HUNTER ESTUARY WETLANDS RAMSAR SITE – KOORAGANG COMPONENT

Formal Assessment of Change

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Hunter Estuary Wetlands Ramsar Site – Kooragang Component

Formal Assessment of Change

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EXECUTIVE SUMMARY

Arcadis Australia Pacific Pty Ltd (Arcadis), in partnership with Umwelt (Australia) Pty Ltd (Umwelt), were engaged by the Department of the Environment and Energy (DoEE) to undertake a formal assessment of the Hunter Estuary Wetlands Ramsar Site (Kooragang component).[1]

Objective and Approach

The objective of the formal assessment was to:

> *"determine if a change in ecological character of the Hunter Estuary Ramsar Site (Kooragang Component) has occurred due to chemical contamination, the significance of the change, and the cause of the change."* (DoEE, 2017).

The investigation takes the form of a formal assessment of change of ecological character undertaken in accordance with the *National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2)*. The assessment investigated changes to critical components, processes and services influencing the ecological character of the site, as they relate to potential contamination issues.

Trigger for Formal Assessment

On the 3 September 2015, the NSW Government announced that PFAS contamination had been detected both on and offsite at the Department of Defence RAAF Base at Williamtown. An Expert Panel was convened to investigate the nature and extent of the contamination and recommend next steps to the NSW Government. This resulted in the NSW Environment Protection Authority advising the NSW Office of Environment and Heritage that there was a strong likelihood that PFAS had caused a change in the ecological character of the Hunter Estuary Ramsar site. OEH subsequently notified the Australian Ramsar Administrative Authority which initiated this formal assessment.

Findings

The National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2) states that the formal assessment is the means whereby the evidence is weighed, the significance of the 'change' is determined, and a considered decision is reached by the relevant parties as to whether or not the change is sufficient to warrant a recommendation to the Administrative Authority that a notification should be made. In accordance with this guidance, this assessment investigated possible changes to critical components, processes and services (CPS) that define the ecological character of the Hunter Estuary Wetlands Ramsar Site (Kooragang component), particularly as they relate to potential chemical contamination issues.

In complex systems, it is often difficult to determine exact causation of change, even if there is a correlation between two or more variables. The outcomes from the assessment presented below show correlations between contaminant concentrations and CPS that suggest that chemical contaminants are impacting negatively on one of more of the CPS.

The Ramsar Convention advocates the application of a 'precautionary' approach to addressing changes in ecological character. If it is scientifically plausible but uncertain that actions, such as chemical contamination in this case, could lead to adverse change in ecological character then actions should be taken to avoid or diminish that adverse change. Additional work is recommended to reduce uncertainty surrounding the cause of the change and to develop appropriate responses to address likely changes.

Table E.1 summarises the findings from this assessment. Further detail is provided in the sections below.

[1] A list of terms and abbreviations is provided in Appendix G.

Table E.1 – Summary of findings from this assessment.

Critical ecological components, processes and services	Potential impacts: scientifically plausible pathways of chemical contamination	Has Change Occurred?*
Intertidal mudflats	Intertidal mudflats are likely to be affected by chemical contamination in sediments. This could result in impacts on food sources to waterbirds. Possible indirect effects of nutrient contamination resulting in low dissolved oxygen levels.	Unknown, but considered likely
Food webs	Refer to birds, frogs, saltmarsh and intertidal mudflats.	Considered likely, but not yet evident in shorebirds (possibly due to ecological time lags).
Migratory shorebirds: Number of species of migratory shorebirds recorded at site annually	Heavy metals (lead) and PFAS: Bioaccumulation through the food chain and direct toxic effects via ingestion of algae, benthic organisms and small fish. Indirect impacts from poor water quality (e.g. low oxygen, algal blooms).	Unknown, but considered unlikely.
Migratory shorebirds: Abundance of migratory shorebirds recorded at the site in summer		Unknown, but considered likely.
Migratory shorebirds: Number of migratory shorebird roost sites	Unknown, but potential impacts unlikely to exist.	Yes, but unlikely to be due to chemical contamination
Eastern curlew (critically endangered)	Heavy metals (lead) and PFAS: Bioaccumulation through the food chain and direct toxic effects via ingestion of algae, benthic organisms and small fish.	Unknown, but considered likely
Saltmarsh community	Nutrients: Facilitating spread of salt tolerant weeds at the upper edge of the saltmarsh	Yes, but unlikely to be due to chemical contamination.
Green and golden bell frog (vulnerable)	Possibly direct toxic effects associated with exposure to heavy metals, PFAS, petroleum hydrocarbons, poly aromatic hydrocarbons, herbicides and pesticides and cyanide (although there is evidence of frogs existing and breeding in ponds with heavy metal contamination).	Unknown, but considered possible (absence of site-specific data)

** This report finds that the CPS listed in this table are at a high risk to chemical contamination present in the waters and sediments of the Kooragang component of the Ramsar site and that changes in the ecological character are likely to be occurring or are likely to occur in the future.*

Ecological Assessment of Change Summary

The Hunter Estuary Wetlands was listed under the Ramsar Convention in 1984. An Ecological Character Description (ECD) for the Hunter Estuary Wetlands Kooragang Component was prepared in 2010 (Brereton and Taylor-Wood 2010). This identifies the following critical components, processes and services (CPS) that define the ecological character of the site:

- The food web and intertidal mudflats;
- The abundance and diversity of shorebirds with a particular focus on the eastern curlew and recently listed threatened species;
- *Sarcocornia* saltmarsh;
- Threatened wetland species including the green and golden bell frog and Australasian bittern; and
- Hydrology (tidal regime and freshwater inflows).

Limits of Acceptable Change (LAC) for the CPS were also set to establish lower bounds that could constitute a change in ecological character. No LAC was set for the potential impacts of chemical contamination on the CPS, although the site had been impacted by industrial processes prior to listing.

This formal assessment considered potential changes in these CPS due to chemical contamination. The outcomes are summarised below. The hydrology CPS was not included as hydrology is not influenced by chemical contamination.

The food web of the intertidal mudflats

The food web of the intertidal mudflats is critical in supporting migratory shorebirds. The infauna of the estuary provides an essential food source for a variety of avifauna. At low tide, shorebirds forage over the mudflats feeding on invertebrates in the mud and sand substrates (infauna).

At the time of listing, there was little information about the intertidal mudflat food webs of the Kooragang Estuary, leading to difficulty in describing a baseline condition and variability of this critical service (Brereton and Taylor-Wood, 2010) and no direct limit of acceptable change for food webs was developed. There is still no readily available assessment of the extent of intertidal mudflat habitat over time to understand whether there has been a change in the intertidal mudflat and the invertebrate fauna.

While the availability of foraging habitat and food is a critical supporting service for migratory shorebirds, any changes in the service may not be reflected in changes in the number of migratory shorebirds given that changes in the number of migratory shorebirds are unlikely to be due solely to changes in the food web in the Hunter estuary. That is, there are factors other than the availability of intertidal mudflats and food web that may impact on migratory shorebirds, including changes to habitats in the flyway external to Kooragang, at breeding grounds and stopover sites that also impact on shorebird numbers.

Risks to shorebird species are considered to exist via bioaccumulation of chemicals through the food chain via ingestion of algae, benthic organisms and small fish. It is considered likely that some chemicals are bioaccumulating in migratory shorebirds foraging in the intertidal mudflats particularly in the Fullerton Cove area and Stockton Sandspit.

There is evidence of bioaccumulation of chemical contaminants in the food web in Fullerton Cove with concentrations higher in fish compared to benthic invertebrates (AECOM, 2018). AECOM (2018) identified that there is potential for unacceptable risks to birds eating vegetation, invertebrates or fish from Fullerton Cove. However, the risk was considered to be acceptable for migratory species that only spend a portion of their time feeding in Fullerton Cove. Although migratory shorebirds would also be exposed to chemical contaminants at other locations along their migratory routes in the East Asian Australasian Flyway (EAAF) (extending from breeding grounds in the Russian tundra, Mongolia and Alaska southwards through east and south-east Asia to non-breeding areas in Indonesia, Papua New Guinea, Australia and New Zealand), they spend up to six months of the year at their primary feeding grounds at the southern extents of the Flyway. The Hunter Estuary Ramsar site is one such feeding

ground. Some juvenile birds will stay in Australia for up to three years before they start the full migration back to the breeding grounds.

Whilst there are significant knowledge gaps in describing the food web of the intertidal mudflats in the Kooragang component and its influence on the ecological character of the site, there a clear and scientifically plausible risk that chemical contaminants are negatively impacting on this CPS.

Shorebirds

Shorebirds, particularly migratory species, are one of the principal justifications for listing of the Kooragang component of the Hunter Estuary Wetlands as a Ramsar Wetland of International Importance. The site contains foraging and roosting habitat for populations of migratory shorebirds during their non-breeding season.

The ECD set two LAC, as follows:

- the annual maximum summer count of migratory shorebirds should not be less than 5,000 birds in five (5) consecutive years; and
- For any given five (5) year period, the average of the annual maximum summer count of eastern curlew for the Hunter estuary should not be less than 600 birds.

The level of confidence for both of these LAC was low (Brereton and Taylor-Wood 2010). An analysis of long term (April 1999 to December 2017) shorebird data was undertaken to identify any changes in shorebird abundance. This showed a slight, albeit statistically non-significant, overall *increase* in migratory shorebird abundance.

The increase in migratory bird abundance is largely due to rehabilitation works at Tomago wetland and the return of sharp-tailed sandpipers in large numbers to this wetland from 2013 onwards.

Removing the influence of the Tomago wetland shows a declining trend in shorebird abundance, as measured by the annual maximum summer count of migratory shorebirds, to less than 5000 birds for the last three years of data. However, this does not constitute an exceedance of the LAC as the threshold is set at five (5) consecutive years.

At the time of listing in 1984, the Kooragang component of the Hunter Estuary Wetlands Ramsar site recorded 900 eastern curlews (*Numenius madagascariensis*), and between 1999 and 2007, there were regularly 400 to 600 eastern curlews (Herbert, 2007a). Analysis of monthly data from 2000 to 2017 shows a decline in abundance of the eastern curlew. This decline is more pronounced in the last four years (2014 to 2017).

While this analysis would indicate that the LAC for the eastern curlew has been exceeded, it is noted that there is a low level of confidence in the LAC. Further, this declining trend of the eastern curlew abundance is reported both nationally and globally (Hansen et al., 2016; Clemens et al 2016). In response, the eastern curlew was listed as ‘critically endangered’ under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in 2015.

Notable changes have occurred for individual species of migratory shorebirds with national decline since 2015 recognised by listing the following species under the EPBC Act:

- bar-tailed godwit (*Limosa lapponica baueri*);
- curlew sandpiper (*Calidris ferruginea*)
- great knot (*Calidris tenuirostris*);
- red knot (*Calidris canutus*); and
- black-tailed godwit (*Limosa limosa*).

These species have also shown a decline in abundance from 2000 to 2017. However, these declines are similar to other coastal Ramsar sites in south-eastern Australia and global declining trends. The extent to which local impacts (e.g. chemical contamination and habitat changes, etc.) have individually contributed to the decline in migratory shorebird abundance at the Kooragang component of the Hunter Estuary is unclear.

While no LAC was set for migratory shorebird 'species diversity', due to an insufficient knowledge of what would constitute a change in ecological character, number of species present at the site could be considered to reflect species diversity. The recent survey data (1999 to 2017) does not show any change in number of species present at the site.

Restoration of estuarine habitats on Ash Island and Hexham Swamp is increasing habitat for migratory shorebirds in the Hunter estuary. Whether this has an effect on numbers of migratory shorebird at the Kooragang component of the Ramsar site, that is whether birds are preferentially using areas external to the Kooragang component, was not tested in this assessment as data for other sites external to the Kooragang component was not available for analysis. Supporting statements on changes in abundance of select shorebird species in the Hunter estuary was provided from a literature review by Hunter Bird Observers Club and updates of the EAAF counts (Clemens et al. 2016).

It is unclear whether declines in shorebird counts may be attributed directly to contamination given other potential confounding factors, including the following:

- changes in roost availability;
- impacts of repeated disturbances (high energetic cost that may compromise their capacity to build sufficient energy reserves for migration);
- poor water quality impacts;
- foraging habitat loss; and
- drought.

However, negative impacts on shorebirds caused by chemical contamination at the Kooragang component of the Hunter Estuary Ramsar site cannot be discounted as there is no known evidence that allows negative impacts to be ruled out.

Saltmarsh

At the time of listing in 1984, saltmarsh covered approximately 582 ha (Williams et al., 2000). Since listing, the extent of saltmarsh has continued to decline, most likely as a result of lags in the ecological responses to the drainage and reclamation works that took place in the lower Hunter Estuary from the late 1950s to 1980 and as a consequence of sea level rises.

Since 1993, a number of restoration projects have commenced in the Hunter estuary to restore saltmarsh shorebird and fish habitat. Notwithstanding localised increases in area of saltmarsh from restoration efforts, recent mapping (Kleinfelder, 2016) has identified that the current extent of saltmarsh within the Kooragang component of the Ramsar wetlands has continued to decline and is now estimated to cover approximately 289 ha. Although this exceeds the LAC, it is recognised that the confidence level for the LAC was low, and that the LAC did not appropriately consider the trajectory of changes occurring at the site at the time of listing.

There is no evidence that changes to saltmarsh extent are attributed to chemical contamination. This declining trend in saltmarsh habitat is recognised in estuaries across NSW and nationally. Saltmarsh was listed as an endangered ecological communities (EEC) under the state *Biodiversity Conservation Act 2016* (BC Act) and as vulnerable under the EPBC Act in 2013.

It is recommended that the recent monitoring in the Tomago wetlands of changes in saltmarsh in response to restoration works should continue to inform iterative management of the Kooragang component of the Ramsar site. Consideration should be given to expanding this monitoring program to assess other areas of saltmarsh in the Kooragang component.

Other Threatened Species

Two other nationally threatened species were highlighted in the ECD as critical to the ecological character of the site - the green and golden bell frog (*Litoria aurea*) and Australasian bittern (*Botaurus poiciloptilus*).

The LAC identified in the ECD for the green and golden bell frog was no more than two (2) years between successful breeding events (defined as the presence of a new first year adult cohort) in at

least one (1) of the three (3) known populations (Brereton and Taylor-Wood, 2010). The level of confidence for this LAC was recognised as low in the ECD due to the absence of long-term data on breeding events and population / movement dynamics (Brereton and Taylor-Wood, 2010).

There remains an absence of long-term data on breeding events, population and movement dynamics within the Kooragang component of the Ramsar site. This precludes an assessment of change in green and golden bell frogs and an assessment of any impacts associated with chemical contamination.

No LAC was set for the Australasian bittern. There is a paucity of data on the occurrence of the Australasian bittern in the Kooragang component of the Hunter Estuary Wetlands Ramsar site and gaps in the knowledge of the status of this species in the wider Hunter estuary. It is unknown whether rehabilitation works in Tomago and Hexham wetlands are altering the availability of habitat for this species, or whether chemical contamination may be impacting on this species. Ongoing monitoring would be required to better inform management of the species and its habitat.

Potential for Change Due to Chemical Contamination

Based on current scientific understandings, the CPS at most risk to chemical contamination are shorebirds and frogs. It is considered likely that some chemicals are bioaccumulating in migratory shorebirds foraging in the intertidal mudflats particularly in the Fullerton Cove area and Stockton Sandspit. Based on an analysis of the data available, the chemicals of primary concern at the Kooragang component of the Ramsar site were identified as lead and PFOS. These chemicals are associated with a range of effects, with lead exposure associated with neurological problems, kidney dysfunction, enzyme inhibition and anaemia, while PFOS exposures are associated with growth inhibition, histopathological effects, atrophied thymus, species diversity changes in a microcosm, and mortality.

Despite the significant data gaps that exist, there is sufficient evidence to indicate that the site has been potentially impacted by a number of contaminants. The screening-level assessment of the available data indicates that some contaminants are present in surface water, sediments, and biota at levels that may pose an unacceptable risk to ecological receptors. Some of these contaminants were likely present in greater concentrations at the time of listing in 1984, suggesting that contaminants which have declined (e.g. metals which have been flushed from the system and / or been 'capped' by deposits of less contaminated sediment) are unlikely to be responsible for any observed changes in ecological character since listing. However, for some persistent contaminants, effects may occur for many years after the initial release.

PFAS at the Ramsar site is predominantly associated with contamination released from RAAF Base Williamtown, where PFAS containing fire-fighting foams were commonly used, stored and disposed of, between the 1970s and mid-2000s (Taylor and Cosenza, 2016). Recent studies have shown that PFAS in Australian human blood serum levels are generally declining due to the removal of PFAS from many consumer goods (Toms et al, 2014), however, there are ongoing increases in concentrations in some biota at higher tropic levels due to biomagnification and bioaccumulation within the environment (Miller et al, 2015).

The findings of this assessment were based on a large quantity of recent, relevant and high quality data for PFAS at the site, and very limited data for other chemicals. Collection of additional site data, particularly for other potential contaminants, would be required to determine whether chemical impacts have resulted in a change in the ecological character of the Ramsar site.

Recommendations

Recommendations arising from this investigation include:

- consultation;
- reducing uncertainty in potential changes to ecological character of the site; and
- development of an action plan to improve understanding of the Ramsar site.

Consultation

Additional consultation that more actively engages with key stakeholders is recommended.

Data Gaps

There are significant data gaps with regards to the assessment of contaminant levels and associated risk within the Hunter Estuary Ramsar site. The following recommendations are made with regards to addressing these data gaps:

- conduct site specific sampling of sediment and surface water throughout the site.
- undertake detailed baseline surveys within the Ramsar site and assess factors such as invertebrate density or species distribution relative to contaminant levels.
- undertake direct toxicity testing of sediment and surface water collected from the site, to assess whether there is a cause-effect relationship between contaminants at the site and toxic effects such as reduced survival, growth inhibition, or reduced fertilisation.

Ramsar Status Assessment

There is possibility of a future change in ecological character associated with chemical contamination, however further information is required.

It is recommended that a watching brief is commenced. This should include development of an action plan, with relevant stakeholders. It is suggested that the action plan focus on improving knowledge of processes and change, to better inform decisions and management. Where relevant, resets to the LAC, based on best available science, should also be considered to improve their relevance and capacity to inform future formal assessments of change.

The action plan should also identify and implement options to fill knowledge gaps and adopt standardised and systematic surveys to allow for comparison of data sets to ensure that further assessments of change are based on the best available science and to identify the contribution of climate change to these changes, particularly for saltmarsh, mangroves and extent of tidal mudflats.

This may include:

- investigation of bioaccumulation of chemicals of concern in the foodweb;
- assessment of geomorphic change at the site;
- investigations of green and golden bell frog at the site;
- investigations of the current status of the Australasian Bittern at the site and potential threats associated with chemical contamination and saltmarsh restoration activities; and
- Review of the LAC to:
  - strengthen the level of confidence that a change in LAC would be a good indicator of a possible change in ecological character; and
  - improve their relevance and capacity to inform future formal assessments of change, including due to chemical contamination.

Longer term strategies for possible interventions may require approvals and environmental assessment or policy investigation and potentially include:

- modification of the boundaries of the Ramsar site;
- scoping and implementation of works, with other stakeholders, to improve north arm sandflats;
- investigation of the feasibility to improve tidal flows under Ramsar Road; and,
- consideration of whether Australasian Bittern is still a critical CPS for this site.

1 INTRODUCTION

Arcadis Australia Pacific Pty Ltd (Arcadis), in partnership with Umwelt (Australia) Pty Ltd (Umwelt), have been engaged by the Department of the Environment and Energy (DoEE) to undertake a formal assessment of whether there has been or is likely to be potential change in the ecological character of the Hunter Estuary Wetlands Ramsar Site (Kooragang component) due to chemical contamination.

As a Contracting Party to the Convention on Wetlands of International Importance (the Ramsar Convention), Australia is obliged to promote the conservation of Ramsar wetlands and wise use of all wetlands and work to ensure that Ramsar sites are managed to protect their ecological character. This assessment has been undertaken to address these obligations.

1.1 Purpose

Under Article 3.2 of the Ramsar Convention, Contracting Parties agree that they will arrange to be informed at the earliest possible time if the ecological character of any listed wetland has changed, is changing or is likely to change as the result of technological developments, pollution or other human interference.

The Commonwealth and state governments have agreed to an approach for undertaking assessments and making Article 3.2 notifications. The assessment must be evidence-based and undertaken in accordance with the National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2).

A potential change in the ecological character of a site may be identified from a number of sources, including the ecological character description, scientific reports, updated site information, monitoring, research, advice from government agencies, site managers, or as a result of a third-party notification.

The purpose of this formal assessment is to determine whether a change in ecological character at the Kooragang component of the Hunter Estuary Wetlands Ramsar site (hereafter referred to as the Kooragang component) has occurred, is occurring or is likely to occur, due to chemical contamination.

1.2 Approach

This assessment investigates changes to critical components, processes and services influencing the ecological character of the site, particularly as they relate to potential contamination issues. The assessment includes:

- A description of the site and recent site conditions, including:
  - Physical factors, including land uses, climate, topography, hydrology, hydrogeology, and geology.
  - Biodiversity and ecological characteristics.
- An assessment of chemical contaminant levels at the site and surrounds;
- Identification and analysis of critical components, processes and services (CPS); and
- Conclusions and recommendations.

1.3 Why is a formal assessment required?

Based on a review of the best available information at the time of listing in 1984, the Kooragang Ramsar Wetland Ecological Character Description (ECD) prepared in 2010 (Brereton and Taylor-Wood) identified that the limits of acceptable change for the following critical components and ecosystem processes have been exceeded:

- The areal extent of the critical component *Sarcocornia* saltmarsh has reduced from an estimated 582 hectares (ha) in 1983 (based on Williams et al. 2000) to 309 ha in 1993 (based on Winning 1996).

- Shorebird abundance has declined exceeding the LAC of no less than 5000 birds in summer for any five (5) year period.

The ECD identified that there are knowledge gaps linked to a number of the components, processes or services that describe the ecological character of the Kooragang component of the Hunter Estuary Wetlands Ramsar site and there was a low level of confidence in the limits of acceptable change (Brereton and Taylor-Wood 2010).

The community and NSW Government have raised concerns about potential contamination of the Hunter Estuary Wetlands Ramsar site by a range of potentially hazardous chemicals and heavy metals which have been used or manufactured in the immediate environs and whether this has or is likely to cause a change in ecological character of the Kooragang component of the Ramsar site.

On the 3 September 2015, the NSW Government announced that PFAS contamination had been detected both on and offsite at the Department of Defence RAAF Base at Williamtown. An Expert Panel was convened to investigate the nature and extent of the contamination and recommend next steps to the NSW Government. This resulted in the NSW Environment Protection Authority advising the NSW Office of Environment and Heritage that there was a strong likelihood that PFAS had caused a change in the ecological character of the Hunter Estuary Ramsar site. OEH subsequently notified the Australian Ramsar Administrative Authority which initiated this formal assessment.

The objective of this formal assessment is to:

> *"determine if a change in ecological character of the Hunter Estuary Ramsar Site (Kooragang Component) has occurred due to chemical contamination, the significance of the change, and the cause of the change."* (DoEE, 2017).

This investigation takes the form of a formal assessment of change of ecological character undertaken in accordance with the *National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2)*.

1.4 Evidence Used for the Assessment

The assessment draws on the following key sources of information:

- Federal and State government publications related to the ecological character of the Hunter Estuary:
  - Ecological Character Description of the Kooragang Ramsar Site (Brereton, R. and Taylor-Wood, E., 2010).
  - Ramsar nomination in 1984.
  - Ramsar Information Sheet (RIS) 1998, 2002 and 2012.
  - Hunter Wetlands National Park Statement of Management Intent (Office of Environment and Heritage (OEH), 2014a) and the Hunter Wetlands National Park Draft Plan of Management (National Parks and Wildlife Service (NPWS), 2015).
- Other available data related to the ecological character of the Hunter Estuary:
  - Monthly monitoring data collected by the Hunter Bird Observers Club (HBOC), 1999 to 2017.
  - Review of publications by HBOC for the Hunter estuary as published in The Whistler, in Stilt and/or special reports on birds of Ash Island, Kooragang Island (bird counts from 1969-1977) and the Hunter Estuary.
  - Vegetation monitoring data for the Tomago Wetland Rehabilitation Project from 2012.
  - OEH BioNet records of threatened species for the Kooragang component of the wetland and a 10 kilometre (km) buffer area.
  - Atlas of Living Australia records.

- Government publications related to assessing the environmental health of the Hunter River, including Office of Environment and Heritage (OEH) and NSW Environment Protection Authority (EPA) Publications:
  - Health of the Hunter (OEH, 2016).
  - Lower Hunter River Health Monitoring Program (OEH, 2017a).
  - Preliminary Ecological Assessment of the Lower to Mid Hunter River Estuary 2015–16, (OEH, 2017b).
  - Lower Hunter River Health Monitoring Program Water Quality Monitoring Program 2014-2015 Report (OEH, 2017c).
  - Lower Hunter River Health Monitoring Program Stormwater 2015 (OEH, 2017d).
- Environmental monitoring reports from specific facilities and industries in the vicinity, and other site-specific investigations and research projects, including:
  - Newcastle Port Corporation Port-wide Strategy – Maintenance Dredging Assessment (CSIRO, 2014a) and Newcastle Port Corporation Port-wide Strategy – Future Capital Dredging Assessment (CSIRO, 2014b).
  - Proposed Extension of Shipping Channels, Port of Newcastle – Sediment Toxicity Investigations (Patterson Britton and Partners, 2003).
  - Hunter River Estuary Water Quality Data Review and Analysis (Sanderson & Redden, 2001).
  - Off-site Ecological Risk Assessment (AECOM, 2018);
  - NSW EPA RAAF Base Williamtown PFAS Contamination – Factsheets and Resources (accessed via EPA website).

Additional evidence used to inform this assessment is listed in the references provided in Section 8**.**

1.5 Regulatory Framework

Australia is a signatory to the Convention on Wetlands of International Importance (the Ramsar Convention), with DoEE the Commonwealth agency responsible for the management of our international obligations as a Contracting Party to the Convention.

The assessment and management of contamination issues is generally managed as a state jurisdiction issue. However, contamination concerns within a Ramsar wetland, necessarily involve the Commonwealth due to their role as the Ramsar Administrative Authority.

This assessment was undertaken with consideration of the following legislation, policy and guidelines.

Commonwealth

- *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act).
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZAST, 2018).
- National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No.1) (NEPC, 2013).
- National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2) Module 3 (DEWHA, 2009).

New South Wales

- *Biodiversity Conservation Act 2016* (the BC Act, 2016).
- *Contaminated Land Management Act 1997 (CLMA, 1997).*
- Guidelines for Consultants Reporting on Contaminated Sites (OEH, 2011).

2 THE RAMSAR SITE

2.1 Site Setting

The Hunter River is a significant waterway, port, transport route, and environmental habitat on the northern NSW coast. Situated at the mouth of the river, the Hunter Estuary Wetlands Ramsar Site (the site) incorporates two segments, the ‘Kooragang’ component and the ‘Hunter Wetlands Centre Australia’ component (Figure 2.1). As this assessment considers the Kooragang component only, the site details discussed herein are limited to a discussion of the Kooragang component.

The Kooragang component (*Figure 2.2*) includes both Kooragang Island and Fullerton Cove on the North Arm of the estuarine section of the Hunter River. Kooragang Island originally comprised of seven (7) islands separated by narrow mangrove lined channels, however, the Kooragang Island was largely reclaimed and formed to its current extent in the 1950s (DoEE, 2016). Fullerton Cove is a large estuarine, mangrove fringed inlet extending north off the North Arm of the Hunter River. Habitat types within the Ramsar site include mangrove forests dominated by Grey Mangrove, Samphire saltmarsh, Paperbark and Swamp she-oak swamp forests, brackish swamps, mudflats, and sandy beaches (DoEE, 2016).

2.1.1 Geomorphology

The Hunter River estuary is classified as a mature barrier estuary characteristically formed by extensive river systems with high sediment loads (Roy et al., 2001). The estuary includes the junction of the Hunter River, Paterson and Williams rivers at Raymond Terrace with tidal limits extending approximately 64 km upstream of the river mouth to Oakhampton, west of Maitland.

Downstream from Oakhampton, the river transitions to river flats with an estuarine delta downstream of Hexham (see Figure 2.1). The estuarine delta is characterized by two main channels (the north arm and south arm) around the smaller Campbell Island and Hexham Island and the larger Kooragang Island (see *Figure 2.2*).

The deepest part of the estuary is in the Port of Newcastle where the depth is maintained by dredging to between 14 and 16 metres. The south arm of the Hunter River is naturally shallower, decreasing from four metres to one metre deep at the junction with the north arm (BMT WBM, 2009). The north arm is much deeper being mostly over five metres deep and up to nine metres deep. Off the north arm of the Hunter River is the large shallow embayment of Fullerton Cove. Fullerton Cove has a maximum depth of two to three metres with large areas of mudflats exposed at low tide.

Since 1910, the Hunter River has been dredged to create and maintain the Port of Newcastle. Channels have been deepened to allow for shipping movements in the south arm of the Hunter River. Annual maintenance dredging in the harbour (including Throsby Basin, Carrington Basin and the south arm of the Hunter River downstream of Port Waratah) removes around 300,000 m^3/year of sediment (MHL, 2003).

Image Source: Nearmap (Feb 2018)
Data Source: Commonwealth of Australia (Department of Environment) (2015)

Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- National Park
- Nature Reserve
- Regional Park
- State Conservation Area

FIGURE 2.1

Locality Map

File Name (A4): R01/4187_008.dgn
20180417 10.58

Image Source: Google Earth (Aug 2017)
Data Source: NPWS (2016), Commonwealth of Australia (Department of Environment) (2015)

0 1 2 3km
1:60 000

Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- National Park
- Regional park
- State Conservation Area

FIGURE 2.2

Kooragang Component of the Hunter Wetlands Ramsar Site

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2.2 Ramsar Criteria

The Hunter Estuary Wetlands Ramsar site was designated in 1984. The latest Ramsar Information Sheet in 2012 identifies that the site satisfies three of the nine Ramsar listing criteria (DoEE 2018c):

- Criterion 2: The Hunter Estuary Wetlands Ramsar site supports two species that are nationally listed:
  - The green and golden bell frog (*Litoria aurea*) listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) has been found within the Kooragang component of the Ramsar site.
  - The Australasian bittern (*Botaurus poiciloptilus*) listed as endangered on both the EPBC Act and the IUCN Red List (Version 2009.1) has been found at both Kooragang and the Hunter Wetlands Centre components of the Ramsar site.
- Criterion 4: The Hunter Estuary Wetlands Ramsar site supports 112 species of waterbirds and 45 species of migratory birds listed under international agreements, including species other than shorebirds such as the great egret (*Ardea alba*), cattle egret (*Ardea ibis*), terns (*Sterna* spp.), glossy ibis (*Plegadis falcinellus*) and white-breasted sea-eagle (*Haliaeetus leucogaster*). The Hunter Estuary Wetlands also provide refuge for waterbirds such as ducks and herons during periods of inland drought.
- Criterion 6: The Hunter Estuary Wetlands Ramsar site regularly supports 1% of the East Asian Australasian Flyway population of the eastern curlew (*Numenius madagascariensis*) and more than 1% of the Australian population of the red-necked avocet (*Recurvirostra novaehollandiae*).

The Kooragang component supports five Ramsar wetland habitat types. Table 2.1 lists the wetland types, from most to least important and describes the occurrence and changes since listing.

Table 2.1 Ramsar Wetland Types in Hunter Estuary Wetlands Ramsar Site (Kooragang component)

Ramsar Wetland Types		Occurrence
Marine/Coastal Wetlands		
F - Estuarine waters	Permanent water of estuaries and estuarine systems of deltas	Fullerton Cove, north arm of the Hunter River and Kooragang Dyke Ponds
I – Inter-tidal forested wetlands	Including mangrove swamps, nipah swamps and tidal freshwater swamp forests	Mangrove communities around Fullerton Cove and along the banks of the north arm of the Hunter River. Swamp oak (*Casuarina glauca*) woodland to the north and west of Fullerton Cove. This community has expanded from 3.4 hectares (ha) in 1984 to 76.67 ha in 2016 and mainly occurs in the Tomago wetland area.
G – Inter-tidal mud, sand or salt flats		Largest area is Fullerton Cove with smaller areas on islands in the north arm of the Hunter River, behind the Kooragang Dykes and on Stockton Sandspit.
H - Intertidal marshes	Including salt marshes, salt meadows, saltings, raised salt marshes; tidal brackish and freshwater wetlands	Saltmarsh and saline pasture in Tomago Wetland area, to the west of Fullerton Cove and saltmarsh on Kooragang Island. Rehabilitation works in the Tomago Wetland area have opened the floodgates allowing increased tidal inundation and the area of freshwater influenced wetlands is decreasing.

Ramsar Wetland Types		Occurrence
Inland Wetlands		
Xf-Freshwater, tree-dominated wetlands	Including freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils	Small patch of broad leaved paperbark (*Melaleuca quinquenervia*) swamp near Tomago Road.

2.3 Land Uses

2.3.1 Across the Catchment

The Hunter River Estuary has been influenced by over 200 years of intensive development activities including reclamation, timber harvesting, land clearing, agriculture, mining, heavy industry and more recently tourism (Williams et al, 2000).

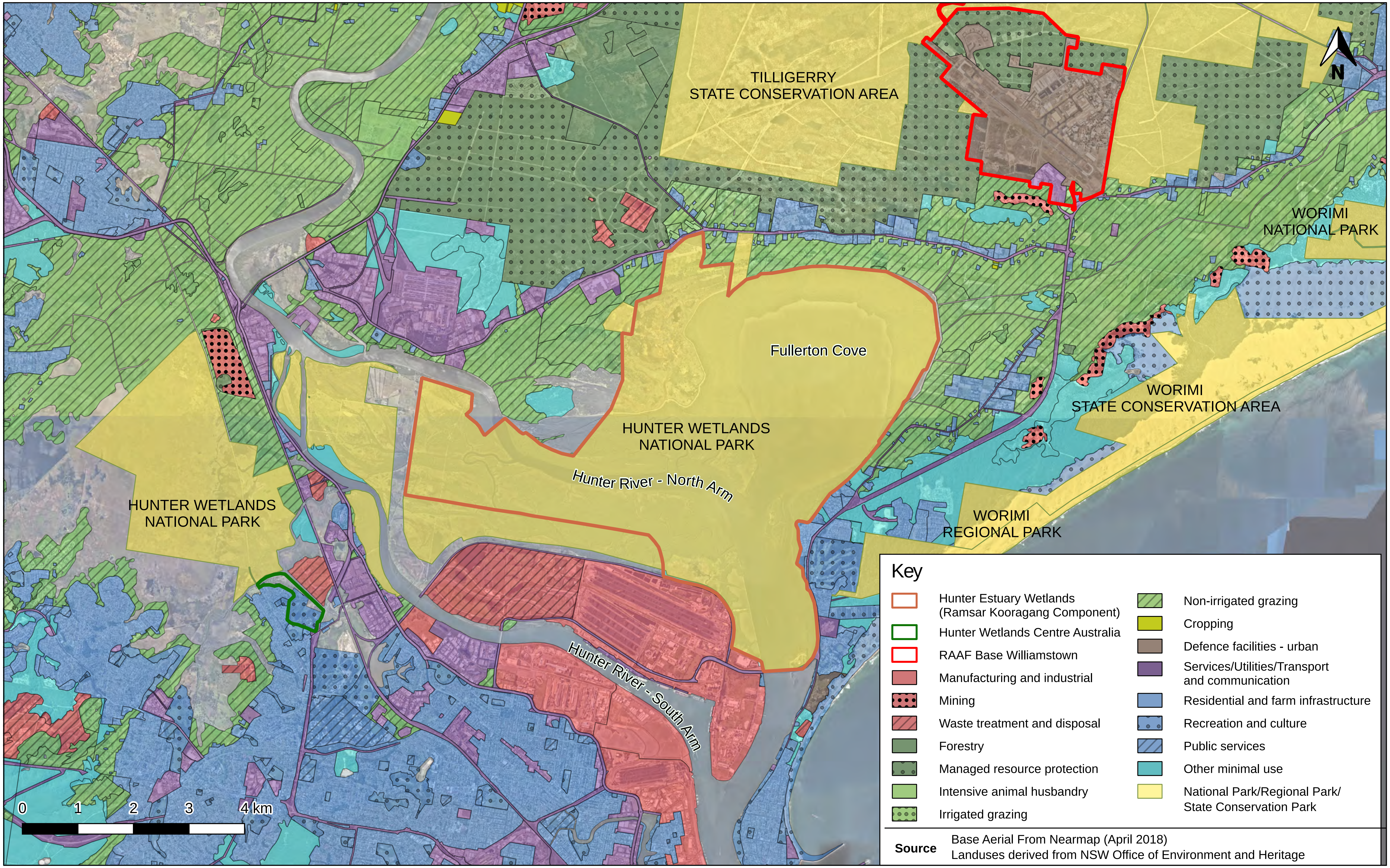
The wider catchment area has been widely cleared and impacted by anthropogenic activities since the early discovery of coal in the Hunter River region in 1796 (Williams et al, 2000). Land uses such as mining and heavy industry at Newcastle have significant potential to impact on water quality and potential chemical contaminant levels at the site, particularly along the Hunter River North Arm. Clearing and agriculture also have significant potential to impact on surrounding hydrology, water quality, and contaminant loading, particularly within Fullerton Cove. Catchment land uses are shown on Figure 2.3 below, taken from OEH (2017c).

Figure 2.3 Conceptual diagram of the highly modified catchment of the Hunter River showing common land use activities and stressors / pollutants (OEH, 2017c).

Increasing urbanisation and population pressures in proximity to the site are also significant factors that will impact on the water quality and contaminant loading within the Ramsar site, due to its location at the base of the wider catchment. Figure 2.4 shows land uses in the locality of the Hunter Estuary Wetlands Ramsar Site.

The Hunter Estuary catchment is located within the Newcastle, Maitland and Port Stephens local government areas (LGA). According to the Australian Bureau of Statistics (ABS), all three LGA's have experienced strong population growth in recent years, with this population growth second in NSW (outside of greater Sydney) to Illawarra (ABS, 2015). The ABS also reported that Stockton and Fullerton Cove to the north of Newcastle experienced the fastest population growth (2.8%) in the statistical area of Newcastle and Lake Macquarie.

Ultimately, the estuary is a receiving water for a diverse range of inputs from waste water treatment plants, agriculture, industry, stormwater and catchment runoff.



Arcadis Project: 10016612

2.3.2 At the Ramsar Site

The Ramsar site is managed as national park estate by NSW National Parks and Wildlife Service (NPWS). The Ramsar site is potentially utilised for a wide range of activities, including nature conservation, nature-based recreational activities (walking, cross country running), habitat restoration, electricity supply infrastructure corridors, commercial and recreational fishing, recreational boating, commercial tourism (kayak adventures), birdwatching, and flood mitigation. There is little public access to much of the government owned and managed land within the site, with a number of private industries or activities located directly adjacent to the site boundaries.

Land uses surrounding the Hunter Estuary Wetlands are shown on Figure 2.4 and include the following:

- Immediately to the west of, and partly overlapping the Kooragang component, is the Ash Island Kooragang Wetland Rehabilitation Project (KWRP). This area has been part of the Hunter Wetlands National Park since 2010;
- The urban area of Newcastle dominates the southern bank of the south arm with the Port of Newcastle development encompassing the south arm and river-side land of the Hunter River downstream of the Tourle Street bridge. The Port of Newcastle is the largest coal export port in Australia with portions of the Hunter River North and South arms regularly dredged;
- Residential areas are present near the south-eastern extent of the Hunter Estuary Wetlands site, to the east of Stockton Sandspit;
- Agricultural activities on reclaimed land adjacent to Fullerton Cove to the north and east (grazing) and on the western end of Kooragang Island. However, much of the agricultural land on Kooragang Island is now within the Hunter Wetlands National Park and/or subject to rehabilitation under KWRP;
- Industry is present at multiple locations along the north and south arms, with associated activities such as construction and licenced discharges occurring. Key industries are listed below, with current EPA licenced discharge locations shown on Figure 2.4 and Figure 2.5:
  - Coal export facilities, Kooragang Island;
  - Orica facility, Kooragang Island;
  - Ameropa (Impact Fertilisers), Kooragang Island;
  - Tomago Aluminium, Tomago; and
  - Fuel Terminal, Kooragang Island.

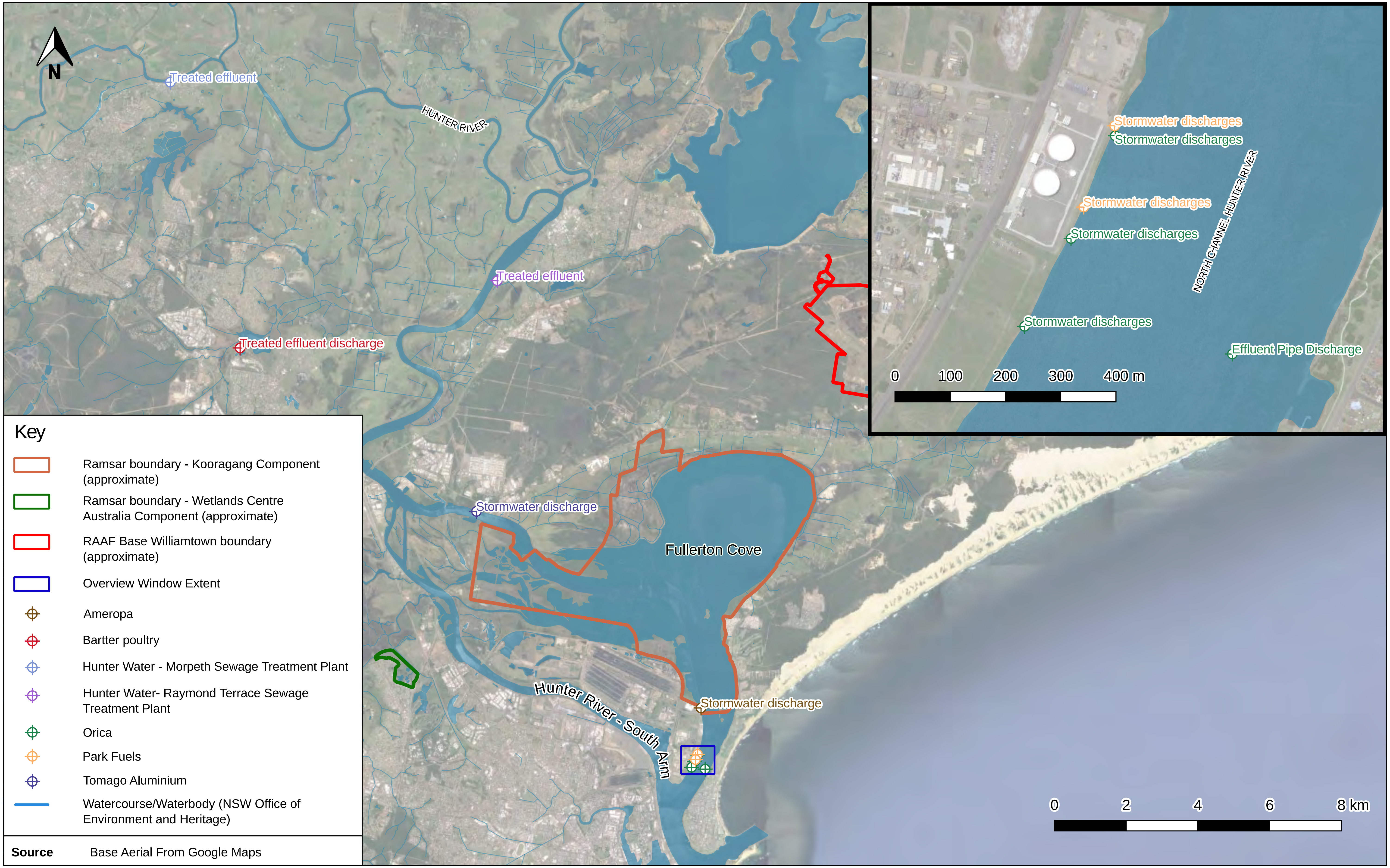
The majority of land located along the banks of the Hunter River and surrounding the Hunter Estuary Wetlands Ramsar site is privately owned. Portside land to the south of the Ramsar site is owned by a number of large corporations, as well as by State Government and Rail Authorities.

The diversity of land ownership throughout the area makes implementing water or environmental management measures challenging, and strategies affecting catchment land are generally complicated by consideration of impacts on private land owners as well as impacts on the environmental health of the Hunter River and its users.

EPA licensed discharge locations | Figure 2.5

Hunter Estuary Ramsar Site – Kooragang Component

Formal Assessment of Change



Source Base Aerial From Google Maps

Arcadis Project: 10016612

2.4 Physical characteristics likely to be influencing ecological character of the site

2.4.1 Climate

The prevailing climate of the Hunter River Estuary is warm and temperate with coastal influence. Summers are warm to hot and humid, winters are cold to mild. The following section summarises the key climate elements that may impact the ecological character of the site.

Table 2.2 provides a summary of climate statistics for the Hunter estuary area showing mean temperature and rainfall climate from the period prior to and including listing of the Ramsar site (1961-1990) and since that time (1981-2010).

Table 2.2 Summary of Monthly Climate Statistics from Newcastle Nobbys Signal Station AWS (BoM, 2018).

Climate Element	Climate Statistics for Relevant Periods		
	1961-1990	1981-2010	1862-2018
Mean maximum temperature (°C) range	16.9 °C July to 24.7 °C in January	17.3 °C July to 25.3 °C in February	16.8 °C July to 25.6 °C in January
Mean minimum temperature (°C)	8.2 °C July to 19.5 °C in February	9.0 °C July to 19.9 °C in February	8.5 °C July to 19.4 °C in February
Highest minimum temperature	15.7 °C July 1990 to 25.5 °C in January 1978	15.7 °C July 1990 to 25.4 °C in January 1991	16.7 °C July 2016 to 26.0 °C in February 2011
Mean annual rainfall (mm)	1143.6 mm	1095.5 mm	1122.06 mm

It is noted, climate records from Nobbys Signal Station are likely influenced by the maritime setting. Records (from 1942 to 2018) from the nearby Williamtown RAAF base (site number 061078) located near the northern edge of the Kooragang component, are warmer and may reflect the prevailing weather condition at the outer edge of the wetland away from the marine influences.

At Williamtown RAAF Base the:

- mean daily temperatures in winter ranges from 6.4°C to 17.1°C in July
- mean daily temperatures in summer from 18.1°C to 28.2°C in January
- mean number of days with a temperature above 30°C and 35°C is three times higher than at Nobby's at 39.7 days and 9.6 days respectively.
- highest temperature records at Williamtown RAAF base was 45.5°C in February 2017 and highest minimum temperature of 26.9°C in February 2011.

2.4.1.1 Climate Change

The NSW and ACT regional climate modelling project (NARCLiM) has identified that there has been a gradual increase in temperatures in the Hunter since the 1960s with more sustained warming over the most recent decades (OEH, 2014b).

The climate change projections and climate change impact profile for near Newcastle for the near future (2020-2039) and far future (2060-2079) as provided in (OEH, 2014b) are summarised as:

- Annual mean maximum temperatures are projected to increase in the near future by 0.5 to 1.0°C and by 1.5 to 2.0°C in the far future.
- There will be more hot days with the number of days per year with a maximum temperature over 35°C likely to increase by 1 to 5 days in the near future and 5 to 10 days in the far future.

- Annual mean minimum temperatures are projected to increase in the near future by 0.5 to 1.0°C and by 2.0 to 2.5°C in the far future and there will be fewer cold nights.
- Annual rainfall is likely to change little though seasonal variations are likely including increased rainfall in summer and autumn and decreased winter and spring rainfall. It is projected that there will be an increase in the frequency of occurrence of high rainfall events in summer and decreased frequency in autumn (Blackmore et al., 2010).
- An increase in average and severe fire weather is projected in summer and spring;
- Sea surface temperatures and sea level will continue to rise and the number of extreme sea level events (when multiple sources of elevated water level interact) will increase.

These climate factors have implications for threats to the health of ecological communities in the Kooragang Ramsar wetlands and shallow nearshore waters in Fullerton Cove. Migratory shorebirds are predicted to be significantly impacted by climate change as expected sea level rises, increased temperatures and more frequent extreme weather events will reduce coastal habitats needed for foraging, breeding and roosting. In addition, the invertebrate food sources for these birds are also likely to be affected which will further impact on shorebird populations.

In Newcastle Harbour the annual mean sea level rise from 1966 to 2006 shows a rise of 1.15 mm/year (Blackmore et al., 2010). The Intergovernmental Panel on Climate Change projected in 2007 sea-level rise of between 18 centimetres (cm) and 59 cm above present levels at the end of the 21st century however recent research indicates that is an underestimate with current observations tracking higher scenarios (Rogers et al., 2014). Blackmore et al. (2010) projected sea level rise in Newcastle of 0.37 m by 2050 and 0.845 m by 2100. Sea level rise will change estuarine habitats, change salinity regimes and impact groundwater dependent ecosystems.

