red- and black-outlined boxes), and cleaner than the sediments in the heads of bays affected by stormwater contamination (black-filled circles).

Remediated areas within the bay are expected to become re-contaminated as sediment from the surrounding environment is redeposited, and also from future stormwater inputs, particularly from the large stormwater drain at the southern end of Kendall Bay.

Benthic Community Studies

The majority of samples, both test sites and background sites, supported marine benthic communities. The differences among sampling locations were typically small-scale differences in the number of animals rather than substantial differences in the number of taxa. Some samples contained no fauna; these were generally in areas where gasworks contaminants were exposed at the surface and were, or were likely to be on the basis of the CSIRO criteria, acutely toxic.

Throughout the majority of the bay the layer of black oily gasworks-contaminated sediment was overlain by 50-300 mm of recent silt containing benthic infauna comparable to that found at other sites, distant from gasworks contamination, in the Parramatta River and its bays.

Infaunal communities appear to show no clear patterns in the abundance and diversity across all bays and sites sampled, indicating that areas within Kendall Bay which are outside of the identified remediation areas are likely to be representative of infaunal communities within the nearby Reference Area embayments sampled in this study.

12 RECOMMENDATIONS

NSW EPA's policy requires that soil remediation and management is conducted with reference to the principle that remediation should not proceed in the event that it is likely to cause a greater adverse effect than leaving the site undisturbed. This principle is of special relevance to the remediation of sediments, the disturbance of which:

- has a high potential to mobilise contaminants into the water column; and
- necessarily destroys any existing ecosystem.

In view of this policy, the following recommendations are made:

1. ERA has shown that two areas in Kendall Bay where oily gasworks sediments are present at or near the sediment surface, one area being on the south-western side and the other midway up the western side, are or are liable to be acutely toxic to benthic organisms due to levels of PAHs and TRHs greatly exceeding the chemical remediation criteria developed by CSIRO from toxicity testing of bay sediments. It is recommended that these sediments be remediated, and this would also remove the high-chronic toxicity sediment.
2. In some areas of the bay the oily gasworks-contaminated sediments are overlain by recently accumulated mud containing benthic fauna comparable to that found outside the area of gasworks contamination. Remediation boundaries for ecological protection (acute toxicity) for these areas should be determined in the 2018 RAP using a weight-of-evidence assessment that considers the above CSIRO criteria, plus bioaccumulation and benthic ecology data, as well as the depth of recently accumulated silt covering the gasworks contamination. Remediation boundaries may be refined using validated surface PAH data from the 2014 RAP.
3. It is not recommended that areas of Kendall Bay where low-moderate chronic toxicity is occurring, or is likely to occur, be remediated because any such remediated areas are expected to become re-contaminated as sediment resuspended from the surrounding Parramatta River, which also commonly has low-moderate chronic toxicity, is redeposited in the bay by the action of tidal currents.

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14 LIMITATIONS OF THIS ERA

This ERA was prepared by S&W for Jemena, solely for the purposes set out herein and it is not intended that any other person(s) or Companies or Government use or rely on the contents of the report. Reliance of other parties on this report is subject to agreement in writing by S&W.

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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. S&W 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 information contained in this report is based on a number of reports and data provided by other parties contracted by S&W and other reports and data from parties not contracted to S&W. The data presented in this report is to the best of our endeavours accurate and reflective of conditions in Kendall Bay and surrounding areas at the time of collection.

Whilst the information contained in the ERA is accurate to the best of our knowledge we cannot guarantee the completeness or accuracy of any of the descriptions or conclusions based on the information supplied or obtained during the investigations and site surveys.

Furthermore, conditions can change within limited periods of time, and this should be considered if the ERA is to be used after any elapsed time period subsequent to its issue. In particular, subsurface conditions may change over time due both to natural processes and human activities. For example, groundwater levels may rise and fall, contaminants may migrate from one place to another, chemical changes may occur over time, the ground may be excavated or filled, sediments may accumulate, be eroded, infilled or excavated. Management decisions should not be based on a report where time has elapsed and conditions may have changed.

The sampling reported herein categorises the actual surface and subsurface conditions only at those points where samples were taken, and only at the time they were taken, and cannot be interpolated to describe surface or subsurface conditions between those points because the nature of the conditions is unknown, and may rely on geological factors which are not apparent, and may change over time.

The ERA, as a whole, represents the findings of the site investigations and should not be copied in part, nor altered in any way. Data, figures, logs, tables etc. have been prepared based on interpretation of field and laboratory data and should not be redrawn or recast for inclusion in other reports, or separated from this report.

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All distances and measurements are subject to accurate survey prior to any works being undertaken. Any measurements quoted in this ERA are nominal only at this stage.