Projected sea level rise modelled for the Hunter Estuary by 2100, with floodgates open, identified:

- That there may be a 20% increase in saline coastal wetland area (mangroves and saltmarsh) under low sea level scenario (sea level rise ranging from 1.2-2.2 mm/year).
- A decrease in the order of 57% potential saline coastal wetland area under high sea-level scenario with the rates of sea level rise exceeding the capacity of the wetlands to proportionally build elevation. Under this scenario nearly all of the Ramsar wetland extent is lost by 2100 (Rogers et al., 2014).

2.4.2 Hydrogeology

The hydrogeology of the Hunter Estuary is characterised by two (2), shallow, unconfined coastal sand aquifers:

- The Tomago Sand Beds aquifer, inferred flow direction of south-southeast toward Fullerton Cove and the lower Hunter River; and
- The Stockton Sand Beds aquifer, inferred flow direction of north-west from the sand dunes parallel to the coast.

The Tomago Tomaree Stockton Coastal Sands groundwater is used to provide the potable water supply to the Newcastle area. The Tomago Sand Beds extend approximately 35 km north from the Hunter River to Port Stephens and cover an area of 183 km^2. Dune and/or coastal sands form a highly permeable aquifer with rapid rainfall recharge. However, the rapid infiltration makes this aquifer susceptible to contamination (Crosbie, 2003).

The Tomago Tomaree Stockton Coastal Sands aquifer is subject to management and protection under the Water Sharing Plan for the North Coast Coastal Sands Groundwater Sources (NOW, 2018a). Shallow groundwater was recorded at between <1.0 m to 2.0 mbgl (meters below ground level) at locations identified surrounding the estuary. Figure 2.6 shows the general arrangement of surface geology and depth of aquifer (AECOM 2016b).

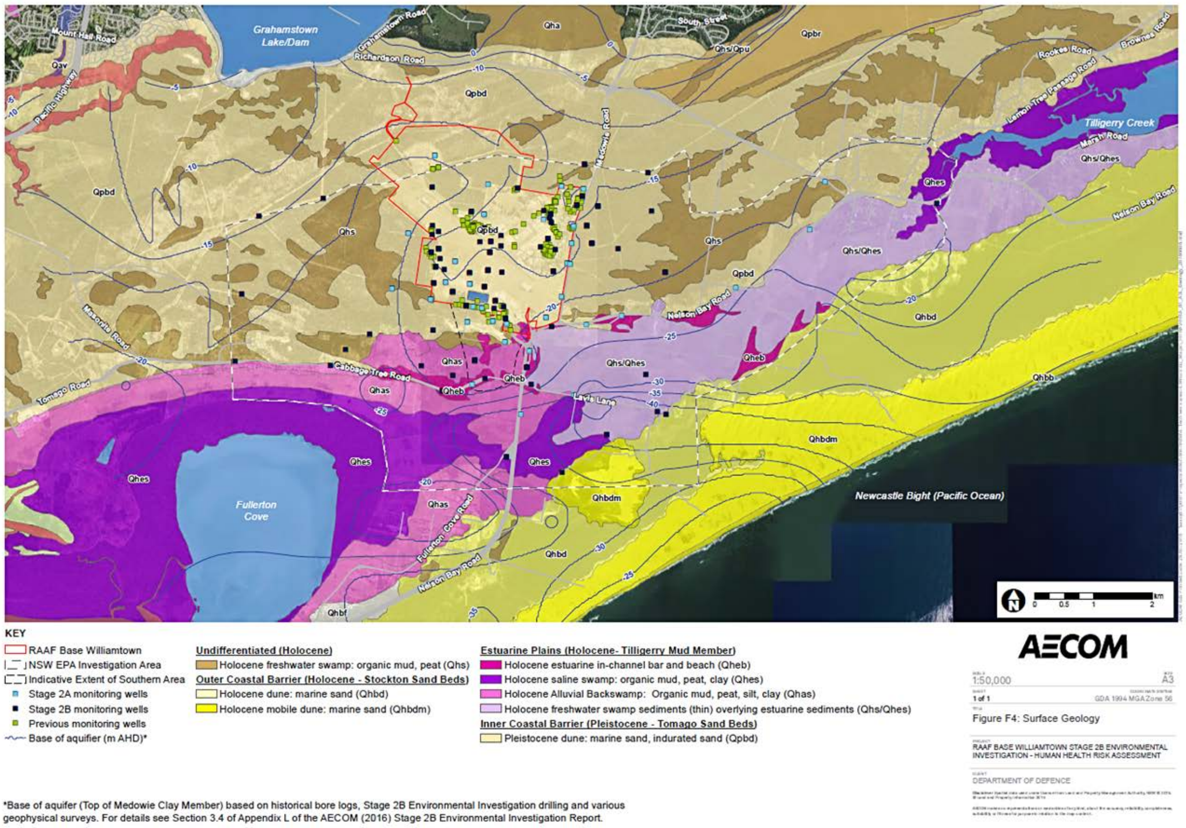


Figure 2.6 Surface Geology (AECOM 2016b)

2.4.3 Hydrology

The Hunter Estuary is located at the lowest topographical point within the catchment, and the site is impacted by upstream flows, catchment drainage, groundwater/ surface water interactions, and flooding. Land immediately adjacent to the estuary is influenced by tidal waters pushing in and surface and groundwater pushing out, creating a large area of direct interaction between the site and the lands and waters surrounding the site. The implications of this inter-connectedness are discussed in the following sections.

2.4.3.1 Surface and Groundwater Interactions

Interactions between streams and alluvial aquifers are considered to be common in the lower Hunter catchment, particularly in proximity to the site, with these alluvial aquifers further interacting with deeper fractured rock aquifers (NOW, 2018b).

Key mechanisms for these interactions include:

- River leakage,
- Diffuse rainfall recharge, and
- Vertical interchange from fractured rocks.

River leakage into the alluvial aquifers of the lower Hunter catchment is considered the main source of recharge for these aquifers, with inputs from river leakage estimated to be four times greater than inputs from rainfall recharge (DoEE, 2018b). This scenario represents a ‘losing’ river system, whereby surface water migrates into surrounding aquifers and groundwater is recharged.

Discharge of groundwater into rivers (referred to as baseflow) can comprise over 50% of river flows in the Hunter subregion, with this volume increasing to nearly 100% during periods of low rainfall and

reduced freshwater river flows (DoEE, 2018b). This represents a 'gaining' river system, whereby groundwater is discharged into the river and contributes to river flows.

Human activities in the catchment have affected water levels, water flows, and the behaviour of the groundwater and surface water interface. Activities such as clearing and development of infrastructure (roads, port, etc) increase the potential for flooding, due to a combination of factors such as raised groundwater levels and reduced capacity to retain rainfall. Mining activities have been shown to alter rates of recharge and flow in the alluvium aquifers, while more recent river regulations and dam management have improved consistency of streamflow and reduced flooding (DoEE, 2018b). Given the high degree of interconnectivity between alluvial and surface water systems of the Hunter catchment, the Water Sharing Plan for 'Hunter Unregulated and Alluvial' areas (DWE, 2009) treats both surface water and alluvial ground waters as a single unit for management purposes (DWE, 2009).

This indicates that while the majority of groundwater recharge in the alluvium aquifers is sourced from river leakage, the majority of river flow is ultimately sourced from baseflow discharges from the alluvium aquifers. The extent to which either flow type is occurring (i.e. is it a gaining or losing river system) would alter with season and location. For the Hunter Estuary Wetlands area, the combination of river leakage, groundwater discharge, and tidal influences would result in complex interactions and potential for large mixing zones between water bodies. This combination of factors can result in a 'pumping' effect, whereby with each change in tide there is a relatively rapid shift between the river system being classed as a losing system or a gaining system.

This has significant implications for contaminant or chemical transport within the lower Hunter catchment, as chemical releases to surface water may directly impact on groundwater and vice versa. A number of factors would impact on the extent to which a chemical release would impact on the surrounding environment, such as mass or volume released, toxicity, solubility, duration of release, etc. Persistent chemicals, such as Per- and Poly-fluoroalkyl Substances (PFAS) or metals, would be transported further as they do not readily degrade in the environment. Less persistent chemicals, such as petroleum compounds, would degrade or be metabolised more rapidly. Solubility is also an important factor with regards to transport of contaminants between surface and groundwaters, with compounds such as PAHs or metals transported as either colloidal material or in the dissolved phase. These compounds may be readily transported into surface waters from surrounding land uses and activities, where a combination of dissolved phase transport and deposition into sediments impact on transport and distribution.

To support this formal assessment, DoEE engaged UNSW to undertake a hydrodynamic modelling exercise that assessed potential contaminant transport within the Hunter Estuary Wetlands Ramsar site and surrounds (Miller et al, 2018). The case studies in the modelling report indicate that point source releases to surface water could potentially migrate to and mix with large portions of the lower Hunter River, with modelling of contaminants showing impacts >10km upstream at 50% of release concentrations. This study did not include groundwater influences. The contaminant transport model report is discussed further in Section 3.4.1.

2.4.3.2 Flood Mitigation

Throughout the history of settlement in the Hunter Valley, floods were frequent, widespread and severe, with flood mitigation works occurring throughout the Hunter River catchment for over 200 years.

A number of measures are currently in place to control flooding of adjacent land, including: levees, spillways, erosion protection, drains and diversion banks throughout the catchment and extending downstream as far as Tomago and Fullerton Cove (NSW Department of Commerce, 2003). These measures were primarily installed between 1956 and 1980, before the time of listing as a Ramsar site.

While major flood mitigation works are largely upstream of Hexham they do include the estuary particularly on the western end of Kooragang Island and around Tomago/ Fullerton Cove/ Stockton. In the Tomago/ Fullerton Cove/ Stockton area large drains in Long Bight Swamp, east of Fullerton Cove were evident on 1928 aerial photographs (Williams et al., 2000). This included Dawsons Drain, the Fourteen Foot Drain and Ten Foot Drain. The Fourteen Foot Drain connected Fullerton Cove with Tilligerry Creek, a tributary of Port Stephens (Williams et al., 2000). Investigations have shown that

these drains provide a preferential pathway for transport of PFAS, and likely other contaminants, into the Ramsar site from the Williamtown RAAF base (AECOM, 2016a; 2016c). These drains also facilitate transport of contaminants associated with other land uses, including agriculture and urbanisation, into the site.

Within the Kooragang component of the wetland, there are a total of 84 structures on creeks and drains comprising 28 bridges, 46 culverts and 10 floodgates (Williams et al., 2000). This includes the 'ring drain' constructed around Fullerton Cove in 1976 and the floodgates at Tomago.

The changes to the estuary arising from the flood mitigation works are illustrated in the series of maps drawn from review of aerial photographs by Williams et al. (2000) (see Figure 2.7). Existing nearby drainage lines/waterways and constructed channels that currently exist are shown on Figure 2.8.

2.4.3.3 Other anthropogenic changes to the physical form of the estuary

Williams et al. (2000) have identified the following anthropogenic changes to the physical form of the estuary, in the period from 1801 to 1994 (see Figure 2.7):

- The number of major islands in the estuary decreased from 21 to six;
- The total number of islands decreased from 29 to 18;
- Kooragang Island was formed from a group of up to 10 islands;
- The total length of shoreline has decreased by approximately 33 km from 154 km to 121 km mostly in Throsby Creek (-12.2 km), eastern Kooragang Island (- 12.9 km) and western Kooragang Island (10.6 km). These changes are most likely the result of large-scale anthropogenic reclamation resulting in a reduction in the number of islands.
- The water area in the lower Hunter has changed with a loss of 1330 ha of open water through reclamation (-740 ha), siltation (-750 ha), dredging (+110ha) and erosion (+50ha) (Williams et al. 2000).

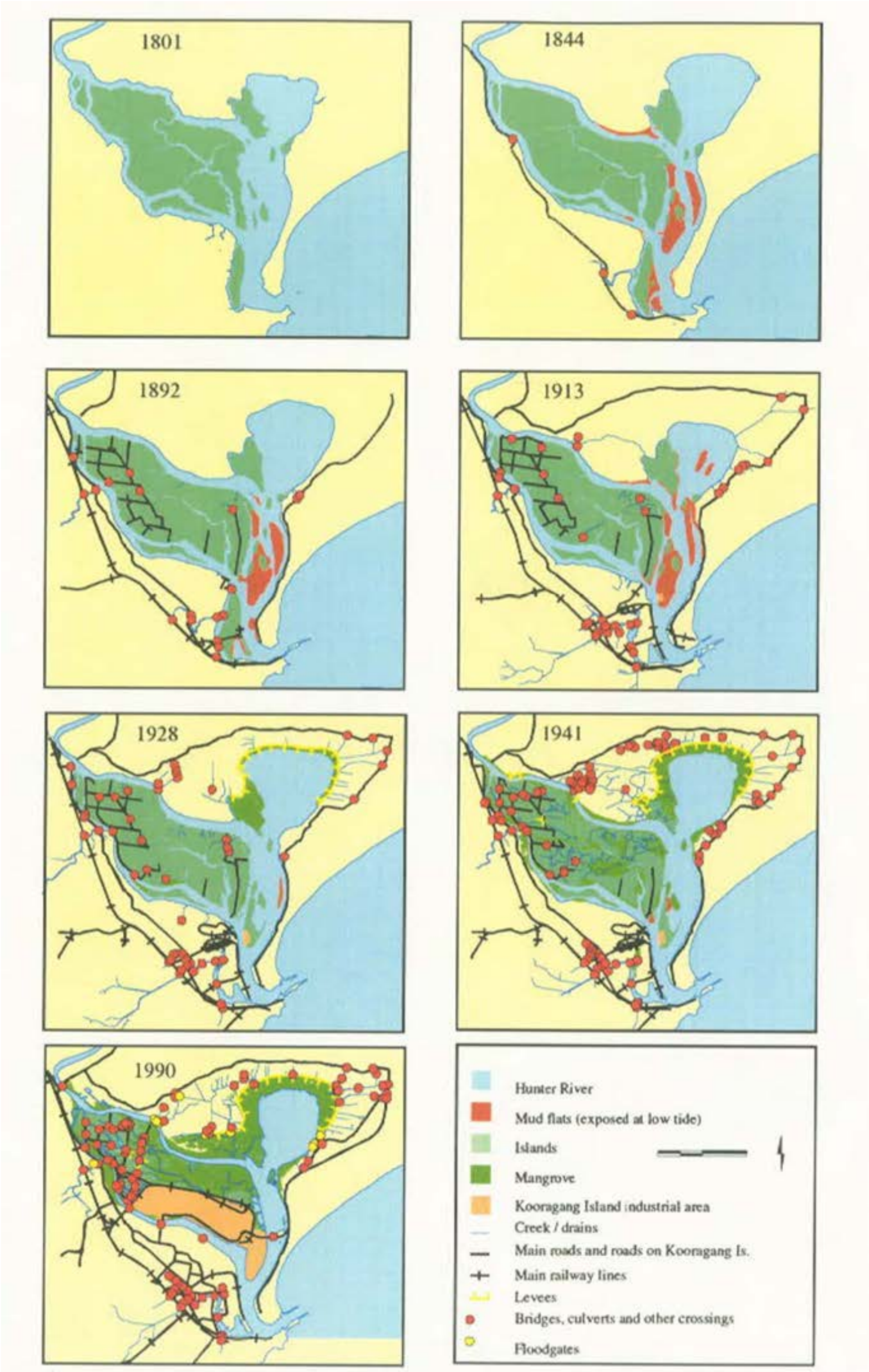


Figure 2.7 Evolution of lower Hunter River – 1801 to 1990 (Williams et al 2000)

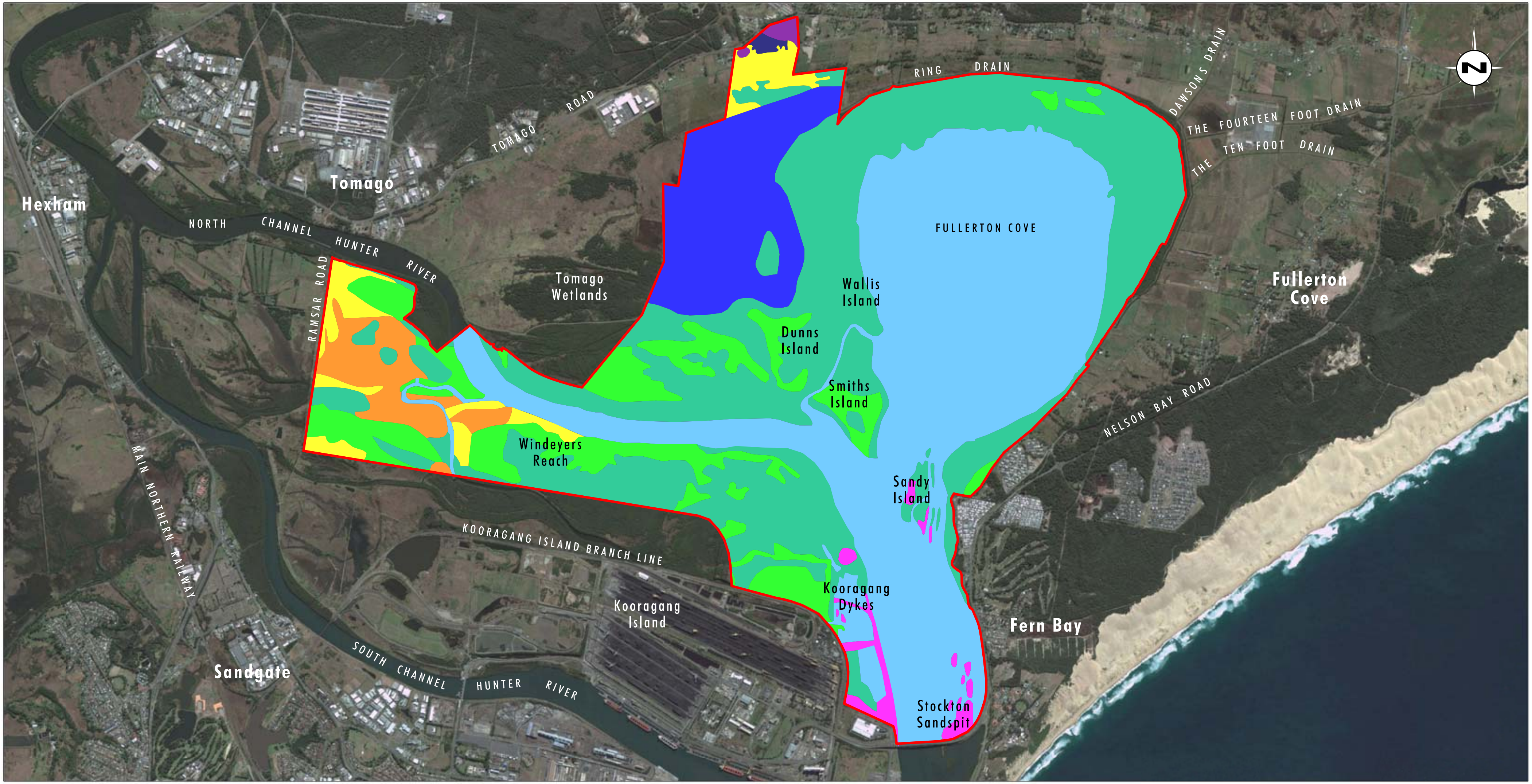


Image Source: Google Earth (Aug 2017)
Data Source: Commonwealth of Australia (Department of Environment) (2015), SEWPAC (2010)

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Legend

- Hunter Estuary Wetlands Ramsar Site Boundary

Kooragang Wetland Types 1983:

- XF - Freshwater Tree Dominated Wetland
- F - Estuarine Waters
- G - Inter-tidal Mud and Sand
- H - Inter-tidal Marshes
- I - Intertidal Forested Wetlands (Mangrove Forests)
- H/I - Intertidal marshes and mangroves

Kooragang Non-wetland Types 1983:

- Pasture
- Saline Pasture
- Dry Eucalypt Forest

FIGURE 2.8

Kooragang Nature Reserve Ramsar Site 1984 Listing

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2.4.4 Water Quality

Water quality within the site is impacted by not just activities that occur within or adjacent to the site, but also by activities that occur further upstream and across the wider catchment.

A detailed discussion of available site-specific water quality parameters is provided in Section 3.0. As would be expected by the long history of anthropogenic activities within the catchment, and with ongoing impacts from land uses such as industry, urbanisation, and agriculture, water quality within the site has been negatively impacted. The NSW EPA administers a number of licenced facilities under the *Protection of the Environment Operations Act 1997* (POEO Act) which may directly impact on the site. These facilities have capacity to alter water quality either directly through manufacturing processes or indirectly through contaminated surface water runoff / discharge into stormwater systems and ultimately into the Hunter River.

Potential chemicals and contaminants that may impact on water quality include:

- Nutrients, from agriculture and industry at Kooragang Island;
- Petroleum hydrocarbons, from diffuse catchment runoff including roads and urbanised areas, and from point sources such as heavy industry and the airport;
- Agricultural chemicals, including pesticides, herbicides, fumigants, and fertilisers;
- Metals from diffuse catchment runoff, mobilisation in ASS leachate, and potential point sources associated with industry;
- PFAS compounds, particularly related to the RAAF Base Williamtown, as well as from catchment runoff; and
- Other contaminants, including polycyclic aromatic hydrocarbons (PAHs), a combustion by-product often found associated with tar, gasworks waste, petroleum sources, etc.

2.5 Biodiversity

2.5.1 Vegetation and Habitats

The Kooragang component contains extensive intertidal mudflats and mangrove forest, occasionally tidal flooded saltmarsh, freshwater lagoons and swamps, and sand dunes supporting coastal forest. The distribution of the vegetation communities within the Kooragang component, based on recent mapping in 2016, is shown in Figure 2.9. Further details of the extent of the vegetation communities at the time of listing in 1984 and recent mapping is provided in Appendix C.

The Kooragang component supports:

- four threatened ecological communities (EEC) as listed under the NSW *Biodiversity Conservation Act 2016* (BC Act) including:
  - Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregions EEC;
  - Freshwater Wetlands on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions EEC;
  - Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner Bioregions EEC; and
  - Swamp Sclerophyll Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions EEC.
- two threatened ecological communities as listed under the EPBC Act:
  - Coastal Swamp Oak (*Casuarina glauca*) Forest of New South Wales and South East Queensland ecological community; and
  - Subtropical and Temperate Coastal Saltmarsh.

Estuarine mangrove forest is dominated by grey mangrove (*Avicennia marina*) and in some areas a shrub layer of river mangrove (*Aegiceras corniculatum*) occurs. The understorey is generally mudflat though samphire (*Sarcocornia quinqueflora*) may occur particularly where the mangroves have invaded estuarine saltmarsh community and/or areas are not subject to regularly tidal inundation. Tidal inundation determines the limit of the mangrove with the distribution of *Avicennia marina* corresponding with mean high-water level.

Estuarine saltmarsh occurs on the landward side of the mangroves mainly in the Tomago wetlands, Smith Island and towards the western end of Kooragang Island with smaller areas occurring along deltaic channels on Kooragang Island. Saltmarsh typically occurs in areas of regular or intermittent tidal influence only flooded by medium to high tides. At Kooragang Island, saltmarsh occurs in areas with a spring tidal range of <0.3 m (Spencer and Howe, 2008).

The saltmarsh community is characterised by transition from:

- low saltmarsh dominated by salt water couch (*Sporobolus virginicus*), samphire (*Sarcocornia quinqueflora*), *Triglochin striata*, *Suaeda australis* and/or *Samolus repens* at lower elevation in areas of mudflats and shallow ponds;
- to a rushland dominated by *Juncus kraussi* at the landward edge of the saltmarsh.

Areas of degraded saltmarsh with a relatively high weed covers were also mapped by Kleinfelder (2016).

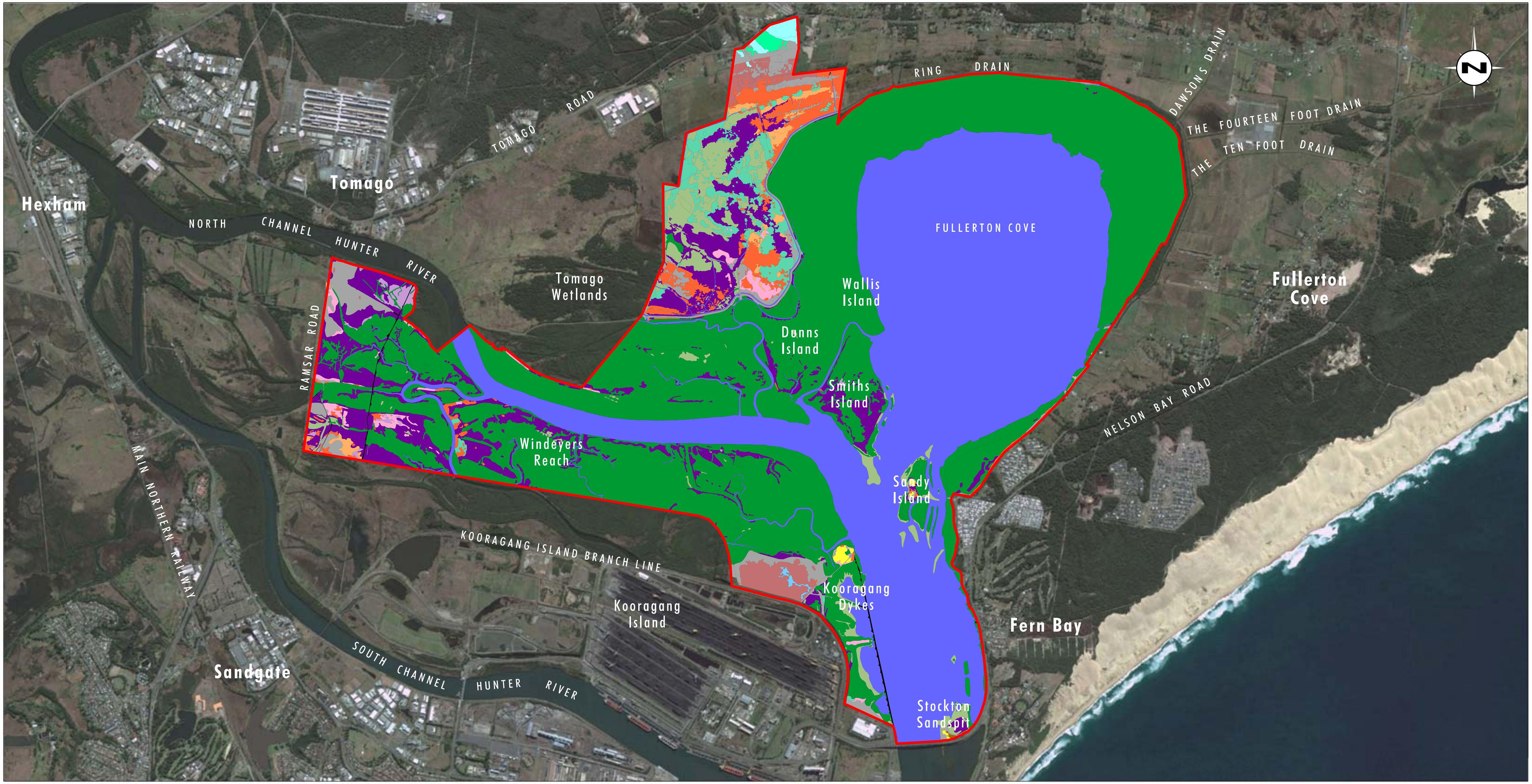

Image Source: Google Earth (Aug 2017)
Data Source: Commonwealth of Australia (Department of Environment) (2015), Kleinfelder (2016)

0 1 2 3km
1:60 000

Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- Brackish Sedgeland/Grassland
- Channels and Estuarine Waters
- Coastal Sand Scrub
- Degraded Saltmarsh
- Exotic Vegetation
- Freshwater Ponds
- Freshwater Reedland
- Freshwater Sedgeland/Rushland
- Intertidal Mudflats and Shallow Ponds
- Mangroves
- Planted Native Vegetation
- Saline Rushland
- Saltmarsh
- Smooth-barked Apple Red Bloodwood Forest
- Swamp Mahogany/Paperbark Forest
- Swamp Oak Forest
- Excluded

FIGURE 2.9

Current Vegetation Communities of the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site (2016)

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20180716 13.03

Both mangrove and saltmarsh communities are vulnerable to climate change and rising sea level, particularly where there is limited opportunity for the communities to migrate landward with the intertidal zone. While the following reference was based on the Sydney region the findings can be related to the Hunter estuary. Saintilan et al. (2013) states that:

- Sea level rise is virtually certain to alter estuarine and coastal lowland ecosystems with seasonal drying likely to degrade freshwater wetlands and higher temperatures likely to cause changes in ecosystems.
- Rising sea level will result in large areas of low-lying land around coastal waterways being exposed to more frequent tidal inundation.
- The changing relationship between sea level and the elevation of the saltmarsh surface has already favoured mangrove and mangrove encroachment is expected to continue.
- Increased ambient carbon dioxide will favour mangrove over saltmarsh, particularly in the upper intertidal environment where mangrove and saltmarsh interact.
- Mangroves may be able to colonise in areas from which saline dry conditions previously excluded them.

Forested wetlands and freshwater wetlands, including reedlands, sedgelands and open water have been mapped mainly in the Tomago wetlands area. The swamp oak forest in 1983 only covered 3.4 ha and was likely to be remnants of a vegetation community that had been cleared for agriculture (Brereton and Taylor-Wood, 2010). The area of swamp oak forest has increased to 76.67 ha in 2016 (see Appendix C). This increase was likely to have occurred following cessation of grazing in the Tomago wetlands (Winning, 1996). Since commencement of restoration works at Tomago wetland, patches of swamp oak forest have been dying back in the Tomago wetlands most likely in response to increased and more prolonged tidal inundation (Kleinfelder, 2015).

2.5.2 Fauna Species

The Kooragang component provides important habitat for a large number of wetland birds including migratory and non-migratory shorebirds. The Kooragang component supports birds in all stages of their life cycle including breeding, migration stopover, roosting, foraging and drought refuge (Brereton and Taylor-Wood, 2010).

Bird habitats include mangroves, saltmarsh, brackish swamps, intertidal mudflats, open water, swamp oak woodland saline pasture and pasture, Stockton Sandspit and Kooragang Dykes (Brereton and Taylor-Wood, 2010).

At least 37 migratory species and 12 threatened fauna species listed under the EPBC Act have been recorded in the Kooragang component (see Appendix D). Since the ECD was published in 2010, several recent additions to the EPBC Act have occurred in 2015 and 2016. These include threatened species listings of migratory birds known from the Kooragang component including: the great knot (*Calidris tenuirostris*), curlew sandpiper (*Calidris ferruginea*), bar-tailed godwit (*Limosa lapponica baueri*), greater sand plover (*Charadrius leschenaultii*), lesser sand plover (*Calidris mongolus*) and eastern curlew (*Numenius madagascariensis*).

Seven frog species have been recorded at the Kooragang component including the green and golden bell frog (*Litoria aurea*), which is listed as vulnerable under the EPBC Act. Only three water bodies within the Kooragang component are inhabited by the green and golden bell frog despite occurring in 19 other water bodies on Kooragang Island (Hamer et al., 2002).

Prior to listing in 1984, a total of 59 fish species were identified as occurring within the Kooragang Wetland (Ruello, 1976) including the estuary stingray (*Dasyatis fluviorum*), which is listed as Vulnerable under the IUCN Red List. While this species is identified as inhabiting mangrove swamps and estuaries where it feeds on shellfish, worms and crustaceans, a review of recent Atlas of Living Australia records for this species identified only two records of one individual both offshore of the entrance to Lake Macquarie in 2006 attributed to NSW Fisheries demersal fish and prawn's surveys.

(http://spatial.ala.org.au/?q=lsid:urn:lsid:biodiversity.org.au:afd.taxon:7d49be32-3d37-4fec-bfe5-c0a07dd714be).

There are no records of this species on the OEH BioNet database (http://www.environment.nsw.gov.au/atlaspublicapp/UI_Modules/ATLAS_/atlasreport.aspx).

3 ASSESSMENT OF CONTAMINATION

3.1 Analytical Data Review

An assessment of concentrations of contaminants within environmental media at the Ramsar site is required, if an understanding of the associated impacts is to be obtained. This assessment has reviewed available analytical data from surface water, sediment, or biota from the Ramsar site and surrounds to assess the potential for contaminants to be present; and if present, assess whether contaminants are at concentrations that may potentially pose a risk of impact to the environment.

Key references that were reviewed and provide the baseline data as discussed in this section are summarised in Section 1.4.

Limited quantitative analytical data was available to assess the measurable concentrations of potential contaminants within the Ramsar site. Catchment based water quality assessments, such as the *Lower Hunter River Health Monitoring Program* (OEH 2017 a,b,c,d), provide general information on factors such as salinity, oxygen levels, turbidity, etc., and provide some data on contaminant concentrations. Sediment investigations associated with Newcastle Port Corporation dredging activities provide an assessment of sediment quality in the South Arm, North Arm, Fullerton Cove and at the mouth of the Hunter River (Patterson Britton and Partners, 2003; CSIRO, 2014a, 2014b).

Specific industries and sites which report their environmental monitoring data provides some relevant contaminant monitoring data for the area (see Section 2.3 and Figure 2.5), although these reports are generally limited in scope and assess targeted analytes at specified discharge points only. Extensive investigations into PFAS contamination (including EPA, 2015 a,b; AECOM, 2018) have enabled a more detailed assessment of this key contaminant.

Based on the known historical land uses and activities that have occurred in, immediately adjacent to, or in areas interconnected to the site (Section 2.3), a number of potential pollution sources are likely to be impacting on contaminant levels at the Ramsar site. Where specific types of contaminants were considered likely to be present but analytical data was not available, a qualitative discussion has been provided.

3.1.1 Characterising Risk

To assess whether the contaminants that are known or suspected to be present may potentially impact on the environment, risk assessment methodologies provide a framework by which impacts can be ranked and understood.

When assessing risk, it is generally defined as a factor of:

Risk = Likelihood x Consequence.

Based on the assigned likelihood (or probability) and the associated potential consequence, risk can be ranked (e.g. low, moderate, high) or categorised as being acceptable or unacceptable (enHealth, 2012a; NEPC, 2013, DoEE, 2018a).

In a more complete sense, risk assessment is "*the process of estimating the potential impact of a … hazard on a specified … system under a specific set of conditions and for a certain time frame*." (enHealth, 2012). This risk assessment process may range from a qualitative, simple, desktop exercise (Tier 1) through to more detailed assessments with data collection, modelling, and more complex investigation and interpretation (Tier 3). It is also a re-iterative process, whereby as more data is collected the understanding of the problem is refined and further stages are better targeted. If a simple or Tier 1 risk assessment indicates risks are potentially unacceptable, then a Tier 2 risk assessment may be triggered. The risk assessment process is shown in the flow chart, refer Figure 3.1 below.

Figure 3.1 Ecological risk assessment framework (adapted from Schedule B5a of the ASC NEPM (NEPC, 2013) and DoEE (2018a)).

For the purposes of this report, a qualitative or preliminary risk assessment has been conducted. This assessment compares available analytical data against published "Tier 1" screening criteria for the identified contaminants. Tier 1 criteria are published by regulators for the purpose of providing a screening tool for assessing potential risk to receptors. These Tier 1 values are designed to be conservative and protective of the majority of receptors. Exceedances of screening criteria for a given chemical generally warrants further investigation, although it is emphasised that screening level criteria are designed to be conservative, and an exceedance does not necessarily represent unacceptable risk.

For the purposes of this assessment, Tier 1 criteria were obtained from the following source:

- ANZAST, 2018. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*

  Water screening criteria for 99% species level of protection were adopted, based on advice presented in the guidelines for slightly to moderately disturbed systems. The guidelines suggest adopting a 99% or 95% level of protection for these systems (e.g. Ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained). The Kooragang component of the Hunter Estuary Ramsar site may be considered to fit into this category. Given the conservation status as a wetland of international significance, the more conservative 99% level of protection was adopted. The 99% level is generally adopted for chemicals that bio-accumulate and biomagnify in wildlife (HEPA, 2018).

  Due to the estuarine nature of the site, both freshwater and marine values were considered for aquatic environments, with the lowest value for either fresh or marine waters adopted for screening purposes within an estuarine environment, in accordance with ANZAST guidance. Given the large

freshwater flows from the catchment that intermingle with the tidal marine waters, consideration of both fresh and marine water values was deemed appropriate for this site.

Screening criteria for the assessment of PFAS compounds were obtained from the following document:

- HEPA, 2018. *PFAS National Environmental Management Plan.*

  Recommended interim values were adopted from the PFAS NEMP. At the time of this assessment, freshwater values were recommended for adoption in the first instance due to the lack of marine data available for the derivation of relevant values.

Contaminants of interest are those that are known or suspected to be present at concentrations high enough to warrant consideration in an assessment of risks, or to create a nuisance (e.g. odours). For this exercise, contaminants of interest are those that are known or suspected to be present at concentrations above the adopted Tier 1 criteria.

3.1.2 Data Analysis

Due to the limited data sets that were available for assessing contaminant concentrations, statistical analysis of temporal or spatial trends was unable to be undertaken for the majority of contaminants of interest. Statistical analysis can provide a more robust method for assessing contaminant levels in the environment, particularly for well mixed, well distributed, or wide spread contaminants, where adoption of a single point concentration may result in an under or over estimate of risk. To undertake statistical analysis, minimum data requirements need to be met, such as a minimum of 10 data points representative of the same 'population' of data (i.e. all data points need to be representative of the area of interest, local conditions, relevant source/s, any exposure units (which vary according to the receptor), etc). As the majority of available analytical data was limited to less than 10 data points collected by different agencies at a range of locations over a number of years, maximum concentrations reported for individual chemicals were adopted, resulting in a generally conservative assessment.

If larger datasets of suitable quality were obtained, statistical analysis using methods such as upper confidence limits (UCL), regression analysis or analysis of variance (ANOVA) may be possible.

3.2 Contaminants of Interest

The sections below summarise the available chemical data collected at the site. Where analytical data were not available from within the site itself, data for the surrounding areas have been summarised.

Analytical data from the site which could be compared against published screening criteria were only available for a limited number of contaminants and groups of chemicals, including nutrients, some metals, and PFAS. The available quantitative data has been presented within the sections below. For other contaminants or groups of chemicals that were considered likely to be present, a qualitative discussion of potential impacts is provided.

3.2.1 Water Quality Parameters

Adverse impacts to surface water quality may occur due to the large number of land use pressures occurring in the catchment. These impacts were considered to be exacerbated by over-clearing and over-grazing activities and the resulting riverbank erosion, which introduced an excessive level of sediment loading into the Hunter River. In areas where imported fill was present, erosion of this fill could have resulted in introduction of other contaminants such as organochlorine pesticides (OCPs), organophosphate pesticides (OPPs), asbestos, metals, polychlorinated biphenyls, etc. While many of these pathways were considered a more significant issue for the South Arm than the upper Hunter River (OEH, 2017a,d), the issues associated with erosion and secondary impacts from diffuse and point sources are also relevant to the North Arm.

3.2.1.1 Available Water Quality Data

Specific chemicals are discussed further below, with general water quality parameters which have been sporadically collected in the lower reaches of the Hunter River summarised below (OEH, 2017a,c,d). Table 3.1 summarises the most complete and recent snapshot of water quality for two points within the site (refer Figure 3.2 below for locations). Water quality data have not been compared against chemical specific screening criteria due to the variable 'normal' conditions experienced in an estuarine environment.

Table 3.1 Water Quality Parameters for Lower Fullerton Cove / Lower North Arm

Sample Location	Temp (ºC)	Salinity (ppt)	Conductivity (mS/cm)	pH (pH units)	DO (%)	Turbidity (NTU; Lab)
W5[1]	22.4	24.6	28.8	7.8	72.4	9.8
W6[2]	20.8	17.8	33.1	8.1	77.3	21.8

Notes:

1 OEH, 2017d. Data collected from stormwater drain near the Impact Fertiliser Site (EPL 5430, ID 1-5) in the North Arm in 2015. Samples collected from between 20-40 cm below water surface.

2 OEH, 2017d. Data collected from Mangrove Creek, Kooragang Wetlands in the North Arm in 2015.

Temp = Temperature. Samples collected from between 20-40 cm below water surface. DO = Dissolved oxygen. NTU; Lab = Nephelometric turbidity units as analysed by the laboratory

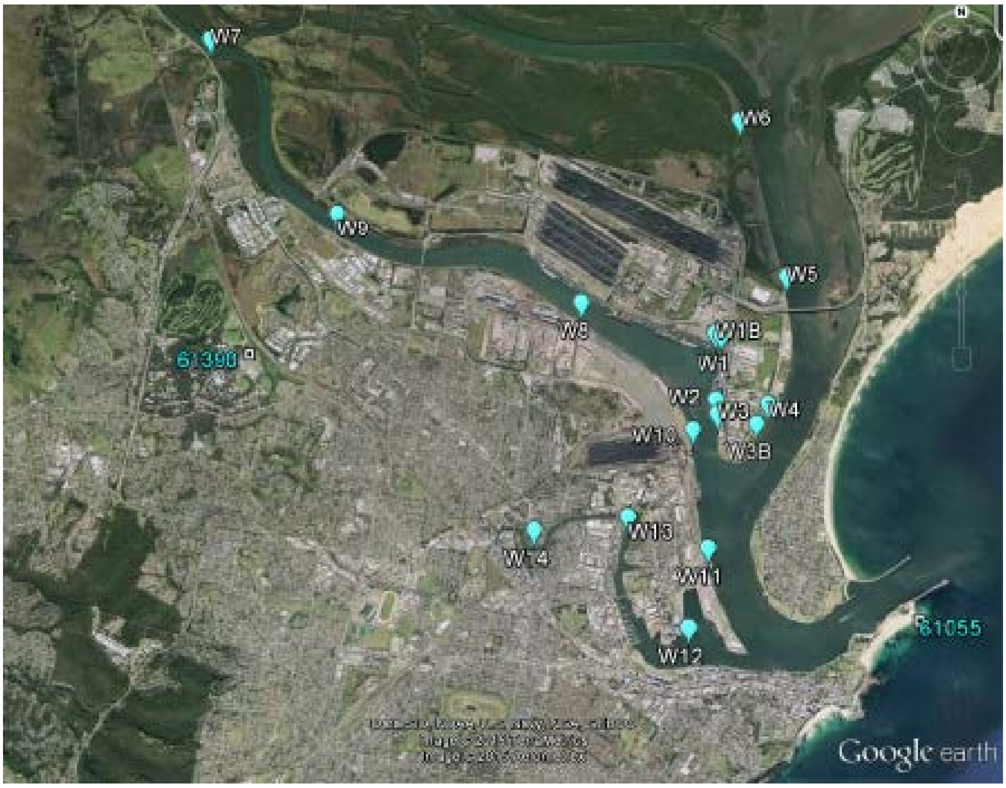


Figure 3.2 Location of stormwater quality sampling sites monitored following rain events (from OEH, 2017d).

3.2.1.2 Potential Impact on the Environment

The normal range of water quality parameters (EC, DO, turbidity, BOD) for a site such as Fullerton Cove would be highly variable, due to factors such as the intertidal nature of the area and frequent heavy rain events. For example, as reported by OEH (2017d), sites within the lower estuary

consistently had DO levels in the range 85–110% in line with the ANZAST guidelines for NSW lowland rivers, due to regular flushing with oxygenated sea water. Further upstream, at Hexham Swamp, where the water is less saline, the estuary had more variable DO levels ranging from 60%, following rainfall events, up to a median of between 73% and 83% (OEH, 2017d).

While variability in water quality parameters is normal in an estuarine environment, monitoring of these parameters can still provide a useful, real time measurement of the health of a water body. For example, sustained periods of particularly low oxygen levels (<60%) or elevated turbidity (>40 NTU) may be an indicator of a significant impact to the water body such as an uncontrolled ongoing release via stormwater that requires further investigation.

Significant changes in factors such as dissolved oxygen or salinity can cause significant impacts if these parameters occur outside of their normal range, particularly if it occurs for an extended period. Extended periods of elevated turbidity can reduce light levels and reduce vegetation health, while long term changes to temperature or salinity can result in unacceptable habitat conditions for a number of species (e.g. changes in saltmarsh extent due to changes in salinity). In addition, rapid deoxygenation, as may occur immediately following a large volume spill of liquids with a high biological oxygen demand (BOD), can result in acute effects such as widespread fish kills.

3.2.2 Petroleum Hydrocarbons

Petroleum hydrocarbons are organic compounds derived from oil, which are commonly found in the environment due to contamination with fuels such as diesel or gasoline. They are comprised of a highly variable mix of compounds that vary in their chemical characteristics and environmental behaviours.

The OEH reports (2017a, d) indicated that the primary source of petroleum hydrocarbons (volatile and semi-volatile fractions ranging from C_6-C_{40}) and associated compounds (e.g. benzene, toluene, ethylbenzene and xylenes) in the lower Hunter include: stormwater discharge events; overland flows from heavy rainfall events; or mobilisation through groundwater from surrounding industrial sites and activities. For example, one industrial site (OneSteel near the South Arm) had unlined oil collection pits that had existed since the 1980s and were a significant source of elevated petroleum hydrocarbon concentrations leaching into groundwater beneath the site with the potential to discharge into the Estuary waters (OEH, 2017a).

3.2.2.1 Available Petroleum Hydrocarbon Data

The major potential sources of petroleum hydrocarbons contamination at the site are considered to be the following:

- Point sources, such as industry with on-site underground or aboveground oil storage tanks, fuel delivery lines, bowsers and related infrastructure such as interceptor traps and oil collection pits.
- Diffuse sources, particularly stormwater drainage channels that collect and funnel a mix of overland runoffs from both industrial and urban activities towards the point of discharge in the Hunter River or surrounds.

At the time of this assessment, the nature and extent of petroleum hydrocarbon impacts from stormwater and / or groundwater discharge could not be determined due to a lack of quantitative petroleum hydrocarbon assessments available for review for the Ramsar site and the broader Hunter River areas adjacent to the North Arm.

Sediment analyses was undertaken for the Newcastle Port Corporation Port-wide Strategy – Maintenance Dredging Assessment (CSIRO, 2014a) to assess contaminant levels in potential dredge sediments of the South Arm and Newcastle shipping channel. Analyses of total petroleum hydrocarbons (TPH) was undertaken on a sub-set of samples collected, with TPH analyses only undertaken on samples that were analysed for bioavailability and direct toxicity testing. The data indicated that “concentrations of TPHs have been detectable, particularly where PAHs (polycyclic aromatic hydrocarbons) have been elevated, but generally below the ‘screening level’ of 550 mg/kg” (CSIRO, 2014a). No analyses for individual TPH compounds, such as benzene, toluene, ethylbenzene, and xylenes (BTEX) were undertaken.

A further review of the literature was undertaken to assess whether any data was available to assess potential background levels of petroleum hydrocarbons within the Hunter River or Australian rivers in general, however no such data was readily available.

3.2.2.2 Potential Impact on the Environment

Assessing the potential ecotoxic effects of petroleum hydrocarbons can be challenging due to the complex nature of the chemical mix that comprises 'petroleum hydrocarbons'. While some individual compounds such as benzene have been well studied, there is limited information available to fully assess the ecotoxic effects of petroleum hydrocarbon mixes.

Following events such as major oil spills, acute effects such as deoxygenation and physical smothering are generally the most significant risk, however the effects from long term releases of dissolved phase petroleum hydrocarbons can result in a range of effects depending on concentrations, exposure duration, stage of life, specific chemicals present in mix, etc. Toxic effects of hydrocarbons reported in laboratory studies included reduced feeding, reduced egg viability and production, reduced growth, and delayed development (Capuzzo et al., 1988). However, at low concentrations petroleum hydrocarbons can act as electron donors and will act as a potential source of carbon and energy for microbes (Doble & Kumar, 2005).

An assessment by RIVM (1999) reviewed the available data to derive a screening level for 'mineral oil' (C_{10}-C_{40} petroleum) in water of 0.6 mg/L, for protection of ecological receptors. Given the lack of analytical data, it is unknown whether petroleum hydrocarbons may be present at concentrations above this level at the site. However, it is noted that petroleum hydrocarbons will degrade rapidly in marine environments, particularly when nutrients are present to promote microbial activity (Harayama, 1999), and low concentration releases and / or diffuse sources would be unlikely to pose an unacceptable risk to ecological receptors.

3.2.3 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a common pollutant which are associated with incomplete combustion of carbon-containing fuels such as petrol, diesel, coal, wood, tobacco, etc. PAHs are generally widespread across urban or industrial areas and can be highly toxic to the environment. PAHs tend to adsorb strongly to sediment, with this adsorption playing an important role in PAH transport and distribution (CCME, 1999); PAHs are therefore more likely to be a potential issue in the sediments of the Ramsar site, rather than from within the water column.

3.2.3.1 Available PAH Data

PAHs are likely to have been released into the lower Hunter via surface and groundwater from a number of sources, particularly areas of heavy industry. OEH (2017a) reported that the BHP Steelworks at Mayfield (which operated from 1915 to 1999) "presumably" released thousands of kilolitres of untreated process water daily into the South Arm of the river, containing elevated PAHs, metals, and hydrocarbons.

Limited data regarding PAH concentrations in the surface water and sediment of South Arm and Fullerton Cove were available for review. An OEH report (2017d) noted that PAH concentrations were not detectable in surface water in the two sites sampled within the Ramsar designation (i.e. lower reaches of the North Arm connecting to the southern boundary of Fullerton Cove as shown in Figure 3.2 above). As PAHs adsorb strongly to sediment, PAHs are therefore considered unlikely to be a significant issue for species such as fish or waterbirds whose diet is principally fish .

PAH distribution in sediment was discussed in the Port-wide Strategy (PWS) dredging assessments, which reported that concentrations of PAHs in sediment had decreased with time (CSIRO, 2014a, 2014b). The PWS reported that total PAHs were below 10 mg/kg between 1985 and 2010 in areas where maintenance dredging occurs, with a maximum total PAH concentration of 5.7 mg/kg reported in the 2014 sampling (compared to the ANZECC sediment screening value for PAHs of 10 mg/kg). Three sediment samples were collected from Fullerton Cove as reference samples (see Figure 3.3)

for comparison against dredged area sediments. Total PAH concentrations in those three locations ranged from 0.35 to 0.89 mg/kg.

The assessment found bioavailability was also low, due to the presence of total organic carbon (TOC) at levels above 1%. TOC is considered to act as a bioavailability modifying factor at levels greater than 0.2% as PAH binding to sediments with higher TOC (CSIRO, 2014a).

Figure 3.3 Fullerton Cove sediment sampling locations, from CSIRO, 2014a.

Historic sediment studies also indicated that PAHs in sediments were not readily bioavailable to ecological receptors at low concentrations, although at higher PAH concentrations the sediments exhibited considerably more toxic effects (Simpson et al., 2001 a,b,c).

OEH (2017d) noted that PAHs are inherently hydrophobic and likely to associate with sediment particles, particularly in the presence of TOC. Due to these chemical properties, the sediments will act as a sink and the chemicals adsorbed will potentially persist until disturbance events occur. Further discussion of the findings of the sediment toxicity tests, as related to a range of contaminants, is provided in Section 3.2.7.

3.2.3.2 Potential Impact on the Environment

As with petroleum hydrocarbons, PAH toxicity can be challenging to assess as PAHs are generally a complex mix of chemicals, of which only a small number are well understood. Generally, PAH toxicity occurs due to biotransformation of PAHs into toxic metabolites, which may cause cell damage, mutagenesis and carcinogenesis (Igwe & Ukaogo, 2015). These toxic intermediate metabolic products are further metabolised to less toxic products, with bioaccumulation within organisms possible, particularly for larger molecule PAHs (CCME, 1999).

Available literature indicates that the potential ecotoxic effect levels for PAHs are as follows:

- LC50 values (median lethal dose lethal concentration for 50% of the exposed population):

  - Marine invertebrates: 0.9 mg/L up to 600 mg/L (CCME, 1999; Echeveste et al., 2009);
  - Marine fish: 1.2 mg/L to 2.4 mg/L (CCME, 1999);
  - Plankton: 90 mg/L (Echeveste et al., 2009);
  - Freshwater fish: <0.5 mg/l, based on speciated individual PAH, including pyrene, phenanthrene, benzo(a)pyrene (CCME, 1999);
- NOAEL or LOAEL (no observed / lowest observed adverse effect levels):
  - Marine fish: NOAEL of 0.12 mg/L (CCME, 1999); and
  - Freshwater fish: LOAEL approximately <0.1 mg/l, based on speciated individual PAH, including phenanthrene and naphthalene (CCME, 1999).

These toxicity values indicate the PAHs are potentially ecotoxic at relatively low concentrations, although it is unlikely that these concentrations are being exceeded in the Ramsar site, based on the data presented by CSIRO (2014a, 2014b). Given their toxicity, however, they remain a watch point.

3.2.4 Agricultural Chemicals and Nutrients

Agricultural practices in the broader area commenced in the 1800s and have had a significant impact on the natural environment of the broader Hunter River catchment (OEH, 2017a). These impacts resulted from a range of factors, including over-clearing, over-grazing, increased erosion, increased nutrient loads, and introduction of agricultural chemicals including pesticides and herbicides. Excessive land clearing occurred along the riverbanks for timber and grazing (sheep and cattle), with agriculture occurring in close proximity to / within the now designated Ramsar site. There is historical evidence supporting the observation that elevated nutrient concentrations follow a significant rainfall event (Brereton, R., and Taylor-Wood, E., 2010).

While it is understood that historical occurrences of uncontrolled runoff likely resulted in flushing of agricultural chemicals such as fertilisers and pesticides into receiving surface waters, there is still significant contribution to nutrient loading from industrial and urban activities. For example, local industry, which includes an ammonia plant and several ammonia source sites on Kooragang Island, contributes significantly to the nitrogen loading in the Hunter Estuary area. These discharges are regulated by the EPA, although EPA licence monitoring requirements generally relate to industrial emissions at the source, such as stack emissions or stormwater pits at a facility, and hence are not directly applicable to an assessment of water quality in the Hunter River. However, sites such as Orica Kooragang Island and Linx Kooragang Island are known ammonia and nutrient generators, with those facilities having been fined by EPA for licence breaches due to releases of nutrients and ammonia as recently as 2014 and 2017, respectively (NSW EPA, 2014; 2017). Although water quality has been reported as improving since 2000, concentrations of dissolved nutrients regularly exceed relevant water quality guidelines, due to ongoing and widespread influx of nutrients from agricultural, urban and industrial runoff throughout the catchment (OEH, 2017c). The large number of sources of nutrients in the surrounding area is reflected in the elevated concentrations of nutrients measured, as discussed below.

3.2.4.1 Available Data

An OEH report (2017d) report indicated that nitrogen and phosphorus concentrations during the 1970s to 1990s in the waters of the Hunter Estuary were up to 50 times higher than the current ecological criteria. The nitrogen and phosphorus concentrations reported as recently as 2014-2015 were reported to be “typically well above NSW trigger values for coastal riverine estuaries”, although a declining trend has been ongoing since the 1990’s (OEH, 2017a).

For the purposes of this review, available nutrient data for locations sampled within Fullerton Cove, the North Arm and the South Arm (~3 km south of the site) have been summarised together in Table 3.2.

Table 3.2 Nutrient Concentrations for Fullerton Cove and Surrounds

Chemical	Concentration (mg/L)		
	Fullerton Cove[1] (Ramsar site)	North Arm[2,3] (Ramsar site; near entrance to Fullerton Cove)	South Arm[3] (Off-site)
Ammonium	<LOR	No data	0.98
Ammonia (as N)	No data	W5: 0.14-59.2 W6: 0.03-0.05	No data
Total Nitrogen	~2,000	W5: 1.15	No data
Nitrates	No data	No data	0.28-5
Orthophosphate	0.049	0.01	0.176
Phosphate (as P)	No data	W5: 0.04-37.7 W6: 0.028	No data

Notes:
A locations map for the 1998 data was not available for review by the original report authors (OEH, 2017a).
1 OEH, 2017a. Data set collected by the State Pollution Control Commission from the middle of Fullerton Cove (1977-1978 study mean based on four measurements).
2 OEH, 2017a. Data set collected by BHP near the entrance of Fullerton Cove
3 OEH, 2017c. Data collected in 2015 by NSW EPA at W5 and W6 (Figure 3.2 above).

There was no data available from any sampling for pesticides or herbicides, particularly those of a persistent nature such as OCPs, within surface water of the site. Some sampling of stormwater for pesticides at Throsby Creek (locations W13 and W14 in Figure 3.2 above) reported no pesticides above the limit of reporting at those locations (OEH, 2017d). In addition, although the analytical results were not available for review, the Port-wide Strategy undertaken in 2014 (CSIRO, 2014a, 2014b) stated that analyses for pesticides were not included in the 2014 sampling as historical sampling had not detected pesticides above the limit of reporting in sediment.

Although it is likely that pesticides and / or herbicides were used across surrounding agricultural or park areas, the types of chemicals used and their rates of application are largely unknown. Discussions with staff at Hunter Local Land Services (Hunter LLS) indicate that most herbicide usage on private land is undocumented, and a wide range of herbicide types may have been used currently and historically (C. Cotter, Hunter LLS, pers comm.). Any such chemicals used, or rates of application, would potentially vary significantly between properties.

Pesticide use in Australia is closely regulated nationally by the Australian Pesticides and Veterinary Medicines Authority (APVMA), and within NSW by the EPA, and any "off-label" use of pesticides (i.e. application of a pesticide in a manner not currently approved by APVMA) requires the pesticide user to apply for a special permit. It is therefore unlikely that pesticides would have been used regularly in an uncontrolled manner in the surrounding areas. The Hunter LLS did report that regular applications of glyphosate along road verges is known to occur along local roads such Cabbage Tree Rd (J. Skinner, Hunter LLS, pers comm.), however this is unlikely to result in any impact to the Ramsar site.

3.2.4.2 Screening Level Assessment

The available data were compared against appropriate screening criteria (as discussed in Section 3.1.1) and are summarised below in Table 3.3.

Table 3.3 Screening Level Assessment – Nutrients

Chemical	Adopted Criteria*	Maximum Conc.*	Exceeds Criterion (Y/N) / Comments
Nutrients (Agricultural Chemicals)			
Ammonia	0.32	On-site: 59.2 (W5)	Y Maximum concentrations indicate that ammonia exceeds the adopted criterion within the Ramsar site.
Nitrate	0.25	Off-site: 21.9 (W2)	Y Maximum concentrations indicate that nitrate exceeds the adopted criterion may exist within the Ramsar site.
Total Nitrogen	0.25	On-site: 2,000 (W5)	Y Total nitrogen (inclusive of nitrogen compounds such as nitrate) exceeds adopted criterion.
Total Phosphorus	0.02	On-site: 40.6 (W5)	Y Total phosphorus (inclusive of various phosphate species) exceeds adopted criterion.

Notes:

* Maximum concentrations historically reported. All results are in mg/L or mg/kg unless otherwise stated. Locations (W1, W2, etc) shown on Figure 3.2 above.

3.2.4.3 Potential Impact on the Environment

Despite the lack of site-specific information available for review, the following are still considered to be key potential issues arising from agricultural practices, and possibly exacerbated by industrial practices, within the catchment:

- Elevated nutrient loads (particularly nitrogen and phosphorus), which could result in eutrophication of the receiving waters. This could in turn result in:
  - Deoxygenation of the water column from excessive algal and plant growth, with some species of algae also directly toxic to organisms; and
  - Direct physical impacts, including smothering, odours.
- Toxicity of herbicides and pesticides. However, it is noted that:
  - Herbicide usage, if occurring, would be associated with applications by individual property owners, and large volume or uncontrolled releases are unlikely;
  - Pesticide usage, if occurring in the surrounding areas, should be in accordance with APVMA requirements;
  - Historical forms of herbicides and pesticides were often highly persistent and highly toxic, and these may be present at low levels within the catchment. It is likely that any such impacts pre-date the Ramsar listing of 1984.

3.2.5 Metals and Inorganics

While metals in the environment are naturally occurring and widespread, elevated levels of many metals, including heavy metals such as lead or mercury, can result in significant ecotoxic effects. Elevated metals in surface water bodies are often associated with pollution and runoff from mining,

roads, industry, historical filling, etc. Metal pollution will generally accumulate in sediments, and bioaccumulation of some metals (e.g. mercury) is a significant potential pathway of exposure.

Inorganic contaminants, such as fluoride or cyanide, may also be naturally occurring while being potentially toxic at elevated levels. Elevated inorganics are often associated with pollution and runoff from industrial sites, particularly gasworks, historical filling, agriculture, etc.

3.2.5.1 Available Metals and Inorganics Data

OEH (2017a) reported that Newcastle's industrial past has resulted in higher than usual background concentrations of metals in the Hunter River. However, historical trends in sediment indicate that concentrations of metals, particularly copper, lead, zinc and mercury, have decreased in the South Arm since the early 1990's (CSIRO, 2014b).

OEH (2017a) summarised available metals data in surface water, considered to be associated with historical industrial waste discharge events from properties located downgradient of the Ramsar site. The report noted that unregulated discharge events occurred predominantly prior to Ramsar listing in the 1980s, when discharge events became better controlled.

The report identified the key metals that have impacted surface water bodies connected to the Lower Hunter River between 1970s to the mid-2010s were arsenic, chromium, copper, zinc and lead. OEH (2017a; 2017d) provide a summary of available data for select metals within Fullerton Cove, the North Arm and the South Arm of the Hunter River, as summarised in Table 3.4 below. It is noted in the OEH (2017d) report that "results for the heavy metals zinc, copper, manganese and arsenic only are presented in this report as only these metals approached or exceeded ANZECC guideline concentrations for 80% protection of marine species". Other metals and inorganic chemicals were analysed as part of this study, but not presented in the report. The complete dataset from the stormwater monitoring investigation (OEH, 2017d) was made available for this study, and is presented in Appendix F.

Whilst the 80% protection level is often used for highly modified and highly contaminated systems (e.g. source of the stormwater), it is not considered appropriate for protection of the Ramsar site, a high conservation value ecosystem. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZAST, 2018) suggest that an 80 or 90% level of protection may be appropriate in measurably degraded ecosystems of lower ecological value, particularly where it may not be practical or feasible to return them to a slightly to moderately degraded system (for example, shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture).

Table 3.4 Metals and Inorganics – Maximum Concentrations in Surface Water in Fullerton Cove and Surrounds

Chemical	Concentration (mg/L)		
	Fullerton Cove[1] (Ramsar site)	North Arm[3] (Near entrance to Fullerton Cove)	South Arm[3] (Off-site)
Copper	No data	0.0068	0.029
Iron	0.195	0.009	2.8
Lead	No data	0.014	0.11
Zinc	0.018	0.034	0.59
Manganese	No data	0.083	0.79
Cyanide	No data	No data	0.008

Chemical	Concentration (mg/L)		
	Fullerton Cove[1] (Ramsar site)	North Arm[3] (Near entrance to Fullerton Cove)	South Arm[3] (Off-site)

Notes:

A locations map for the 1998 data set was not available for review by the original report authors (OEH, 2017a).

1 OEH, 2017a. Data set collected by the State Pollution Control Commission from the middle of Fullerton Cove (1977-1978 study mean based on four measurements).

2 OEH, 2017a. Data set collected by BHP near the entrance of Fullerton Cove (1982 data; unspecified whether study mean or maximums presented).

3 OEH, 2017d and associated datasets (Appendix F). North Arm data from W5 and W6 sampling points (Figure 3.2 above).

Limited chemical data was available for sediments collected from within the Ramsar site, as most studies concentrated on the South Arm and areas outside of the Ramsar designation. While the sediment sampling summary provided in the OEH report (2017a) did not specify the exact locations of all samples collected, only one sample was determined to be within the site (as collected in 2014 from the North Arm). As part of the dredging assessment works three sediment samples were collected within Fullerton Cove and three were collected along the North Arm and analysed for metals (CSIRO, 2014a) (see Figure 3.3 above). The metals data from the available sediment data points within the Fullerton Cove, North Arm, and South Arms are summarised in Table 3.5 below, with maximum concentrations for metals reported above background levels summarised. No on-site biota data relating to metals were presented in any of the information reviewed.

Table 3.5 Metals – Maximum Concentrations for Sediment Samples in Fullerton Cove and Surrounds

Chemical	Concentration (mg/kg)			
	Fullerton Cove[1]	North Arm[1]	South Arm (Max)[1]	South Arm (95% UCL)*
Copper	25.5	2.6	66	35
Lead	11.5	3.3	100	42
Zinc	203	38	350	180
Mercury	0.04	0.03	0.11	0.06

Notes:

* 95%UCL values were calculated for dredged area sediments and reported by CSIRO (2014a)

1 CSIRO (2014a), OEH (2017b).

The metals data from the available the Orica licenced discharge point located 1 km downstream of the site is summarised in Table 3.6 below, with annual discharge amount volume for metals summarised by reporting period.

Table 3.6 Metals concentrations for Reporting Periods 2009-2015 from Orica Licensed Discharge Point 23

Reporting Period	Discharged Amount* (kg/year)		
	Arsenic	Chromium VI	Zinc
2009-2010	No data	1.5	9,272
2010-2011	8.2	16.4	247
2011-2012	10.8	10.1	216
2012-2013	18.5	5.6	371
2013-2014	18.4	<9	276
2014-2015	9.1	<9	273

Notes:
* OEH, 2017a. Available data for some licensed discharges from Orica's discharge point (NSW EPA licensed Point 23) downgradient of the site.

The metals data of samples collected from the 'first-flush capture pits' at the Impact Fertiliser site located within the southern portion of the Ramsar site, is summarised in Table 3.7 below, with maximum reported total concentration for the reporting period.

Table 3.7 Current Metals Concentrations from Collection Pits at the Impact Fertiliser Site

Licensed Site	Total Metals Concentration (mg/L)				
	Arsenic	Cadmium	Lead	Mercury	Zinc
Impact Fertilisers[1]	0.005	0.0002	<0.001	0.0001	0.067

Notes:
1 Impact Fertilisers, 2017. Current (Nov 2017) maximum reported total concentrations from "First Flush Capture Pits 1-4". Concentration data for discharged waters were not available for review.

For some licensed sites (i.e. Tomago Aluminium Company and Park Fuels Kooragang Terminal), there were no surface water monitoring requirements at the point of discharge or a very limited set of parameters unrelated to this study were monitored, and hence their annual EPA reporting did not provide relevant data for this assessment.

3.2.5.2 Screening Level Assessment

The available data was compared against appropriate screening criteria (discussed in Section 3.1.1 above), as summarised below in Table 3.8. Although there is no quantitative data available for many of these contaminants within the Ramsar site, data is typically available from the South Arm. The hydrodynamic water quality modelling undertaken by UNSW in 2018 (Miller et al, 2018) indicates a pathway for contaminant transport from the South Arm into the Ramsar site. This study also predicts that contaminant levels of up to 80% of those recorded in the South Arm may occur in parts of the Ramsar site.

Table 3.8 Screening Level Assessment – Metals and Inorganics

Chemical	Adopted Criteria*	Maximum Conc.*	Exceeds Criterion (Y/N) / Comments
Surface Water			
Copper	0.0003	South Arm: 0.029 North Arm: 0.0068	Y There were limited quantitative data for copper from within the Ramsar site for assessment. The available data indicate exceedances of the adopted criterion exist within the Ramsar site.
Iron	0.3[2]	South Arm: 2.8 Fullerton Cove: 0.195	N The available iron concentration data indicates no exceedances of criteria in the Ramsar designation, with elevated concentrations in the South Arm. Iron is an essential element to aquatic plants and animals and is not considered a chemical of interest in the Ramsar site based on available data.
Lead	0.001[1]	South Arm: 0.11 North Arm: 0.014	Y There was limited quantitative data from within the Ramsar site for assessment. The available data indicates that lead concentrations in exceedance of the adopted criterion exist within the Ramsar site, with concentrations up to 0.11 mg/L being reported in shoreline seeps near Mayfield in the South Arm (OEH, 2017a).
Manganese	0.08	South Arm: 0.793 North Arm: 0.083	Y Maximum concentrations in the Ramsar area are marginally above the adopted criterion, with elevated concentrations up to 1.4 mg/L historically reported in shoreline seeps near Mayfield in the South Arm (OEH, 2017a). More current sampling indicates maximum manganese concentrations in the South Arm have decreased, however data indicates Mn concentrations are consistently at or above the 99% protection level criterion in the South Arm.
Zinc	0.0024[1]	Off-site: 0.59 North Arm: 0.034	Y Zinc was detected in exceedance of the adopted criterion. However, this trigger value may increase if site-specific water hardness levels are above 30 mg/L as $CaCO_3$, as zinc toxicity is known to decrease with increasing water hardness and increasing salinity levels (ANZAST, 2018).
Cyanide	0.002	South Arm: 0.008	Y There were no quantitative data from within the Ramsar site for assessment. Maximum concentrations suggest that cyanide concentrations in exceedance of the adopted criterion may exist within the Ramsar site.
Sediment			
Copper	65	On-site: 25.5	N

Chemical	Adopted Criteria*	Maximum Conc.*	Exceeds Criterion (Y/N) / Comments
			Not considered to be a contaminant of potential concern in sediment at the Hunter Estuary.
Lead	50	On-site: 11.5	N Not considered to be a contaminant of potential concern in sediment at the Hunter Estuary.
Zinc	200	On-site: 203	N Not considered to be a contaminant of potential concern in sediment for the Hunter Estuary.
Mercury	0.15	On-site: 0.04	N Not considered to be a contaminant of potential concern in sediment at the Hunter Estuary

Notes:

* Maximum concentrations historically reported. All results are in mg/L or mg/kg unless otherwise stated.

1 Trigger value derived assuming a water hardness of 30 mg/L (as $CaCO_3$) adopted.

2 An interim "indicative" level recommended, as based on Canadian studies summarised within ANZAST (2018) due to insufficient data to derive a reliable trigger value.

3 Trigger value for inorganic forms of mercury was adopted. No values for could be derived for methyl mercury due to insufficient data (ANZAST, 2018).

3.2.5.3 Potential Impact on the Environment

Different metals and inorganics exhibit different toxic effects, with copper, lead, manganese, zinc and cyanide potential chemicals of concern for the site. In particular, as lead bioaccumulates and is potentially highly toxic to organisms, it was identified as a key contaminant due to potential impacts on ecosystems and high trophic levels. Although manganese and cyanide have been flagged in Table 3.8 as potential chemicals of interest due to an exceedance of adopted criteria, the exceedances are minor and may not be reflective of concentrations within the Ramsar site itself. The following additional information is provided with regards to lead effects. Further discussion on site specific sediment toxicity tests is presented in Section 3.2.7.

Copper

- Copper will be present in variable forms in surface water, including: dissolved phase form, dissolved bound form (e.g. colloids), or a particulate form. The majority of copper in surface water at the site is present as the bioavailable dissolved phase forms (OEH, 2017d).
- Copper exposure can result in inhibited growth, inhibited larvae development, and mortality (ANZAST, 2018). Toxic effects of copper and lead appear to be synergistic (ANZAST, 2018).
- Copper bioaccumulates but does not biomagnify (CCREM, 1987).
- Acute toxicity effect values for freshwater species range from approximately 0.005 mg/L up to 21 mg/L, with toxic effect values for marine species ranging from approximately 0.005 mg/L to 6 mg/L (ANZAST, 2018).
- Reported concentrations of copper in surrounding waters were above lower range effect concentrations.

Lead

- Lead will be present in variable forms in surface water, including: dissolved phase form, dissolved bound form (e.g. colloids), or a particulate form (Eisler, 1988).

- Lead exposure can result in excessive mucous formation, which can coat the gills and impair respiration, while in vertebrates, sub-lethal lead poisoning is characterised by neurological problems, kidney dysfunction, enzyme inhibition and anaemia (ILA, 2012).
- Lead toxicity is largely correlated with the dissolved phase fraction.
- Lead bioaccumulates but does not biomagnify, with lead concentrations usually highest in algae and benthic organisms, and lowest in upper trophic level predators (NYS, 1998).
- LC50 values for marine species range from approximately 0.1 mg/L to 5 mg/L (NYS, 1998).
- LOAEL values ranged from 0.01 mg/L to 0.4 mg/L (NYS, 1998).
- Reported concentrations of lead in surrounding waters were above the reported LOAELs.

Zinc

- Zinc will be present in variable forms in surface water, including: dissolved phase form, dissolved bound form (e.g. colloids), or a particulate form. The majority of zinc in surface water at the site is present as the bioavailable dissolved phase forms (OEH, 2017d).
- Zinc exposure can inhibit calcium uptake in fish, but little is known about mechanisms of sublethal toxicity; mortality is often a sensitive endpoint for exposure to aquatic species (Hogstrand, 2011).
- Zinc bioaccumulates, but not to a significant extent, and does not biomagnify (ANZAST, 2018).
- NOEC values for marine species range from approximately 0.015 mg/L to >7 mg/L, with toxic effects decreasing with increasing salinity, increasing hardness, and decreasing pH (ANZAST, 2018).
- Reported concentrations of zinc in surrounding waters were above the reported NOECs.

3.2.6 Per- and Poly-fluoroalkyl Substances (PFAS)

PFAS are surfactants characterised by fully fluorinated carbon chains where all hydrogen atoms (present in the nonfluorinated analogues from which they are notionally derived) have been replaced with fluorine atoms. These compounds form strongly bonded molecules that are highly persistent, and are both hydrophobic and lipophilic (OECD, 2002). Due to these properties, PFAS have been in use for decades for various household and industrial applications, usually to make items non-stick, water repellent, resistant to fire, weather and stains (HEPA, 2018).
While PFAS will disperse in the aqueous phase upon release and have a relatively high aqueous solubility (>500 mg/L), PFAS will absorb to suspended particulates readily and are ultimately expected to settle and reside in sediment (Environment Canada, 2004).

Of the thousands of individual PFAS compounds that have been identified, the individual PFAS most commonly assessed in Australia are:

- Perfluorooctane sulfonate (PFOS).
- Perfluorooctanoic acid (PFOA).
- Perfluorohexane sulfonate (PFHxS).

Due to the proximity of the Ramsar site to an identified source of PFAS (RAAF Base Williamtown; the “Base”) and the known ability of PFAS to bioaccumulate through to upper trophic levels in the food chain, PFAS are considered to be key contaminants of interest for the site.

PFAS at the Ramsar site is predominantly associated with contamination released from the Base, where PFAS containing fire-fighting foams were commonly used, stored and disposed of, between the 1970s and mid-2000s (Taylor and Cosenza, 2016). While fire-fighting foam storage areas and landfill waste disposal facilities may also be sources of PFAS contamination, fire training areas are the predominant source areas. The presence of PFAS at the site is predominantly driven by two main mechanisms of transport:

1. shallow groundwater beneath the base discharging towards Fullerton Cove; and

2. transport of surface water along drainage lines that direct surface water towards Fullerton Cove and the estuary (AECOM, 2016a).

3.2.6.1 Available PFAS Data

Within the Ramsar Site

Site-specific PFAS data in soil, sediment and biota have recently been collected (AECOM, 2018). This data included the current Defence investigation into PFAS impacts in the Ramsar site and surrounds (AECOM, 2018) and data collected by NSW EPA and OEH (EPA, 2015a,b). The AECOM (2018) dataset included PFAS concentrations measured in soil, sediment, surface water and biota, as summarised in Table 3.9 and Table 3.10 below. Sample locations are shown in Figure 3.4 below.

Concentrations of PFAS in surface sediments of Fullerton Cove (0.0 to 0.1m below ground level (bgl)) near the outlet of Dawson Drain are generally higher than deeper sediments (0.1 to 0.2m bgl) (AECOM, 2018) with concentrations significantly decreased with increased distance from the drain outlet.

Table 3.9 PFAS Concentrations in Environmental Media at Fullerton Cove

Matrix	Detectable Concentration Range (min-max)					
	PFOS	PFOA	PFHxS	PFHxA	PFHpA	PFDS
Sediment[1] (mg/kg)	0.0002-0.0293	0.0005-0.0012	0.0003-0.0025	0.0002	0.0003	0.001
% of Samples with PFAS Detected	*75*	*4*	*4*	*1*	*1*	*1*
Surface Water[2]* (µg/L)	0.02	-	0.02	-	-	-
% of Samples with PFAS Detected *	*3*	-	*3*	-	-	-

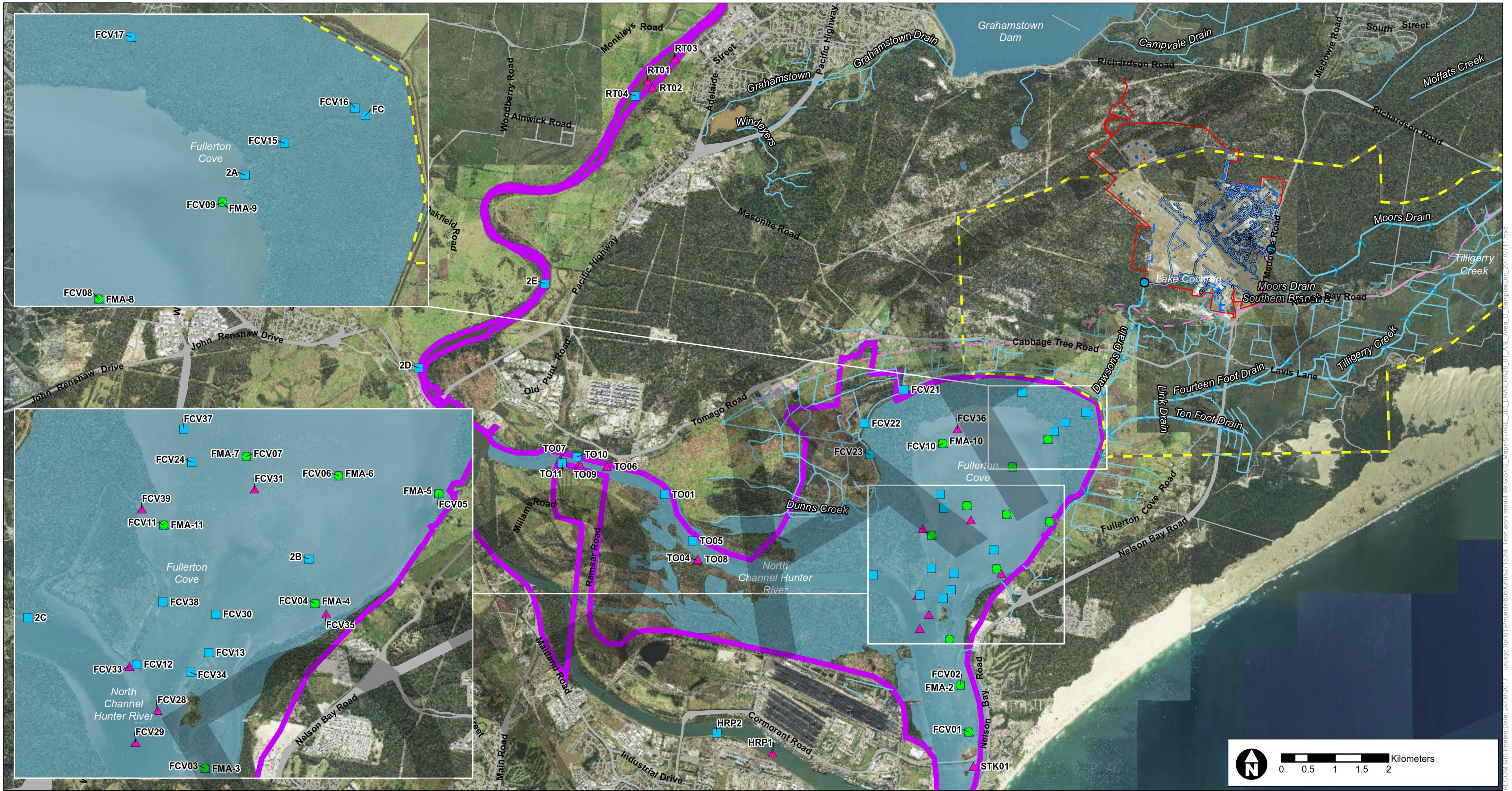
Notes:

nd = Not detected PFOS = Perfluorooctane sulfonate; PFOA = Perfluorooctanoic acid; PFHxS = Perfluorohexane sulfonate; PFHxA = Perfluorohexanoic acid; PFHpA = Perfluoroheptanoic acid; PFDS = Perfluorodecane sulphonic acid

1 AECOM, 2018. Table 2 Sediments.

2 AECOM, 2018. Table 3 Surface Water.

* It is noted that the limit of reporting was <0.01 µg/L, which is above the PFOS screening criteria of 0.00023 µg/L, hence samples which were 'non-detect' may still exceed screening criteria.



KEY

- RAAF Base Williamtown
- NSW EPA Investigation Area
- Open Drain
- Underground Pipe
- Surface Water Discharge Points
- Off-Site Open Channel and Flow Paths
- Interpreted Surface Water Flow Direction
- Boundary Between Tilligerry Mud and Tomago Sand Beds
- Assessment Area D
- Soil Sample Location
- Biota Sample Location
- Sediment Sample Location
- Surface Water Sample Location

AECOM

SCALE 1:70,000 SIZE A3

SHEET 1 of 1 COORDINATE SYSTEM GDA 1994 MGA Zone 56

TITLE
Figure F10: Area D Sample Locations

PROJECT
RAAF BASE WILLIAMTOWN 2017 STAGE 2B ECOLOGICAL RISK ASSESSMENT

CLIENT
DEPARTMENT OF DEFENCE

IMPORTANT NOTE: Refer to Section 8.2 regarding data characteristics and uncertainties
Not all available data is presented herein. For privacy reasons, selected sample locations have been removed under advice from private property owners

Table 3.10 PFAS Concentrations in Aquatic Biota at Fullerton Cove

Biota	Detectable Concentration Range (min-max; mg/kg)									
	PFOS	PFOA	PFHxS	PFOS + PFHxS[8]	PFHxA	PFPeA	PFDcA	PFHpA	PFNA	PFBuA
Fish[1,2]	0.0013-0.31	nd	0.00054-0.0065	0.0018-0.3107	nd	Nd	0.0009	nd	nd	nd
Fish[5]	0.0003-0.019	nd	-	-	-	-	-	-	-	-
% Detected*	*100*	-	*38*	-	-	-	*5*	-	-	-
Benthic Invertebrates[1,3]	0.0005-0.085	0.00033-0.03	0.0006-0.016	0.0008-0.0921	0.00054-0.001	Nd	0.0011	0.00065-0.011	0.00056-0.0027	nd
Crab[5,6]	0.0005-0.003	nd	-	-	-	-	-	-	-	-
Prawn[5,6,7]	0.0096-0.025	0.0005-0.00055	-	-	-	-	-	-	-	-
% Detected*	*96*	*64*	*64*	-	*11*	-	*4*	*21*	*11*	-
Algae[1,4]	0.0004-0.0016	nd	0.001-0.0015	0.0016-0.0031	nd	0.00063	nd	nd	nd	0.001
% Detected*	*100*	-	*10*	-	-	*10*	-	-	-	*10*

Notes:

nd = Not detected at levels above the standard practical quantitation limits; PFOS = Perfluorooctane sulfonate; PFOA = Perfluorooctanoic acid; PFHxS = Perfluorohexane sulfonate; PFHxA = Perfluorohexanoic acid; PFPeA = Perfluoro-n-pentanoic acid; PFDcA = Perfluorodecanoic acid; PFHpA = Perfluoroheptanoic acid; PFNA = Perfluorononanoic acid; PFBuA = Perfluoro-n-butanoic acid

***** The percentage of samples with detectable PFAS concentrations. Only includes data from the Williamtown ERA raw data.

1 AECOM, 2018. Table 4 Biota Data. A total of the following collected: 21 primary fish samples (see note 2), 28 primary benthic invertebrate samples (see note 3) and 10 branched algae samples (see note 4).

2 Sampled species include: yellow-finned bream, dusky flathead, bridled goby, sea mullet, glass perchlet, southern herring, and tailor.

3 Sampled species include: sentinel crab, paddle worm, periwinkle, clam, semaphore crab, yabby, sand crab, prawn, mud crab, polychaete worm (unspecified) and brine shrimp.

4 All samples comprised unspecified branched algae.

5 NSW EPA, 2015b. Preliminary PFOS Risk Assessment for Seafood – Tilligerry Creek and Fullterton Cove. Fish sample size = 14; prawn sample size = 8; crab sample size = 9.

6 NSW EPA, 2015a. Preliminary PFOS Risk Assessment for Seafood – Hunter River Prawns. Prawn sample size = 4.

7 Concentration range (min-max) of available concentrations from NSW EPA 2015a and 2015b.

8 Manually combined PFOS and PFHxS concentrations as reported for each sample. Where PFOS or PFHxS was not detectable at levels below the standard practical quantitation limits (PQL), the full value of the PQL was conservatively considered as part of the total. The maximum total concentration from each biota group was utilised for the screening assessment.

The NSW EPA sampled surface water along the north-eastern portions of the Fullerton Cove ring drain (NSW EPA, 2016) and reported concentrations of PFOS at 0.001-0.0096 mg/L, based on six samples collected in Fullerton Cove (as per Figure 3.5 below)

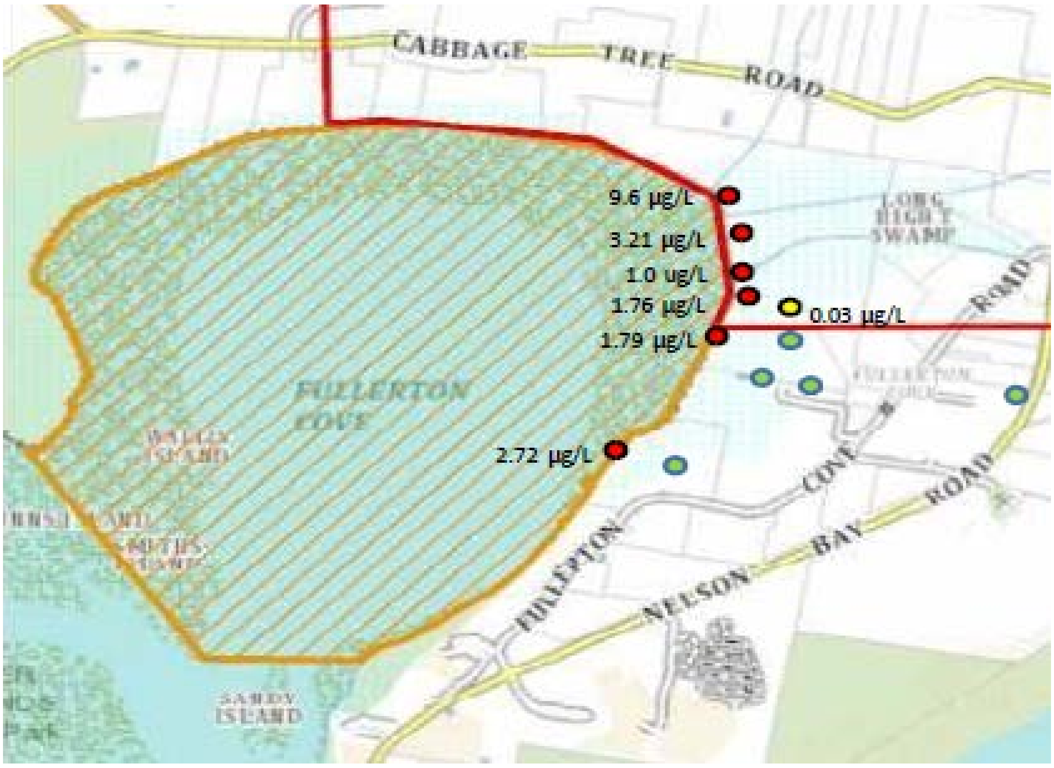


Figure 3.5 Locations of surface water samples analysed for PFOS by NSW EPA (NSW EPA, 2016).

3.2.6.2 Screening Level Assessment

The available data was compared against appropriate screening criteria, as summarised below in Table 3.11.

Table 3.11 Screening Level Assessment – Metals and Inorganics

Chemical	Adopted Criteria*	Maximum Conc.*	Exceeds Criterion (Y/N) / Comments
Surface Water			
PFOS	Aquatic ecosystems: 2.3×10^{-7}	0.00002	Y Based on the data reviewed from AECOM, (2018), PFOS was detectable at one location above limit of reporting (LOR) in the Fullerton Cove sampling (noting that the LOR was above the screening criteria) but was detected in all 6 samples collected by the EPA in 2016 (see Figure 3.2). Given the LOR (0.01 µg/L) was elevated, the maximum concentration reported was adopted for screening (rather than calculating a 95% UCL), as the maximum was only marginally above the LOR.
Sediment			

Chemical	Adopted Criteria*	Maximum Conc.*	Exceeds Criterion (Y/N) / Comments
PFOS	NA	On-site: 0.0293	Y PFOS is a known bioaccumulator and the values reported indicate a potential for exposure to aquatic ecological receptors in the receiving environment at the Hunter Estuary. Considering the above, and in the absence of a reliable screening criterion for PFOS in sediments, this compound is a key chemical of interest at the site.
PFOA	NA	On-site: 0.0012	Y PFOA is known to bioaccumulate and the values reported indicate a potential for exposure to aquatic ecological receptors in the receiving environment at the Hunter Estuary. Considering the above, and in the absence of a reliable screening criterion for PFOA in sediments, this compound is a key chemical of interest at the site.
Biota			
PFOS	Biota: 0.0082 mg/kg[1]	On-site[2] Algae: 0.0031 Benthic invertebrates[3]: 0.0921 Fish: 0.311	Y PFOS may pose unacceptable risk to ecological receptors in the Hunter Estuary. Risks to estuary bird species are considered to exist through bioaccumulation through the food chain via ingestion of algae, benthic organisms and fish. PFHxS is also known to bio-accumulate and could, in its own right, pose an unacceptable risk to ecological receptors in the Hunter Estuary.

* Maximum concentrations historically reported. All results are in mg/L or mg/kg unless otherwise stated.

1 Interim ecological direct exposure for wildlife diet criterion (avian diet) adopted.

2 Manually combined PFOS and PFHxS concentrations as reported for each sample. The maximum total concentration from each biota group was utilised for the screening assessment.

3 The maximum concentration for any benthic invertebrates (including prawns and crab, that were only screened for PFOS at the time of sampling) was conservatively adopted in the Tier 1 screening.

3.2.6.3 Potential Impact on the Environment

The detailed Ecological Risk Assessment (ERA) conducted by AECOM for assessment of PFAS at the Williamtown RAAF base concluded that there was potential for unacceptable risks to aquatic receptors at the Hunter Estuary Wetlands site (AECOM, 2018). It stated that fish eating birds, in particular, may experience an unacceptable risk due to bioaccumulation and dietary exposures within the estuary.

There is limited data to enable an assessment of potential ecotoxicity of many of the different types of PFAS that may be present in the environment, with studies to date largely focused on PFOS and PFOA. However, evidence to date indicates that PFOS tends to bioaccumulate more than other PFAS.

The following further information is noted with regards to PFAS effects on the environment:

- adverse effects noted during ecotoxicity studies include: developmental effects, growth inhibition, histopathological effects, atrophied thymus, species diversity changes in a microcosm, and mortality (Environment Canada, 2004, 2017).

- for PFOS, acute studies (as defined in defined in Warne *et al.* [2018]), are available for a range of aquatic species from phyla such as Annelida, Arthropoda, Chordata, Mollusca, Nematoda, Platyhelminthes, and Rotifera. Reported effect concentrations range upwards from 8.28 µg/L in Zebrafish (*Danio rerio*, phylum Chordata) (Jantzen *et al*., 2016) and 49.1 µg/L (10-d NOEC, MacDonald *et al.,* 2004) for midge larvae (*Chironomus tentans,* phylum Arthropoda).
- also for PFOS, chronic studies are available for a range of aquatic species from phyla including Arthropoda, Bacillariophyta, Chlorophyta, Chordata, Cyano-bacteria, Mollusca, Platyhelminthes, and Tracheophyta. Reported effects concentrations range upwards from 0.734 µg/L in second generation (F2) Zebrafish (*Danio rerio*, phylum Chordata) (180-d LOEC, Keiter et al 2012); 5 µg/L in first generation (F1) Zebrafish embryos (mortality in *Danio rerio*, phylum Chordata) (8-d NOEC, Wang et al., 2017); and 10 µg/L for delayed time to gosner stage in Northern Leopard Frogs (*Lithobates pipiens* (formerly *Rana pipiens*) (Hoover et al., 2017).
- again for PFOS, development effects have been reported in aquatic invertebrate tests, including time to emergence, larval development time, metamorphosis success, and hatching time. Reported effects ranged upwards from 2.3 µg/L for time to total emergence in midge larvae (*Chironomus tentansmagna*, phylum Arthropoda) (20-d NOEC, MacDonald et al., 2004).
- NOECs for PFOS and aquatic species range from approximately 0.734 µg/L and 2.3 µg/L (Keiter et al 2012; MacDonald et al., 2004)
- Due to the significant rates of bioaccumulation and biomagnification that may occur with PFOS, bioaccumulation factors (BAFs) are elevated. BAFs, which are the ratio of the concentration within biota relative to the source media, are highly variable within and between species, and also vary with changes in environmental factors such as salinity. Bioaccumulation for PFAS is more significant in freshwater aquatic environments. PFOS BAFs can therefore vary over several orders of magnitude, and empirical data (i.e. site-specific sampling) generally provides a better estimate of bioaccumulation than application of a reference BAF value. BAFs from some key studies are indicated below:
  - 3,000 for surface water to fish (OECD, 2002; RIVM, 2010).
  - >50,000 for surface water to air breathing mammals such as dolphins (SA EPA, 2017).

The Australian screening criteria for PFOS in surface water were derived based on species sensitivity distribution (SSD) modelling (HEPA 2019 and 2018). The 99% protection level for surface waterbodies of 0.00023 µg/L was derived using nationally agreed methods. Ingestion exposures by upper trophic level species exposed to higher concentrations due to bioaccumulation and biomagnification are considered to be environmentally relevant. (Roscales et al., 2019; Muir et al., 2017; Munoz et al., 2017; Holzer et al., 2011; Gobas et al., 2009; Conder et al., 2008; Arnot and Gobas 2006; Giesy et al., 2001; Russell et al. 1999).

3.2.7 Sediment Toxicity Data

The findings of several direct whole sample toxicity studies (Simpson et al., 2001a,b,c,d) conducted on sediment samples collected from the South Arm were summarised by OEH (2017a). In addition, further direct toxicity tests on whole sediment samples was undertaken as part of recent dredging assessment works (CSIRO, 2014a,b).

The most recent CSIRO work undertook sediment toxicity tests on three samples from the South Arm (in proposed dredge areas), three reference samples from within Fullerton Cove (see Figure 3.3 above) and three reference samples from within the North Arm, and found:

- No acute toxicity was observed in any of the sediment toxicity tests at any location.
- Samples from the dredging areas did not exhibit any toxicity in sub-lethal (chronic) reproduction tests on amphipods.
- One sample from Fullerton Cove was moderately toxic to amphipod reproduction, although the toxic effect observed was not significantly different to the observed controls.

- Samples were tested for a range of metals and physical parameters (grain size, organic carbon, etc), but were not tested for PFAS.

The toxicity tests provide a whole of sample assessment of toxicity, and do not assess the potential toxicity of any individual toxicants.

The findings from the Simpson et al work, as summarised by OEH (2017a), is presented below:

- Analyses completed included: total metals, PAH, acid volatile sulphide, bioavailable metal component, radionuclides, tributyltin, elutriate tests for metals, organochlorine pesticides, sediment toxicity testing with benthic microalgae and burrowing amphipods.
- Concentrations of zinc, lead, mercury, nickel and PAH exceeded ANZAST sediment guidelines.
- Findings indicated that the contaminant load was largely not bioavailable. An exception occurred where PAH concentrations were elevated in sediments in proximity to the BHP property (Simpson et al., 2001c).
- Sediment toxicity tests (Simpson et al, 2001d) eliminated the following chemicals as possible toxicants in the sampled sediments: metals (silver, arsenic, cadmium, copper, mercury, nickel, lead, selenium and zinc), OCPs, ethylbenzene, xylenes, dissolved sulphide and ammonium.
- Sediment toxicity tests (Simpson et al, 2001d) indicated that PAHs were possible toxicants.

A subsequent study by URS (2004) of risk posed by the existing contaminant status of sediments from the South and North Arms of the Hunter River to human and ecological receptors was summarised in the OEH (2017a) report, with key points summarised as follows:

- Chemicals assessed: PAH, TPH, cadmium, copper, nickel, lead, mercury and zinc.
- Sediments exhibited toxic effects to ecological receptors at 6 of 10 intertidal sites from the South Arm (adjacent to BHP Steelworks) and 2 sites from the North Arm.
- No causal relationship was able to be established in this review but did note a correlation between highly contaminated sediments and apparent lowered diversity in benthic communities within the intertidal zones.
- Simpson et al. (2001d) identified that for similar sediments in which PAH impacts were present (especially when enriched), the PAHs acted as potential toxicants to aquatic receptors.

3.3 Qualitative Risk Assessment

Throughout the history of the Hunter River, uncontrolled industrial and agricultural activities have adversely impacted the quality of soils, sediments, groundwater and receiving surface waters of the Hunter Estuary. These impacts are present in key media (i.e. sediments and surface water) to which site-specific sensitive ecological receptors are exposed. However, the full nature and extent of the impacts at the Hunter Estuary Wetlands Ramsar site cannot be determined comprehensively due to significant data gaps.

The data that are available are generally consistent with that summarised in the Ecological Character Description (Brereton, and Taylor-Wood, 2010). Most historical reports indicated that metals and nutrient enrichment tended to occur outside the Ramsar site closer to the South Arm of the Hunter River area. However, impacts within the Ramsar site cannot be fully disregarded.

Based on the history of the catchment and surrounding areas, the following were considered potential contaminants of interest for an assessment of ecological impacts at the Hunter Estuary Wetlands Ramsar site:

- Metals, including arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium and zinc;
- Polycyclic aromatic hydrocarbons (PAHs);
- Petroleum hydrocarbons;

- Agricultural chemicals, including organochlorine pesticides (OCPs), organophosphate pesticides (OPPs), herbicides (e.g. trifluralin and potentially others);
- Nutrients (nitrogen and phosphorus compounds), associated with both agricultural and industrial sources;
- Cyanide; and
- PFAS.

An assessment of potential risk associated with many of these compounds was unable to be undertaken due to the lack of any analyses within the Ramsar site. From the results of the Tier 1 screening assessment and associated discussions above (Sections 3.2.1 to 3.2.7), contaminants currently present at levels of potential concern to ecological receptors within environmental media at the site were identified as:

- Surface water: nitrate, total nitrogen, total phosphorus, lead, and PFOS.
- Sediments: PFOS.
- Biota: PFOS and PFHxS.

Based on significant potential for uncertainty, and / or significant potential for ecotoxic effects at low concentrations, the following contaminants are considered potentially of interest and remain significant data gaps in this assessment:

- Metals, including arsenic, cadmium, chromium, copper, iron, manganese, nickel, selenium and zinc; and
- Polycyclic aromatic hydrocarbons.

The following potential contaminants were considered unlikely to pose a significant risk, due to the likelihood that use of these chemicals was limited in extent or volume (pesticides and herbicides), or the ecotoxicity or persistence of the contaminants indicated that low level releases were not a significant issue (petroleum hydrocarbons). These contaminants included:

- Petroleum hydrocarbons; and
- Agricultural chemicals, including OCPs, OPPs, herbicides (e.g. trifluralin and potentially others).

3.4 Key Contamination Issues

3.4.1 Spatial and Temporal Trends

The available dataset is insufficient to enable a robust assessment of spatial and temporal trends in contaminant concentrations throughout the Ramsar site. An understanding of these trends is key to any assessment of the scale and magnitude of contamination issues (i.e. how widespread are contaminants and how do concentrations vary spatially), and to any assessment of the impact of contamination over time (i.e. can changes in contaminant levels be correlated with changes in the ecosystem).

The contaminant transport modelling report prepared for DoEE (Miller et al, 2018) provides some evidence of how contaminants may migrate in surface water and sediment through the lower Hunter. The contaminant transport report indicates that the lower Hunter is relatively well mixed with high rates of contaminant transport. There are two hydrologically distinct areas of the Ramsar site: a) the North Arm channel and b) Fullerton Cove. Contaminant distribution and transport behaviours differ between these two areas.

Conservative modelling of point source releases in the South Arm indicates that contaminants can travel greater than 10 km up-stream due to tidal influences, with subsequent migration of contaminants down the North Arm and into Fullerton Cove.

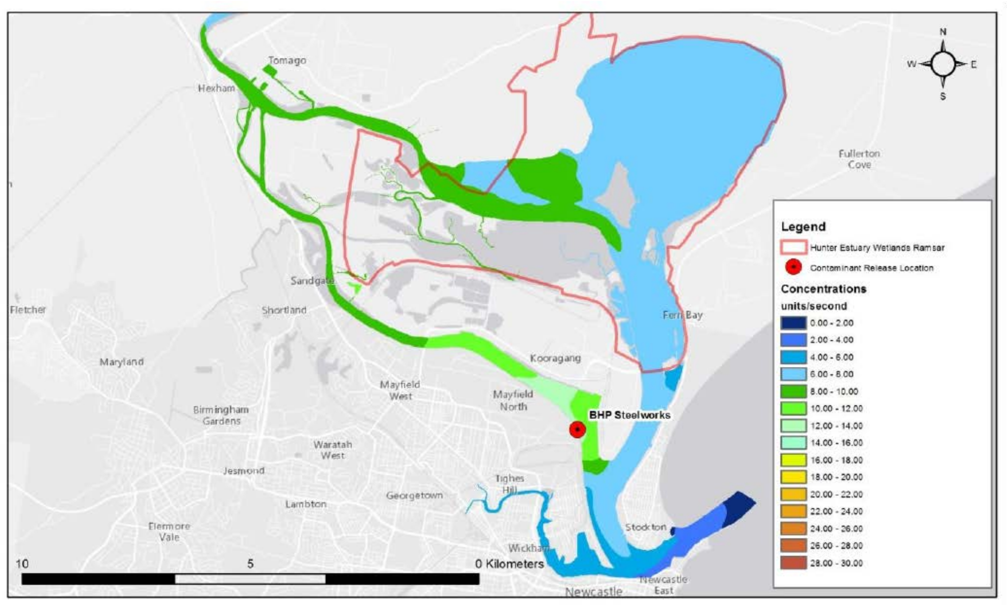
The contaminant transport modelling (Figure 3.6a, b) indicates that activities in the South Arm have a significant potential to impact on surface water and sediment quality within the North Arm component

of the Ramsar site. This modelling also suggests that there may be some impacts on water quality within Fullerton Cove from contaminants in the South Arm, however wind-induced mixing, that was not included in the modelling, may reduce any impacts. Transport of sediment in the form of sands and gravels is predicted along the North Arm and South Arm. However, sediment transport is predicted to be limited within Fullerton Cove, suggesting that any sediment bound contaminants could reside in this area for considerable time. The impact of contaminants residing in the sediment would be potentially mitigated as they “may have been transported from the estuary during flood periods, buried by deposition, chemically transformed or be limited in transport mechanisms by flocculation, aggregation or settling” (Miller et al, 2018).

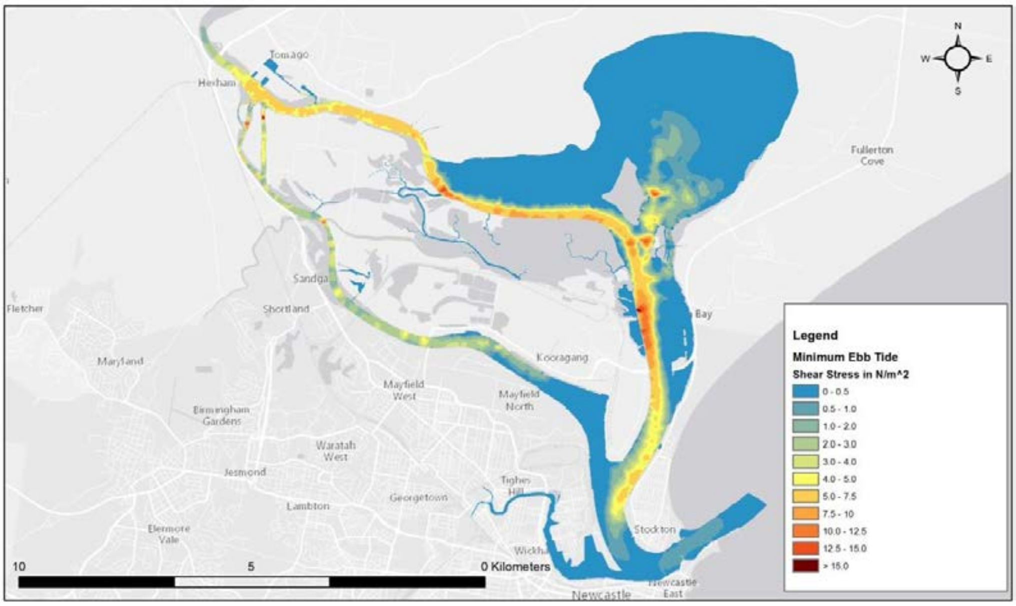
Available data from the site is generally limited to targeted investigations, and temporal data is limited. Sampling of sediment and surface water in the South Arm indicate a number of contaminants have declined in concentration over time, particularly metals and PAHs (OEH, 2017a; CSIRO, 2014a). Given that the industrial sources of contaminants in the South Arm have been significantly reduced since 2000, it is considered likely that contaminants originating from this source into the Ramsar site would largely have been flushed from the estuary system. Further sampling within Fullerton Cove would be required to substantiate this claim.

Improvements in environmental regulations, licensing, and industry behaviours are likely to have resulted in reduced contaminant releases and levels over time. This trend is supported by the reduced metal concentrations in sediment in the South Arm, particularly after the closure of the BHP Steelworks (CSIRO, 2014a). Other factors such as dredging, or deposition of new sediment would alter contaminant concentrations at the sediment-water interface over time.

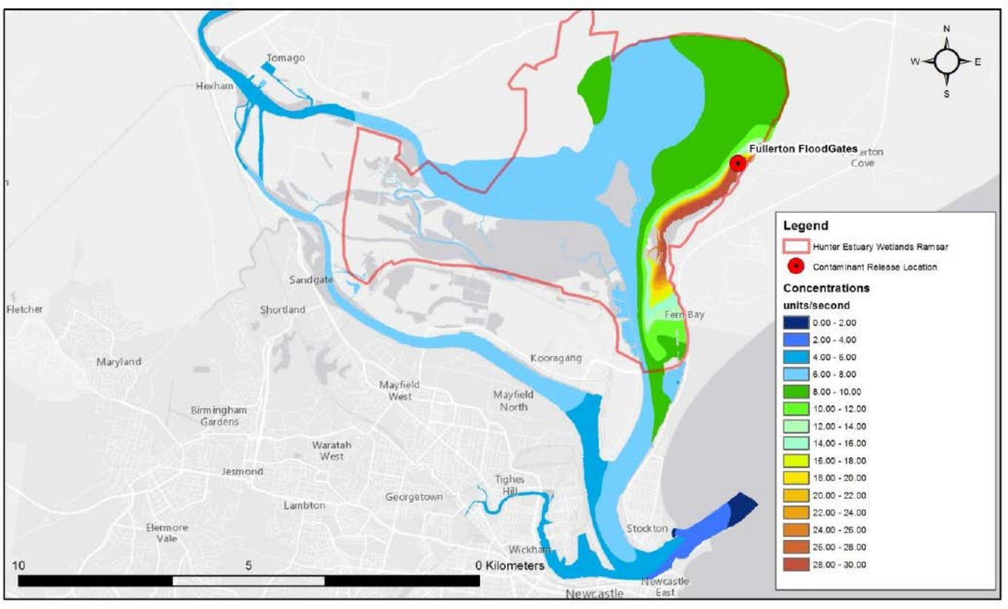
The contaminant transport modelling (Figure 3.6) has also identified the potential for significant impacts on Fullerton Cove, in particular, from contaminants released from the Fullerton Cove floodgates. This location represents the source of PFAS contamination from Williamtown base into the Ramsar site. The report notes that “there is likely to be a much higher concentration near the source of release due to the lesser tidal exchange at these sites”. It also notes that, wind-induced mixing, which was not modelled, may disperse the contaminants throughout Fullerton Cove. Temporal changes in PFAS cannot be assessed, noting that PFAS products are no longer in use at the Williamtown RAAF base.



a) End of simulation mid tide contours of constituent concentration released at the former BHP Steelworks site



b) Bed shear stress minimum ebb tide



c) End of simulation mid tide contours of constituent concentration released at the Fullerton Cove Floodgates site

Figure 3.6 Outputs from contaminant transport modelling in the lower Hunter Estuary (Miller, 2018, WRL, 2018).

3.4.2 Direct Chemical Effects

Based on the qualitative risk assessment presented above, the following chemicals are either known or considered likely to be present in the Hunter Estuary Wetlands Ramsar site, at concentrations above adopted screening criteria:

- Nitrate, Total Nitrogen, and Total Phosphorous;
- Metals, including Lead; and
- PFAS, including PFOS, PFHxS.

These compounds were reported within surface waters and sediments at the site, with some compounds, including PFOS, PFHxS, and mercury detected in biota, including fish, algae, and invertebrates. These data indicate that bioaccumulation of these compounds is occurring or has occurred within the food web at the site and surrounds.

The exceedances of adopted screening criteria indicate that direct toxic effects on biota are possible at the site, due to contact with contaminants present within surface water or sediments at the site, or via ingestion through the food chain.

These exposures may result in the following direct effects:

- Nutrients: Direct effects may include promotion of excessive growth of algae or plants and associated deoxygenation of water column. Can promote weeds and exotic species. May impact fringing aquatic flora and fauna communities at the site.
- Metals: Potentially directly toxic to aquatic fauna exposed to low concentrations. Bioaccumulation a significant potential exposure pathway, and biomagnification is significant for mercury. Exposure at high trophic levels potentially the most significant risk from mercury. Effects can include impaired reproduction, growth, or survival.
- PFAS: Potentially directly toxic to aquatic fauna exposed to low concentrations. Bioaccumulation and biomagnification are significant potential exposure pathways, particularly for PFOS, with PFAS likely to persist in sediments indefinitely. Effects can include growth inhibition, species diversity changes in a microcosm, and mortality.

The potential for contaminants to behave in an antagonistic or synergistic manner when mixes of chemicals occur in the environment is not well understood. Toxicity tests undertaken in controlled laboratory environments generally entail exposing test species to a single chemical or a related group of chemicals such as PAHs. It is therefore difficult to assess whether exposures to a mix of chemicals, such as PFAS, metals, PAHs, etc, may result in effects that are independent, additive, or otherwise. Direct toxicity tests on whole samples collected from within the environment (e.g. the sediment toxicity tests discussed in Section 3.2.7) provide one tool for assessing site specific toxicity of mixes of contaminants.

3.4.3 Secondary Impacts

In addition to direct toxic effects on organisms due to contact with contaminants, indirect effects on the local ecosystem can also occur as a result of contamination. It is generally acknowledged that understanding contaminant effects at ecosystem levels is a challenge in ecotoxicology and ecological risk assessment, in part due to a traditional focus on direct toxic effect studies and use of common test species (Preston, 2002).

To understand ecosystem level impacts due to contamination, the following key processes and factors should be assessed:

- Changes to community structure, including biodiversity and species richness, ecological diversity, and dominance; and
- Ecological processes that control ecosystem functioning, including primary and secondary productivity, biological processes such as decomposition, and biogeochemical cycles (Ramade, 1997).

Without further site specific assessment of a number of these factors, the ability to correlate contamination levels within the Hunter Estuary Wetlands Ramsar site with ecosystem level effects is limited. Exposure to contaminants which are known or likely to be present at the site (e.g. lead or PFOS) may result in increased mortality and subsequent population declines. This may impact community structure, with variable effects between species (i.e. some species will be more sensitive to toxic effects than other species) likely to impact species diversity.

Factors such as reduced density of benthic invertebrates should also be considered when assessing indirect or secondary impacts. A reduction in benthic inveterate density may have significant implications for migratory birds, due to reduced foraging potential. As discussed in Section 3.2.7, one study undertaken in the South Arm reported a correlation between highly contaminated sediments

and lowered diversity in benthic communities within the intertidal zones (URS, 2004; summarised in OEH, 2017a), indicating this factor may be of importance for the Hunter Estuary Wetlands Ramsar site.

Studies which comprehensively assess ecosystem level effects are limited in number, with the following international studies providing some evidence of potential trends in ecosystem level impacts due to contamination in estuaries:

- A "multiparameter environmental assessment" undertaken in the lower Passaic River of Newark, New Jersey found that:
  - contaminant levels in sediment were elevated and impaired survival of amphipods, with body burdens of fish and crabs for copper, silver, zinc and DDT at concentrations that exceeded toxicity thresholds (Ludwig & Iannuzzi, 2005).
  - exposures due to ingestion of fish and invertebrates by migratory birds would not pose a risk [assuming background exposures from other sites were low], with local fish-eating species estimated to have unacceptable intakes of chromium, mercury, selenium, zinc, PCBs, dioxins, and DDT.
  - Calculated hazard quotients for assessing risk to migratory and local bird species indicated risks to local bird species were consistently approximately 2 orders of magnitude higher than risks to migratory birds, due to their much greater exposures.
- Contaminated sediments of the Calcasieu Estuary in Louisiana were reported to be impacted by heavy metals including chromium, copper, lead, mercury, nickel and zinc, PAHs, PCBs, pesticides, etc, with reduced benthic invertebrate density reported in proximity to point sources (MacDonald et al, 2011). The available publications did not present a breakdown of the chemical analytical data, due to a focus on comparative ecotoxicity sediments tests and risk assessment.
- A literature review by Fleeger et al. (2003) found that pollution with contaminants such as petroleum hydrocarbons, PAHs, metals, nutrients, pesticides, etc, have been shown to change behaviours, competition, predation, and grazing, potentially altering species abundances or community composition. Increases in abundance of primary producers were observed in various studies, due to either increased nutrient and / or carbon sources promoting growth, or due to 'top-down' effects when predators grazers are selectively eliminated by contaminants.
- Frogs and amphibians have historically been considered as potential indicator species for identifying the presence of contamination, however recent studies have reported that many amphibians are relatively resilient and other species such as benthic invertebrates may be better indicators of encroaching contamination impacting on an ecosystem (Kaplan, 2009).

Site specific assessment of factors such as species distribution and abundance relative to contaminant levels would be required to enable a more robust assessment of these potential issues.

4 ASSESSMENT OF CRITICAL COMPONENTS AND ECOSYSTEM SERVICES

4.1 Ecological character and critical components, processes and services

The ecological character of a wetland is defined by its critical components and processes which, through their interactions, provide benefits and services.

The ECD (Brereton and Taylor-Wood, 2010) identified the following ‘critical components’ and ‘ecosystem processes’ that define or strongly influence the ecological character of the Kooragang component:

- waterbirds, particularly migratory shorebirds.
- the green and golden bell frog (*Litoria aurea*), a nationally threatened species.
- *Sarcocornia* saltmarsh which supports migratory shorebirds.
- intertidal mudflats which provide foraging habitat for migratory shorebirds.
- hydrology (tidal regime and freshwater inflows) which is a major influence on the distribution and extent of saltmarsh and mangroves.

The ECD identifies the critical ‘ecosystem benefits’ and ‘supporting services’ that firstly, determine or strongly influence the ecological character of the Kooragang component, and support the criteria under which the site was listed, are:

- Food web of the intertidal mudflats which support migratory shorebirds (critical component).
- Biodiversity particularly:
  - Diversity of estuarine habitats that provide important roosting and foraging sites for migratory shorebirds;
  - infauna in the intertidal mudflats which provide foraging resource for migratory shorebirds.
- Threatened wetland species, habitats and ecosystems particularly for the green and golden bell frog (*Litoria aurea*).

A high-level review of the environmental setting of the Kooragang component has been provided in Chapter 2. This section builds on this background, describes the history, existing condition/extent of the site and determines if there has been a change or whether there is likely to be a change due to human causes, particularly chemical contamination, in the following critical components and ecosystem services:

- The food web and intertidal mudflats.
- The abundance and diversity of shorebirds with a particular focus on the eastern curlew and recently listed threatened species.
- *Sarcocornia* saltmarsh.
- Threatened wetland species including the green and golden bell frog and Australasian bittern.

For each of the key critical components and ecosystem services assessed below, the following questions and issues are addressed:

- Why is it important to the site?
- What is the Limit of Acceptable Change (LAC)?
- What has changed, and is it significant?
- Are any of the changes potentially linked to chemical contamination?
- What measures are in place to address the impacts?

- Knowledge gaps, if any.

4.2 Intertidal Mudflats and the Food Web

4.2.1 Why is it Important to the Site?

One of the critical components of the Kooragang component is that it supports a large abundance and diversity of migratory shorebirds (Brereton and Taylor-Wood, 2010). The food web of the intertidal mudflats is critical in supporting migratory shorebirds. These mudflats are formed by deposition of layers of sediments from upstream which are trapped by mangroves and/or deposited by slow moving water. Sediments are laid down in various strata within which specific invertebrate species are found. Microbes that are the primary decomposers of detritus form the basis of the food chain. These microbes, detritus and algae provide an important food resource for an abundance of infauna that primarily consists of polychaete worms and oligochaete worms, bivalve molluscs and amphipods.

The infauna of the estuary provides an essential food source for a variety of avifauna. At low tide, shorebirds forage over the mudflats feeding on invertebrates in the mud and sand substrates (infauna). Each species has a particular foraging behaviour, which is influenced by the length of the beak (how deep into the substrate they can forage) and leg length (determines the depth of the water they can forage in). Consequently, the intertidal mudflats can support large numbers of various migratory and non-migratory shorebirds including bar-tailed godwit (*Limosa lapponica baueri*), black-tailed godwit (*Limosa limosa*), whimbrel (*Numenius phaeopus*), eastern curlew (*Numenius madagascariensis*), great knot (*Calidris tenuirostris*), red knot (*Calidris canutus*), Terek sandpiper (*Xenus cinereus*), curlew sandpiper (*Calidris ferruginea*), common greenshank (*Tringa nebularia*), marsh sandpiper (*Tringa stagnatilis*), Pacific golden plover (*Pluvialis fulva*) and double-banded plover (*Charadrius bicinctus*), black-winged stilt (*Himantopus himantopus*), pied oystercatcher (*Haematopus longirostris*), masked lapwing (*Vanellus miles*) and great egret (*Ardea alba*) (Herbert, 2007a). Conversely, when the mudflats are inundated at high tide, the infauna resource is opened up to fish, which provide a food resource for other groups of birds such as gulls, terns and cormorants.

Most wading species migrate to and breed in the northern hemisphere during the Australian winter. Fat reserves to allow this are built up prior to departure in Australian estuaries. Immature birds or less healthy ones may remain behind. Thus, the available mudflats are required year-round and are essential to conserving future breeding stocks. Due to the highly specialised manner in which migratory birds feed upon the infauna of the mudflats they are highly sensitive to alterations in mudflat strata, such as may occur from dredging, prawning, propeller strikes, bait collection and pollution (NPWS, 1998). Unlike roosts, the biological complexity of feeding areas on the mudflats means they cannot be artificially created over the short term.

The major feeding areas for migratory shorebirds within the Kooragang component of the Hunter Estuary Wetlands Ramsar site includes the intertidal mudflats of Fullerton Cove that fringe the north-eastern end of Kooragang Island and the east back of the north arm of the Hunter River (including Fern Bay) upstream of Stockton Bridge and the and North Arm Sandflats behind the Kooragang Dykes (Moss, 1983; Herbert, 2007a) (see Figure 4.1).

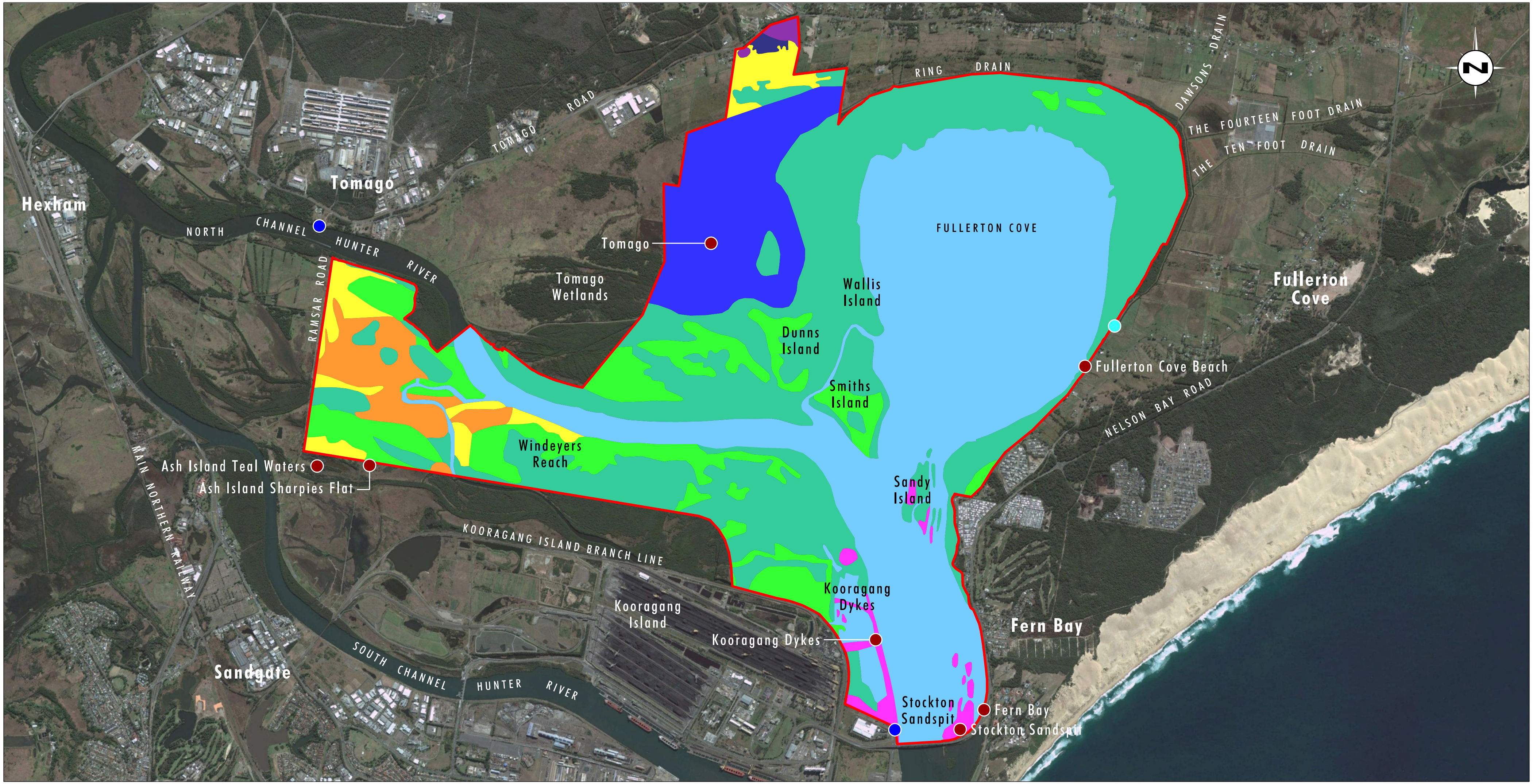


Image Source: Google Earth (Aug 2017)
Data Source: Commonwealth of Australia (Department of Environment) (2015), SEWPAC (2010)

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Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- HBOC Survey Location
- EPA Licensed Stormwater Discharege Location
- Williamtown RAAF Base Surface Discharge Location

Kooragang Wetland Types 1983:

- XF - Freshwater Tree Dominated Wetland
- F - Estuarine Waters
- G - Inter-tidal Mud and Sand
- H - Inter-tidal Marshes
- I - Intertidal Forested Wetlands (Mangrove Forests)
- H/I - Intertidal marshes and mangroves

Kooragang Non-wetland Types 1983:

- Pasture
- Saline Pasture
- Dry Eucalypt Forest

FIGURE 4.1

Shorebird Habitats within the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site

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Feeding times are also extended by the delays in filling and/or emptying of the flats behind the Kooragang Dykes caused by the restricted drainage points along the wall. The Kooragang Dykes is a 1.5 km rock retaining wall built in the 1960s as part of reclamation works. The Kooragang Dyke wall assists in the channeling of river flow thus contributing to the depth of the main shipping channel (NPSW, 1998). The area behind the wall now supports intertidal mudflats and provides an important feeding area as well as an important high tide roost (Spencer 2010, Herbert 2007).

The invertebrate fauna (infauna) of the Kooragang component was described in the ECD (Brereton and Taylor-Wood, 2010) as:

- The infauna (e.g. polychaete worms, molluscs and copepods) of Fullerton Cove is typical of south-east Australian estuarine infauna and also characteristic of intertidal meiofauna worldwide at higher taxonomic resolutions.
- The major groups of aquatic invertebrates include prawns, oysters and benthic invertebrates (crustaceans, isopods, amphipods and copepods, crabs, marine snails and marine worms such as polychaetes) (MHL, 2003). Of the pelagic invertebrate fauna, copepods are dominant, however, a shift from estuarine to freshwater invertebrates occurs when salinity drops to between approximately 10 and 0 parts per million (Genders, 2001).
- Throughout the intertidal margins (from the lower intertidal mudflats, through the mangroves and saltmarsh) there are a variety of size classes within the infauna community.
- The benthos in and around the mangrove forests on Kooragang Island also supported aquatic invertebrates such as crabs, marine snails, marine worms, and crustaceans (Clarke and Miller, 1983; The Ecology Lab, 2001). Mangroves also provide a source of vegetative material used as a food source by many taxa including prawns (Ruello, 1976).
- Rocky reefs and artificial structures such as the Kooragang Dykes provide habitat for oysters, barnacles, sea squirts and crabs; however, detailed presence and abundance surveys had not been conducted on these habitats at the time of listing (The Ecology Lab, 2001).

There is an absence of seagrass within the estuary and for this reason the fish assemblages are not similar to nearby estuaries. Surveys in 2003 for proposed dredging of the Hunter River found an abundance of yellowfin bream (*Acanthopagrus australis*), luminous bay squid (*Loliolus noctiluca*), school prawn (*Metapenaeus macleayi*), mulloway (*Argyrosomus japonicus*), tarwine (*Rabdosargus sarba*), sandy sprat (*Hyperlophus vittatus*) and silver biddy (*Gerres subfasciatus*) in order of decreasing abundance (The Ecology Lab, 2003). Most of these are species are important for commercial and recreational fishing.

Estuarine benthic fauna sampling undertaken in 2011 in the north arm of the Hunter River, near Kooragang Dykes, identified 52 macroinvertebrate species. Overall the most abundant invertebrate groups were phoronids and polychaetes, with the most abundant polychaete families being Capitellidae and Nephtyidae. The bivalve genus Semellidae was widespread, being present at 50% of the sampling sites. Semellidae also had a total abundance similar to phoronids and polychaetes. The most abundant crustacea was the amphipod family Hyalidae, however only small numbers were found (Umwelt, 2012).

4.2.2 Limit of Acceptable Change

At the time of listing, there was little information about the intertidal mudflat food webs of the Kooragang Estuary, leading to difficulty in describing a baseline condition and variability of this critical service (Brereton and Taylor-Wood, 2010).

No direct LAC for food webs has been developed. However, as this service is linked to changes in the presence of migratory shorebirds foraging habitat, it will be indirectly assessed through changes in the abundance and diversity of migratory shorebirds (refer to Section 4.3). While the availability of foraging habitat and food is a critical supporting service for migratory shorebirds, any changes in the service may not be reflected in changes in the number of migratory shorebirds given that changes in the number of migratory shorebirds are unlikely to be due solely to changes in the food web in the Hunter estuary. That is, there are factors other than the availability of intertidal mudflats and food web

that may impact on migratory shorebirds, including changes to habitats in the flyway external to Kooragang at breeding grounds and stopover sites that also impact on shorebird numbers.

Given the range of factors that influence migratory shorebirds, it is suggested that linking a LAC for intertidal mudflat foodwebs to migratory shorebird abundance may not be appropriate. Instead, consideration could be given to developing a LAC relating to availability of high-quality foraging habitat.

4.2.3 What has changed? Is it significant?

While quantification of changes in extent of tidal mudflats over time has not been determined as part of assessments of change in vegetation and habitats in the Kooragang component of the Hunter Estuary Wetlands Ramsar Site, a review of available information has identified the following changes:

- Changes in the distribution and extent of mudflats exposed at low tide from European settlement until 1990 is shown in Figure 2.7. Historically, there has been a substantial decrease of tidal mudflats from Tomago, Fullerton Cove, Hexham Swamp, Ironbark Creek and the original Hunter deltaic islands due to land reclamation (MacDonald, 2001).
- Channel dredging may be linked to increase tidal range facilitating mangrove expansion and loss of saltmarsh and/or intertidal mudflats.
- Mangrove expansion throughout most of the Hunter estuary has resulted in the loss of tidal mudflats along the north bank of the North Arm of the Hunter River, in proximity to Tomago (Figure 2.9). The increase in sedimentation of Fullerton Cove has come about from increased sedimentation within the Hunter River system (MHL, 2007). This can result in a subsequent increase in elevation within Fullerton Cove and thus facilitate mangrove expansion into this mudflat, which would modify a large expanse of invaluable shorebird habitat (MacDonald, 2001). Causes of mangrove incursion and colonisation are not well understood, but may be associated with climate change, altered tidal regimes, sedimentation and subsidence (MacDonald, 2001). Similar changes are occurring in other Australian estuaries.
- Winning (1986) and Outhred and Buckney (1983) included intertidal mudflat in calculations of bare ground or open water, respectively. Figure 4.1 shows the distribution of intertidal mudflats at the time of listing based on mapping of bare ground by Outhred and Buckney (1983).
- Geering (1995) identified that the Hunter estuary supports up to 750 ha of intertidal mudflat exposed for 5.5 to 6.5 hours twice daily.
- Changes in the viable habitat in the Hunter estuary since the 1970s indicates that historical wader roosting and foraging sites have become significantly degraded (MHL, 2007).
- Kleinfelder (2016) recently mapped the extent of intertidal mudflats and shallow ponds in the Kooragang component (see Figure 2.9) at 95.45 ha (Appendix C). However, comparison of this result with earlier maps is problematic given that this level of habitat differentiation was not undertaken previously.
- A search of publically available references did not find any recent surveys of infauna that would add to a discussion of the significance of the food web to the ecological character of the Kooragang component and/or add to discussions of what has changed.

Dredging and changes in the tidal range in the Hunter Estuary has reportedly resulted in deposits of finer silts on the mudflats at Kooragang Dykes and in Fullerton Cove has led to a muddier substrate. This change has been recognised as altering foraging habitat particularly for smaller shorebirds such as the curlew sandpiper and lesser sand plover (Ann Lindsey, HBOC, pers. comm.).

While data for the lesser sand plover was limited, analyses on the maximum summer counts for the curlew sandpiper from 2000 to 2017 revealed that this species abundance was declining (Appendix B). Approximately 2000 individuals were recorded in 2002, however these numbers began to sharply decline over the subsequent decade with a low of less than 200 birds recorded in 2014. Since then, the numbers have begun to climb slowly to 400 to 500. Similar declines have been recorded for other species including the eastern curlew (*Numenius madagascariensis*), bar-tailed godwit (*Limosa*

lapponica baueri), red knot (*Calidris canutus*), great knot (*Calidris tenuirostris*) and black-tailed godwit (*Limosa limosa*) (Appendix B).

It is not clear whether these changes are attributable to changes to inter-tidal mudflat composition and extent other factors operating within or external to the site.

4.2.4 Potential Impact from Contamination

Shorebirds are top predators in the mudflat ecosystem and they accumulate many persistent environmental contaminants such as lead and cadmium (Kim and Koo 2010). Migratory shorebirds may be exposed to chronic pollution during their time in Australia and are most at risk from bioaccumulation of human made chemicals in their feeding areas (Australian Government 2015). The food web (particularly infauna) is the most likely pathway for bioaccumulation of chemical contaminants.

PFOS is extremely persistent and has substantial bio-accumulating and biomagnifying properties binding to proteins (rather than fat) in the blood and accumulating in the liver. PFOS is considered to be the main driver of risks associated with PFAS exposure.

Levels of nitrate, total nitrogen, total phosphorus and lead all exceed ecological screening criteria and were identified as contaminants of interest in surface water samples (see Section 3.2). PFOS levels in sediment and biota also exceeded criteria and pose unacceptable risk to ecological receptors in the Hunter Estuary (see Section 3.2).

Risks to shorebird species are considered to exist through bioaccumulation through the food chain via ingestion of algae, benthic organisms and small fish. It is considered likely that PFOS and other chemicals are bioaccumulating in migratory shorebirds foraging in the intertidal mudflats, particularly in the Fullerton Cove area and Stockton Sandspit. Contaminant exposure may have a number of negative effects, with heavy metals such as mercury and lead of primary concern in a marine environment because they are non-essential, common and highly toxic, with effects on reproduction, egg hatchability, hatchling survivorship, susceptibility to disease and neurobehavioral development (Burger et al., 2015).

Concentrations of PFAS in surface sediments of Fullerton Cove (0.0 to 0.1m below ground level (bgl)) near the outlet of Dawson Drain are generally higher than deeper sediments (0.1 to 0.2m bgl) (AECOM, 2018) with concentrations significantly lower with increased distance from the drain outlet. Concentrations of PFOS in surface water, sediment and biota are at a level of potential concern to ecological receptors (see Section 3.2.6.3 and Section 3.3). Shorebirds that forage in shallow sediments are likely to be more highly exposed than shorebirds that forage to greater depths.

There is evidence of bioaccumulation of chemical contaminants in the food web in Fullerton Cove and nearby Port Stephens estuaries in both laboratory and field studies (Taylor et al, 2018; AECOM 2018) (Section 4.2) with concentrations higher in fish compared to benthic invertebrates sampled (AECOM, 2018). A recent preliminary investigation in Fullerton Cove identified that PFAS are being detected in the muscle and liver tissues of a range of commonly exploited species of fish, prawns and crabs (Taylor and Johnson, 2016; Taylor et al 2018). Reported concentrations in fish from Fullerton Cove in 2016 and 2017 were lower than the adopted fish tissue screening benchmark (AECOM 2018).

PFAS (including PFOS) have also been detected in bird eggs (e.g. in Australian white ibis and silver gull (Thompson et al., 2011) and a range of coastal and off-shore species in North America (Miller et al, 2015), indicating potential for toxic effects on bird eggs. Migratory shorebirds increase their feeding rate in the approaching period prior to their departure from the Hunter Estuary. While the implications of increased intake of PFAS as a result of increased feeding is difficult to predict (AECOM 2018), the bioaccumulative nature of PFOS may mean that increased ingestion prior to departure may pose a risk.

Migratory shorebirds are also exposed to chemical contaminants at other locations along their migratory routes in the EAAF (extending from breeding grounds in the Russian tundra, Mongolia and Alaska southwards through east and south-east Asia to non-breeding areas in Indonesia, Papua New Guinea, Australia and New Zealand).

Bioaccumulation of the heavy metals (lead, cadmium, iron, zinc and copper), due to long term exposure, has been detected in the Okgu Mudflat, Korea in the EAAF in the feathers of migratory shorebirds (terek sandpipers (*Xenus cinereus*), great knots (*Calidris tenuirostris*) and red-necked stints (*Calidris ruficollis*) (Kim and Oh, 2012)). Lead concentrations in feathers collected in Korea exceeded the potential toxicity threshold level while levels of essential elements such as iron, zinc and copper concentrations in the feathers were within the normal range of other studies for wild birds in the world (Kim and Oh, 2012).

Lead and cadmium are nutritionally nonessential elements and dietary exposure to elevated concentrations can be toxic causing sublethal and reproductive effects and reduced growth rates of bone (Kim and Oh, 2012).

Okgu Mudflat in Korea was a major stop-over site in the EAAF with migratory shorebirds staying for two to three weeks. Shorebirds are in the Hunter for a longer period (up to 6 months), with some juvenile birds staying for up to three years, and it is likely that the shorebirds are bio-accumulating heavy metals however there is no data to confirm this. Whether any of these chemicals are impacting on the development of migratory shorebirds such that it is a factor in any change or likely change in the ecological character of the wetland is unclear.

4.2.5 What measures are in place to address the impacts?

The Hunter Wetlands National Park Draft Plan of Management (NPWS, 2015) lists management measures that are in place that may minimise existing impact on intertidal mudflats and food webs, including:

- Actively manage the hydrology using water management structures and selective areas of active mangrove management to minimise the effects of the tidal range changes on habitat loss of saltmarsh and intertidal mudflats.
- Continue with the implementation of existing significant wetland restoration projects and seek opportunities to improve habitat through targeted restoration projects.
- Undertake strategic removal of mangroves.
- Work with Port of Newcastle to ensure a rapid and effective response should an oil spill or pollution incident occur.
- Continue to involve HBOC in management decisions related to shorebird habitat.

Where possible, an undisturbed soil and mudflat horizon should be maintained to maximise the abundance and availability of invertebrate prey items for migratory birds, waterfowl and fish; and minimise or prevent oxidation of potential acid sulphate soils and promote habitat diversity (NPWS, 1998).

Activities which are shown to significantly affect the mudflat strata within the reserves will be prohibited. NPWS will negotiate with relevant authorities an agreement to minimise dredging in the Hunter River to that necessary for safe navigational passage of shipping.

4.2.6 Knowledge Gaps

The following knowledge gaps have been identified in the ECD and this formal assessment:

- There is limited available information on changes in tidal range and the impact on changes in the distribution of intertidal mudflats. While Williams et al. (2000) has looked at changes in open water (including intertidal mudflats) and mangroves over the period 1954 to 1994 this has not specifically been investigated for changes in the extent of intertidal mudflats over time, particularly since listing.
- Monitoring of tidal range changes at a range of locations associated with the Kooragang component would assist in evaluating the need for a direct limit of acceptable change associated with this critical process.

- Mapping of vegetation/habitats to monitor changes in extent and distribution of saltmarsh, mangroves and intertidal mudflats to assess if shorebird habitat continues to decline should be undertaken regularly (i.e. once every five years).
- There is no recent information on the infauna, particularly soft sediment invertebrates, their habitat requirements, distribution and response to change in environmental conditions in the estuary.
- Further investigation is required to assess whether there has been bioaccumulation in shorebirds and what impacts this may have on the birds. This investigation should also consider other resident species that forage in this area to rule out remote causes.

4.2.7 Conclusions

The major feeding areas for migratory shorebirds within the Kooragang component of the Hunter Estuary Wetlands Ramsar site includes the intertidal mudflats of Fullerton Cove that fringe the north-eastern end of Kooragang Island, the North Arm Sandflats behind the Kooragang Dykes and the east bank of the north arm of the Hunter River (including Fern Bay) upstream of Stockton Bridge (Herbert, 2007a, Spencer 2010). Dredging and changes in the tidal range in the Hunter Estuary has reportedly resulted in deposits of finer silts on the mudflats at Kooragang Dykes and in Fullerton Cove has led to a muddier substrate. This change has been recognised as providing habitat that is less suitable for the smaller shorebirds such as the curlew sandpiper and lesser sand plover (Ann Lindsey, HBOC, pers. comm.).

There is no readily available assessment of the extent of intertidal mudflat habitat over time to understand whether there has been a change in the intertidal mudflat and the invertebrate fauna.

There are significant knowledge gaps in describing the food web of the intertidal mudflats in the Kooragang component including but not limited to habitat requirements, distribution and response of shorebirds to change in environmental conditions (including chemical contaminants) in the estuary.

4.3 Shorebirds

4.3.1 Why is it important to the site?

Shorebirds, particularly migratory species, are one of the principal justifications for listing of the Kooragang component of the Hunter Estuary Wetlands as a Ramsar Wetland of International Importance. The site contains foraging and roosting habitat for populations of migratory shorebirds during their non-breeding season.

Around the time of listing, the site regularly supported 17 species of migratory shorebirds with a total of 6800 individuals being recorded in the Hunter Estuary (Herbert 2007a). A review of available data has identified that in 1984 regularly occurring migratory shorebirds included the black-tailed godwit (*Limosa limosa*), bar-tailed godwit (*Limosa lapponica baueri*), whimbrel (*Numenius phaeopus*), eastern curlew (*Numenius madagascariensis*), marsh sandpiper (*Tringa stagnatilis*), common greenshank (*Tringa nebularia*), terek sandpiper (*Actitis hypoleucos*), grey-tailed tattler (*Heteroscelus brevipes*), ruddy turnstone (*Arenaria interpres*), great knot (*Calidris tenuirostris*), red knot (*Calidris canutus*), red-necked stint (*Calidris ruficollis*), sharp-tailed sandpiper (*Calidris acuminata*), curlew sandpiper (*Calidris ferruginea*), Pacific golden plover (*Pluvialis fulva*), lesser sand plover (*Charadrius mongolus*) and broad-billed sandpiper (*Limicola falcinellus*). In addition, the site also recorded 900 eastern curlews (*Numenius madagascariensis*) in 1984, which was recognised as supporting more than 1% of the EAAF population for the species (Herbert 2007a). At that time, the site also supported more than 1% of the Australian population of the lesser golden plover (*Pluvialis dominica*) population (now recognised as the Pacific golden plover (*Pluvialis fulva*)).

The site is also important for non-migratory shorebirds including red-necked avocets (*Recurvirostra novaehollandiae*), black-winged stilts (*Himantopus himantopus*), ducks, grebes, cormorants, herons, egrets, water hens, ibis, darters, spoonbills, coots, gulls and terns.

Black-winged stilts have been identified as a breeding resident at the site, with over 1000 individuals of this species recorded at the time of listing (Herbert, 2007a).

The Kooragang component of the Hunter Estuary Wetlands Ramsar site contains waterbird habitat mainly for foraging and roosting (see Figure 4.1). Breeding habitat is also present in the form of freshwater swamps with open water and dense vegetation, however these habitats are limited as most swamps are brackish. Nevertheless, a total of 20 species of waterbird have been recorded breeding at the site and include ducks, crakes, moorhens, swamphens, coots, masked lapwings, red-capped plovers and black-fronted dotterels.

More recent studies (OEH, 2015) have identified that there are 34 species listed under international migratory bird agreements frequenting the Kooragang component of the Hunter Estuary Wetland Ramsar site, with eight threatened migratory species as listed under the BC Act and seven threatened migratory birds as listed under the EPBC Act (see Appendix D).

4.3.2 Limit of Acceptable Change

The LAC for migratory shorebirds was set in the ECD at:

- For any five (5) consecutive years there will be no instance of all years recording a maximum summer annual count of migratory shorebirds of less than 5000 birds. That is a change in ecological character has been detected when the annual maximum summer count of migratory shorebirds is less than 5000 birds in five (5) consecutive years.
- For any five (5) year period there will be no instance of all years recording a maximum summer annual count of eastern curlew for the Hunter estuary of less than 600 birds.

The level of confidence for both of these LAC was low (Brereton and Taylor-Wood 2010).

In addition, while no LAC was set in the ECD, the maximum number of species of migratory shorebirds recorded at the site annually is identified as a critical ecological component, process and service of the Kooragang component. This formal assessment has considered whether there has been changes in the diversity of shorebirds that regularly visit the wetland.

4.3.3 What has changed, and is it significant?

Changes in Abundance of Migratory Shorebirds

The ECD for the Kooragang component of the Hunter Estuary Wetlands Ramsar site indicates that a significant decline in the abundance and diversity of migratory shorebirds has occurred since the 1970s (Herbert 2007a; Brereton and Taylor-Wood 2010) as evident by following counts:

- Maximum counts either side of 1984 (1970 to 1989) ranged from 10,000 in 1970 to 5,000 in 1988 and this was considered natural variability (Herbert, 2007a).
- By 1999 maximum counts of migratory shorebirds in the estuary had decreased to 3500 individuals; approximately 50% (Herbert, 2007a).
- Spencer (2010) found that there was a 42% decline in total numbers of migratory shorebirds in the Hunter estuary (including the Kooragang component) from 1980 to 2007 with a 28% decline from 1990 to 2007, at the rate of 1.6%/year decline.
- Mean summer counts for the Hunter estuary (including the Kooragang component) declined from $4{,}244^{\pm 778}$ in the 1990s to $3{,}036^{\pm 130}$ birds in 2000-2007. Mean over winter counts declined from $450^{\pm 68}$ in the 1990s to $358^{\pm 34}$ birds in 2000-2007. However, maximum counts of migratory shorebirds in the Hunter estuary over summer (January/February) or winter did not decline between the 1990s and 2000-2007 (Spencer 2010).
- Since 1999, the abundance of migratory shorebirds has reportedly remained stable with numbers ranging from 2967 to 3626 individuals from the 1999 to 2007 period (Herbert, 2007a).

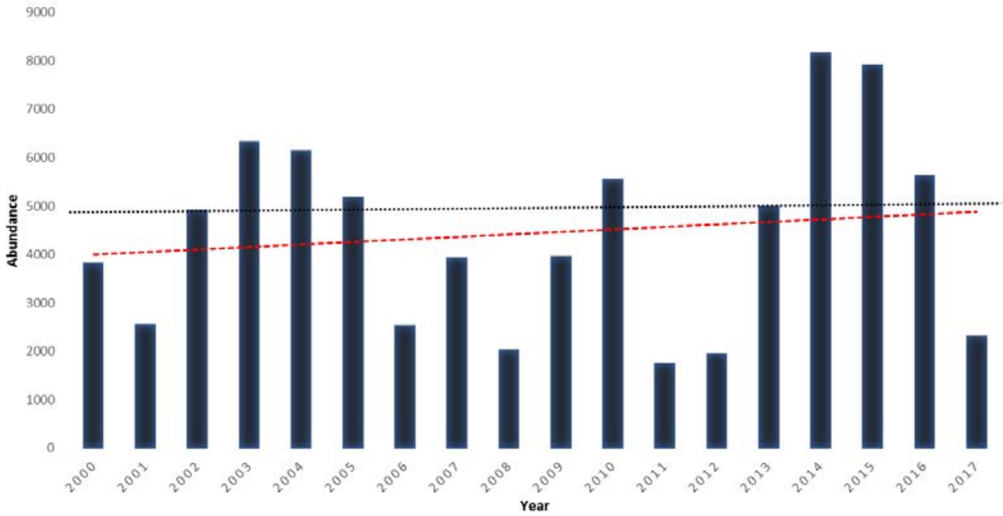
Since 1999 monthly shorebird data has been collected by HBOC at six locations within the Kooragang component as shown in Figure 4.1. Surveys at the Tomago wetland site were added to the monthly shorebird surveys in January 2014. The Tomago wetland site was added to the surveys to monitor numbers of shorebirds using the rehabilitation area. Monthly surveys are completed during the same

high tide event over a three-hour period, except where circumstances such as unfavourable weather, cause some sites to be surveyed on the day before or after the main survey day (Stuart et al., 2013). Surveys are centred around the time of peak tide (Stuart et al., 2013).

The systematic collection of monthly shorebird data by HBOC since April 1999 provides a more reliable data set for analysis and has been used to inform this assessment. An analysis of long term (April 1999 to December 2017) has been undertaken to identify if there has been a change in shorebird abundance. The analyses methods and results are provided in full in Appendix B.

Analyses of summer maximum counts of migratory shorebirds from for all of the survey sites (see Section 3.2 of Appendix B) identified the following changes:

- There has been a slight, albeit statistically non-significant, overall increase in migratory shorebird abundance in the Ramsar site including Tomago wetland rehabilitation area (see Figure 4.2). The most parsimonious models for predicting the migratory shorebird summer abundance included the southern oscillation index, rainfall and Lake Eyre rainfall, with the southern oscillation index being significant (see Section 3.2 of Appendix B).
- Counts ranged from a low of 4745 individuals in 2011 to a high of 11,993 individuals in 2015.
- Annual summer abundance was less than 5000 individuals for the years 2000, 2001, 2002, 2005, 2006, 2007, 2008, 2010, 2011, 2013 and 2017.
- Between 2000 and 2017 there was no instance of the maximum summer annual count of migratory shorebirds being less than 5000 birds for any five consecutive year period. Therefore, the LAC was not exceeded according to these data.



Data obtained from HBOC monthly shorebird surveys. Red dotted line represents the line of best fit. Black dashed line represents the LAC of 5000 individuals.

Figure 4.2 Relationship of maximum summer counts of migratory shorebirds from 2000 to 2017 in the Kooragang component of the Hunter Wetlands Estuary Ramsar site.

These findings are contrary to declining trends discussed in the ECD (Brereton and Taylor-Wood, 2010) and reported in the literature (Clemens et al., 2016).

As shown in Figure 4.3 and Figure 4.4 these findings are largely associated with addition of Tomago wetland sites to the routine monthly shorebird counts in 2014. This was in response to rehabilitation of habitat in the Tomago wetlands and associated gradual return of shorebirds to the wetland (Lindsey and McNaughton, 2012) particularly since 2012 when the site became subject to tidal inundation (Stuart, 2016).

The proportion of shorebirds recorded in the Tomago wetlands, relative to the remainder of the Kooragang component of the Ramsar wetland is shown graphically in Figure 4.3.

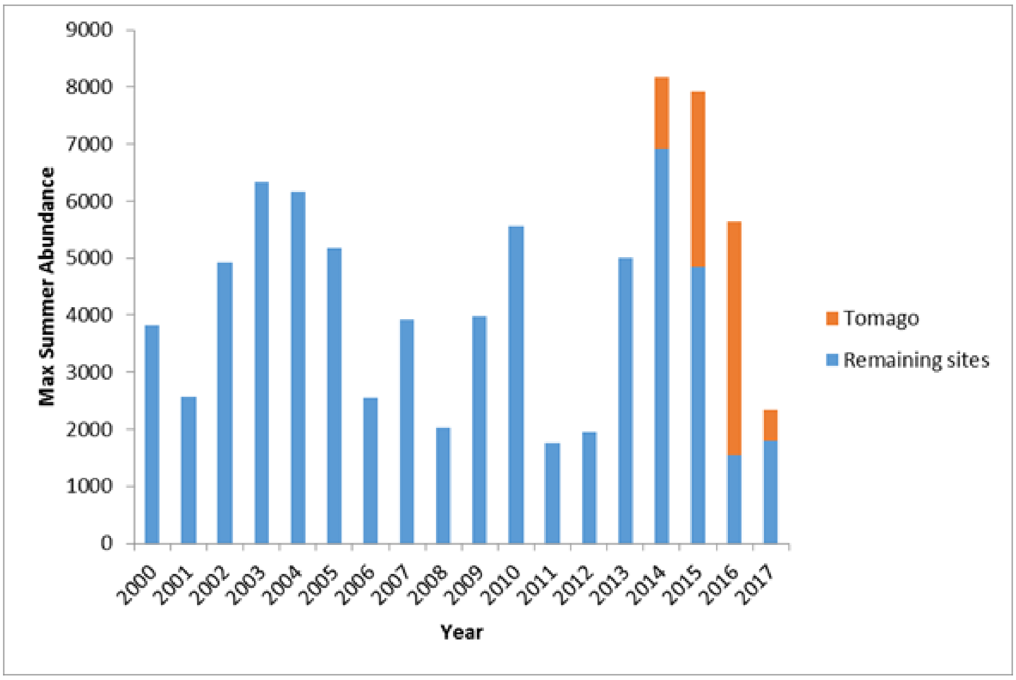
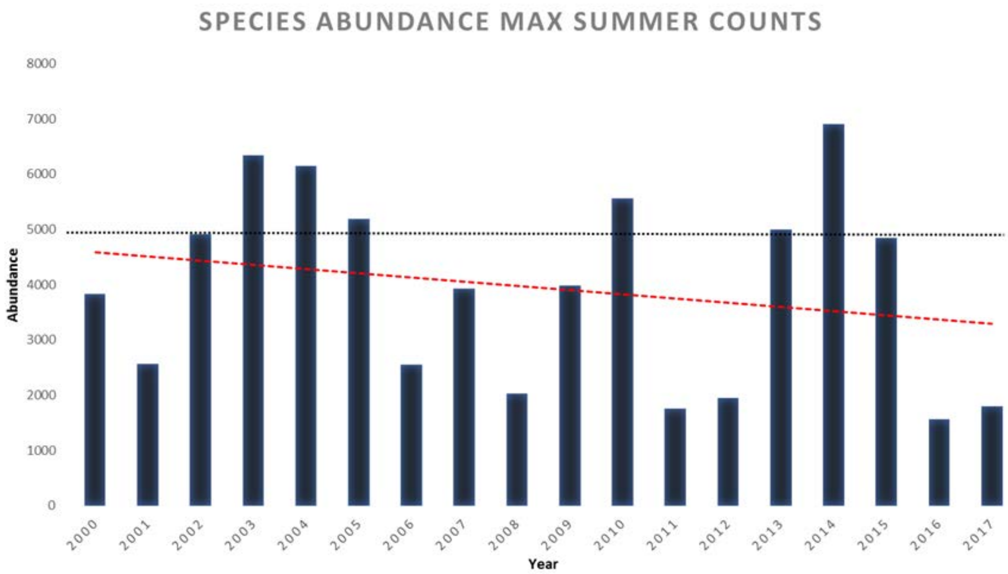


Figure 4.3 Maximum summer counts of migratory shorebirds from 2000 to 2017 in Kooragang component of the Hunter Wetlands Estuary Ramsar site (blue) and proportion of numbers recorded in the rehabilitating Tomago wetlands from 2014 onwards (orange).

If shorebird count data for Tomago wetland from start of 2014 is not included in the analysis of summer counts of migratory shorebirds the trend in abundance shows a decline and the maximum summer annual count is less than 5000 birds for the last three years of data (see Figure 4.4). However, this does not trigger exceedance of the LAC as the threshold is set at five consecutive years.



Data obtained from HBOC monthly shorebird surveys. Red dotted line represents the line of best fit. Black dashed line represents the LAC of 5000 individuals.

Figure 4.4 Relationship of maximum summer counts of migratory shorebirds from 2000 to 2017 in the Kooragang component of the Hunter Wetlands Estuary Ramsar site excluding Tomago wetland survey data from 2014 to 2017.

It should be noted that 90% of summer birds counts at Tomago wetlands are attributed to sharp-tailed sandpipers (*Calidris acuminata*).

More than 90% of the EAAF population of sharp-tailed sandpipers visit Australia in the non-breeding season (Stuart 2016). Sharp-tailed sandpipers will migrate to both ephemeral inland wetlands (in response to inland rainfall) and coastal wetland habitats with 39 sites in Australia recognised as internationally significant, supporting more than 1% (ie more than 1,600 birds) of the EAAF population (Bamford et al 2008). At that time, the Hunter estuary (including the Kooragang component) was not recognised as internationally significant for this species. However, since then, sharp-tailed sandpiper numbers in the Hunter estuary have been increasing from 1255 birds in 2004 and 1133 birds in 2009 (during inland drought) to approximately 7000-8000 birds since 2013. These birds are predominantly foraging in the rehabilitating estuarine habitats in the Tomago and Hexham wetlands and only infrequently and in low numbers at Ash Island (Stuart, 2016).

Prior to flood mitigation works in the mid-1970s Tomago wetlands was known as the primary nocturnal roost site of most of the shorebirds in the Hunter Estuary (Herbert, 2007), supporting a diverse and numerous population of sharp-tailed sandpipers, Pacific golden plover, Latham’s snipe, marsh sandpiper and wood sandpiper (Clarke and van Gessel 1983 in Lindsey and McNaughton 2012). Following opening of floodgates in Tomago wetlands numbers of sharp-tailed sandpipers have been increasing in this part of the Ramsar site from 26 in December 2009 (Lindsey and McNaughton 2012), to 700 in late 2012, with several thousand recorded foraging and roosting in 2013-2014 and 2014-2015 (Stuart 2016). Other shorebirds recorded at Tomago include black-winged stilts, Pacific golden plover, common greenshank, marsh sandpiper, red-necked avocets and curlew sandpipers.

Sharp-tailed sandpipers have been observed to foraging in saltmarsh nearly all day, regardless of tidal period and time of day and are only occasional visitors to inter-tidal mudflats (Spencer 2010). Foraging habitats in Tomago wetland area remain relatively constant in a given day and are preferred by this species.

Similarly, at Hexham Swamp in the Hunter Wetlands National Park (but not the Hunter Estuary Wetlands Ramsar Site), rehabilitation of tidal inundation and changes in wetlands has increased habitat for migratory shorebirds with the number of sharp-tailed sandpipers increasing from 1057 birds in 2012-2013 with several thousand in the 2013-2014 season and 2014-2015 season (Stuart 2016).

Increase in abundance of species may also be accounted for by higher counts of red-necked avocets in 2003 and 2015. The Kooragang component of the Hunter Estuary Wetlands Ramsar site is significant for the red-necked avocet. Since 1990, between 2-5% of the Australian population of this endemic shorebird have been present (Stuart 2017). There have been three periods of prolonged absence of 12 to 18 months in 2000-2001, 2010-2011 and 2016-2017 related to strong La Nina weather patterns and inland rain events (Stuart 2017). This species roosts at Stockton Sandspit in a tidal lagoon but has been observed recently feeding and roosting in ponds on Ash Island (Stuart 2017) in the KWRP area, external to the Ramsar wetland boundary.

Changes in Abundance of Eastern Curlew

At the time of listing in 1984, the Kooragang component of the Hunter Estuary Wetlands Ramsar site recorded 900 eastern curlews (*Numenius madagascariensis*), and between 1999 and 2007 there were regularly 400 to 600 eastern curlews (Herbert, 2007a). This species has been recorded throughout the Kooragang component and adjacent habitats (see Figure 4.5).

Analysis of the monthly data as provided in detail in Section 3.3 of Appendix B has demonstrated a pattern of decline in the abundance of the eastern curlew over time from 2000 to 2017. In particular, these declines appear more pronounced in the last four years (2014 to 2017) (Figure 4.6).

Image Source: Google Earth (Aug 2017)
Data Source: Commonwealth of Australia (Department of Environment) (2015), ATLAS (2018)

0 1 2 3km
1:60 000

Legend

Hunter Estuary Wetlands Ramsar Site Boundary
Eastern Curlew

FIGURE 4.5

Records of Eastern Curlew within the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site and Surrounding Kooragang Island

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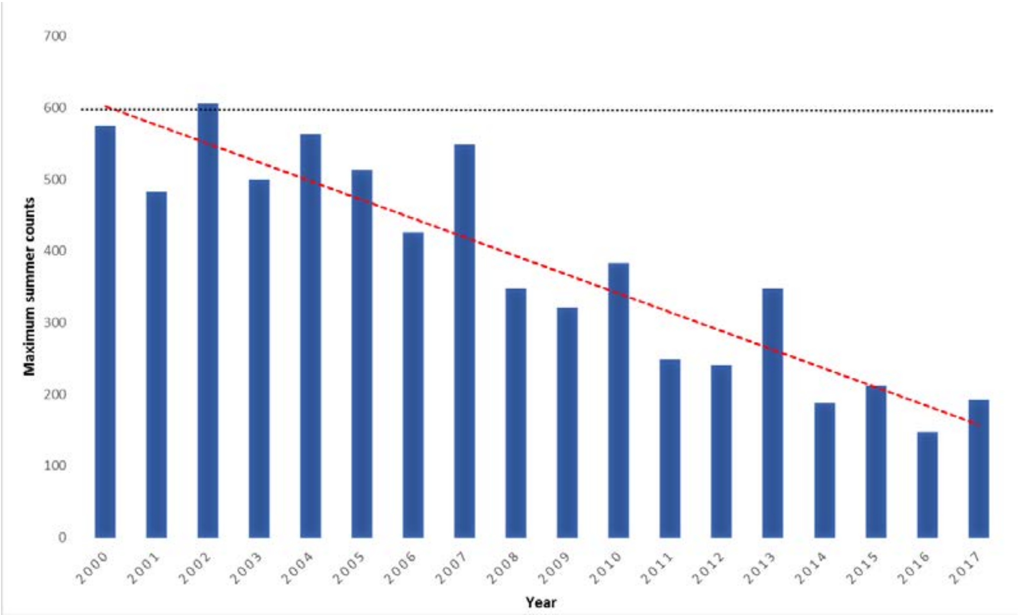
20180706 14.03



Data obtained from HBOC monthly shorebird surveys. Red dotted line represents the line of best fit. Black dashed line represents the LAC of 600 individuals.

Figure 4.6 Relationship of maximum summer counts of eastern curlews from 2000 to 2017 in the Kooragang component of the Hunter Wetlands Estuary Ramsar site.

This finding is supported by analysis completed by HBOC members that has identified a decline in eastern curlew counts in the estuary as a whole (not just Kooragang component) between 1999 and 2015 by 4.5% year-on-year based on mean summer counts (Roderick and Stuart, 2016). This decline is also evident at the nearby Port Stephens (2004 to 2015) however not to the same magnitude (2.9% decline) (Roderick and Stuart, 2016).

Recent analysis of the abundance of the eastern curlew at the Towra Point Nature Reserve Ramsar site in southern Sydney, has identified that the annual average summer counts have remained relatively stable ($134.7^{\pm 20.2}$) over five (5) consecutive years (2011/2012 to 2015/2016) and were similar to those recorded at listing (133) (Umwelt and Avifauna, 2017). Comparative analysis (ANOVA) between the two Ramsar sites identified a marked decline in summer counts in the Hunter estuary (Umwelt and Avifauna, 2017) supporting analysis undertaken for this assessment.

At a national level, localised declines in eastern curlews have been documented in South Australia and south-east Tasmania (Close and Newman, 1984; Thomas, 1987; Reid and Park, 2003). While localised declines may be a result of local movement patterns or temporary emigrations (Warnock et al., 1995; Butler et al., 2002), significant declines in the Australia population of the eastern curlew have been identified (Hansen et al., 2016; Clemens et al 2016). This has been recognised with listing of eastern curlew as critically endangered under the EPBC Act in 2015 (note that this species was not previously listed on the EPBC Act prior to 2015).

On a global basis there has also been a decline in the population of the eastern curlew. At the timing of listing it was considered that the Kooragang component supported over 5.9% of the eastern curlew population (see Appendix A). Based on estimates of the population in the EAAF population in 2008 it was identified that the Hunter estuary supports more than 1% of the EAAF population which was identified as 380 individuals (Bamford et al., 2008).

A recent review of the EAAF population of migratory shorebirds estimated that on best available data, the EAAF population of the eastern curlew is 35,000 and 1% population would therefore need to be at least 350 birds (Hansen et al, 2016).

Since 2000 the maximum summer counts of eastern curlew have been declining (see Figure 4.6) and since 2012, even with the recent revision of the 1% population to 350 birds, the Kooragang component may no longer support 1% of the EAAF population. Therefore, the Ramsar wetland may no longer meet Criterion 6 for listing as a Ramsar wetland for this species.

Furthermore, the LAC for eastern curlew numbers is that for any five (5) year period, the maximum annual summer count of the species will not be less than 600 individuals. The maximum annual summer count of eastern curlews has been less than 600 birds for the 2002 to 2017 (16 year) period, with a range of 188 to 563 individuals (mean of 346 individuals) recorded in this time. While this analysis would indicate that the LAC for the eastern curlew has been exceeded, it is noted that there is a low level of confidence in the LAC and even at the time of the ECD the 600 bird count was likely to have been exceeded.

Changes in Abundance of Recently Listed Threatened Species

Australia is at the southern end of the EAAF and recent studies have highlighted how threats to migratory shorebirds in the EAAF are growing with large losses of coastal habitat in east Asia where the birds refuel (staging habitat) during migration (Clemens, 2016) particularly in the Yellow Sea (Hansen et al., 2016).

A recent study by Clemens (2016) revealed long-term decreases in 12 of 19 migratory and four resident shorebirds in Australia including the bar-tailed godwit, black-tailed godwit, common greenshank, curlew sandpiper, eastern curlew, grey plover, lesser sand plover, Pacific golden plover, red-necked stint, ruddy turnstone, sharp-tailed sandpiper, Terek sandpiper, black-fronted dotterel, black-winged stilt, red-kneed dotterel and red-necked avocet. Clemens (2016) identified that declines in numbers of shorebirds are often greater south of 27.8°S latitude (approximately Queensland – NSW border).

Analyses of monthly data from 1999 to 2017 has identified notable changes have occurred for migratory shorebirds that have been listed as threatened under the EPBC Act since 2015 with all demonstrating a decline in summer abundance over time from 2000 to 2017 (Appendix B).

For the bar-tailed godwit (*Limosa lapponica baueri)*:

- Listed as vulnerable under the EPBC Act in May 2016;
- Occur in the saline part of the Hunter estuary with the main daytime high tide roosts at Kooragang Dykes and Stockton Sandspit, and nocturnal roosts Windeyers Reach. Mainly forages for worms, molluscs, crustaceans, insects and some plant material in exposed sandy or soft mud substrates in Fullerton Cove, Kooragang Dyke ponds, Stockton Sandspit, sandflats at Kooragang Dyke and occasionally on Ash Island. Occurs in low numbers in other sites in the Hunter estuary (Herbert 2007; Spencer 2010). Spencer (2010) found that more than 90% of bar-tailed godwits forage during low tides, primarily in the west side of Fullerton Cove, and 50% continue to forage up to three hours after low tide behind Kooragang Dyke.
- There has been marked decline in summer abundance (see Section 3.4.1 of Appendix B).
- These findings are supported by analysis completed by HBOC members that have identified a decline in bar-tailed godwit in the Hunter Estuary (not just Kooragang component) between 1999 and 2015 by 9.6% for year-on-year based on mean summer counts and 15.7% for peak counts (Roderick and Stuart, 2016).
- The decline in numbers for the bar-tailed godwit was also evident at the nearby Port Stephens (2004 to 2015) however not to the same magnitude (4.0% decline) (Roderick and Stuart, 2016).
- Numbers of bar-tailed godwit in Botany Bay have also declined between 2002 and 2016 (Umwelt and Avifauna, 2017).
- The percentage decline per annum in mean summer counts and peak numbers observed in the Hunter estuary is greater than that provided in Clemens et al (2016) for southern Australia, being 1.33% per annum (Roderick and Stuart, 2016). This suggests that the decline in the Hunter is associated with localised impacts and likely to be due to loss/degradation of foraging and roosting habitat, and metabolic costs of human disturbance. Recreational boats and fishers have been identified as a significant cause of disturbance for this species (Spencer 2010).

For the black-tailed godwit (*Limosa limosa*):

- Listed as vulnerable in NSW under the BC Act.

- Occur in the saline part of the Hunter estuary primarily at Kooragang Dykes and Stockton Sandspit (Herbert 2007), foraging in the flats behind the Kooragang Dykes and in the western shores of Fullerton Cove (Spencer 2010).
- There has been marked decline in summer abundance (see Section 3.4.6 of Appendix B).
- These findings are supported by analysis completed by HBOC members that have identified a decline in black-tailed godwit in the estuary between 1999 and 2015 by 1.9% for year-on-year based on mean summer counts and 4.5% for peak counts (Roderick and Stuart, 2016).
- The percentage decline per annum in peak numbers observed in the Hunter estuary is greater than that provided in Clemens et al (2016) for southern Australia being 3.22% per annum (Roderick and Stuart, 2016).

For the curlew sandpiper (*Calidris ferruginea*):

- Listed as critically endangered in the EPBC Act in May 2015.
- Is a small shorebird that forages on Ash Island and Deep Pond (external to the Ramsar site) and in intertidal mudflats in North Arm Sandflats behind Kooragang Dyke, Stockton Sandspit and Fullerton Cove (Herbert 2007; Spencer 2010) in the Ramsar site. A number of areas of preferred habitat external to the Ramsar site (including Big Pond and the Stockton Sewage Treatment Works) have been lost.
- There has been marked decline in summer abundance (see Section 3.4.5 of Appendix B).
- Historically curlew sandpipers had been one of the most common species in the Hunter estuary, regularly exceeding 1500 birds but since 1999 totals have not exceeded 570 birds (Spencer 2010). Spencer (2010) identified that there had been a significant decline (83%) in mean counts of curlew sandpiper in the Hunter estuary from the 1980s to 2007. A significant decline was also observed at Corner Inlet in Victoria.
- The mean number of curlew sandpipers in the Hunter estuary was significantly greater than in Botany Bay between 2002 and 2007 and in 2009 however since 2009 numbers in the Hunter estuary have declined (Umwelt and Avifauna, 2017).
- The decline of curlew sandpiper in the Hunter estuary and Botany Bay (Umwelt and Avifauna, 2017) was matched by a similar clear trend in south east Australia of 80% decline between 1980 and 2005 (Gosbell and Clemens, 2006). This suggests that the decline in the Hunter is associated with external factors in the EAAF. The conservation advice for this species recognises that the observed decline in numbers in Australia stems from ongoing loss of inter-tidal mudflat habitat at key migration staging sites in the Yellow Sea and a succession of very poor breeding seasons in the Arctic in the 1990s (Dawes 2011).
- The curlew sandpiper EAAF population is now estimated at 90,000 (down from 180,000 in Bamford (2008)) and there is strong evidence of a decline in number of curlew sandpiper in Australia with 6.1% decrease in abundance over time (Clemens et al 2016).

For the red knot (*Calidris canutus*):

- Listed as endangered in the EPBC Act in May 2016
- This species typically uses the Hunter estuary as a staging point between late August and November, before continuing southwards to Victoria or to New Zealand with only low numbers staying in the Hunter (Herbert 2007; Roderick and Stuart, 2016; Crawford and Herbert 2017). They migrate through the Hunter in waves staying only short periods, generally less than two weeks (Crawford and Herbert 2017).
- The Hunter estuary is the only important location for the red knot in the Hunter region with birds rarely recorded anywhere else, favouring Stockton Sandspit (Roderick and Stuart, 2016) and Kooragang Dykes. There have been high numbers recorded external to the Ramsar site at Ash Island Area E and at Milhams Pond on Ash Island (Herbert 2007).
- There has been a marked decline in summer abundance since 1999 (see Section 3.4.3 of Appendix B).

- Populations at Botany Bay have declined between 2002 and 2016 (Umwelt and Avifauna, 2017).
- Based on peak counts Roderick and Stuart (2016) have identified a 6% year-on-year decline since 1999 however there is some uncertainty in this due to fluctuations in the season. With large numbers passing through and only staying for short periods, as well as some abnormal high peak counts recorded in 2006 and 2001 (Roderick and Stuart 2016), at Area E and Milhams Pond on Ash Island, external to the Ramsar site. Roderick and Stuart (2016) propose that most probably the numbers of red knot passaging through the Hunter are decreasing in line with the national decline of 5.64% in southern Australia as determined by Clemens et al (2016).
- The red knot EAAF population is now estimated at 110,000 (Clemens et al (2016)), down from 220,000 previously published in Bamford (2008). The population in the EAAF is threatened by wetland degradation in staging sites in East Asia.
- However, Crawford and Herbert (2017) note that the regular monthly shorebird counts may underrepresent the numbers of this species as they travel through the estuary in waves and are therefore not all are here at any one time. Also, the peak numbers may occur before or after the single count per month.

There is insufficient evidence to determine whether changes in numbers of these threatened shorebirds observed at Hunter Estuary are caused by global or local influences. It is highly likely that any changes will be a combination of both global and local influences, with different species potentially impacted by different levels of global and local influences.

Migratory Shorebird Species Diversity

Data from 1970 to 1989 on the annual migratory shorebirds at the Kooragang Estuary identified an annual median maximum of 18 species (Herbert, 2011, unpublished data). The baseline range of migratory shorebird species diversity for the 1970 to 1989 period was 17 to 18 species (Herbert, unpublished data 2011).

No LAC was set for migratory shorebird diversity as there is a limited understanding of what would constitute a significant decline in species richness resulting in a change in ecological character. Three measures of migratory shorebird species diversity (richness, Shannon's index and evenness) were used to assess relationships with a selection of potential predictor variables (see Section 3.1 of Appendix B).

In the period 2003 to 2007, species richness was recorded as declining compared to the baseline of 18 species. This decline was within one to five species, with the maximum species richness being 16, 17, 16, 16 and 13 species in respective years from 2003 to 2007.

Since 2007, the migratory shorebird species richness has increased slightly yet remained stable. The annual median maximum for the 2008 to 2017 period was 18 species (comparable with the baseline threshold), which ranged from 15 species in 2008 to 20 species in 2012. There was a slight, albeit non-significant, relationship between species richness during the 2000 to 2017 period. Richness remained relatively stable during this time with minor variation (i.e. to the magnitude of one to six species).

While no LAC has been set for migratory shorebird species diversity, based on the initial median maximum number of 18 species recorded around the time of listing, there has since been no significant change according to recent survey data.

4.3.4 Potential Impact from Contamination

As noted in Section 4.2.4, there are a number of chemicals of interest that may pose unacceptable risk to shorebird species. In particular, risks are considered to exist through bioaccumulation through the food chain via ingestion of algae, benthic organisms and small fish.

It is unclear whether declines in shorebird counts may be attributed directly to contamination given other potential confounding factors, including: changes in roost availability; impacts of repeated disturbances (high energy cost that may compromise their capacity to build sufficient energy reserves for migration); poor water quality impacts; foraging habitat loss; and drought. Further, the migratory

nature of the shorebirds and reliance upon different habitats across the EAAF provides multiple locations for potential exposure to chemical contaminants, albeit for shorter durations than the birds spend at the Hunter Estuary Ramsar site. As stated previously, chemicals that bio-accumulate through the food chain could have a negative impact on shorebirds, and cumulative exposure to these chemicals would increase this impact. However, chronic chemical contamination impacts cannot be discounted as having a negative impact on shorebirds particularly as there is no known contrary evidence.

4.3.5 What measures are in place to address the impacts?

The Hunter Wetlands National Park Draft Plan of Management (NPWS, 2015) lists management measures to address the impacts on shorebirds, including:

- Actively manage the hydrology using water management structures and selective areas of active mangrove management to minimise the effects of the tidal range changes on habitat loss of saltmarsh and intertidal mudflats.
- Continue with the implementation of existing significant wetland restoration projects and seek opportunities to improve habitat through targeted restoration projects, management of tidal flows and selective removal of mangroves.
- Continue to support HBOC in their shorebird monitoring, habitat restoration and research activities.
- Work with Port of Newcastle to ensure a rapid and effective response should an oil spill or pollution incident occur.
- Manage the impacts of acid sulfate soils on the waterways by flushing strategies including opening flood gates.
- Implement relevant strategies in the priorities action statement for threatened shorebirds.
- Promote and seek funding to research and implement maintenance and expansion of saltmarsh/shorebird habitat.
- Plan for strategic additions of saltmarsh and shorebird habitat to the park taking into account predicted sea level rise.
- Weed monitoring and management.
- Fire management.
- Management of predators particularly foxes.
- Continue to involve HBOC in management decisions related to shorebird habitat.
- Support HBOC to provide information to the community on opportunities for bird watching and conservation.
- Installation of educational signs to reduce conflict between recreational activities (particularly bait collection and fishing) in shorebird habitat along Kooragang Dykes.

These measures have been prioritised in the draft Plan of Management (NPWS, 2015) and some of the low priority management responses may not currently be in place.

4.3.6 Knowledge Gaps

While the abundance of shorebirds has declined since the time of listing based on recent counts (i.e. 6800 in 1986 to 3500 in 1999), there is little information as to whether this is a true decline or whether these numbers reflect movements. The available foraging habitat for shorebirds has declined due to human actions (reclamation and flood mitigation) and with expansion of mangroves. However, restoration works in Tomago Swamp, Hexham Swamp and Kooragang Island have gone some way to reversing this with shorebirds, particularly sharp-tailed sandpipers, more frequently recorded in Tomago wetlands and Hexham Swamp since 2013. It is likely that the sharp-tailed sandpipers are moving between both wetlands. A review of numbers and species in restoring habitats in the Ramsar

site and immediate environs is required to identify whether birds are moving from the Ramsar site to restoring habitats nearby on Ash Island (KWRP) and at Hexham Swamp; and whether use of the restored habitat changes with maturation of habitats.

There is a knowledge gap in the collection of shorebird data particularly with respect to night time roosting behaviour at both Windeyers Reach and also in the habitats being created in Tomago wetlands. Particularly for Windeyers Reach, where access difficulties mean this area is not routinely surveyed.

Further research is required to develop an appropriate method to assess trends in shorebirds. The analysis used in this report is relatively simplistic and provides only a first pass statistical analysis. More complex analysis would provide both more certainty about trends and further insights into the correlation of trends in shorebird populations with other events, impacts or environmental change.

The need for more robust LAC is addressed below:

- There is currently no LAC set for shorebird diversity. The LAC should not only account for number of species but consider also the abundance of each individual species to avoid the results being skewed by occurrence in the wetland of low number of one individual species.
- The limits of acceptable change should be quantified, based on fine scale data collected on a monthly basis and should relate to an appropriate reference site to measure real time changes on a local scale, allowing for comparison between two similar sites in the East Asian Australasian Flyway (EAAF) while not detracting from the EAAF scale migratory shorebird population trends.

Change in the abundance and diversity of shorebirds may be due to a number of factors including offshore impacts in the EAAF, prevailing weather conditions, and the extent of saltmarsh and intertidal mudflats. There is no evidence that any change in abundance of individual species is related to chemical contamination of infauna.

4.3.7 Conclusion

In contrast to earlier findings in the ECD that the LAC of abundance of migratory shorebirds has been exceeded, statistical analysis of summer maximum counts of migratory shorebirds from 2000 to 2017 has revealed a slight, albeit statistically non-significant, overall increase in migratory shorebird abundance. This is largely due to rehabilitation works at Tomago wetland particularly the return of sharp-tailed sandpipers in large numbers to this wetland from 2013 onwards.

Notable changes have occurred for individual species of migratory shorebirds with national decline recognised with listing as threatened species under the EPBC Act since 2015 (Appendix B). These species included the black-tailed godwit (*Limosa lapponica baueri*), curlew sandpiper (*Calidris ferruginea*), great knot (*Calidris tenuirostris*), red knot (*Calidris canutus*) and black-tailed godwit (*Limosa limosa*). All of these species have demonstrated a decline in summer abundance at Kooragang component of the Hunter Estuary wetland over time from 2000 to 2017. However, these declines were typically similar to global declines and declines at other coastal Ramsar sites in south-eastern Australia, making it unclear the extent to which local impacts (e.g. chemical contamination) at the Kooragang component of the Hunter are influencing shorebirds.

Previously, the Kooragang component regularly supported 1% of the EAAF population of eastern curlews as the threshold for this species is 380 birds (Bamford et al., 2008) (meeting Criterion 6 for Ramsar listing). However, this has not been the case since 2002 with the mean number of maximum summer counts of eastern curlews recorded from 2002 to 2017 being 346 birds. Even with the recent reduction of the 1% population of the EAAF to 350 birds (Hansen et al., 2016), the Kooragang component may no longer support 1% of the EAAF population. Therefore, the Ramsar wetland may no longer meet Criterion 6 for listing as a Ramsar wetland for this species. However, the Kooragang component still regularly supports more than 1% of the Australian population of the red-necked avocet which is also part of criteria 6.

There is a limited understanding of what would constitute a significant decline in species richness resulting in a change in ecological character. In the period 2003 to 2007, species richness was recorded as declining compared to the baseline of 18 species. This decline was in within one to five species, with the maximum species richness being 16, 17, 16, 16 and 13 species in respective years

from 2003 to 2007. Since 2007, the migratory shorebird species richness has increased slightly yet remained stable.

While no LAC has been set for migratory shorebird species diversity, based on the initial median maximum number of 18 species recorded around the time of listing, there has since been no significant change according to recent survey data.

It is recommended that management authorities:

- continue to support HBOC monitoring and that the HBOC continue to have a role in management decisions related to shorebird habitat;
- Identify nocturnal roost sites;
- Actively manage and protect high priority habitats (roost sites and saltmarsh), reduce disturbance stress from not only predators but members of the public; and
- continue to support and have a key role in rehabilitation efforts in Tomago wetlands and other restoration sites in the Hunter estuary.

The restoration of estuarine habitats on Ash Island and at Hexham Swamp is increasing habitat for migratory shorebirds in the Hunter estuary. Whether this has an adverse effect on numbers of migratory shorebirds in the Kooragang components of the Hunter Estuary Wetlands Ramsar site was not tested in this assessment as data for other sites external to the Kooragang component was not available for analysis. Supporting statements on changes in numbers of select shorebird species in the Hunter estuary was provided from a review of published literature by members of the HBOC and updates of the EAAF counts (Clemens et al 2016).

4.4 Saltmarsh

4.4.1 Why is it important to the site?

Recent mapping of the Kooragang component has identified that the largest continuous patches of saltmarsh occur in the western end of the Ramsar wetland on Kooragang Island, on Smiths Island at the mouth of Fullerton Cove and in the Tomago Wetland restoration area (see Figure 2.11). Smaller patches occur near Windeyers Reach on Kooragang Island and along channels on the northern shores of Kooragang Island (see Figure 2.11).

Saltmarsh is important to the Kooragang wetland and its values as an international wetland, as it contributes to the productivity of the system, contributes to estuarine food webs, nutrient and energy cycling, and supports the biodiversity of the region providing important wildlife habitat for birds, fish, both aquatic and terrestrial invertebrates, and insectivorous bats. It also has a role in estuary and flood management, dampening floodwaters, reducing erosion, trapping sediments and pollutants.

Sarcocornia dominated saltmarsh has been identified as one of the most important habitats for migratory and non-migratory shorebirds. The *Sarcocornia* saltmarsh provides important secondary feeding areas for migratory shorebirds, after intertidal mudflats. The saltmarsh also provide important roosting habitat for shorebirds.

The saltmarsh vegetation is an important feeding site for shorebirds particularly the sharp-tailed sandpiper (*Calidris acuminata*), Pacific golden plover (*Pluvialis fulva*), Lathams snipe (*Gallinago hardwickii*), common greenshank (*Tringa nebularia*), marsh sandpiper (*Tringa stagnatilis*) and wood sandpiper (*Tringa glareola*) (Brereton and Taylor-Wood, 2010).

Migratory shorebirds are known to roost at high tide in saltmarsh at Windeyers Reach, Kooragang Dykes and on the Stockton Sandspit (Spencer and Howe, 2008; Brereton and Taylor-Wood, 2010). Kooragang Dykes and the Stockton Sandspit are the two major day roosts while Windeyers Reach, since drainage of Tomago wetlands, is the main night roost (Spencer and Howe, 2008; Herbert 2007). Windeyers Reach occurs on the northern bank of Kooragang Island to the east of Moscheto/Mosquito Creek (see Figure 4.1) and has been known to support large flocks of eastern curlew (*Numenius madagascariensis*) and bar-tailed godwits (*Limosa lapponica*) (Spencer and Howe, 2008). Spencer

found that the combination of shallow water with saltmarsh is an important microhabitat choice at Windeyers Reach (Spencer and Howe, 2008).

Some migratory shorebirds known to breed in saltmarsh include the black-winged stilt (*Himantopus himantopus*), red-capped plover (*Charadrius ruficapillus*) and masked lapwing (*Vanellus miles*). Saltmarsh also acts as a drought-refuge for some Australian-breeding shorebird species including the black-fronted dotterel (*Elseyornis melanops*), black-winged stilt (*Himantopus himantopus*) and red-necked avocet (*Recurvirostra novaehollandiae*).

A further coastal wetland/saltmarsh specialist that is resident breeding in Kooragang is the white-fronted chat (*Epthianura albifrons*), listed as vulnerable under the NSW BC Act, and known from Tomago Wetlands and Hexham Swamp (Roderick and Stuart, 2016).

Saltmarsh is also a source of nutrition and habitat for commercial and recreational fish during spring tides and is a highly productive source of mollusc and crab larvae that is exported with the tide (Mazumder, 2004).

The saltmarsh conforms to the threatened ecological community listing as an endangered ecological community (EEC) under the NSW BC Act *Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions*; and, as a vulnerable ecological community (VEC) under the EPBC Act *Subtropical and Temperate Coastal Saltmarsh*.

4.4.2 Limit of Acceptable Change

At the time of listing in 1984, saltmarsh covered approximately 582 ha (Williams et al., 2000). The ECD identified that the extent of saltmarsh has steadily declined in the estuary since 1954 because of changing hydrology and mangrove expansion (Brereton and Taylor-Wood, 2010).

The LAC for saltmarsh was set at:

- The areal extent of saltmarsh does not fall below 466 ha i.e. the areal extent at the time of listing (582 ha) minus a 20% mapping error.

The level of confidence for this LAC was recognised as low in the ECD (Brereton and Taylor-Wood, 2010).

4.4.3 What has changed and is it significant

The ECD identified that at the time of setting the limits of acceptable change, the area of saltmarsh had declined by 41% since listing to 339 ha and that the LAC had been exceeded.

The following discussion provides information to substantiate this finding and to identify whether this trend has continued since 2010 and likely causes. The discussion also considers changes in mangroves.

Change from Listing until 1994

The extent of saltmarsh and mangroves prior to listing of the Kooragang component and in the 10 years after listing was assessed by Williams et al. (2000) as part of a review of the history of changes to estuarine wetlands of the lower Hunter River for the KWRP. Williams et al. (2000) mapped mangrove, saltmarsh and open water areas from aerial photos (1954 to 1994) identify a general trend of decrease in amount of open water (mostly due to reclamation), saltmarsh decline and mangrove increase.

Based on the findings of Williams et al. (2000), from the time of acceleration of industrial development in the 1950s through to 1994, there have been marked changes in the extent of mangroves and saltmarsh in the Kooragang component either side of the north arm of the Hunter River. The changes and interacting processes and human influences that may have caused the changes include:

- In the Tomago/Fullerton Cove area there has been a 42% expansion in mangroves and a 78% decline in saltmarsh and 117 ha (or 10%) decline in open water. The decline in open water is due to expansion of mangroves into Fullerton Cove and the north arm of the Hunter River. The decline

in saltmarsh markedly increased following flood mitigation works from 403 ha in 1976 to 333 ha in 1986 and 111 ha in 1994. This is most likely due to alterations in tidal inundation and freshwater expansion from flood mitigation works in 1976 as well as upslope expansion of mangroves.

- The marked impact of flood mitigation works and agricultural activities on the occurrence of saltmarsh in the immediate environs of the Kooragang component is particularly evident in the Tomago/Fullerton Cove area where:
  - In the Fullerton Cove area prior to the flood mitigation works in the 1970s, saltmarsh occurred along Dawsons Drain, The Fourteen Foot Drain and Ten Foot Drain and over farmland around the Kooragang component. Area of saltmarsh was mapped as 336 ha in 1966, declining to 195 ha in 1976 to 111 ha in 1986 and 77 ha in 1994 (Williams et al., 2000).
  - Similarly, in the Tomago wetland area to the west of the Kooragang component, saltmarsh occurred along constructed drains and natural drainage channels, post flood mitigation works the extent declined from 200 ha in 1976 to 140 ha in 1986 and 32 ha in 1994.
- On Kooragang Island there has been a 116% expansion in mangroves and a 47% decline in saltmarsh and 28 ha (or 9%) decline in open water in the Kooragang component Ramsar site. The decline in open water is due to expansion of mangroves in the waters behind the Kooragang Dyke and along the river. After gazettal of the nature reserve in 1984, the decline in saltmarsh slowed in the Ramsar site and stopped in the nature reserve. It is also noted that changes in saltmarsh on Kooragang Island in the KWRP area, to the west of Ramsar Road, have reversed since 1986 with an increase in the extent of saltmarsh.

The decline in saltmarsh in the Kooragang component is consistent with the findings of Saintilan and Williams (1999) who found that there has been a general decline in saltmarsh in south east Australia since the 1940s. In the 28 estuaries they included in their study they reported declines of between 15 and 100%. Mangrove expansion within estuaries is a near ubiquitous trend in south eastern Australia (Saintilan and Williams, 1999) primarily along tidal drainage lines.

The expansion of mangroves into saltmarsh is likely to be influenced by interactions between tidal inundation, sedimentation, elevation and salinity with temperature and human changes (such as dredging and development) also playing a role (Saintilan et al., 2014). Saintilan et al. (2014) highlight that this is a global phenomenon occurring in contrasting settings, suggesting that global changes are contributing to an increased capacity of mangroves to survive in previously marginal intertidal environments. These global changes include elevated sea-level, elevated atmospheric carbon dioxide and higher temperatures (Saintilan et al., 2014).

Table 4.1 provides an extract from a study by Rogers, Wilton and Saintilan (2006) to explain decline of saltmarsh in response to elevation changes specifically for an area of Kooragang Island known as Area E to the south of the Kooragang component of the Ramsar site and west of the railway. Vertical accretion in saltmarsh in the Hunter estuary (0.98 to 3.37mm/year) is at the lower end of the reported range for southeast Australia (0.3 to 5.1 mm/year) (Howe et al. 2009). Vertical accretion in mangroves in the Hunter estuary (1.89 to 3.66mm/year) is also at the lower end of the reported range for southeast Australia (0.7 to 9.5 mm/year) (Howe et al. 2009). These low rates are consistent with the findings of Rogers et al. (2006) as provided in Table 4.1. Vertical accretion rates correlated with estuary water level (Howe et al., 2009).

Relative to other estuarine sites in NSW and Victoria, Kooragang Island was considered relatively stable with only minimal mangrove expansion and vertical accretion translating directly to saltmarsh elevation change (Rogers et al., 2006) (see Table 4.1).

Table 4.1 Changes in mangroves and saltmarsh in 'Area E' at Kooragang Island (Rogers et al., 2006)

Measurement	Mangrove	Mixed	Saltmarsh
Change in area from 1954 to 1994 (ha)[1]	532 to 636 20% increase	Not available	930 to 422 54% decrease
Mean surface elevation change (mm/year)	1.98±0.98	2.05±0.98	1.92±0.98

Measurement	Mangrove	Mixed	Saltmarsh
Mean vertical accretion (mm/year)	4.72±0.05	4.19±1.25	2.03±0.38
Mean compaction (mm/year)	-2.74	-2.14	-0.11

1. Areal extent for Kooragang Island from Williams et al. (2000).

Changes since Restoration Works Began in 1994

Since 1993 a number of restoration projects have commenced in the Hunter estuary on Stockton Sandspit, Kooragang Island, Tomago Wetlands and Hexham Swamp under the KWRP. The works are aimed at restoring saltmarsh providing shorebird habitat and fish habitat largely through modifications to flood mitigation works. The areal extents provided by Williams et al. (2000) provide a baseline for assessment of change over this period.

Recent mapping by Kleinfelder (2016) has reviewed changes in the extent of saltmarsh and mangroves in the Hunter Wetlands National Park. This was based on aerial photograph interpretation and field investigations. The area of mangroves and saltmarsh are provided in Table 4.2. The recent mapping also further delineated mangrove and saltmarsh vegetation cover to assess current colonisation of the saltmarsh and mangroves (Kleinfelder, 2016). These results will inform management activities (particularly identifying areas to target for removal of mangroves).

Table 4.2 Mangrove-Saltmarsh Classification and extent in 2016

Vegetation Type	Mangrove Cover Category	Kooragang component of Ramsar Site (ha)	Hunter Wetlands National Park (ha)
Saltmarsh	0-10%, saltmarsh present	261.09	520.96
Saltmarsh	11-30%, saltmarsh present	27.5	38.01
Mangroves	11-30%, no saltmarsh present	2.17	23.07
Mangroves	31-60%, saltmarsh present	40.82	55.22
Mangroves	31-60%, no saltmarsh present	18.97	32.70
Mangroves	61-100%, saltmarsh present	46.69	49.68
Mangroves	61-100%, no saltmarsh present	1281.40	1529.65
	Total area	**1678.64**	**2249.29**

While saltmarsh rehabilitation works in the Tomago wetlands have increased saltmarsh habitat, primarily the form dominated by *Sporobolus virginicus* and *Triglochin striata* (Kleinfelder, 2015), by 10.7 ha the trend of a decline in the extent of saltmarsh has continued. As evident by recent mapping which identified the current extent of saltmarsh (including *Sarcocornia* saltmarsh, degraded saltmarsh and saline rushland) within the Kooragang component of the Ramsar wetlands at 289 ha (see Table 4.2). This is a loss of approximately 50 ha of saltmarsh since 1994 (at which time there was approximately 339 ha of saltmarsh). The recent loss of saltmarsh is most likely due to expansion of mangroves as there has been an additional 78 ha of mangroves mapped in 2016 (1390 ha) relative to 1994 (1312 ha).

The expansion of mangroves into saltmarsh is likely to be influenced by interactions between tidal inundation, sedimentation, elevation and salinity with temperature and human changes also playing a role (Saintilan et al. 2014). Saintilan et al. (2014) highlight that this is a global phenomenon occurring in contrasting settings, suggesting that global changes are contributing to an increase capacity of mangroves to survive in previously marginal intertidal environments. These changes include elevated sea-level, elevated atmospheric carbon dioxide and higher temperatures (Saintilan et al. 2014).

Saltmarsh extent at the Ramsar site has declined 15% over the last 22 years. The current estimate of extent of saltmarsh is 293 ha less than at listing or a decline of 50%. Decline in the extent of saltmarsh has occurred across New South Wales and nationally as is recognised through listing of the community as endangered under the BC Act and vulnerable nationally under the EPBC Act in 2013.

These changes in ecological character are important for this site not only from the perspective of an impact on a state listed EEC and federally listed vulnerable ecological community but also because of the impacts that the reduction in habitat has on migratory shorebirds, fish and other species reliant upon saltmarsh habitat.

4.4.4 Potential Impact from Contamination

While AECOM (2018) has identified elevated levels of PFOS in aquatic plants, including saltwater couch (a saltmarsh species), from uptake of chemicals in groundwater in the Dawsons Drain area, this represents an exposure pathway primarily for herbivorous waterbirds through ingestion of plants. Similarly, sediments and infauna in saltmarsh may have elevated levels where exposed to discharge. However, chemical contamination by metals and PFOS are not anticipated to have a direct adverse effect on the extent or community structure of the saltmarsh communities.

Changes to water quality parameters, particularly increased nutrients, outside of the ‘normal’ range can impact on saltmarsh community through facilitating spread of salt tolerant weed species particularly at the upper saltmarsh zone.

4.4.5 What measures are in place to address the impacts?

Current management measures in place to address the decline in saltmarsh are focused on restoration of tidal inundation, removal of flood mitigation structures and management of expansion of mangroves into saltmarsh. These activities are focused in the Tomago wetlands area, Stockton Sandspit and Kooragang Dykes.

The Hunter Wetlands National Park Draft Plan of Management (NPWS, 2015) lists management measures that are in place to address the impact for saltmarsh and these are listed in previous discussions for migratory shorebirds.

The coastal saltmarsh in the Hunter Estuary is also recognised as the only key management area for the BC Act listed ecological community under the OEH Saving Our Species program in NSW. Management activities at the site are focused on threats from weeds, competition with native vegetation, disturbance from recreational activities and hydrological changes.

4.4.6 Conclusions

The decline in the extent of saltmarsh as noted at the time of listing and in the ECD is continuing to this day and has exceeded the LAC.

It is recommended that monitoring of changes in saltmarsh in response to restoration works should continue to inform iterative management plan of the site to continue to improve availability of this critical component of the ecological character of the Kooragang component of the Ramsar site. Consideration should be given to including other parts of the wetland in the monitoring program occurring in the Tomago wetlands.

As suggested in the recent review of the ecological character of the Towra Point Ramsar Wetland site (Umwelt and Avifauna, 2017), development of a standardised methodology and more regular surveying would be an important tool in monitoring changes in saltmarsh cover. This should be done

in conjunction with studies of tidal inundation and elevation to identify whether a change in ecological character will continue in the future. This methodology should consider key diagnostic and condition thresholds in the EPBC Act listing advice as a means to provide a standardised condition assessment.

As an example, the EPBC Act listing of the subtropical and temperate coastal saltmarsh community as vulnerable is based on the following diagnostic characteristics (see http://www.environment.gov.au/ biodiversity/threatened/communities/pubs/118-conservation-advice.pdf for further details and explanation):

- Latitude
- Broad geomorphic context – coastal margin, along estuaries, coastal embayments and low wave energy coasts
- Places with at least some tidal connection (including supratidal areas, ICOLLS and groundwater tidal influence)
- Sandy or muddy substrate, including coastal clay pans
- Dense to patchy areas of characteristic saltmarsh plant species and in a mosaic with bare sediment
- Proportional cover with tree canopy species such as Melaleuca and Mangrove is less than 50%; sea grass is also less than 50%.

In addition, condition thresholds for the saltmarsh community include:

- In an ecotone region, if 50% or more of the groundcover/understory is coastal saltmarsh vegetation, then the community is considered to be coastal saltmarsh
- A patch of saltmarsh is a discrete and continuous area or mosaic, but it may contain bare substrate or small scale disturbances provided they do not affect its overall functionality
- Patches of saltmarsh within a mosaic that are within 30 m of each other, and collectively are 0.1 ha or more are considered to be the ecological community
- As noted above, tidal influence (broadly defined and including periodic or intermittent) is essential.

There are also a number of exclusions from coastal saltmarsh, including areas of ‘saltmarsh’ that contain more than 50% weeds.

There is no evidence that any of the changes to saltmarsh extent are associated with chemical contamination.

As part of the next steps after this formal assessment, it is recommended that the LAC for saltmarsh should be reviewed in consultation with the scientific community, to provide for a higher level of confidence and to recognise projects to restore habitat in the Ramsar site and allow for any lag in extent of saltmarsh that would be expected in the restoration project.

4.5 Green and Golden Bell Frog

4.5.1 Why is it important to the site?

The green and golden bell frog (*Litoria aurea*) is listed as endangered under the BC Act and as vulnerable under the EPBC Act. The species has suffered a 90% decline in its distribution, which currently exists as disjunct populations restricted to the coast (Mahony, 1999; Mahony et al., 2013).

The Lower Hunter population of green and golden bell frogs contain two key populations:

- Kooragang Island/Ash Island; and
- Sandgate/Hexham Swamp.

The Kooragang component of the Hunter Estuary Wetlands Ramsar site forms part of Kooragang Island/Ash Island population, which has been described as containing one of the largest remaining

green and golden bell frog populations on mainland NSW (Hamer and Mahony, 2010). Over the past 70 years, the Hunter Estuary has undergone a series of major changes (summary in Williams et al., 2000), which has resulted in the current landscape comprising a series of fragmented wetlands interspersed with industrial developments, pasture and suburban developments (DECC, 2007). Within this mosaic, the green and golden bell frog uses several habitats depending on its ecology. Permanent water bodes that are natural or have formed as a result of unnatural activities such as flood mitigation structures and along linear infrastructure features like roads, railway lines and access tracks have been used as breeding habitat (DECC, 2007). Temporary aquatic habitat in the form of ephemeral waterbodies such as grassy swales, drainage depressions and culverts that become inundated during periods of heavy rainfall are also used as breeding habitat for the species (Hamer et al., 2008; DECC, 2007).

Foraging and basking habitat occurs in wetland areas comprised of fringing vegetation types such as reeds and sedges (Hamer et al., 2002). These include waterbodies that are brackish in nature and the green and golden bell frog has been recorded using saline wetlands. Exposure to saline waters has been shown to inhibit the growth of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) (Stockwell et al., 2008) which causes the disease chytridiomycosis; one of the major causes for green and golden bell frog declines (Skerratt et al., 2007).

Movement habitat is generally typified by wet areas such as creek lines, drains, periodic damp areas, connecting or partially connecting vegetation, easements, laneways and even open areas that do not restrict movement (DECC, 2007). Green and golden bell frog movement is often associated with rainfall events when frogs move across the landscape and occupy newly formed waterbodies (Hamer, 2008).

At and since the time of listing there has been no available data on the abundance of the green and golden bell frog within the Ramsar site. A study on the population dynamics of the species on Kooragang Island recorded an estimated population of more than 1000 individuals across 21 occupied wetlands (Hamer et al., 2002). Within the Ramsar site, the green and golden bell frog has been recorded in wetlands on the western edge (Hamer et al., 2002) and within the *Juncus* Swamp on the eastern end of Kooragang Island near the Kooragang Dykes (Brereton and Taylor-Wood, 2010) (see Figure 4.7). Breeding events have been recorded in ponds that occur at the south western corner of the Ramsar site on Kooragang Island (Hamer et al., 2002) (Figure 4.8). The majority of the records and survey effort occurs to the west and south of the Ramsar wetland boundary in the KWRP area and parts of the industrial land to the south of the railway (Figure 4.7). Recent records occur immediately to the west of Ramsar Road on the western boundary of the Kooragang component and to the south of the Ramsar wetland. It is likely that Ramsar Road acts as a levee and limits tidal flows with this only occurring during king tide events (2.2 m tides) (M. Mahony pers. comm., 2018). While Ramsar Road is unlikely to present a barrier to movement of frogs, as there are anecdotal records of green and golden bell frogs crossing roads and railways on Ash Island, increasing tidal flows may provide for expansion of known habitat.

Populations in the industrial land are occurring in wetland systems including leachate ponds with heavy metal contamination (M. Mahony pers. comm., 2018). It is likely that there is some groundwater movement from the industrial land to habitats located to the north of the railway, where there are known records of the species, however the impact (if any) that this is having on the species is unknown.

There are no historical or recent records of the green and golden bell frog from the Tomago or Fullerton Cove wetlands area (M. Mahony pers. comm., 2018).

One of the wetlands identified as being used for breeding by Hamer et al. (2008) occurs just within the boundary of the Kooragang component (Figure 4.8). Furthermore, two water bodies adjacent to the wetland referred to above also recorded evidence of being used for breeding by the green and golden bell frog (Hamer et al., 2008). These waterbodies are located just outside the Ramsar site at Ramsar Road (Figure 4.8) but are close enough for individuals to move in and out of the Ramsar site (Hamer et al., 2008).

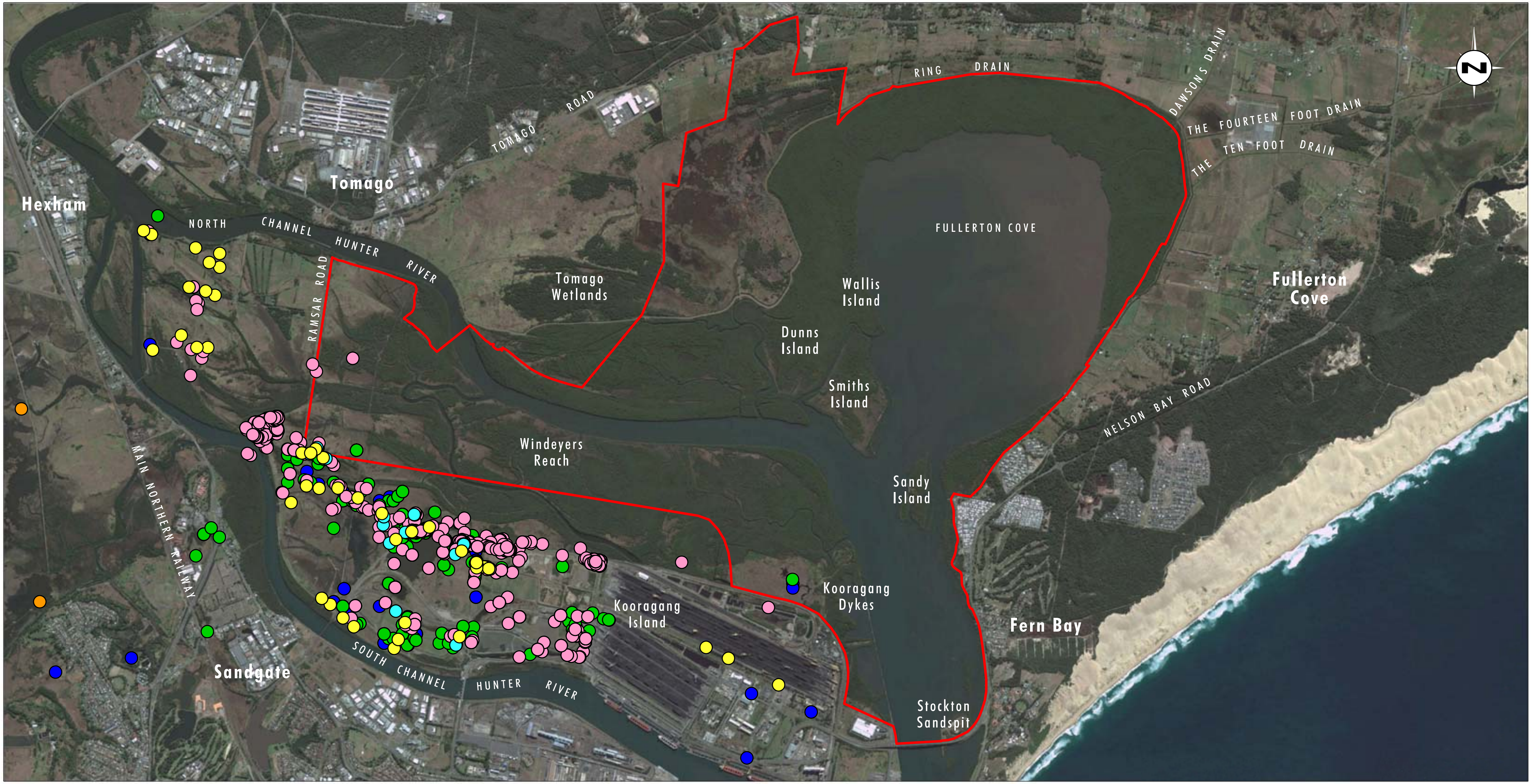


Image Source: Google Earth (Aug 2017)
Data Source: Commonwealth of Australia (Department of Environment) (2015), ATLAS (2018), Hamer (2002, 2008)

0 1 2 3km
1:60 000

Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- Green and Golden Bell Frog (Hamer Record 2002)
- Green and Golden Bell Frog (Hamer Record 2008)
- Green and Golden Bell Frog (ATLAS Record 1980 - 1989)
- Green and Golden Bell Frog (ATLAS Record 1990 - 1999)
- Green and Golden Bell Frog (ATLAS Record 2000 - 2009)
- Green and Golden Bell Frog (ATLAS Record 2010 - 2016)

FIGURE 4.7

Records of Green and Golden Bell Frog within the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site and Surrounding Kooragang Island

File Name (A4): R01/4187_005.dgn
20180706 14.05

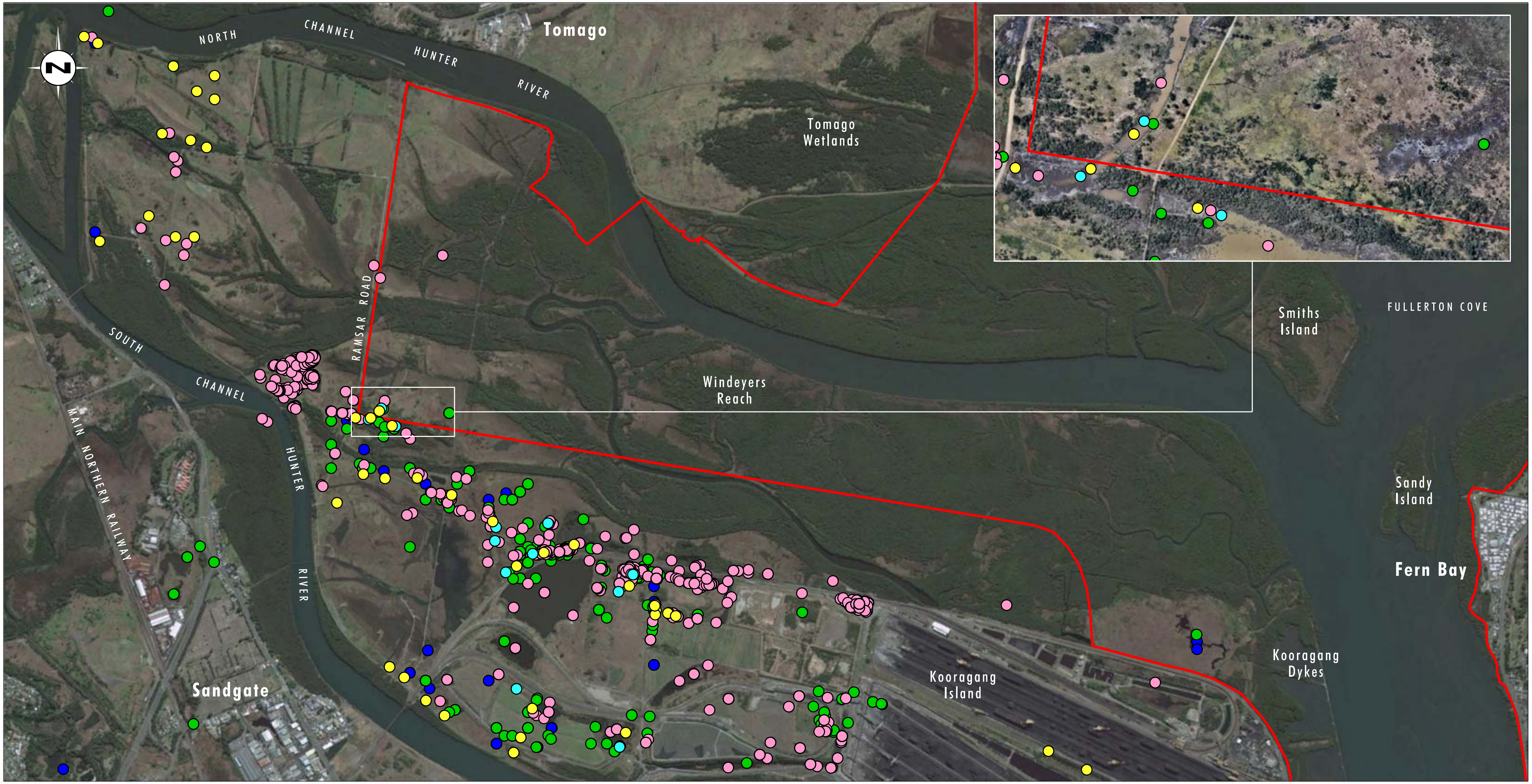


Image Source: Google Earth (Aug 2017), Nearmap (Feb 2018)
Data Source: Commonwealth of Australia (Department of Environment) (2015), ATLAS (2018), Hamer (2002, 2008)

0 100 200 400m
Inset

0 0.5 1.0 2.0km
1:35 000

Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- Green and Golden Bell Frog (Hamer Record 2002)
- Green and Golden Bell Frog (Hamer Record 2008)
- Green and Golden Bell Frog (ATLAS Record 1990 - 1999)
- Green and Golden Bell Frog (ATLAS Record 2000 - 2009)
- Green and Golden Bell Frog (ATLAS Record 2010 - 2016)

FIGURE 4.8

Records of Green and Golden Bell Frog within the Kooragang Island from 1984 to 2016

File Name (A4): R01/4187_010.dgn
20180706 14.11

4.5.2 Limit of Acceptable Change

The LAC set for the green and golden bell frog as defined in the ECD (Brereton and Taylor-Wood, 2010) as "there are no more than two (2) years between successful breeding events (defined as the presence of a new first year adult cohort) in at least one of the three known populations".

The level of confidence for this LAC was recognised as low in the ECD given the absence of long-term data on breeding events; and also population and movement dynamics (Brereton and Taylor-Wood, 2010).

4.5.3 What has changed, and is it significant?

Changes to the population of green and golden bell frogs within the Ramsar site are largely unknown. As noted above, there is an absence of long-term data on breeding events, population and movement dynamics and accordingly this assessment does not have information to support an assessment of whether there has been a change or is likely to be a change.

It is noted that prior to substantial changes in vegetation at Kooragang Island in the nineteenth century, the estuary had extensive areas of saltmarsh and swamp forest communities (both saline and brackish/fresh) (Winning, 1996). Since then, the areas of saltmarsh have been significantly reduced as a result of mangrove encroachment and changes in land practices (DECC, 2007). Dramatic reductions of areas of freshwater wetlands associated with floodplain features and the outer fringes of saline wetlands have also occurred due to development and modified land uses (DECC, 2007). These habitat areas would have supported significant habitats for the green and golden bell frog prior to modification of the landscape.

Since the time of listing, the distribution and abundance of the green and golden bell frog has been impacted by the chytrid fungus (Brereton and Taylor-Wood, 2010). Green and golden bell frogs have been recorded within the Kooragang component since the 1990s, however most of the records for Kooragang Island occur to the south and west of the site (Figure 4.8). Based on the habitat determinants of the green and golden bell frog on Kooragang Island, the species was identified as preferring waterbodies with an abundance of emergent sedges and reeds (Hamer et al., 2002); habitats that are likely to occur within the Ramsar site.

While, the green and golden bell frog has been recorded using ephemeral and permanent fresh/brackish wetlands (Hamer et al., 2002), the fresh/brackish wetlands inhabited by the species predominantly occur in areas that were previously comprised of saltmarsh, tidal flats and open saline water bodies (MHL, 2003). Tidal restriction, water table recession and land subsidence are primarily responsible for the conversion of saline wetlands to fresh/brackish systems (MacDonald, 2001). While brackish (salinity up to 4.5 ppt) conditions have demonstrated increased survival of green and golden bell frogs infected with chytrid (Stockwell et al., 2008; Clulow et al., 2017), higher limits of this salinity range have resulted in reduced tadpole growth (Stockwell et al., 2015); a factor that requires consideration given the LAC refers to breeding events of the species (Brereton and Taylor-Wood, 2010).

4.5.4 Potential Impact from Contamination

Currently there is little knowledge of the effects chemical contamination may have on green and golden bell frogs in the Hunter Estuary, due to a paucity of published material on this topic. Generally, contaminants such as pesticides, herbicides, fungicides, fertilizers and heavy metals have been shown to impact many species of amphibians (Sparling et al., 2000; Blaustein et al., 2003). Such impacts have included reduced activity and development in the larval stage (i.e. tadpoles), and reduced survivorship and endocrine disruption in the adult stage (Blaustein et al., 2003). For green and golden bell frogs, the impact of chemical contaminants may differ between the life stages of the frog.

Adult green and golden bell frogs have also been recorded occupying habitat previously subjected to human contamination from heavy metals; these contaminants may inhibit the effects of the chytrid fungus, providing a potential benefit to the frogs (Goldingay and Newell, 2005; Threlfall et al. 2008). Since there has been limited research on the population of green and golden bell frogs within the

Ramsar site, any understanding on the potential impacts on the population from chemical contamination is virtually unknown.

4.5.5 What measures are in place to address the impacts?

The only management measures identified in the Plan of Management for this species is to provide ongoing support for research programs for green and golden bell frogs including research on chytrid fungus (NPWS, 2016). Other non-specific measures include implementation of relevant strategies as identified in recovery plans for this species.

NPWS have also recognised the need for working cooperatively with companies that have planning approval to undertake habitat compensatory works on Ash Island and provide necessary consents, leases, or licences for the works as required (NPWS, 2016).

4.5.6 Knowledge Gaps

The main knowledge gap for the green and golden bell frog is that there is no recent information on breeding events for the species within the Kooragang component of the Hunter Estuary Wetlands Ramsar site. Surveys for the green and golden bell frog are required in suitable habitat within the Ramsar site focussing on detecting recruitment and breeding events in order to obtain information for identifying the LAC for this species. The three ponds identified as being inhabited by the species should be the focus of these surveys as breeding has been recorded in them previously (Hamer et al., 2002).

Furthermore, survey effort for detecting the species should focus on areas that have not been previously surveyed, but potentially provide suitable habitat. For instance, there is some likelihood that green and golden bell frogs occur in suitable habitat within the Ramsar site to the north-east of the Ash Island sites, however this habitat (if present) would be highly ephemeral (M. Mahony pers. comm., 2018). Ephemeral habitats benefit the frogs as they provide additional breeding areas and would facilitate movement.

4.5.7 Conclusion

This assessment finds that any change in ecological character for the green and golden bell frog is impossible to determine based on the deficiency of data required for assessing the LAC.

It is recommended that studies are undertaken in the Ramsar wetland adjacent to the known records to identify whether the green and golden bell frog is present, is breeding and to inform a review of the LAC and whether this species is an appropriate indicator of ecological condition.

While the habitat value of the Kooragang component has not been the subject of recent studies it Is likely that drainage structures and Ramsar Road itself presents a barrier to tidal flows. Consideration should be given to improving tidal flows and reduce the barrier afforded by Ramsar Road to create more brackish wetlands as green and golden bell frog habitat as saline environments inhibit chytrid growth.

Further, consideration may be given to re-defining the Ramsar site boundaries to encompass the adjacent Hunter Wetlands National Park lands on Kooragang/Ash Island as green and golden bell frogs are predominantly recorded in the National Park area south of the Ramsar site.

4.6 Other Threatened Waterbirds

4.6.1 Why is it important to the site?

At the time of listing in 1984, a total of 100 species of waterbirds had been recorded within the Kooragang component of the Hunter Estuary Wetlands Ramsar site (Brereton and Taylor-Wood, 2010). Of these, 20 species have been recorded breeding within freshwater swamp habitats in the

site. Although freshwater swamp habitats are limited within the Kooragang component due to most areas being brackish wetlands, foraging and roosting habitat for waterbirds still exists within the site.

The nationally threatened waterbird the Australasian bittern (*Botaurus poiciloptilus*) has been recorded in the Kooragang component of the Ramsar site. Samphire Flats, located on the western side of Fullerton Cove, has been identified as important habitat for the Australasian bittern, with possible breeding habitat located in the adjacent area to the west of the North/South drain, just outside the Ramsar site (Lindsey and McNaughton, 2012). These brackish wetland habitats are dominated by sedges, reeds and broad-leaved cumbungi and provide foraging habitat for the Australasian bittern (Clarke and Van Gessel, 1983) (Figure 4.9).

4.6.2 Limit of Acceptable Change

There is no LAC set for the Australasian Bittern.

4.6.3 What has changed, and is it significant?

In the Kooragang component of the Hunter Estuary Wetlands Ramsar site the Australasian bittern is a rare resident known from Samphire Flats and the Rice Paddy at Tomago. A recent regional status update identified that regional numbers are possibly declining and that Tomago wetlands no longer provides suitable habitat and that there is also loss of habitat at the nearby Hexham Swamp (Roderick and Stuart, 2016). It is also unknown whether the Australasian bittern actually breeds in the Hunter Estuary (BirdLife Australia, 2018).

Monthly surveys of Tomago wetland area by HBOC from 2007 through till 2012 had identified this species and the Australian little bittern (*Ixobrychus dubius*) and black bittern (*Ixobrychus flavicollois*) in the Tomago wetlands (Lindsey and McNaughton, 2012). More recent studies in 2017/2018 flushed one individual from reedland in Tomago wetland to the west of the Ramsar site, at five locations/occasions on Ash Island to the west and south of the Ramsar site, and in Hexham Swamp (BirdLife Australia, 2018) (see Figure 4.9). Most of these observations were chance encounters by community observers during other activities (BirdLife Australia, 2018).

BirdLife Australia (2018) has identified the population in the Hunter estuary as one of the most important coastal sites for the Australasian bittern in NSW.

Given that the Australasian bittern is typically associated with dense cover of reeds, sedges and rushes in permanent and seasonal freshwater wetland and occasionally estuarine reedbeds, it is likely that they are threatened by hydrological management practices, in particular the restoration works in the Tomago wetlands which is changing habitat from freshwater influences that have dominated since after flood mitigation works in 1976, to reinstate brackish/saline habitats particularly saltmarsh. Drainage of wetlands and reduction in water quality are recognised as threats to this species.

It may be that the restoration works are causing a change in the character of the wetlands such that the Australasian bittern will no longer occur there. HBOC members have identified that the Australasian bittern may persist in the adjacent ‘Rice Paddy’ as that area is proposed to only receive salt water intermittently (Lindsey and McNaughton, 2012). This has been supported by the recent observation of an individual flushed from these wetlands in 2017.

Image Source: Google Earth (Aug 2017)
Data Source: Commonwealth of Australia (Department of Environment) (2015), ATLAS (2018), Birdlife Australia (2018)

Legend

- Hunter Estuary Wetlands Ramsar Site Boundary
- Australasian Bittern 1980 - 1989
- Australasian Bittern 1990 - 1999
- Australasian Bittern 2000 - 2009
- Australasian Bittern 2010 - 2012
- Australasian Bittern (Birdlife Australia 2018)

FIGURE 4.9

Records of Australasian Bittern within the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site and Surrounding Kooragang Island

File Name (A4): R01/4187_004.dgn
20180706 13.59

4.6.4 Potential Impact from Contamination

Given that the Australasian bittern forages on animals of wetlands including fish, eels, crayfish, frogs, insects, snakes, lizards and occasionally small birds and mammals it would be exposed to contaminants that bioaccumulate. In particular, chemicals known to bio-accumulate in biota via exposure through the food-chain, including lead and PFAS, would be key potential contaminants of concern for managing risks to the Australasian bittern.

Whether chemical contamination and any potential adverse impacts on development and/or reproduction of this species has occurred in the Ramsar wetland is unknown. There is significant potential for confounding factors to influence any such assessment, including changes in availability of habitat due to alteration of surface water hydrology, impacts of disturbances, poor water quality impacts, detrimental fire regimes and predation.

4.6.5 What measures are in place to address the impacts?

Generic management measures identified in the Hunter Wetlands National Park Draft Plan of Management (NPWS 2015) that are in place to address the impact on the Australasian bittern include:

- Implement relevant strategies in the priorities action statement for Australasian bittern.
- Fire management.
- Management of predators particularly foxes.
- Continue to involve HBOC in management decisions related to shorebird/waterbird habitat.

When designing management regimes to reinstate tidal hydrology, it is recommended that consideration be given to the continued provision of freshwater habitats in the Tomago wetlands for Australasian Bittern.

4.6.6 Knowledge Gaps

Given that the Australasian Bittern is a cryptic species it is not readily detected and its status is difficult to quantify. BirdLife Australia (2018) has identified the following knowledge gaps for this species:

- Behavioural studies to establish habitat usage, whether the birds are resident, nomadic or migratory,
- While there are past records of multiple birds suggesting that the Australasian bittern is likely to breed in the Hunter estuary, behavioural studies are required to establish whether they breed in the Hunter estuary.

It is also noted that this species is not the subject of regular monitoring.

4.6.7 Conclusion

There is a paucity of data on the occurrence of the Australasian bittern in the Kooragang component of the Hunter Estuary Wetlands Ramsar site and gaps in the knowledge of the status of this species in the wider Hunter estuary. It may be that the rehabilitation works in Tomago wetland and Hexham wetland are altering the availability of habitat for this species however ongoing monitoring would be required to better inform management of the species and its habitat.

5 CONCEPTUAL SITE MODEL

Based on the information reviewed and summarised in the previous sections, the following summary of the conceptual site model (CSM) was developed. A CSM represents an overview of contamination sources, relevant receptors and exposure pathways by which the sources may reach and / or impact upon the identified receptors.

5.1 Sources of Contamination

A number of source types and source areas where contaminants were used and introduced into the environment were identified. These are discussed through the site background discussion on land uses in Section 2.4, with chemical specific data summarised in Section 3.2. Generally, the most significant potential sources of contamination were associated with the following:

- Current and historical industrial activity at Kooragang Island;
- Agricultural land uses surrounding Fullerton Cove;
- Urbanisation and associated diffuse sources to stormwater;
- Wider catchment activities, including mining, clearing, etc.; and
- Williamtown RAAF Base and airport.

These activities have resulted in the presence of contamination in sediment, surface water, and biota of the Ramsar site. The results of the Tier 1 screening assessment and associated discussions (Section 3) indicated that the following contaminants were known to be present at levels of potential concern to ecological receptors:

- Surface water: nitrate, total nitrogen, total phosphorus, lead, and PFOS.
- Sediments: PFOS.
- Biota: PFOS and PFHxS.

The following contaminants were considered to be potentially present within the site, although the concentrations of these contaminants cannot be quantified due to a lack of data and hence the level of risk cannot be assessed:

- Petroleum hydrocarbons;
- Agricultural chemicals, including OCPs, OPPs, herbicides (e.g. trifluralin and potentially others).
- Metals, including arsenic, cadmium, chromium, iron, nickel, selenium (noting some metals analyses was conducted by OEH in 2014 (OEH, 2017d) but were not detailed in the available report as only metals above the adopted criteria were discussed); and
- Polycyclic aromatic hydrocarbons.

5.2 Receptors of Interest

For the purposes of this CSM, receptors are considered to include the ‘critical components’ and ‘ecosystem processes’ that define or strongly influence the ecological character of the Kooragang component. These were identified in the ECD (Brereton and Taylor-Wood, 2010) as:

- Waterbirds, particularly migratory shorebirds;
- Green and golden bell frog (*Litoria aurea*), a nationally threatened species;
- *Sarcocornia* saltmarsh, which supports migratory shorebirds;
- Intertidal mudflats which provide foraging habitat for migratory shorebirds; and
- Hydrology (tidal regime and freshwater inflows) which is a major influence on the distribution and extent of saltmarsh and mangroves.

The critical ‘ecosystem benefits’ and ‘supporting services’ that influence the ecological character and support the criteria under which the site was listed, include:

- Food web of the intertidal mudflats which support migratory shorebirds (critical component).
- Biodiversity, particularly:
  - Diversity of estuarine habitats that provide important roosting and foraging sites for migratory shorebirds;
  - infauna in the intertidal mudflats which provide foraging resource for migratory shorebirds.
- Threatened wetland species, habitats and ecosystems, particularly the green and golden bell frog (*Litoria aurea*).

5.3 Exposure Pathways

The relative significance of exposure pathways is dependent on a number of factors, such as the rate of exposure / intake, the concentrations within the impacted media at the point of exposure, and the characteristics or sensitivities of the receptor group.

Ecological receptors may be exposed to impacted environmental media through:

- Direct uptake from surface water or sediments.
- Bioaccumulation via the ecological food web.

Furthermore, as discussed in Section 3.4.2, broader ecosystem processes should be considered if a robust consideration of all potential impacts is to be completed. Although this step can be challenging, and the strength of any relationships will be dependent on the quality of any site-specific datasets obtained, the following factors may represent ‘exposure pathways’ for contamination to impact upon the local environment:

- Changes to community structure, including biodiversity and species richness, ecological diversity, and dominance; and
- Changes to ecological processes that control ecosystem functioning, including primary and secondary productivity, biological processes, and biogeochemical cycles.

5.4 Risk Ranking of Potentially Complete Pathways

As presented in the preliminary CSM discussed above, there are a number of potentially complete linkages which may impact upon the ecological character of the Ramsar site. The table below summarises the source, pathway, receptor linkages that are considered potentially complete, and provides a relative risk ranking for each potentially complete pathway. The risk levels assigned are defined as follows:

- Low risk – linkages likely to be incomplete, with negligible exposure to contaminants likely to occur via this pathway.
- Medium risk – linkages potentially complete, however unacceptable risk is unlikely based on known or likely source concentrations, transport pathways, or receptor characteristics. Further data collection would assist in closing data gaps and confirming whether pathway is complete or potentially significant.
- High risk – linkages likely to be complete. Based on available information, there is significant uncertainty and / or these linkages require more detailed investigation or risk assessment.

Any prioritisation for further works should match these rankings, with high risk pathways generally high priority for further investigation, refer Table 5.1.

Table 5.1 Summary of risk rankings for key source, pathway, receptor linkages

Contaminant/s	Pathways	Receptors	Risk
Key Contaminants			
Nutrients – nitrogen and phosphorous	Direct toxic effects Indirect effects, incl. oxygen depletion	Saltmarsh Biodiversity / mudflats	**High**
Metals: lead	Direct toxic effects Bioaccumulation Indirect ecosystem effects	Waterbirds Green and golden bell frog Food web / biodiversity / mudflats	**High**
Other metals	Direct toxic effects Indirect ecosystem effects	Waterbirds Green and golden bell frog Food web / biodiversity	Medium
PFAS	Direct toxic effects Bioaccumulation Indirect ecosystem effects	Waterbirds Green and golden bell frog Food web / biodiversity / mudflats	**High**
Other Potential Contaminants			
Petroleum Hydrocarbons	Direct toxic effects	Green and golden bell frog Saltmarsh Food web / biodiversity	Low
PAHs	Direct toxic effects Indirect ecosystem effects	Waterbirds Green and golden bell frog Food web / biodiversity / mudflats	Medium
Herbicides and Pesticides	Direct toxic effects Bioaccumulation Indirect ecosystem effects	Waterbirds Green and golden bell frog Food web / biodiversity / mudflats	Medium
Cyanide	Direct toxic effects Indirect ecosystem effects	Waterbirds Green and golden bell frog Food web / biodiversity	Medium

As presented in the preliminary CSM presented above, there are a number of potentially complete linkages associated with risk to ecological receptors and processes, due to contamination. Further assessment of these pathways may be required to determine whether contaminants have in fact resulted in a change of ecological character of the Ramsar site. A number of pathways have been

identified as potentially representing “medium’ risk levels, largely due to the lack of analytical data. Further data collection would be required to reduce uncertainty and refine the assessment.

6 CONCLUSIONS

The National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2) states that the formal assessment is the means whereby the evidence is weighed, the significance of the 'change' is determined, and a considered decision is reached by the relevant parties as to whether or not an ecological change is sufficient to warrant a recommendation to the Administrative Authority that a notification should be made. In accordance with this guidance, this assessment investigated potential changes to critical components, processes and services (CPS) that define the ecological character of the Hunter Estuary Wetlands Ramsar Site (Kooragang component), particularly as they relate to potential chemical contamination issues.

Information sources used to inform a decision on change in ecological character include: the ecological character description, scientific reports, updated site information, monitoring, research, advice from government agencies, site managers, and any third-party notifications.

In complex systems, it is often difficult to determine exact causation of change, even if there is a correlation between two or more variables (e.g. if there is a correlation between contamination levels and migratory bird numbers, does this necessarily indicate causation whereby a contaminant has caused all or part of the decline in migratory bird numbers?). However, causation can be inferred from assessing all available observational data, including chemical data, ecological surveys, ecotoxicity studies, and other field studies. By applying appropriate scientific reasoning and with consideration of any relevant criteria, an inference of causation can be made. Relevant criteria for implying causation across multiple datasets could include: strength, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment, analogy (Hill, 1965). Multiple lines of evidence, weight of evidence, and statistical analysis are all important tools for informing these criteria.

The outcomes from the assessment as summarised below indicate that a number of chemical contaminants are present within the Ramsar site at concentrations that may pose a risk to ecological receptors, with changes in key ecosystem CPS also reported. Based on the available evidence, it is likely that chemical contaminants are impacting negatively on one or more of the CPS.

The Ramsar Convention advocates the application of a precautionary approach when considering change in ecological character. A lack of complete certainty in a change or likely change in ecological character should therefore not preclude actions to address potential changes.

6.1 Ramsar Status Assessment

The ecological character of the Ramsar site is defined by its critical components and processes which, through their interactions, provide benefits and services.

The critical components of the Kooragang component of the site are:

- waterbirds, particularly migratory shorebirds.
- the green and golden bell frog (*Litoria aurea*), a nationally threatened species.
- *Sarcocornia* saltmarsh which supports migratory shorebirds.
- intertidal mudflats which provide foraging habitat for migratory shorebirds.
- hydrology (tidal regime and freshwater inflows) which is a major influence on the distribution and extent of saltmarsh and mangroves.

Critical 'ecosystem benefits' and 'supporting services' determine or strongly influence the ecological character and support the criteria under which the site was listed. These are:

- Food web of the intertidal mudflats which support the migratory shorebirds critical component.
- Biodiversity, particularly:
  - diversity of estuarine habitats that provide important roosting and foraging sites for migratory shorebirds;
  - infauna in the intertidal mudflats which provide foraging resource for migratory shorebirds.

- Threatened wetland species, habitats and ecosystems particularly for the green and golden bell frog (Litoria aurea) and Australasian bittern.

This study has investigated whether there has been or is likely to be an unacceptable change in any of the CPS, and the potential cause of this change. The ecological character description for each Ramsar wetland includes LACs for each CPS that, if exceeded, may indicate a change in ecological character. Many of the LACs developed for the Hunter Estuary Ramsar site (Kooragang component) were set in the absence of sufficient baseline data. As such, they typically represent a low level of confidence that exceedance of the LAC would constitute a change in ecological character. There was also no LAC set for the potential impacts of chemical contamination on the CPS.

The table in Appendix E provides a summary of the findings of this investigation as to whether the ecological character of the site, as defined by the CPS, has changed or is likely to change as a result of chemical contamination since the time of Ramsar listing. The table also includes an assessment of the appropriateness of the LACs as specified in the Ecological Character Description. This assessment is based on the best available scientific evidence as presented in Chapter 4 and consideration of the level of confidence for each LAC.

Potential for Change Due to Chemical Contamination

Based on current scientific understandings, the CPS at most risk to chemical contamination are shorebirds and frogs. It is considered likely that chemicals including PFOS (and to a lesser extent other PFAS such as PFHxS, PFOA, etc) and heavy metals such as lead are bioaccumulating in migratory shorebirds foraging in the intertidal mudflats particularly in the Fullerton Cove area and Stockton Sandspit. The chemicals of primary concern at the Kooragang component of the Ramsar site were identified as lead and PFOS. These chemicals are associated with a range of effects, with lead exposure associated with neurological problems, kidney dysfunction, enzyme inhibition and anaemia, while PFOS exposures are associated with growth inhibition, histopathological effects, atrophied thymus, species diversity changes in a microcosm, and mortality. It should be noted that these findings were based on a large quantity of recent, relevant and high-quality data for PFASs at the site, and very limited data for other chemicals.

Migratory birds passing though the wetland will have significantly reduced exposures to site related contaminants compared to locally native species, although it is also likely that exposures to common contaminants such as lead and PFOS would occur at multiple feeding grounds along the migration route. As migratory birds consume the majority of their diet during fattening periods prior to migration, refuelling non-breeding points represent the most significant sources of dietary intakes and potentially contaminant exposure (e.g. Australia and New Zealand at the southern end of the flyway and breeding areas at the northern end of the flyway).

It is unclear whether contamination has contributed to observed declines in shorebird counts given other potential causal or confounding factors, including: changes in roost availability; impacts of repeated disturbances (high energetic cost that may compromise their capacity to build sufficient energy reserves for migration); poor water quality impacts (other than contaminants); foraging habitat loss; drought; and contribution from background / migratory route impacts. Regardless, chemical contamination cannot be discounted as having a negative impact on shorebirds particularly in the absence of any contrary evidence.

Despite the significant data gaps that exist, there is sufficient evidence to indicate that the site has been impacted by a number of contaminants. The screening-level assessment of the available data indicates that some contaminants are present in surface water, sediments, and biota at levels that may pose an unacceptable risk to receptors. Some of these contaminants may have been present in greater concentrations at the time of listing of the Ramsar site than currently, suggesting that contaminants which have declined (e.g. PAHs or heavy metals) are unlikely to be responsible for any observed changes in ecological character since listing. However, for some persistent contaminants, toxic effects may occur for many years after the initial release.

PFAS at the Ramsar site is predominantly associated with contamination released from RAAF Base Williamtown, where PFAS containing fire-fighting foams were commonly used, stored and disposed of, between the 1970s and mid-2000s (Taylor and Cosenza, 2016). Recent studies have shown that PFAS in Australian human blood serum levels are generally declining due to the removal of PFAS

from many consumer goods (Toms et al, 2014), however there are ongoing increases in concentrations in some biota at higher tropic levels due to biomagnification and bioaccumulation within the environment (Miller et al, 2015).

Additional site data and site-specific risk assessment may be required to definitively determine whether chemical impacts have resulted in a change in the ecological character of the Ramsar site.

6.2 Supporting Evidence – Contamination Assessment

Based on the limited quantitative data for the wide range of chemicals that may exist within the Hunter Estuary Wetlands Ramsar Site (Kooragang Component), the following can currently be concluded:

- At the time of Ramsar designation, historical, industrial and agricultural activities had significantly impacted the Hunter River and the Ramsar site.
- Industrial and agricultural activities in close proximity to the Hunter Estuary Ramsar site have decreased in intensity since the time of listing.
- Considerable remediation of contaminant sources in the South Arm of the Hunter Estuary has occurred since 2000.
- There are two hydrologically distinct components of the Ramsar site: a) North Arm channel and b) Fullerton Cove. Contaminants originating from the South Arm are readily transported upstream and subsequently into the North Arm, and to a lesser extent into Fullerton Cove.
- The Hunter Estuary is subject to considerable tidal flushing (Miller et al., 2018), and flushing during flood events. Large floods occurred in the Hunter River estuary in 1990, 1998, 2000 and 2007.
- It is likely that a significant portion of any historical chemical contamination, as associated with former industrial activity in the South Arm that may have impacted on the Ramsar site, have been largely degraded, buried, or exported from the estuary.
- Contaminant transport modelling has identified the potential for significant impacts on Fullerton Cove from contaminants released from the Fullerton Cove floodgates. This location represents a primary source of PFAS contamination in surface water draining from the Williamtown base into the Ramsar site. The Miller et al (2018) report notes that "there is likely to be a much higher concentration near the source of release due to the lesser tidal exchange at these sites". It also notes that wind-induced mixing, which was not modelled, may disperse the contaminants throughout Fullerton Cove. There is insufficient data to assess temporal changes in PFAS, noting that PFAS products are no longer in use at the Williamtown RAAF base.
- The current nature and extent of contaminant levels from current and previous industrial and agricultural sources within the Ramsar site cannot be fully quantified due to the lack of analytical data for many potential contaminants of interest.
- Contaminants currently known to be present within the Ramsar site at levels of potential concern to ecological receptors are:
  - In surface water: nitrate, total nitrogen, total phosphorus, lead, and PFOS.
  - In sediments: PFOS.
  - In biota (fish, benthic invertebrates): PFOS and PFHxS.
- Other contaminants that may be present at the Ramsar site, due to past industrial and agricultural practices and could impact on the ecological character include:
  - Metals, including arsenic, cadmium, chromium, copper, iron, manganese, nickel, selenium and zinc, as metals are common contaminants that are generally persistent, ecotoxic, and bioaccumulative; and
  - Polycyclic Aromatic Hydrocarbons (PAHs).

  However, there is insufficient data to ascertain whether these chemicals are present and if so, whether levels are sufficiently high to impact on the ecological character. Sampling of sediment and surface water in the South Arm indicate a number of contaminants have declined in

concentration over time, particularly metals and PAHs (OEH, 2017a; CSIRO, 2014a). Industry in the South Arm was likely a primary source of these contaminants, and as these sites have been substantially remediated in the past 20 years it is likely that the metals and PAHs across the wider Hunter estuary have also declined. It is therefore unlikely that these contaminants would be impacting the site to a greater extent than at the time of Ramsar listing in 1984.

7 RECOMMENDATIONS

7.1 Consultation

The National guidance (DEWHA 2009) requires the assessment of change in ecological character to include evidence of appropriate consultation with the relevant government management agency and the site manager/landowner. Some consultation has occurred, as follows:

- Consultation with the DoEE, Department of Defence, EPA and the OEH, as members of the Steering Committee, throughout the development of this formal assessment.
- The National Parks and Wildlife Service (NPWS) managers of the Hunter Wetlands National Park to source information.
- Hunter Bird Observers Club for provision of monthly bird data to inform the analysis and observations from some members in the Kooragang component and broader Hunter estuary.
- Professor Michael Mahony of the University of Newcastle was interviewed to identify further information on the green and golden bell frog population particularly whether there have been any breeding events in the Kooragang component.
- Staff at the Hunter LLS to discuss potential agricultural chemical use in the surrounding area.

Additional consultation that more actively engages with key stakeholders is recommended, if ongoing management actions or assessment works are to be undertaken.

7.2 Data Collection and Research Needs

7.2.1 Contamination Assessment

As discussed within this report, there are major data gaps with regards to conducting a baseline assessment of contaminant levels and associated risk within the Hunter Estuary Ramsar site. Although data gaps have been noted with regards to available analytical data within the Ramsar site, particularly Fullerton Cove, inferences regarding contaminant trends can be made based on data from the South Arm and surrounds. To address key data gaps and to ensure any further assessments are appropriately targeted, he following recommendations are made:

- Conduct further site-specific sampling of sediment and surface water within the Ramsar site, to confirm contaminant levels and enable ongoing assessment of contaminant trends to inform further assessment of whether chemical contamination is having an adverse change in the ecological character of the wetland. Contamination investigations should incorporate the following considerations, where feasible:
  - Targeting samples at locations where contamination is most likely to occur, including at stormwater and drain outlets, along modelled preferential pathways for transport of surface water and sediment, and at sediment deposition zones.
  - Collection of temporal trend data for key analytes at representative locations, to assess seasonal variability and changes in concentrations of key contaminants such as PFAS over time.
  - Sampling and analyses for a broad range of potential contaminants to assess whether they are present, and if present whether concentrations indicate a potential for ecological changes to occur. Additional analytes may include the following, noting not all analytes would be relevant across all areas and any sampling could be targeted to reduce redundancy in the sampling suite:
    - Metals, including arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, selenium and zinc.
    - Polycyclic aromatic hydrocarbons (PAHs);

  - Petroleum hydrocarbons;
  - Agricultural chemicals, including OCPs, OPPs, and herbicides;
  - Nutrients (nitrogen and phosphorus compounds; and
  - Cyanide.

This information would identify any other contaminants that could be affecting the ecological character of the site.

In addition to chemical specific analyses, further data collection that specifically investigates whether contaminants have altered the local ecosystem or impacted on specific receptors may also be considered. This could include:

- Undertake baseline surveys within the Ramsar site, and at an appropriate control site, and assess factors such as invertebrate density or species distribution relative to contaminant levels in the environment.
  - This method provides a robust approach to assessing the correlation between contaminant levels and ecosystem health, with stronger datasets obtained with more sample locations and selection of an appropriate control site/s.
  - This exercise can result in significant costs, particularly to obtain a dataset that is robust.
- Undertake direct toxicity testing of sediment and surface water collected from the site, to assess the level of toxicity posed by the site-specific combination of contaminants at the site.
  - This method considers site specific impacts only and may not indicate what factors or contaminants drive any toxic effects observed (e.g. if PAHs, PFAS, and metals were all present, then any toxic effects observed may not be able to be correlated with a specific toxicant).

7.2.2 Ramsar Status Assessment

While this assessment acknowledges that the limits of acceptable change (LAC) for both saltmarsh and the eastern curlew have been exceeded it is noted that both of these limits of acceptable change have a low level of confidence due to the lack of a robust long-term dataset at the time of setting the LAC. Of these two critical components, the eastern curlew is most likely to be impacted by chemical contamination.

There is also the possibility of a future change in ecological character associated with chemical contamination, however further information is required to substantiate this.

It is recommended that a watching brief is commenced. This should include development of an action plan with relevant stakeholders. It is suggested that the action plan focus on improving knowledge of processes and change to better inform decisions and management. Where relevant, resets to the limits of acceptable change, based on best available science, should also be considered to improve their relevance and capacity to inform future formal assessments of change.

The action plan should also identify and implement options to fill knowledge gaps and adopt standardised and systematic surveys to allow for comparison of data sets to ensure that further assessments of change are based on the best available science and to identify the contribution of climate change to these changes, particularly for saltmarsh, mangroves and extent of tidal mudflats. This may include:

- Further investigations of bioaccumulation in the foodweb, including collection of information on:
  - the infauna, particularly soft sediment invertebrates, their habitat requirements, distribution and response to change in environmental conditions in the estuary
  - bioaccumulation of chemicals in shorebirds and if this has affected the shorebirds.
- Studies of geomorphic change at the site, particularly affecting the distribution of intertidal mudflats, to provide more directed evidence about the extent to which climate change and human induced processes are impacting on the critical processes which underpin the Ramsar values and

the changes that have been observed, along with the likely trajectory of changes. This will also inform management options.

- Further investigations of green and golden bell frog within the Kooragang component of the Hunter Estuary Wetlands Ramsar site. Surveys for the green and golden bell frog are required in suitable habitat within the Ramsar site focussing on detecting recruitment and breeding events in order to obtain information for identifying the LAC for this species. These investigations should also record the contaminant levels within the habitat. The three ponds identified as being inhabited by the species should be the focus of these surveys as breeding has been recorded in them previously (Hamer et al. 2002).
- Further investigations of the current status of the Australasian Bittern in the Kooragang component.
- Review of the LAC for eastern curlew, and potentially other shorebirds, having regard to latest scientific advice and any relevant threat abatement plans.

The above responses can be commenced quickly (or in some cases continued, providing funding is available). Some of these responses will require collaboration between organisations such as Hunter Local Land Services, OEH, Hunter Bird Observers Club, Kooragang Wetland Rehabilitation Project Steering Committee, Newcastle City Council and Port Stephens Council.

Other possible interventions may require some approvals and environmental assessment or policy investigation and could potentially include:

- modification of the boundaries of the Ramsar site to take into account the dynamic changes to migratory shorebirds habitat, Australasian bittern habitat and green and golden bell frog in the lower Hunter estuary to include the Hunter Wetlands National Park boundaries and Hexham Swamp Nature Reserve.
- scoping and implementation of ongoing works to improve the value of the north arm sandflats behind the Kooragang Dykes (e.g. works to stabilise the dykes but retain the gap in the wall)
- Investigation of the feasibility to improve tidal flows under Ramsar Road, with NPWS
- consideration of whether Australasian Bittern is still an indicator species for the listing given that the current restoration works are aimed at restoring a brackish environment at the expense of freshwater habitats. This will also need to consider future management of the site to make it resilient to the impacts of climate change.
- Review of listing for criterion 6 as the Kooragang component no longer supports 1% of the EAAF population (Hansen, et al., 2016) of the eastern curlew however it still regularly supports more than one percent of the Australian population of the red-necked avocet and also supports more than 1% of the EAAF population of sharp-tailed sandpipers. If required, update RIS accordingly.

8 REFERENCES

ABS, 2015. *Regional Population Growth, Australia, 2014-15: New South Wales State Summary.* Available at: http://www.abs.gov.au/ausstats/abs@.nsf/Previousproducts/3218.0Main%20Features202014-15?opendocument&tabname=Summary&prodno=3218.0&issue=2014-15&num=&view

AECOM, 2016a. *Stage 2B Environmental Investigation Report, RAAF Base Williamtown, Williamtown, NSW*, AECOM Services Pty Ltd, June 2016.

AECOM, 2016b. *Off-site Human Health Risk Assessment – July 2016, RAAF Base Williamtown Stage 2B Environmental Investigation Stage*, AECOM Services Pty Ltd, August 2016.

AECOM, 2016c. *Preliminary Ecological Risk Assessment, December 2016, RAAF Base Williamtown Stage 2B Environmental Investigation (Revision 1)*, AECOM Services Pty Ltd, December 2016.

AECOM, 2018*. RAAF Base Williamtown 2017 Stage 2B Ecological Risk Assessment*, AECOM Services Pty Ltd.

ANZAST, 2018. *National Water Quality Management Strategy: Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Canberra: Australian and New Zealand Environment and Conservation Council.

Arnot, J.A. and Gobas, F.A.P.C., 2006, A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environmental Review* 14: 257-296.

Australian Government 2015. The Wildlife Conservation Plan for Migratory Shorebirds.

Australian Government, 2016. *Regional Population Growth, Australia Online Database*. Australia Bureau of Statistics. Available at: http://www.abs.gov.au/ausstats/abs@.nsf/Previousproducts/3218.0Main%20Features202014-15?opendocument&tabname=Summary&prodno=3218.0&issue=2014-15&num=&view.

Australian Government, 2017. *PFAS Response Online*, Department of Primary Industries. Available at: https://www.dpi.nsw.gov.au/biosecurity/pfas-response.

Australian Museum, 2012. *A History of Ash Island Online Article*. Available at: https://australianmuseum.net.au/a-history-of-ash-island.

Bamford M., Watkins D., Bancroft, W., Tischler, G. and Wahl, J. 2008*. Migratory Shorebirds of the East Asian - Australasian Flyway; Population Estimates and Internationally Important Sites*. Wetlands International - Oceania. Canberra, Australia.

BirdLife Australia, 2018. Hunter Estuary Australasian Bittern Study. For BHP Billiton.

Blackmore, K.L., Goodwin, I.D. and Wilson, S. (2010) *Case Study 4: Potential impacts of climate change on extreme events in the coastal zone of the Hunter, Lower North Coast and Central Coast region.* Report prepared for the Hunter and Central Coast Regional Environmental Management Strategy, NSW.

Blaustein, A. R., Romansic, J. M., Kiesecker, J. M. and Hatch, A. C. 2003. Ultraviolet radiation, toxic chemicals and amphibian population declines. *Diversity and Distributions,* 9(2), 123-140.

BMT WBM, 2009. *Hunter Estuary Management Study*, BMT WBM Pty Ltd, September 2009.

BMT WBM, 2016. *Hunter Estuary Coastal Zone Management Plan*, BMT WBM Pty Ltd., original September 2009, revised September 2016.

BoM, 2018a. Climate statistics for Australian locations – Newcastle Nobbys Signal Station AWS. Available at: http://www.bom.gov.au/climate/averages/tables/cw_061055.shtml

BoM, 2018b. *Average annual, monthly and seasonal evaporation.* Available at: http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp

Boyd, R., 2001. *Geology and Soils of the Hunter Catchment and Evolution and Sedimentation of the Hunter Estuary*. A report for Manly Hydraulics Laboratory as part of the Hunter Estuary Processes Study.

Brereton, R. and Taylor-Wood, E., 2010. *Ecological Character Description of the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site.* Report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPAC), Canberra.

Burger, J., Tsipoura, N., Niles, LJ., Gochfeld, M., Dey, A., and Mizrahi, D. 2015. *Mercury, Lead, Cadmium, Arsenic, Chromium and Selenium in Feathers of Shorebirds during Migrating through Delaware Bay, New Jersey: Comparing the 1990s and 2011/2012.* Toxics. (3) 63-74

Butler, R.W., Shepherd, P.C.F. and Lemon, M.J.F., 2002. Site fidelity and local movements of migrating Western Sandpipers on the Fraser River estuary. *Wilson Bulletin* 114, 485-490.

Canadian Government, 2017 (as referenced in PFAS NEMP, 2018). *Canadian Environmental Protection Act, 1999, Federal Environmental Quality Guidelines, Perfluorooctane Sulfonate (PFOS)*, Gatineau, Quebec, February 2017

CCME, 1999. *Canadian Water Quality Guidelines for the Protection of Aquatic Life: Polycyclic aromatic hydrocarbons (PAHs).* Canadian Council of Ministers of the Environment, 1999.

CCREM, 1987. *Canadian Water Quality Guidelines*. Inland Waters Directorate, Environmental Canada, Canadian Council of Resource and Environmental Ministers, Ottawa.

Canadian Government, 2013. *Mercury in the food chain*. Accessed: https://www.canada.ca/en/environment-climate-change/services/pollutants/mercury-environment/health-concerns/food-chain.html

Capuzzol, JM, Moore, MN, & Widdows, J., 1988. *Effects of toxic chemicals in the marine environment: predictions of impacts from laboratory studies*. Aquatic Toxicology, 303-311.

Clarke, C.J. and Van Gessel, F.W.C. 1983. Habitat evaluation – birds. In J Moss. (ed). An investigation of the natural areas: Kooragang Island, Hunter River. 1983. Report prepared by C.D. Field and Associates and Insearch Ltd. Department of Environment and Planning, Sydney.

Clemens, R.S. 2016. Ecology and Conservation of Australia's Shorebirds. Thesis submitted for degree of Doctor of Philosophy at the University of Queensland, School of Biological Sciences.

Clemens, R.S., Rogers, D.I., Hansen, B.D., Gosbell, K., Minton, C.D.T., Straw, P., Bamford, M., Woehler, E.J., Milton, D.A., Weston, M.A., Venables, B., Weller, D.R., Hassell, C., Rutherford, B., Onton, K., Herrod, A., Studds, C.E., Choi, C.Y., Dhanjal-Adams, K.L., Murray, N.J., Skilleter, G., and Fuller, R.A., 2016. Continental-scale decreases in shorebird populations in Australia. *Emu*. 116:119-135

Close, D. and Newman, O. M. G., 1984. The decline of the Eastern Curlew in south-eastern Australia. *Emu-Austral Ornithology*, *84*(1), 38-40.

Clulow, S., Gould, J., James, H., Stockwell, M., Clulow, J., & Mahony, M. 2018. Elevated salinity blocks pathogen transmission and improves host survival from the global amphibian chytrid pandemic: Implications for translocations. *Journal of Applied Ecology*, *55*(2), 830-840.

Conder, J.M., Hoke, R.A., de Wolf, W., Russell, M.H. and Buck, R.C., 2008, Are PFCAs bioaccumulative? A critical review and comparison with regulatory criteria and persistent lipophilic compounds. *Environmental Science and Technology* 42: 995−1003.

Creese, R.G., Glasby, T.M., West, G, and Gallen, C. (2009). Mapping the habitats of NSW estuaries. Industry and Investment NSW – Fisheries Final Report Series No 113.

Crawford, L and Herbert, C (2017) Red Knot on migration through the Hunter Estuary, New South Wales. Stilt 71:14-24.

CSIRO, 2014a. *Newcastle Port Corporation Port-wide Strategy – maintenance dredging assessment*. Prepared for Newcastle Port Corporation (NPC).

CSIRO, 2014b. *Newcastle Port Corporation Port-wide Strategy – future capital dredging assessment*. Prepared for Newcastle Port Corporation (NPC).

Dawes, J., 2011. The declining population of curlew sandpiper *Calidris ferruginea* indicates that it may now be endangered in New South Wales. Stilt 60:9-13.

Department of the Environment (DoE) 2015. Wildlife Conservation Plan for Migratory Shorebirds 2015. Commonwealth of Australia.

Doble, M. & Kumar, A, 2005. Petroleum Hydrocarbon Pollution, Ch 24. In: *Biotreatment of Industrial Effluents*, Eds: Mukesh Doble, Anil Kumar. Butterworth-Heinemann, Pages 241-253,

Department of Environment and Climate Change (DECC) (NSW). 2007. Draft Management Plan for the Green and Golden Bell Frog Key Population in the Lower Hunter. Department of Environment and Climate Change (NSW), Sydney.

Department of Environment, Water, Heritage and the Arts (DEWHA), 2009. National Guidance on Notifying Change in Ecological Character of Australian Ramsar Wetlands (Article 3.2). Module 3 of the National Guidelines for Ramsar Wetlands – Implementing the Ramsar Convention in Australia. Commonwealth of Australia.

DoEE, 2016. *Hunter Estuary Wetlands Online Interactive Database.* Available at: http://www.environment.gov.au/cgi-bin/wetlands/ramsardetails.pl?refcode=24.

DoEE, Accessed 2018a*. Ecological Risk Assessment*. Accessed: http://www.environment.gov.au/science/supervising-scientist/research/ecological-risk

DoEE, 2018b. *Bioregional Assessment Program – Hunter Subregion*. Accessed: https://www.bioregionalassessments.gov.au/assessments/hunter-subregion

DoEE, 2018c. Australian Wetlands Database Ramsar wetlands. Accessed: https://www.bioregionalassessments.gov.au/assessments/hunter-subregion

DPI, 2016. *Fishing closures at Williamtown to be lifted.* Available at: https://www.dpi.nsw.gov.au/about-us/media-centre/releases/2016/fishing-closures-at-williamtown-to-be-lifted

DWE, 2009. W*ater Sharing Plan. Hunter unregulated and alluvial water* sources. Department of Water and Energy, NSW, August 2009. Accessed: http://www.water.nsw.gov.au/__data/assets/pdf_file/0009/548838/wsp_hunter_rules_summary_hunter_regulated_river_alluvial.pdf

DSEWPAC in 2010. Wetlands and the Ramsar Convention, fact sheet. Accessed: http://www.environment.gov.au/water/wetlands/publications/wetlands-and-ramsar-convention

Echeveste, P & Agustí, S & Dachs, J., 2009. Cell size dependent toxicity thresholds of polycyclic aromatic hydrocarbons to natural and cultured phytoplankton populations. *Environmental pollution*. 158. 299-307.

Eisler, R., 1988. *Lead hazards to fish, wildlife, and invertebrates: a synoptic review.* U.S. Fish and Wildlife Service Biological Report 85, Contaminant Hazard Reviews Report No. 14.

Eklund E., 2007. *Historical Anniversaries and Commemorations in Newcastle, NSW*. Public History Review, 2007.

enHealth, 2012a. *Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards*. enHealth Council.

Environment Canada, 2004. *Canadian Environment Protection Act, 1999 (CEPA)*: Environmental Screening Assessment Report on Perfluorooctane Sulfonate, Its Salts and Its Precursors that Contain the $C_8F_{17}SO_2$ or $C_8F_{17}SO_3$ Moitey. April 2004.

Environment Canada, 2017. *Canadian Environment Protection Act, 1999 (CEPA)*: *Draft Federal Environmental Quality Guidelines Perfluorooctane Sulfonate (PFOS).* February 2017.

Environment Canada, 2018, Canadian Environment Protection Act 1999 (CEPA): Federal Environmental Quality Guidelines for Perfluorooctane Sulfonate (PFOS). June 2018.

Fleeger, J., Carman, K., & Nisbet, R., 2003. Indirect effects of contaminants in aquatic ecosystems. *Science of The Total Environment*. 317(1-3); 207-233.

Giesy, J.P and Kannan, K., 2001, Global Distribution of Perfluorooctane Sulfonate in Wildlife. *Environmental Science and Technology* 35: 1339-1342.

Geering, D.J, 1995. Ecology of migratory shorebirds in the Hunter River estuary. Shortland Wetlands Centre, Newcastle.

Genders, A.J., 2001. Distribution and abundance of larval fishes and invertebrates along the Hunter River estuary, New South Wales, Australia, with specific reference to the effects of floodgates, MSc thesis, University of Newcastle.

Goldingay, R. and Newell, D. 2005. Population estimation of the green and golden bell frog *Litoria aurea* at Port Kembla. Australian Zoologist, 33(2), 2010-2016.

Gobas, F.A.P.C., de Wolf, W., Burkhard, L.P., Verbruggen, E., and Plotzke, K., 2009, Revisiting Bioaccumulation Criteria for POPs and PBT Assessment. *Integrated Environmental Assessment and Management* 5 (4): 624-637.

Gosper, D. G., 1981. Birds of the Hunter and Richmond Rivers, NSW. *Corella* 5(1): 1-18.

Hamer, A. J., Markings, J. A., Lane, S. J. and Mahony, M. J. 2004. Amphibian decline and fertilizers used on agricultural land in south-eastern Australia. *Agriculture, Ecosystems and Environment*. 102, 299-305.

Hamer, A. J., Lane, S. J. and Mahony, M. J. 2002. Management of freshwater wetlands for the endangered green and golden bell frog (*Litoria aurea*): roles of habitat determinants and space. *Biological Conservation*, *106* (3), 413-424.

Hamer, A. J. and Mahony, M. J. 2010. Rapid turnover in site occupancy of a pond-breeding frog demonstrates the need for landscape-level management. *Wetlands*, *30*(2), 287-299.

Hansen, B.D., Fuller, R.A., Watkins, D., Rogers, D.I., Clemens, R.S., Newman, M., Woehler, E.J., and Weller, D.R, 2016. Revision of the East Asian-Australasian Flyway Population Estimates for 37 listed Migratory Shorebird Species. Unpublished report for the Department of the Environment. BirdLife Australia, Melbourne.

Harayama et al, 1999. Petroleum Biodegradation in Marine Environments. *J. Molec. Microbiol. Biotechnol*, 1:1, 63-70.

HEPA, 2018. *PFAS National Environmental Management Plan*, The Heads of EPAs Australia and New Zealand (HEPA), January 2018.

HEPA, 2019, *PFAS National Environmental Management Plan*, version 2.0 (consultation draft). Heads of Environment Protection Agencies Australia and New Zealand (HEPA), January 2018; Environment Protection Agency Victoria, Melbourne [accessed via: www.epa.vic.gov.au/your-environment/land-and-groundwater/pfas-in-victoria/pfas-nemp-2-0].

Herbert, C. 2007a. *Distribution, abundance and status of birds in the Hunter Estuary.* Report to Newcastle City Council. Hunter Bird Observers Club. Special Publication No. 4.

Hill A.B. 1965. The Environment and Disease: Association or Causation? *J R Soc Med.* 1965;58(5):295–300. DOI:10.1177/003591576505800503, as referenced in: https://medium.com/datadriveninvestor/correlation-and-causation-part-2-how-to-infer-causation-from-observational-data-19de1ba3338b

Hogstrand, 2011. *Zinc – Fish Physiology*. Volume 31, Part A.

Holzer, J., Goen, T., Reupert, R., Raufuss, K., Kraft, M., Muller, J., and Wilhelm, M., 2011, Perfluorinated Compounds in Fish and Blood of Anglers at Lake Mohne, Sauerland Area, Germany. *Environmental Science and Technology* 45(19): 8046-8052 [DOI: 10.1021/es104391z].

Hoover, G.M., Chislock, M.F., Tornabene, B.J., Guffey, S.C., Choi, Y.J., De Perre, C., Hoverman, J.T., Lee L.S., and Sepulveda M.S., 2017, Uptake and depuration of four per/polyfluoroalkyl substances (PFASs) in northern leopard frog *Rana pipiens* tadpoles. *Environmental Science and Technology* Letters 4: 399-403.

Howe, A.J. Rodriguez, J.F., and Saco, P.M., 2009. Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter estuary, southeast Australia. *Estuarine, Coastal and Shelf Science* 84: 75-83.

Kleinfelder, 2015. *2015 Annual Vegetation Monitoring Report. Tomago Precinct Hunter Wetlands National Park*. For NSW NPWS. June 2015.

Kooragang Wetland Rehabilitation Project (KWRP), 2010. *Kooragang Wetland Rehabilitation Project Management Plan: Moving from Establishment to Sustainable Management.*

Igwe, JC & UKaogo, PO., 2015. Environmental Effects of Polycyclic Aromatic Hydrocarbons*. Journal of Natural Sciences Research*, Vol 5, No 7.

ILA, 2017. *Lead in Aquatic Environments: Understanding the Science.* International Lead Association, London.

Impact Fertilisers, 2018. *Monitoring of Flush Pit Discharge Online Database*. Available at: http://www.impactfertilisers.com.au/wp-content/uploads/Monitoring-Flush-Pit-Discharge-Analysis.pdf.

Jantzen, C.E., Annunziato, K.A., Bugel, S.M., and Cooper, K.R, 2016, PFOS, PFNA and PFOA sub-lethal exposure to embryonic zebrafish have different toxicity profiles in terms of morphometrics, behaviour and gene expression. *Aquatic Toxicology* 175: 160-170.

Kaplan, 2009. Amphibians rarely give earliest warning of pollution. *Nature*, 10, 1038.

Keiter, S., Baumann, L., Färber, H., Holbech, H., Skutlarek, D., Engwall, M., and Braunbeck, T., 2012, Long-term effects of a binary mixture of perfluorooctane sulfonate (PFOS) and bisphenol A (BPA) in zebrafish (*Danio rerio*). *Aquatic Toxicology* 118-119: 116-129.

Kim, J and Koo, T-H (2010) Acute and/or chronic contaminants of heavy metals in shorebirds from Korea. J. Environ. Monit., 12: 1613-1618.

Kim, J. and Oh, JM. 2012. Monitoring of heavy metal contaminants using feathers of shorebirds, Korea. *Journal of Environmental Monitoring 2012* (14),651-656.

KWRP, 2018. *History of the Hunter Estuary (Kooragang Wetland Rehabilitation Project (KWRP) Online Website.* Available at: https://kooragangwetlands.com/history-of-the-hunter-estuary/.

Lindsey, A., and McNaughton, N, 2012. Birds of Tomago Wetlands, Hunter Wetlands National Park 2007-2012. *The Whistler 6* (2012): 1-10.

Ludwig, D. & Iannuzzi, T. 2005. Incremental Ecological Exposure Risks from Contaminated Sediments in an Urban Estuarine River. *Integrated Environmental Assessment and Management,* 1(4);374–390

MacDonald, T., 2001. *The terrestrial ecology of the Hunter River Estuary.* A report prepared for Manly Hydraulics Laboratory as part of the Hunter Estuary Processes Study.

MacDonald, D.D., Ingersoll, C.G., Kemble, N.E. et al., 2011. Baseline Ecological Risk Assessment of the Calcasieu Estuary, Louisiana: Part 3. An Evaluation of the Risks to Benthic Invertebrates Associated With Exposure to Contaminated Sediments. *Arch Environ Contam Toxicol,* 61: 29.

MacDonald, M.M., Warne, A.L., Stock, N.L., Mabury, S.A., Solomon, K.R., and Sibley, P.K., 2004, Toxicity of perfluorooctane sulfonic acid and perfluorooctanoic acid to *Chironomus tentans*. *Environmental Toxicology and Chemistry* 23: 2116-2123.

Mahony, M. J., 1999. Review of the declines and disappearances within the bell frog species group (*Litoria aurea* species group). *Declines and disappearances of Australian frogs*, Campbell A. (ed). Australia, 81–93.

Mahony, M. J., Hamer, A. J., Pickett, E. J., McKenzie, D. J., Stockwell, M. P., Garnham, J. I., and Clulow, S., 2013. Identifying conservation and research priorities in the face of uncertainty: a review of the threatened bell frog complex in eastern Australia. *Herpetological Conservation and Biology*, *8* (3), 519-538.

Manly Hydraulics Laboratory (MHL), 2003. *Hunter Estuary Processes Study*. NSW Department of Commerce. Report No. MHL1095.

Mazumder, D., 2004. *Contribution of saltmarsh to temperate estuarine fish in southeast Australia.*

Miller et al, 2015. Temporal trends of perfluoroalkyl substances (PFAS) in eggs of coastal and offshore birds: Increasing PFAS levels associated with offshore bird species breeding on the Pacific coast of Canada and wintering near Asia. *Environmental Toxicology and Chemistry*, 34:8, 1799-1808.

Miller et al, 2018. *Hunter Estuary Wetlands Ramsar Contaminant Transport Modelling*. Department of the Environment and Energy. Report No. WRL 2018/31

Moss, 1983. *An investigation of the natural areas: Kooragang Island, Hunter River. 1983*. Report prepared by C.D. Field and Associates and Insearch Ltd. Department of Environment and Planning, Sydney.

Muir, D., Bossi, R., and Carlsson, P., 2017, Per- and polyfluoroalkyl substances. In *AMAP, 2017, AMAP Assessment 2016: Chemicals of Emerging Arctic Concern*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, pp. 3–58.

Munoz, G., Budzinski, H., Babut, M., Drouineau, H., Lauzent, M., Le Menach, K., Lobry, J., Selleslagh, J., Simonnet-Laprade, C., and Labadie, P., 2017, Evidence for the Trophic Transfer of Perfluoroalkylated Substances in a Temperate Macrotidal Estuary. *Environmental Science and Technology* 51: 8450-8459 [DOI: 10.1021/acs.est.7b02399].

National Climate Change Adaptation Research Facility (NCCARF), 2018. CoastAdapt. Climate change and sea-level rise in the Australian region. https://coastadapt.com.au/climate-change-and-sea-level-rise-australian-region Accessed March 2018.

National Parks and Wildlife Service (NPWS), 1998. Kooragang Nature Reserve and Hexham Swamp Nature Reserve Plan of Management.

National Parks and Wildlife Service (NPWS), 2015. Hunter Wetlands National Park Draft Plan of Management. NSW NPWS. September 2015

NEPC, 2013. *National Environment Protection (Assessment of Site Contamination) Amendment Measure 1999 (as amended and in force on 16 May 2013).* National Environment Protection Council.

NOW, 2018a. *Water Sharing Plans*. NSW Government, Office of Water. Available at: https://www.water.nsw.gov.au/water-management/water-sharing/plans-commenced/water-source/nccs-gw

NOW, 2018b. *Catchments and Basins*. NSW Government, Office of Water. Available at: https://www.water.nsw.gov.au/water-management/catchments-old/hunter-catchment

NSW Department of Commerce, 2003. *Hunter Estuary Processes Study, Report MHL1095*, New South Wales Department of Commerce, Manly Hydraulics Laboratory, November 2003.

NSW EPA, 2014. *Media Release – Prosecution of Orica for a further ammonia emission at Kooragang Island*. Available at: https://www.epa.nsw.gov.au/news/media-releases/2014/epamedia14040801

NSW EPA, 2015a. *Preliminary PFOS Risk Assessment for Seafood – Hunter River Prawns, Williamtown Contamination Expert Panel*, New South Wales Environment Protection Authority.

NSW EPA, 2015b. *Preliminary PFOS Risk Assessment for Seafood – Tilligerry Creek and Fullerton Cove, Williamtown Contamination Expert Panel*, New South Wales Environment Protection Authority.

NSW EPA, 2016. *Surface Water – PFOS Analytical Results Summary – Fullerton Cove, NSW*, New South Wales Environment Protection Authority, June 2016.

NSW EPA, 2017. *Media Release – Linx Logistics Pty Ltd fined $15,000 after Urea Spill.* Available at: https://www.epa.nsw.gov.au/news/media-releases/2017/epamedia19091703

NSW EPA, 2018. *Public Registers Online Database*. Available at: https://www.epa.nsw.gov.au/licensing-and-regulation/public-registers.

NSW Government, 2018. *Greater Newcastle Metropolitan Planning Online Database*, Department of Planning and Environment. Available at: http://www.planning.nsw.gov.au/Plans-for-your-area/Greater-Newcastle-metropolitan-planning.

NSW Legislation, 1997. *Contaminated Land Management Act 1997 No. 140*, Current version as of July 2017.

NYS, 1998. *New York State Aquatic Fact Sheet: Ambient Water Quality Values for Protection of Aquatic Life. Substance: Lead, Dissolved.* Accessed: https://www.epa.gov/sites/production/files/2015-06/documents/ny_al_394_03121998.pdf

OECD, 2002. Hazard assessment of perfluorooctane sulfonate (PFOS) and its salts. Ref: ENV/JM/RD(2002)17/FINAL, November 2002.

OEH, 2010. *State of the Catchments (SOC) Hunter-Central Rivers Region – State Plan Target*, Office of Environment and Heritage, New South Wales.

OEH, 2011. *Guidelines for Consultants Reporting on Contaminated Sites*, Office of Environment and Heritage, New South Wales, August 2011.

OEH, 2014a. *Statement of Management Intent Hunter Wetlands National Park*. June 2014.

OEH, 2014b. *Hunter climate change snapshot*. November 2014

OEH, 2015. *Hunter Wetlands National Park – Draft Plan of Management*.

OEH, 2016. *Health of the Hunter: Report Card 2015-2016*, Office of Environment and Heritage, New South Wales.

OEH, 2017a. *Lower Hunter River Health Monitoring Program, Legacies of a century of industrial pollution and its impact on the current condition of the lower Hunter River estuary*, Office of Environment and Heritage, New South Wales, August 2017.

OEH 2017b. *Preliminary Ecological Assessment of the Lower to Mid Hunter River Estuary 2015-16*, Office of Environment and Heritage, New South Wales, August 2017.

OEH, 2017c. *Lower Hunter River Health Monitoring Program, Water Quality Monitoring Program 2014-2015 Report*, Office of Environment and Heritage, New South Wales, August 2017.

OEH, 2017d. *Lower Hunter River Health Monitoring Program, Stormwater Quality Monitoring Program 2015 Report*, Office of Environment and Heritage, New South Wales, August 2017.

Orica, 2018. *Kooragang Island Water Monitoring Online Database.* Available at: http://www.orica.com/Sustainability/Environmental-Monitoring-Data/Kooragang-Island/Water-Monitoring#data.

Outhred, R.K., and Buckney, R.T., 1983. *Vegetation survey*. In, J. (ed). An investigation of the natural areas: Kooragang Island, Hunter River. 1983. Report prepared by C.D. Field and Associates and Insearch Ltd. Department of Environment and Planning, Sydney.

Park Pty Ltd, 2018. *Park Fuels EPL Licencing Monitoring Data Online Database*. Available at: http://parkfuels.com.au/page/pirmp.

Port Stephens Council, 2012. *Annual Report, Volume 3: State of the Environment Report*, Port Stephens Council, New South Wales, November 2012.

Preston, B, 2002. Indirect effects in aquatic ecotoxicology: implications for ecological risk assessment. *Environmental Management,* 29(3):311-23.

Ramade, F. 1997. Assessment of damage to ecosystems: a major issue in ecotoxicological research. *Qual Assur*., 5(3):199-220.

Reid, T., & Park, P., 2003. Continuing decline of Eastern Curlew, Numenius madagascariensis, in Tasmania. *Emu*, *103*(3), 279-283.

RIVM National Institute for Public Health and the Environment, 2010. *Environmental risk limits for PFOS: A proposal for water quality standards in accordance with the Water.* Report 601714013/2010.

Roderick, M. and Stuart, A., 2016. Threatened bird species in the Hunter Region 2016 status review. In *The Whistler* 10: 33-49.

Rogers, K., Wilton, K.M., and Saintilan, N., 2006. Vegetation change and surface elevation dynamics in estuarine wetlands of southeast Australia. *Estuarine, Coastal and Shelf Science* 66, 559-569.

Rogers, K., Saintilan, N., and Copeland, C., 2014. Managed retreat of saline coastal wetlands: challenges and opportunities identified from the Hunter River Estuary, Australia. *Estuaries and Coasts*, 37 (1) 67-78.

Rogers, K, 2016. A case study of good coastal adaptation on the Hunter River NSW. Case Study of CoastAdapt, National Climate Change Adaptation Research Facility, Gold Coast.

Rose G., Jones W.H. and Kennedy D.R., 1966. *Newcastle 1:250 000 Geological Sheet SI/56-02, 1st edition*. Geological Survey of New South Wales, Sydney.

Roy, P. S., Williams, R. J., Jones, A. R., Yassini, R., Gibbs, P. J., Coates, B., West, R. J., Scanes, P. R., Hudson, J. P., and Nichol, S., 2001. Structure and function of south-east Australian estuaries. *Estuarine, Coastal and Shelf Science* 53:351-384.

Roscales, J.L., Vicente, A., Ryan, P., Gonzalez-Solis, J., and Jimenez, B., 2019, Spatial and Interspecies Heterogeneity in Concentrations of Perfluoroalkyl Substances (PFASs) in Seabirds of the Southern Ocean. *Environmental Science and Technology* [DOI: 10.1021/acs.est.9b02677].

Ruello, N.V. 1976. *Environmental and biological studies of the Hunter River.* Operculum, pp. 76-84

Russell, K., Erskine, J. and Glamore, W., 2012. *Tomago Wetland Rehabilitation Project: Integrated, Innovative Approaches*. In: NSW Coastal Conference 2012.

Russell, W.R., Gobas, F.A.P.C., and Haffer, G.D., 1999, Role of Chemical and Ecological Factors in the Trophic Transfer of Organic Chemicals in Aquatic Food Webs. *Environmental Toxicology and Chemistry* 18: 1250-1257.

Saintilan, N., and Williams R.J., 1999. Mangrove transgression into saltmarsh environments in South-East Australia. *Global Ecology and Biogeography*, 8, 117-124.

Saintilan, N., Wilson, N., Rogers, K., Rajkaran, A. and Krauss, K. W., 2014. Mangrove expansion and salt marsh decline at mangrove poleward limits. *Global Change Biology*, 20 (1), 147-157.

Sanderson & Redden, 2001. *Hunter River Estuary Water Quality Data Review and Analysis*, Centre for Sustainable Use of Coasts and Catchments, Ourimbah Campus, University of Newcastle, December 2001.

SA EPA, 2017. *Per and polyfluorinated alkyl substances (PFAS) in the marine environment – Preliminary ecological finding*s. SA EPA, Adelaide.

Simpson et al., 2001a. *Chemical and ecotoxicological testing of dredged sediment from Newcastle Harbour: MPT Stage 1 Capital Dredging, CSIRO Energy Technology Investigation Report*, CET/IR399, CSIRO.

Simpson et al., 2001b. *Chemical and ecotoxicological testing of dredged sediment from Newcastle Harbour: South Arm Master Plan Dredge Area, CSIRO Energy Technology Investigation Report*, CET/IR400R, CSIRO.

Simpson et al., 2001c. *Chemical and ecotoxicological testing of dredged sediment from Newcastle Harbour: MPT Stage 2 / K7 area, CSIRO Energy Technology Investigation Report*, CET/IR401R, CSIRO.

Simpson et al., 2001d. *Relationships between chemical contaminants and ecotoxicological effects for dredged Newcastle Harbour sediments, CSIRO Energy Technology Investigation Report*, ET/IR435R, CSIRO.

Simpson et al., 2002. *Relationships between PAHs and ecotoxicological effects on Algae, Amphipods and Bivalves for Newcastle Harbour Sediments, CSIRO Energy Technology Investigation Report,* ET/IR541R, CSIRO.

Skerratt, L. F., Berger, L., Speare, R., Cashins, S., McDonald, K. R., Phillott, A. D., Hines, H. B. and Kenyon, N. 2007. Spread of chytridiomycosis has caused the rapid global decline and extinction of frogs. *EcoHealth* **4**:125–134.

Sparling, D. W., Linder, G. and Bishop, C. A. 2000. Ecotoxicology of amphibians and reptiles. SETAC Press, Pensacola, Florida

Spencer, J. and Howe, A., 2008. *Estuarine wetland rehabilitation and ecohydraulics: the links between hydraulics, sediment, benthic invertebrates, vegetation and migratory shorebird habitat. Summary of major findings and recommendations*. Final report to the Kooragang Wetland Rehabilitation Project and Energy Australia. May 2008.

Stockwell, M. P., Clulow, S., Clulow, J. and Mahony, M. 2008. The impact of the amphibian chytrid fungus *Batrachochytrium dendrobatidis* on a green and golden bell frog *Litoria aurea* reintroduction program at the Hunter Wetlands Centre Australia in the Hunter Region of NSW. *Australian Zoologist* **34**:379–386.

Stockwell, M. P., Storrie, L. J., Pollard, C. J., Clulow, J., and Mahony, M. J. 2015. Effects of pond salinization on survival rate of amphibian hosts infected with the chytrid fungus. *Conservation Biology*, 29, 391–399.

Stuart, A., Herbert, C., Crawford, L., Lindsey, A., Roderick, M., McNaughton, N., Powers, J., and Huxtable, L., 2013. Hunter Estuary Population Counts 1999-2010. Stilt 63-64 (2013): 46-49

Stuart, A (2017) Red-necked Avocet *Recurvirostra novaehollandiae* in the Hunter Estuary of New South Wales. Stilt 71: 3-8

Taylor, M.P. and Cosenza, I.J., 2016. *Review of the New South Wales Environment Protection Authority's Management of Contaminated Sites, Final Report*, Macquarie University, New South Wales, December 2016.

Taylor, M.D., Beyer-Robson, J., Johnson, D.D., Knott, N.A., and Bowles, K.C., 2018. Bioaccumulation of perfluoroalkyl substances in exploited fish and crustaceans: spatial trends across two estuarine systems. Marine Pollution Bulletin 131:303-313.

The Ecology Lab., 2001. *Hunter Estuary Processes Study: Aquatic Ecology*. Report to Manly Hydraulics Laboratory, Final Draft June 2001.

The Ecology Lab Pty Ltd, 2003. *Proposed Extension of Shipping Channels, Port of Newcastle; Appendix G, Assessment of Aquatic Ecology*. Report prepared for GHD Pty Ltd.

Thompson, J., Roach, A., Eaglesham, G., Bartkow, M.E., Edge, K., and Mueller, J.F., 2011. Perfluorinated alkyl acids in water, sediment and wildlife from Sydney Harbour and surroundings. Marine Pollution Bulletin 2: 2869-2875.

Threlfall, C. G., Jolley, D. F., Evershed, N., Goldingay, R. L. and Buttember, W. A. 2008. Do green and golden bell frogs *Litoria aurea* occupy habitats with fungicidal properties? Australian Zoologist, 43(3), 350-358.

Tomago Aluminium, 2018. *Monitoring Results Online Database.* Available at: http://www.tomago.com.au/health-safety/monitoring-results.

Toms et al, 2014. Decline in perfluorooctane sulfonate and perfluorooctanoate serum concentrations in an Australian population from 2002 to 2011. *Environment International*, 71:74-80.

Umwelt Australia Pty Ltd (Umwelt), 2012. *Ecological Assessment for Port Waratah Coal Services (PWCS) Proposed Terminal 4 (T4) Project, Port of Newcastle NSW*.

Umwelt Australia Pty Ltd (Umwelt) and Avifauna Research and Services, 2017. *Towra Point Nature Reserve Ramsar Site Formal Assessment of Change in Ecological Character.* Prepared for Australian Government Department of the Environment and Energy.

URS, 2004. *Human health and ecological risk assessment of sediments in the south arm of the Hunter River: Final Report*, URS Australia Pty Ltd, Sydney, New South Wales.

URS, 2015. *AFFF PFAS, RAAF Base Williamtown, Williamtown NSW*, URS Australia Pty Ltd, September 2015.

Wang, S., Zhuang, C., Du, J., Wu, C., and You, H., 2017, The presence of MWCNTs reduces developmental toxicity of PFOS in early life stage of zebrafish. *Environmental Pollution* 222: 201-209.

Warne, M., Batley, G. van Dam, R., Chapman, J., Fox, D.R., Hickey, C., and Stauber, J., 2018, *Revised Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants – update of 2015 version*. Prepared for the revision of the Australian and New Zealand

Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra, 48 pp.

Water Research Laboratory (WRL), 2018. *Supplementary Letter: Hunter Estuary Wetlands Ramsar Contaminant Transport Modelling Additional Results of Bed Shear*. Department of the Environment and Energy. WRL Ref: WRL2018059 BMM 20181217

Williams, R.J, F.A. Watford and V. Balashov., 2000. *Kooragang Wetland Rehabilitation Project: History of Changes to estuarine Wetlands of the Lower Hunter River.* NSW Fisheries Final Report series No.22 (2000).

Warnock, N., Page, G. W., and Stenzel, L. E., 1995. Non-migratory movements of Dunlins on their California wintering grounds. *The Wilson Bulletin*, 131-139

West, R.J., Thorogood, C., Watford, T., and Williams, R. J., 1985. An estuarine inventory for New South Wales, Australia. Fisheries Bulletin 2. Division of Fisheries, Sydney. September 1985.

Winning, G., 1996. *Vegetation of Kooragang Nature Reserve and Hexham Swamp Nature Reserve and adjoining land.* Report for NSW National Parks and Wildlife Service. The Wetlands Centre, Shortland, NSW.

APPENDIX A

Ramsar Information Sheets

NAME:	Kooragang Nature Reserve
I.U.C.N COMMISSION ON NATIONAL PARKS AND PROTECTED AREAS CLASSIFICATION:	Nature Reserve
LOCATION:	(a) General Co-ordinates - 32° 51' 30"S 151° 46' 00"E (b) Description - Located in the Hunter River catchment approximately 7 km north of Stockton adjacent to Fullerton Cove N.S.W. (c) Map - Williamstown 1:25,000 orthophotomap; Newcastle 1:63,360
AREA DEDICATED:	Approximately 2,206 ha.
LEGAL PROTECTION:	Dedication under Section 49(1) of the New South Wales National Parks and Wildlife Act 1974, with By-laws under Section 155 of that Act.
DATE ESTABLISHED:	25 March 1983.
LAND TENURE:	Lands of the Crown dedicated under the New South Wales National Parks and Wildlife Act 1974.
MANAGEMENT AUTHORITY:	National Parks and Wildlife Service of N.S.W.
PHYSICAL DESCRIPTION:	Part of Hunter River catchment as a modified delta with islands and creeks. Extensively modified by man in part.
HABITAT TYPES:	Estuarine wetland vegetation communities including mangroves, saltmarshes, brackish and freshwater swamps and tidal mudflats.
WATERFOWL CONSERVATION VALUE:	The area is noted for its birdlife particularly migratory waders. One hundred and ninety species of birds have been recorded, representing 25% of the species known in Australia.

The total number of waders recorded was 5,020 compared to 5,816 waders in the total Hunter River wetland (National Parks and Wildlife Service 1983). Overall, 38 of the 66 species of migratory waders presently covered in the Japan-Australia Migratory Birds Agreement occur in this wetland area. (National Parks and Wildlife Service 1983).

Also of significance is the occurrence (1983) of 14.6% of the total observed population of the Lesser Golden Plover Pluvialis dominica and 5.9% of the Eastern Curlew Numenius madagascariensis.

GENERAL CONSERVATION

The conservation value of Kooragang Nature Reserve lies in the fact that it is a large area of productive estuarine wetland containing a variety of wetland habitat types. The area is ecologically diverse and represents a significant genetic pool for wetland species in the region.

Of special interest is its international significance to waterbirds, particularly migratory species. Several rare waders have been recorded in the reserve for example, the Ringed Plover Charadrius hiaticula, Large Sand Plover Charadrius leschenaultii, Little Curlew Numenius minutus, Pectoral Sandpiper Calidris melanotos and Ruff Philomachus pugnax.

The area also has significance as an important part of the nutrient budget of the lower Hunter estuarine system.

MANOR MANAGEMENT PROBLEMS:

Existing problems are noxious plants and animals, access and the problem of rubbish dumping owing to its vicinity to urban areas. The water levels in the area west of Fullerton Cove will require active management.

PROHIBITED ACTIVITIES:

Those activites controlled by By-laws under the National Parks and Wildlife Act, 1974.

SELECTION CRITERIA MET:

Of the recommended criteria to be used in identifying Wetlands of International Importance, the Kooragang Nature Reserve meets criteria 1(b), 2(a), 2(b) and 3.

REFERENCE MATERIALS:

"Kooragang Island/Fullerton Cove Proposed Nature Reserve". Investigation Report - S.L. Hodges, 1980 National Parks and Wildlife Service
National Parks and Wildlife Service, 1983 - Results from the 1983 Summer Wader Counts. Internal Report.

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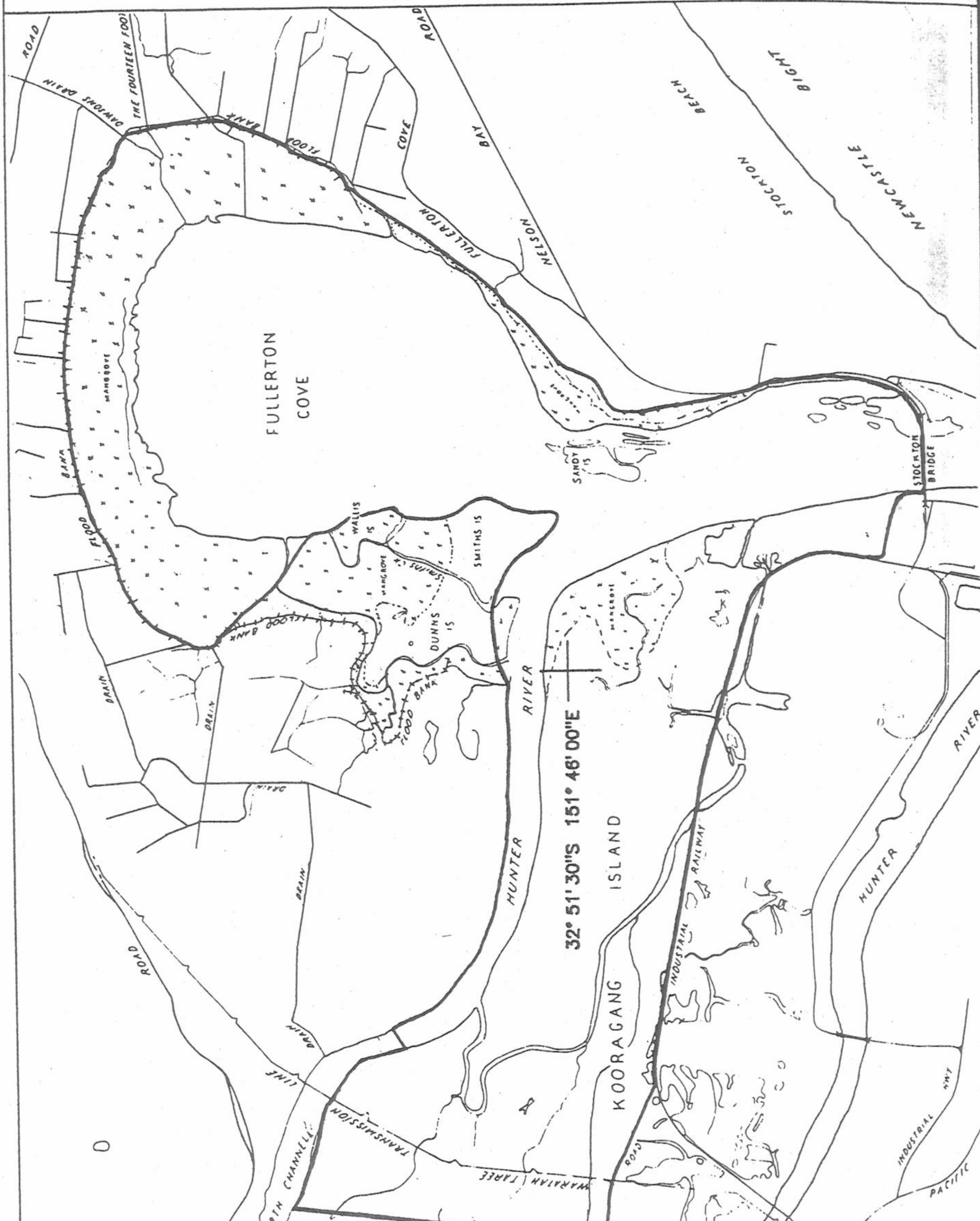
National Parks and Wildlife Service, 1983 - Results from the 1983 Summer Wader Counts. Internal Report.

KOORAGANG NATURE RESERVE



1km NORTH SCALE 1:45,000

Information Sheet on Ramsar Wetlands

Categories approved by Recommendation 4.7 of the Conference of the Contracting Parties

1. **Date this sheet was completed/updated**: October 2002

2. **Country**: Australia

3. **Name of wetland**: Hunter Estuary Wetlands

4. **Geographical coordinates**:
Kooragang: Latitude: 32^{0} 51'S; Longitude: 151^{0} 46'E
Shortland: Latitude: 32^{0} 53'S; Longitude: 151^{0} 41'E

5. **Elevation**: 0-10m ASL

6. **Area**: **Kooragang** - 2,926 hectares; **Shortland** – 45 hectares

7. **Overview**:
The Hunter Estuary Wetlands Ramsar site comprises Kooragang Nature Reserve (designated to the Ramsar list in 1984) and Shortland Wetlands. The boundary of Shortland Wetlands is 2.5 km from Kooragang Nature Reserve and is connected to it by a wildlife corridor consisting of Ironbark Creek, the Hunter River and Ash Island.

Kooragang Nature Reserve lies in the estuarine section of the Hunter River. The Reserve and surrounding areas have become known as one of the most important bird study areas in New South Wales. The area is extremely important as both a feeding and roosting site for a large seasonal population of Palaearctic shorebirds and as a waylay site for transient migrants. The site also supports a significant number of birds that over-winter.

Shortland Wetlands is a small but unique complex of wetland types surrounded by urban development along three boundaries. Previously degraded, this urban wetland has been restored with the key objectives of wetland conservation, education and community involvement. The site provides habitat for a diverse range of wetland species, including waterbirds at a critical stage of their lifecycles and threatened species.

8. **Wetland Type**:

marine-coastal:	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Zk(a)**
inland:	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**Sp**	**Ss**	**Tp**	**Ts**	
	U	**Va**	**Vt**	**W**	**Xf**	**Xp**	**Y**	**Zg**	**Zk(b)**			
human-made:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Zk(c)**		

Please now rank these wetland types by listing them from the most to the least dominant:

Kooragang Nature Reserve: I, F, H, G, J, K, E, D

Shortland Wetlands: Ts, Ss, Xf, Type 2

9. **Ramsar Criteria**: (please circle the applicable criteria; see point 12 below)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**

These criteria are:

Criterion 1: Contains a representative, rare or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.

Criterion 3: Supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region."

Criterion 4: Supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.

Criterion 6: Regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

Please specify the most significant criterion applicable to this site:

Criterion 4

10. **Map of site included**? Please tick **YES** --or-- **NO**

11. **Name and address of the compilers of this form**:

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12. Justification of the criteria

Criterion 1:

Shortland Wetlands is unique in that it has, within its 45ha site, a combination of high conservation value near-natural wetlands (Melaleuca Swamp Forest, freshwater reed marsh, coastal estuarine mangrove-lined creek) and high conservation value artificial wetlands (constructed freshwater lagoons, coastal estuarine Casuarina-lined channel, model farm dam). It is the only complex of this type found within the Sydney Basin biogeographic region. The Melaleuca Swamp Forest in particular represents a wetland type that, although once very widespread, is poorly represented in the Sydney Basin biogeographic region.

Criterion 3:

Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin biogeographic region. Winning (1996) identified 112 species of vascular plants at Kooragang Island (Appendix 4) which form many distinct habitat types (see Category 16). The Mangrove and Saltmarsh areas are particularly good examples of these plant communities.

The most significant wetland plant community at Shortland Wetlands is the Melaleuca Swamp Forest, dominated by Broad-leaved Paperbark *(Melaleuca quinquenervia*). The Swamp Forest is remnant of a plant community that was once very wide spread in this area and is now poorly represented in the Sydney Basin biogeographic region.

The Hunter Estuary Wetlands are also important for maintaining a high diversity of birds within the biogeographic region with over 250 species recorded (Appendix 1).

Criterion 4:

Kooragang Nature Reserve is widely recognised for its importance in the conservation of migratory birds (Geering 1995; NPWS 1998). At least 38 species of migratory birds recorded at Kooragang and 21 species of migratory birds at Shortland Wetlands are presently listed under International treaties including the Japan-Australia and China-Australia Migratory Bird Agreements (JAMBA and CAMBA) (Appendix 1).

In 2000, 4,800 migratory shorebirds were recorded in the Hunter Estuary (Straw 2000). Kooragang Nature Reserve regularly supports 15 species of migratory shorebird. Shortland Wetlands regularly provides habitat for at least seven species of migratory shorebird, particularly when muddy margins of the ponds become exposed (Appendix 1).

Kooragang and Shortland Wetlands also support a large number of species at a critical seasonal stage of their breeding cycle. Twenty-four of the 28 bird species recorded breeding at Shortland also occur at Kooragang (see Appendix 2).

The site provides refuge for a number of species during periods of critical inland drought. These species include Freckled Duck (*Stictonetta naevosa)*; Pink-eared Duck (*Malacorhynchus membranaceus)*; Australian Pelican (*Pelecanus conspicillatus)*; and Glossy Ibis (*Plegadis falcinellus)* (Albrecht and Maddock 1985). The site is also

important for local resident ducks, herons and other waterbirds, with up to 2000 ducks recorded at Shortland Wetlands during dry periods (Winning 1989).

Criterion 6:

Kooragang Nature Reserve regularly supports between 2% and 5% of the East Asian-Australasian Flyway population of Eastern Curlew *(Numenius madagascariensis)*, with counts ranging from 320 to 900 birds between 1989 and 2000 (Straw 2000). The 1% population threshold for this species is 210 individuals (Rose and Scott 1997).

13. **General location**

The Hunter Estuary Wetlands Ramsar site comprises Kooragang Nature Reserve (designated to the Ramsar list in 1984) and Shortland Wetlands. Although the sites are not contiguous they have significant linkages.

Kooragang Nature Reserve is located in the estuary of the Hunter River, approximately 7km north of Newcastle on the coast of New South Wales. Shortland Wetlands are located in the Ironbark Creek Catchment in the suburb of Shortland, 12km northwest of Newcastle and 2.5 km from Kooragang Nature Reserve. The Ironbark Creek Catchment, which also includes Hexham Swamp, is a sub-catchment of the Hunter Estuary.

The two sites are linked hydrologically and by a wildlife corridor consisting of Ironbark Creek, the Hunter River and Ash Island (NPWS 1998). The sites are complementary as together they provide a representative range of wetland types found in coastal estuaries within the Sydney Basin biogeographic region. They provide habitat for a great diversity of flora and fauna species that are common to both sites and are highly used by numerous waterbird species for feeding and roosting.

The population of Newcastle in 2000 was over 140,000.

14. **Physical features**

Kooragang Nature Reserve

Kooragang Nature Reserve comprises Kooragang Island and Fullerton Cove, two areas that lie in the estuarine section of the Hunter River.

Kooragang Island originally consisted of several smaller islands or bars (NPWS 1998). Attempts to control deposition and siltation of the Newcastle port area resulted in the artificial filling of channels and the construction of training walls (NPWS 1998). Fullerton Cove is a large, shallow embayment north of Kooragang Island. It has a maximum depth of two to three metres at its centre and at low tide large areas of mudflats are exposed.

The lower Hunter River is a barrier estuary formed by the deposition of sediments in swamps and flats lying between the inner and outer coastal barrier sands (NPWS 1998). The sediments on Kooragang Island and adjacent estuarine areas comprise black silty and highly saturated soft clays to a depth of about 2m which are underlain by a light grey and

silty sand (NPWS 1998). Salinities may vary from 70% in evaporative salt marsh areas to 8% behind levees where the soil is generally more fertile and regularly flooded by fresh water (NPWS 1998).

Most soils of Kooragang Island are only slightly acidic, although small areas of sandy clays supporting brackish swamps can reach significantly low pH and create the potential for acid sulphates to occur, should they be permanently dried out or drained (NPWS 1998).

The tidal variation for Kooragang Island is 0.1m to 2m. Average annual rainfall at Williamtown (nearest gauging station) is 1088 mm. The mean temperature ranges from 22.7°C to 12.2°C.

Shortland Wetlands

Shortland Wetlands is a restored and remnant wetland bounded on the south by the suburb of Shortland, on the east by a major arterial road, on the north by an old landfill site and on the west by Ironbark Creek and Hexham Swamp. There are strong ecological links between Hexham Swamp, Shortland Wetlands and the western end of Kooragang Nature Reserve (NPWS 1998).

Shortland Wetlands is situated on Quaternary estuarine/lacustrine sediments including silts and clays (Matthei 1995). The site consists of seven discreet but interconnected ponds and a freshwater channel. Four of these ponds are natural and three are man-made. The man-made ponds have been constructed on old landfill sites that were subsequently used as sporting fields.

Water flows from adjacent urban areas into the wetlands and is controlled by various methods. It flows from south-east to north-west through the ponds and exits the site into Ironbark Creek. The average size of the ponds is $14m^2$ and each pond varies in depth from 0.4m to 1m (Bischof and Brown 1996). Most ponds are permanent, with varying water levels, although the Reed Marsh dries bi-annually. Water may be pumped into ponds from a nearby channel but this is rarely done. There is no tidal variation. The catchment area is not known but includes the urban suburbs of Shortland, Waratah West and Warabrook.

Water quality is consistent with natural, freshwater ponds. Abiotic measurements indicate that pH is generally between 6.2 and 7.9. Water temperature varies seasonally between 14°C and 24°C and turbidity is usually less than 10ntu. Salinity is less than 1% (Grace and Francesconi 1997).

The water flowing from Shortland Wetlands enters Ironbark Creek and subsequently the Hunter River. At peak flood times Shortland Wetlands becomes a storage area for approximately $42,000m^3$ of water (Sinlaparommard 1999).

15. **Hydrological values**:

Kooragang Nature Reserve

Kooragang Island originally consisted of seven islands that were mostly separated by narrow mangrove lined channels. One of the larger channels was Moscheto Creek which

linked the north and south arms of the river. In the 1950s the islands were reclaimed and as a result the hydrological regime of what became “Kooragang Island” and the Hunter Estuary was modified (NPWS 1998).

Restrictions in tidal, normal and flood river flows have resulted from the reclamation. Flows through the south arm of the Hunter River have increased. Moscheto was occluded at its southern end by an industrial railway to become tidal via the north arm only (NPWS 1998).

In 1970 a levee bank was built around Fullerton Cove in an effort to ameliorate flooding in low-lying areas of Newcastle, downstream of Kooragang Island (NPWS 1998). Drains were installed to reclaim the significant wetland areas behind the levees for agriculture. This levee provides some protection to agricultural lands during minor floods but the levee is overtopped in major floods (NPWS 1998).

Shortland Wetlands

Shortland Wetlands are a natural drainage depression, a remnant of extensive tidal and floodplain wetlands that once extended east of Ironbark Creek. Changes in the natural flow regime have been caused by the construction of floodgates on Ironbark Creek and a drainage canal from Sandgate Road to Ironbark Creek, the establishment of a garbage dump, the construction of a power transmission line and associated access roads and development as a sporting complex (Winning 1989). These actions restricted the entry of saline tidal water, changing the wetlands from a brackish to fresh water regime (Winning 1989). All of these actions pre-date the establishment of Shortland Wetlands as a Wetlands Centre.

Water flowing into Shortland Wetlands today is generated by local rainfall and run-off from nearby suburbs. Stormwater pipes and culverts collect stormwater from lands and suburbs to the south, east and north and deliver water to the Wetlands (NCC 2000).

Shortland Wetlands delivers water to Ironbark Creek or to a constructed channel via a series of drainage points along Ironbark Marsh and on the northern boundary of the site. However, the flow occurs only after periods of heavy rain or when Ironbark Marsh is at full capacity (Sinlaparommard 1999).

Shortland Wetlands is valuable for the storage of rainfall and stormwater which provide habitat for significant wetland fauna and flora species. The Wetlands enable the recycling of nutrients that enter the site in stormwater or through the activity of nesting birds.

16. **Ecological features**

Kooragang Nature Reserve

Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin bioregion.

Habitat types mapped within the site (Briggs, Dames and Moore, Outhred and Buckney *in* NPWS 1998) include:

- Mangrove forests dominated by Grey Mangrove (*Avicennia marina*) and some River Mangrove (*Aegiceras corniculatum*);
- Saltmarsh dominated by Samphire (*Sarcocornia sp*.) and Saltwater Couch (*Sporobolus virginicus*). The saltmarsh community to the west of Fullerton Cove was once the largest in the region (Moss 1983). The present levee bank and drains have led to it being replaced with drier pasture grasses such as Paspalum (*Paspalum vaginatum*), Buffalo, Kikuyu (*Pennisetum clandestinum*) and Couch (*Cynodon sp*.);
- Saline and freshwater pastures are dominated by Couch and other agricultural grasses, sedges and introduced weeds;
- Swamp Forests consisting of Swamp She-oak (*Casuarina glauca*) and Paperbarks (*Melaleuca spp*.) that are now limited;
- Rainforest communities exist in remnants on Kooragang Island. Isolated individual Fig trees (*Ficus spp*.) and Cabbage Tree Palms (*Livistona australis*) occur;
- Brackish swamps and standing open water containing Sedges (*Scirpus spp*.) and other aquatic species; and
- Other important habitats include standing open water, mudflats, sandy beaches and rock retaining walls.

Shortland Wetlands

Shortland Wetlands were originally part of the estuarine wetlands of lower Ironbark Creek, with saltmarsh and mangroves extending well into the present site.

Today the site represents a remnant wetland that maintains its ecological connections to fresh, brackish and saline wetlands elsewhere in the estuary through its connection to Ironbark Creek. Although the floodgates on Ironbark Creek are still in place, their management is to be modified in the near future, allowing increased tidal flows into the creek system. This may enhance the brackish wetland values on the site.

The main habitats and vegetation types on the site include restored semi-permanent/seasonal freshwater ponds and marshes, natural semi-permanent/seasonal brackish ponds and marshes, freshwater swamp forests and a coastal estuarine creek.

Variations in water levels in the ponds result in a significant range of vegetation succession across the site annually, contributing to biodiversity values, especially in macro-invertebrate populations.

Over 150 flora species occur on the site (Appendix 4) within 22 vegetation communities (Beretta 1998). Floral communities include: Closed *Commersonia* Forest, Closed Mangrove Forest, Open Planted Rainforest, *Casuarina* Forest, Open *Melaleuca* Swamp Forest, Open Woodland, Wet Heath, *Banksia* Shrubland, *Acacia* Shrubland, Water Couch Wet Meadow, Closed *Typha* Rushland, Closed *Phragmites* Reed Swamp, *Juncus* Rushland and several large remnant Eucalypts.

The site contains a high diversity of original and rehabilitated plant communities and has undergone a committed landscaping effort (see Category 17).

Since 1996 over 32,000 trees have been planted on the site into four zones:

1. Visitor Centre Zone (native Australian plants);
2. Constructed Wetlands (plants native to the local region);
3. Natural Wetlands (plants native to the site); and
4. Rainforest Zone (a rehabilitated rainforest).

These plantings have significantly changed the landscape, enhancing natural processes on the site. The distribution and abundance of these plant communities create a stable and complex ecosystem that contributes to hydrologic processes, soil stabilisation and fauna diversity. The reedy margins provide breeding and feeding areas for waterfowl and vegetation in shallow pool margins provides foraging sites for shorebirds.

17. **Noteworthy flora**

Kooragang Nature Reserve

A list of flora species compiled by Winning (1996) identified 112 species of vascular plants at Kooragang Island (Appendix 4) which form many distinct habitat types (see Category 16). The Mangrove and Saltmarsh areas are particularly good examples of these plant communities.

The estuarine herb *Zannechellia palustris* has been recorded immediately adjacent to the western end of the Reserve. This herb is only found in the Newcastle/Lake Macquarie area and along Ironbark Creek. The rainforest vine *Cynanchum elegans* is listed as Endangered under both State (TSC Act) and Commonwealth (EPBC Act) legislation. It occurs adjacent to the western boundary of the Reserve and has only been recorded in 40 other sites in NSW (NPWS 1998).

Shortland Wetlands

The most significant wetland plant community at Shortland Wetlands is the Melaleuca Swamp Forest, dominated by Broad-leaved Paperbark *(Melaleuca quinquenervia*). The Swamp Forest is remnant of a plant community that was once very wide spread in this area and is now poorly represented in the Sydney Basin bioregion.

Shortland Wetlands is significant for a range of plant communities that have been successfully re-introduced to the site, including:

- Open Rainforest developed around remnant rainforest species dominated by Turpentine (*Syncarpia glomulifera),* Lilly Pilly *(Acmena smithii),* Scentless Rosewood *(Synoum glandulosum),* Cheese Tree *(Glochidion ferdinandi)* and Bleeding Heart *(Omalanthus populifolius*);
- Open Eucalypt woodland dominated by Swamp Mahogany (*Eucalyptus robusta*), Red Bloodwood (*Eucalyptus gummifera*) and Grey Gum (*Eucalyptus punctata*);
- Melaleuca Shrubland dominated by Ball Honeymyrtle (*Melaleuca nodosa*), Swamp Paperbark (*Melaleuca ericifolia*), Prickly-leaved Paperbark (*Melaleuca styphelioides*), and Swamp Millet (*Isachne globosa*);
- Acacia Shrubland dominated by Sydney Golden Wattle *(Acacia longifolia*);

- Wet Heath dominated by *Callistemon citrinus, Banksia robur* and Christmas Bells (*Blandfordia grandiflora*); and
- Casuarina Forest dominated by Swamp Oak (*Casuarina glauca*).

18. **Noteworthy fauna**

The Hunter River Estuary is renown for its birdlife. Over 250 species of birds have been recorded across the Hunter Estuary Wetlands site (Appendix 1). The occurrence of migratory waterbirds is of particular importance. In 2000, 4,800 migratory shorebirds were recorded in the Estuary (Straw 2000). At least 45 migratory species presently listed under the Japan-Australia Migratory Bird Agreement (JAMBA) and/or the China-Australia Migratory Bird Agreement (CAMBA) have been recorded at the site including 38 species at Kooragang and 21 species at Shortland, with 14 of these species common to both areas (Appendix 1).

The Estuary has supported more than one percent of the Australian populations of sixteen migratory wading species (Smith 1991) and based on this criterion has been ranked as the fifth most important site for shorebirds in Australia (Watkins 1993). It has also been recognised as the most important area for shorebirds in NSW (Smith 1991).

The site provides habitat for numerous threatened species listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act) (see Appendix 1). The Green and Golden Bell Frog (*Litoria aurea*) is also listed as vulnerable nationally under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). A project is currently underway to re-introduce the Bell Frog to Shortland Wetlands. The Australasian Bittern (*Botaurus poiciloptilus)* is also listed as vulnerable globally (IUCN 2000) and the Red Goshawk (*Erythrotriorchis radiatus*) is vulnerable nationally (EPBC Act).

Threatened species (under the TSC Act) include Black-necked Storks (*Ephippiorhynchus asiaticus)*, Australasian Bittern, Comb-crested Jacana (*Irediparra gallinacea)* and Magpie Geese (*Anseranas semipalmata)*. Black-necked Storks regularly use the site during their nomadic movements throughout the lower Hunter region. Australasian Bittern occur as a small, probably breeding population, but are rarely seen because of their secretive nature. Comb-crested Jacana is a rare species within the lower Hunter region. It has been reported at Kooragang Island and is a rare visitor to Shortland Wetlands. In 1987, the Wetlands Centre initiated a re-introduction of the locally extinct Magpie Goose and now supports a breeding population of more than 100 Geese. The Centre is one of four centres hosting a Freckled Duck captive-breeding program.

A total of seven mammal species have been recorded at Shortland Wetlands with only two of these being native. Several species of frogs, tortoise, skinks and snakes have been recorded at the site, all of which are common to the region (Appendix 3). Records for these species are currently not available for Kooragang.

The Hunter Estuary contains about 15 species of commercially important fish, crustacea and molluscs. The industry has been estimated at around a half a million dollars annually with major components being mullet, jewfish, prawn and oyster fisheries which together provide about 8% of the NSW annual catch (NPWS 1998).

Pond life at Shortland Wetlands is abundant. Six species of fish have been recorded (see Appendix 3). A wide diversity of macro-invertebrates is present including many sensitive insect larvae. Macro-invertebrate surveys routinely record molluscs, bloodworms, caddisfly larvae, gastropods, beetles, bugs, water fleas, seed shrimps, copepods and nymph forms of dragonfly, damselfly, stonefly and mayfly (Bischof and Brown 1996).

19. **Social and cultural values**

Kooragang Nature Reserve

Kooragang Nature Reserve and the surrounding areas have become known as one of the most important bird study areas in New South Wales. The Reserve is used for both research and recreational birdwatching. Limited recreational fishing is also undertaken within the Reserve.

The Worimi and Awabakal Aboriginal tribes were the earliest inhabitants of the lower Hunter Estuary (NPWS 1998). There are numerous middens and campsites scattered throughout the lower Hunter but they occur particularly along the riverbanks and within the dunes along Stockton Bight. The nearest Aboriginal sites outside the Reserve come from the dunes and coastal forests between Fullerton Cove and Stockton Bight where many and varied sites are known to occur (NPWS 1998).

There are a few European historic sites within Kooragang Nature Reserve. These include concrete footings of an old munitions store on Sandy Island, a timber bridge, a mature Moreton Bay Fig associated with early farming and a half submerged timber drogher.

Shortland Wetlands

Historically the site now occupied by Shortland Wetlands would have been well-used by Aboriginal people as a food and materials source due to their productive and dynamic nature. The present site was occupied by the Pambalong people, a smaller tribe of the Awabakal People (Sokoloff 1974). Shortland Wetlands contains a significant archaeological site that is believed to have been a factory site for the production of stone tools (Bangent 1990; Winning 1989).

Shortland Wetlands have retained their importance in the fabric of the local community since a community campaign to save and restore the wetlands. In 1984 the actions of the local conservation group gained support for the restoration of the degraded wetlands and the development of Shortland Wetlands Centre. This was a very ambitious project at that time. Now trading as The Wetlands Centre Australia, the Centre continues to attract strong community support and involvement.

The Wetlands Centre promotes wetland conservation and wise use through communication and education, passive recreation and community involvement and acts as a focal point for community-based environmental interest groups that represent valuable partnerships. The Hunter Bird Observers Club, Australian Plant Society and the Society for Frogs and Reptiles contribute expertise and resources to the sustainable management of the site. The successful restoration of Shortland Wetlands has been supported by the investment of many thousands of volunteer man-hours and valuable partnerships with relevant interest groups such as those mentioned above.

20. **Land tenure/ownership**

Kooragang Nature Reserve

The site is Crown Land dedicated as a Nature Reserve under the NSW *National Parks and Wildlife Act 1974*. Surrounding lands are a mixture of Freehold and other public authority managed lands.

Shortland Wetlands

The site is owned by Shortland Wetlands Centre, Ltd, trading as The Wetlands Centre Australia, a company limited by guarantee and owned by its (600) members. It operates as a not-for-profit conservation organisation and is managed by a volunteer Board of Directors.

Land ownership in the surrounding area includes residential landholders, Newcastle City Council, Hunter Water Corporation, NSW Roads and Traffic Authority, Hunter Catchment Management Trust and NSW National Parks and Wildlife Service.

21. **Current land use**

Kooragang Nature Reserve

The site is permanently dedicated as a Nature Reserve and is used as a nature conservation area. A substantial amount of ornithological, wetlands ecology and fisheries research together with bird watching is undertaken within the Reserve. Surrounding areas are privately owned and used for heavy industry and pastoral activities.

Two areas adjoining Kooragang Nature Reserve are being rehabilitated (known as the Kooragang Wetland Rehabilitation Project) and are used for conservation purposes.

Shortland Wetlands

The Shortland Wetlands site is used for wetland conservation, education and passive recreation.

From 1984 the aim was to develop a wetland centre based on Slimbridge in the United Kingdom, to complement the restoration project. This project has matured alongside the restoration work. The site is well established as an education and eco-tourism destination. Providing public access for education purposes requires on-going management to assure that ecological values are not threatened.

The immediate surrounding area includes residential, water delivery infrastructure, a sports ground, roads, former local government landfill site, market gardens, railway line, a cemetery, as well as significant conservation areas adjacent to the site. It is important to note that approximately one-third of the Newcastle Local Government Area is classified as wetland. However, Newcastle also has an industrial economic base, including coal imports, a working port and small, medium and heavy manufacturing.

22. Factors (past, present or potential) adversely affecting the site's ecological character, including changes in land use and development projects

Kooragang Nature Reserve

Introduced animals are a moderate threat to the Reserve. Domestic dogs (*Canis familiaris*), foxes (*Vulpes vulpes*) and cats (*Felis cattus*) affect bird populations through direct disturbance and predation. Black Rat (*Rattus rattus*), Brown Rat (*Rattus norvegicus*) and House Mouse (*Mus musculus*) compete with native species in the area. Rats are also known to take both waterfowl eggs and their hatchlings as food. There are limited numbers of hares and rabbits in the Reserve, however they are a minor threat due to lack of suitable habitat.

Introduced weeds are a moderate threat to the Reserve. Four weeds are established within the Reserve and include Bitou bush (*Chrysanthemoides monilifera*), Alligator Weed (*Alternanthera philoxeroides*), Water hyacinth (*Eichornia crassipes*) and Pampas Grass (*Cortaderia selloana*). Sharp Rush (*Juncus acutus*) occurs in part of the Reserve but is considered a minor threat.

The lower catchment of the Hunter River is highly industrialised and urbanised. The mouth of the River has been developed as one of Australia's most important ports. Further industrial expansion adjacent to the Reserve is proposed and potential impacts on the Ramsar values are currently being assessed. Land development continues near the Reserve and upstream along the Hunter River and this could accelerate soil erosion and water pollution in the vicinity of the Reserve. Soil erosion and water pollution are considered moderate threats.

Air pollution from nearby aluminium and steel industries is a minor threat. Oil spills are considered a major threat but to date none have occurred within the Reserve.

Shortland Wetlands

In 1971, floodgates were installed in Ironbark Creek. The purpose of this installation was to mediate flood control for surrounding areas. The Hunter Catchment Management Trust is proposing to open the floodgates in an attempt to re-introduce natural water flows and a tidal influence. Modelling suggests that this will have an insignificant impact on Shortland Wetlands although it may impact slightly on the western edge of the site. Currently, the Hunter Catchment Management Trust is conducting a trial by opening the floodgates in a limited way in order to monitor change.

There is potential for development of the landfill site adjacent to Shortland Wetlands that is owned by Newcastle City Council and has been closed since 1992.

A proposed extension to the existing freeway to the east of the site could potentially impact on the wetland. There is, however, a buffer zone between the Ramsar site and the development proposal.

Many exotic plant species occur at Shortland Wetlands (see Appendix 4). The spread of weeds may be enhanced by local residents who dump rubbish on the site, clear vegetation near their fences and plant exotic tree species. The most serious aquatic weed species include Alligator Weed (*Alternanthera philoxeroides)*, Dock (*Rumex spp*.) and Pennywort (*Hydrocotyle bonariensis)*.

Introduced animals that pose the most serious threat to native fauna at the site include the Black Rat (*Rattus rattus*), House Mouse (*Mus musculus*), Red Fox (*Vulpes vulpes*), domestic Cat (*Felis catus*), Common Myna (*Acridotheres tristus*), Common Starling (*Sturnus vulgaris*) and Mosquito Fish (*Gambusia holbrooki*).

The Black Rat poses a threat to shore-breeding birds, shorebirds, and the Long-necked Tortoise by predating eggs and nestlings. Red Foxes have been recorded preying on juveniles of Egrets and pose a threat to other species such as ground nesting and ground feeding birds. Rabbits may enhance the effects of soil erosion and Brown Hares pose a threat to the regeneration of vegetation. Predation by Mosquito Fish is listed as a key threatening process under the NSW *TSC Act 1995*. It is considered a threat to the Green and Golden Bell Frog (Morgan and Butterner *in* NPWS 2002b) as well as macro-invertebrate communities.

Some of the remnant natural wetlands on the site have exhibited signs of eutrophication, such as emission of odorous gases (e.g. Hydrogen sulphide), algal blooms and dominance by eutrophytes (e.g. *Triglochin procera, Spirodela pusilla, Azolla spp.*). Eutrophication may occur as a result of a concentration of nutrients, changes in water quality parameters such as pH, urban run-off and a buildup of bird faeces. The substrate of the artificial ponds may also increase eutrophication as it contains high nutrient material which was previously dumped on the site as fill.

23. **Conservation measures taken**

Kooragang Nature Reserve

Since the gazettal of Kooragang Nature Reserve in 1983, 720ha have been added to the Reserve which currently totals 2,926ha. The Plan of Management (NPWS 1998) which aims to preserve and enhance the area for nature conservation has been implemented and includes:

- Water quality and catchment management;
- Management of native and introduced flora and fauna;
- Wetland rehabilitation;
- Cultural heritage;
- Fire management; and
- Use and promotion of the Nature Reserve.

Specific conservation measures currently being undertaken, or undertaken recently, include:

- Rehabilitation of Sandy Island for migratory shorebird roosting;
- Mangrove removal and ongoing management of the Stockton Sandspit for shorebird roosting;
- Artificial roost construction in Fullerton Cove;
- Monthly shorebird monitoring;

- Pampas grass control is anticipated in early 2003; and
- A management strategy for the control of Alligator weed.

Shortland Wetlands

The site was established as a conservation reserve in 1985. The site restoration has included the creation of two new ponds, development of tracks, building of structures and interpretation to support education uses. Management plans using a catchment management approach were developed and implemented to guide restoration work, on-going management and public access. A long-term revegetation plan has been implemented to improve degraded habitat and introduce new habitat types.

Management is under the direction of a volunteer site committee which meets quarterly and includes staff, volunteers and technical advisors.

Monitoring of a broad range of ecosystem functions and values has been intermittent. Monitoring of bird species, egret breeding and ibis roosting and recording of plant species have been maintained.

The Wetlands Centre is one of four centres hosting a Freckled Duck captive-breeding program. The program began with 17 ducks and since 1993, 52 ducklings have hatched and 36 have survived. Fifteen of these have been given to Tidbinbilla Nature Reserve as part of their captive-breeding program.

The restoration of the site has been used to promote broad conservation of all local wetlands. The involvement of the local community has played a major role in the restoration project, site management, project development, plantings, programs and administration.

Some areas of Shortland Wetlands and Kooragang Nature Reserve (see Map 2) are covered by State Environmental Planning Policy 14, Coastal Wetlands (SEPP 14), which aims to ensure coastal wetlands are preserved and protected.

24. **Conservation measures proposed but not yet implemented**

Kooragang Nature Reserve

Rehabilitation of wetland areas within and adjacent to the Reserve have been undertaken under the auspice of the Kooragang Wetland Rehabilitation Project. The Project aims to restore and/or enhance the habitat for migratory birds and waterfowl and has proposed that:

- Lands within the Reserve previously reclaimed for agriculture and flood mitigation are to be rehabilitated to wetland;
- The hydrology created by artificial regulation devices on parts of Kooragang Island are to be modified; and
- Degraded vegetation communities in the Reserve are to be rehabilitated.

Tidal regimes will be introduced into the Tomago buffer lands to increase the wetland habitat in the Nature Reserve.

Shortland Wetlands

A Management Plan to guide the on-going management and wise use of Shortland Wetlands is currently being prepared. The Plan builds on and aims to enhance the management practices that have been in place since the start of the restoration project in 1984-85. The Plan is designed to accommodate the on-going involvement of local communities. The Wetlands Centre's focus on communication, education and public awareness has influenced the objectives and actions in the Plan. A key aim will be the development and implementation of a Monitoring Plan to identify changes in key factors relevant to the ecological character of the site.

25. **Current scientific research and facilities**

Kooragang Nature Reserve

The only research facility in the Nature Reserve is a small bird hide at Stockton Sandspit.

Kooragang Island has been the subject of a number of ecological studies undertaken by various parties including the University of Newcastle, Hunter Bird Observers Club, Shortland Wetlands Centre, Hunter Catchment Management Trust, Ironbark Creek Catchment Management Committee, Kooragang Wetland Rehabilitation Project, Hunter Water Corporation and various environmental consultancy companies.

Currently research is being undertaken in the following areas:

- Banding and plumage studies of wading birds, water bird counts, the success of waterbird breeding and changes in migration patterns;
- Geomorphological changes to the Hunter River Estuary;
- Water quality monitoring; and
- Alligator weed.

Shortland Wetlands

There are no active research facilities currently operating on the site. However, there is a significant body of work about the site, its development and Centre activities that has been produced by students and by technical staff employed as consultants in past years. The Wetlands Centre has produced 37 scientific publications, 4 reports, poster papers at international conferences and contributed to three books. An extensive bibliographical list of publications relating to The Wetlands Centre (Burgess 2002) is held in the Wetlands Centre Library.

Research related to the site forms part of the Wetlands Centre Library collection. The library is extensive and unique. It has grown over the past 17 years to form a detailed collection of resources which describe local wetlands and environmental issues. The library is available to the public and is staffed by volunteers who respond to community needs.

There is good potential for the on-going involvement of research students from nearby Newcastle University in projects relevant to the management of the site.

26. **Current conservation education**

Kooragang Nature Reserve

Kooragang Nature Reserve offers significant opportunity for environmental education since it is readily accessible to a large number of people from Newcastle and the lower Hunter Valley.

Shortland Wetlands Centre provides interpretation of the area. It also organises regular visits to the Nature Reserve for researchers and students of wetland conservation.

The Kooragang Wetland Rehabilitation Project also has interpretation facilities and a model environmentally sustainable farm adjacent to the Nature Reserve. The erection of education facilities in the bird hide at the Stockton Sandspit are also proposed.

Signs that outline the principles of the Ramsar Convention and the conservation values of the Ramsar Site have been erected at the site.

Shortland Wetlands

The Wetlands Centre uses communication and education as key processes to promote wetland values, conservation and wise use management. Development on the site to support education includes the Visitors Centre, an extensive system of tracks, viewing platforms, decks, boardwalks and interpretation signs. An elevated birdhide provides access to nesting and roosting birds. Canoe facilities allow access to tidal creeks adjacent to the site.

The Visitors Centre is a large building containing an interpretation display with live and static displays, free-standing binoculars, information booklets and brochures, a souvenir shop, café, facilities and offices. Disabled access is available in the Centre and on some of the walks. A Sensory Trail provides access to the wetlands for visitors with sensory impairment.

The Wetlands Centre's school education program is underpinned by a valuable partnership with NSW Department of Education and Training (DET). The Wetlands Environmental Education Centre, a DET facility, manages the programs for approximately 8000 school visitors annually. Students from kindergarten to year 12 enjoy programs relevant to the NSW curriculum and their stage of schooling.

The Wetlands Centre programs and achievements have resulted in a greater understanding of wetlands in the Hunter region, increasing community support for other major wetland rehabilitation projects. This provides an excellent demonstration of the role education can play to build understanding of wetland values and functions.

27. **Current recreation and tourism**:

Kooragang Nature Reserve

Kooragang Nature Reserve is not promoted as a tourist destination. Some limited, low impact recreational uses are permitted within the Nature Reserve and include fishing, boating and bird watching. The Nature Reserve has approximately 5000 visitors per year.

Shortland Wetlands

Shortland Wetlands offer a range of outdoor recreation facilities with very easy access to high-conservation-value wetlands for visitors. Facilities include bush-walking trails, boardwalks, observation decks, elevated bird hide and canoes.

As an ecotourism facility, The Wetlands Centre complements other attractions in Newcastle and provides environment-focused tourism supported by environmental education.

28. **Jurisdiction**

Territorial: Government of New South Wales
Functional: NSW National Parks and Wildlife Service; Newcastle City Council.

29. **Management authority**

Shortland Wetlands Centre Ltd is responsible for management of Shortland Wetlands:

The Wetlands Centre Ltd
PO Box 292
Wallsend NSW 2287
Phone: 02 4951 6466

NSW National Parks and Wildlife Service is responsible for management of Kooragang Nature Reserve:

Manager
Hunter Coast Area
Locked Bag 99
Nelson Bay Delivery Centre NSW 2315
Phone: 02 4984 8200

30. **Bibliographical references**:

Albrecht, G. and M. Maddock (1985). Avifauna of the Shortland Wetlands. *Wetlands* (*Australia*) **5**(2): 53-69.

Bangent, B. (1990). *Aboriginal Interpretation at Shortland Wetlands Centre*. Unpublished.

Barden, W. (2002). *Birds of the Wetlands Centre*. Unpublished.

Baxter , G.S. (1994). The location and status of egret colonies in coastal NSW. *Emu* **94**: 255-262.

Beretta, M. (1998). *Flora of the Shortland Wetlands, NSW*. University of Newcastle, NSW. Unpublished thesis.

Bischof, H. and N. Brown (1996). *Hydrology, water quality and macroinvertebrates of the Shortland Wetlands*. University of Newcastle, NSW. Unpublished thesis.

Burgess, B. (2002). *The Restoration and Development of Shortland Wetlands as a Centre for Wetland Conservation and Education: a Bibliography*. The Wetlands Centre, Newcastle, NSW.

Geering, D. (1995). *Ecology of migratory shorebirds in the Hunter River Estuary*. Shortland Wetlands Centre, NSW.

Grace, M. and N. Francesconi (1997). The Shortland Wetlands Centre. University of Newcastle, NSW. Unpublished thesis.

IUCN (2000). *IUCN Red List of Threatened Species.* IUCN, Gland, Switzerland and Cambridge, UK.

Lightfoot, P. (2000). *Tree planting at The Wetlands Centre at Shortland, Newcastle*. The Wetlands Centre, Shortland, NSW.

MacDonald Wagner (1984). *Ecological study of State Highway No. 23 (Shortland to Pacific Highway Corridor)*. Department of Main Roads, Hunter Division, NSW.

Maddock, M. (2002). Ibis in the Lower Hunter. *The Wetlander* **16**(2): 11-12.

Matthei, L.E. (1995). Soil Landscapes of the Newcastle 1:100 000 Sheet Map, Department of Land & Water Conservation, Sydney.

Moss, J. (1983). An Investigation of the Natural Areas of Kooragang Island, Hunter River. NSW Department of Environment and Planning.

NCC (2000). *Newcastle Stormwater Management Plan*. Newcastle City Council, Newcastle, NSW.

NPWS (1998). *Kooragang Nature Reserve and Hexham Swamp Nature Reserve Plan of Management*. NSW National Parks and Wildlife Service. Hurstville, NSW.

NPWS (2002a). Atlas of NSW Wildlife. Database of flora and fauna sightings in NSW. NSW National Parks and Wildlife Service. Hurstville, NSW.

NPWS (2002b). *Predation by* Gambusia holbrooki – *The Plague Minnow. Draft Threat Abatement Plan.* NSW National Parks and Wildlife Service. Hurstville, NSW.

Rose, P.M. and D.A. Scott (1997). *Waterfowl Population Estimates – Second edition*. Wetlands International Publ. 44, Wageningen, The Netherlands.

Sinlaparommard, J. (1999). Stormwater runoff quality at the Shortland Wetlands. Callaghan, NSW, University of Newcastle. Unpublished thesis.

Smith, P. (1991). *The biology and management of waders (Suborder Charadrii) in NSW*. NSW NPWS Species Management Report Number 9. NSW National Parks and Wildlife Service. Hurstville, NSW.

Sokoloff, B. (1974). *The Woromi: Hunter Gatherers at Port Stephens*. Part 1. Hunter Natural History, **6**(3): 166 – 169.

Straw, P. (2000). *Hunter Estuary Wader Habitat Investigation*, *Stage 2*. Unpublished report to NSW National Parks and Wildlife Service.

Watkins, D. (1993). *A national plan for shorebird conservation in Australia*. Australian Wader Studies Group.

Winning, G. (1989). *The Wetlands Centre: Site Management Plan 1990-1994*. The Wetlands Centre, Shortland, NSW. Unpublished.

Winning, G. (1996). *Vegetation of Kooragang Nature Reserve and Hexham Swamp Nature Reserve and adjoining land*. Report for NSW National Parks and Wildlife Service. The Wetlands Centre, Shortland, NSW.

Appendix 1

Bird species recorded at Shortland Wetlands and Kooragang Nature Reserve

Records for Shortland Wetlands from Barden (2002). Records for Kooragang derived from Holmes, van Gessel and Kendall, Morris, Clarke and van Gessel *in* NPWS 1998; and NPWS (2002a).

Key

V1 Listed as 'Vulnerable' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

V2 Listed as 'Vulnerable' under the NSW *Threatened Species Conservation Act 1995*

V3 Listed as 'Vulnerable' under the *IUCN Redlist of Threatened Species 2000*

E1 Listed as 'Endangered' under the EPBC Act

E2 Listed as 'Endangered' under the NSW *Threatened Species Conservation Act 1995*

M Migratory species listed under international treaties: Japan-Australia or China-Australia Migratory Bird Agreements (JAMBA or CAMBA)

***** Introduced species

\# Recorded at the site

nr Not recorded at the site

Scientific Name	Common Name	Status	Shortland	Kooragang
GALLIFORMES				
Phasianidae	**Old World Quail and Pheasant**			
Coturnix chinensis	King Quail		**nr**	#
Coturnix ypsilophora	Brown Quail		#	#
ANSERIFORMES	**WATERFOWL**			
Anatidae	**Ducks, Geese and Swans**			
Anas castanea	Chestnut Teal		#	#
Anas clypeata	Northern Shoveler	**M**	#	**nr**
Anas gracilis	Grey Teal		#	#
Anas platyrhynchos	Mallard		#	**nr**
Anas querquedula	Garganey	**M**	#	**nr**
Anas rhynchotis	Australasian Shoveler		#	#
Anas superciliosa	Pacific Black Duck		#	#
Aythya australis	Hardhead		#	#
Biziura lobata	Musk Duck		#	#
Chenonetta jubata	Australian Wood Duck		#	#
Cygnus atratus	Black Swan		#	#
Dendrocygna arcuata	Wandering Whistling-Duck		#	**nr**
Dendrocygna eytoni	Plumed Whistling-Duck		#	#
Malacorhynchus membranaceus	Pink-eared Duck		#	#
Oxyura australis	Blue-billed Duck	**V2**	#	**nr**

Scientific Name	Common Name	Status	Shortland	Kooragang
Stictonetta naevosa	Freckled Duck	**V2**	**#**	**#**
Tadorna tadornoides	Australian shelduck		**nr**	**#**
Anseranatidae	**Magpie Goose**			
Anseranas semipalmata	Magpie Goose	**V2**	**#**	**nr**
PODICIPEDIFORMES	**GREBES**			
Anhingidae	**Darters**			
Anhinga melanogaster	Darter		**#**	**#**
Pelecanidae	**Pelicans**			
Pelecanus conspicillatus	Australian Pelican		**#**	**#**
Phalacrocoracidae	**Cormorants**			
Phalacrocorax carbo	Great Cormorant		**#**	**#**
Phalacrocorax melanoleucos	Little Pied Cormorant		**#**	**#**
Phalacrocorax sulcirostris	Little Black Cormorant		**#**	**#**
Phalacrocorax varius	Pied Cormorant		**#**	**#**
Podicipedidae	**Grebes**			
Podiceps cristatus	Great Crested Grebe		**nr**	**#**
Poliocephalus poliocephalus	Hoary-headed Grebe		**nr**	**#**
Tachybaptus novaehollandiae	Australasian Grebe		**#**	**#**
CICONIIFORMES	**HERONS, STORKS AND IBIS**			
Ardeidae	**Herons and Egrets**			
Ardea alba	Great Egret	**M**	**#**	**#**
Ardea ibis	Cattle Egret	**M**	**#**	**#**
Ardea intermedia	Intermediate Egret		**#**	**#**
Ardea pacifica	White-necked Heron		**#**	**#**
Botaurus poiciloptilus	Australasian Bittern	**V2, V3**	**#**	**#**
Butorides striatus	Striated Heron		**nr**	**#**
Egretta garzetta	Little Egret		**#**	**#**
Egretta novaehollandiae	White-faced Heron		**#**	**#**
Ixobrychus flavicollis	Black Bittern	**V2**	**nr**	**#**
Ixobrychus minutus	Little Bittern		**#**	**#**
Nycticorax caledonicus	Nankeen Night Heron		**#**	**#**
Ciconiidae	**Storks**			
Ephippiorhynchus asiaticus	Black-necked Stork	**E2**	**#**	**#**
Threskiornithidae	**Ibis and Spoonbills**			
Platalea flavipes	Yellow-billed Spoonbill		**#**	**#**
Platalea regia	Royal Spoonbill		**#**	**#**
Plegadis falcinellus	Glossy Ibis	**M**	**#**	**#**
Threskiornis molucca	Australian White Ibis		**#**	**#**
Threskiornis spinicollis	Straw-necked Ibis		**#**	**#**
FALCONIORMES	**DIURNAL BIRDS OF PREY**			
Accipitridae	**Hawks, Eagles and Kites**			
Accipiter cirrocephalus	Collared Sparrowhawk		**#**	**nr**
Accipiter fasciatus	Brown Goshawk		**#**	**nr**
Accipiter novaehollandiae	Grey Goshawk		**#**	**nr**
Aquila audax	Wedge-tailed Eagle		**#**	**nr**
Aviceda subcristata	Pacific Baza		**#**	**#**
Circus approximans	Swamp Harrier		**#**	**#**

Scientific Name	Common Name	Status	Shortland	Kooragang
Circus assimilis	Spotted Harrier		#	**nr**
Elanus axillaris	Black-shouldered Kite		#	#
Erythrotriorchis radiatus	Red Goshawk	**V1, E2**	#	**nr**
Haliaeetus leucogaster	White-bellied Sea-Eagle	**M**	#	#
Haliastur indus	Brahminy Kite		#	**nr**
Haliastur sphenurus	Whistling Kite		#	#
Hieraaetus morphnoides	Little Eagle		#	**nr**
Lophoictinia isura	Square-tailed kite	**V2**	**nr**	#
Pandion haliaetus	Osprey	**M, V2**	#	**nr**
Falconidae	**Falcons**			
Falco berigora	Brown Falcon		#	**nr**
Falco cenchroides	Nankeen Kestrel		#	#
Falco longipennis	Australian Hobby		#	#
Falco peregrinus	Peregrine Falcon		#	#
Falco subniger	Black Falcon		**nr**	#
GRUIFORMES	**RAILS, CRANES AND BUSTARDS**			
Rallidae	**Rails, Crakes and Gallinules**			
Fulica atra	Eurasian Coot		#	#
Gallinula tenebrosa	Dusky Moorhen		#	#
Gallirallus philippensis	Buff-banded Rail		#	#
Porphyrio porphyrio	Purple Swamphen		#	#
Porzana fluminea	Australian Spotted Crake		#	#
Porzana pusilla	Baillon's Crake		#	#
Porzana tabuensis	Spotless Crake		#	#
Rallus pectoralis	Lewin's Rail		**nr**	#
CHARADRIIFORMES				
Burhinidae				
Burhinus grallarius	Bush Stone Curlew	**E2**	**nr**	#
Charadriidae	**Plovers and Lapwings**			
Charadrius bicinctus	Double-banded Plover		**nr**	#
Charadrius hiaticula	Ringed Plover	**M**	**nr**	#
Charadrius lescenaultii	Greater Sand Plover	**M,V2**	**nr**	#
Charadrius mongolus	Mongolian Plover	**M,V2**	**nr**	#
Charadrius ruficapillus	Red-capped Plover		**nr**	#
Charadrius veredus	Oriental Plover	**M**	**nr**	#
Elseyornis melanops	Black-fronted Dotterel		#	#
Erythrogonys cinctus	Red-kneed Dotterel		#	#
Pluvialis dominica	Lesser Golden Plover	**M**	**nr**	#
Pluvialis fulva	Pacific Golden Plover		**nr**	#
Pluvialis squatarola	Grey Plover	**M**	**nr**	#
Vanellus miles	Masked Lapwing		#	#
Vanellus tricolor	Banded Lapwing		**nr**	#
Glareolidae				
Glareola maldivarum	Oriental Pratincole	**M**	**nr**	#
Haematopodidae	**Oystercatchers**			
Haematopus fuliginosus	Sooty Oystercatcher	**V2**	**nr**	#

Scientific Name	Common Name	Status	Shortland	Kooragang
Haematopus longirostris	Pied Oystercatcher	**V2**	**nr**	#
Jacanidae	**Jacanas**			
Irediparra gallinacea	Comb-crested Jacana	**V2**	#	#
Laridae	**Gulls, Terns and Skuas**			
Chlidonias hybridus	Whiskered Tern		#	#
Chlidonias leucopterus	White-winged Black Tern	**M**	#	#
Chlidonias niger	Black Tern	**M**	**nr**	#
Larus dominicanus	Kelp Gull		**nr**	#
Larus novaehollandiae	Silver Gull		#	#
Sterna albifrons	Little Tern	**M,E2**	**nr**	#
Sterna bergii	Crested Tern		**nr**	#
Sterna caspia	Caspian Tern	**M**	#	#
Sterna hirundo	Common Tern	**M**	**nr**	#
Sterna nilotica	Gull-billed Tern		**nr**	#
Sterna paradisea	Arctic Tern		**nr**	#
Sterna striata	White-fronted Tern		**nr**	#
Recurvirostridae	**Stilts and Avocets**			
Cladorhynchus leucocephalus	Banded Stilt		**nr**	#
Himantopus himantopus	Black-winged Stilt		#	#
Recurvirostra novaehollandiae	Red-necked Avocet		#	#
Rostratulidae	**Snipes**			
Rostratula benghalensis	Painted Snipe	**M**	**nr**	#
Scolopacidae	**Sandpipers**			
Actitis hypoleucos	Terek Sandpiper		**nr**	#
Arenaria interpres	Ruddy Turnstone		**nr**	#
Calidris acuminata	Sharp-tailed Sandpiper	**M**	#	#
Calidris alba	Sanderling	**M,V2**	**nr**	#
Calidris canutus	Red Knot	**M**	**nr**	#
Calidris ferruginea	Curlew Sandpiper	**M**	#	#
Calidris melanotus	Pectoral Sandpiper	**M**	**nr**	#
Calidris minuta	Little Stint		**nr**	#
Calidris ruficollis	Red-necked Stint	**M**	#	#
Calidris tenuirostris	Great Knot	**M,V2**	**nr**	#
Gallinago hardwickii	Latham's Snipe	**M**	#	#
Heteroscelus brevipes	Grey-tailed Tattler		**nr**	#
Heteroscelus incanus	Wandering Tattler		**nr**	#
Limicola falcinellus	Broad-billed Sandpiper	**M,V2**	**nr**	#
Limnodromus semipalmatus	Asian Dowitcher	**M**	**nr**	#
Limosa haemastica	Hudsonian Godwit		**nr**	#
Limosa lapponica	Bar-tailed Godwit	**M**	**nr**	#
Limosa limosa	Black-tailed Godwit	**M,V2**	**nr**	#
Numenius madagascariensis	Eastern Curlew	**M**	**nr**	#
Numenius minutus	Little Curlew	**M**	**nr**	#
Numenius phaeopus	Whimbrel	**M**	**nr**	#
Philomachus pugnax	Ruff	**M**	**nr**	#
Tringa glareola	Wood Sandpiper	**M**	#	#
Tringa nebularia	Common Greenshank	**M**	#	#

Scientific Name	Common Name	Status	Shortland	Kooragang
Tringa stagnatilis	Marsh Sandpiper	**M**	#	#
Tryngites subruficollis	Buff-breasted Sandpiper	**M**	**nr**	#
Xenus cinereus	Terek Sandpiper	**V2**	**nr**	#
COLUMBIFORMES	**PIGEONS AND DOVES**			
Columbidae	**Pigeons and Doves**			
Chalcophaps indica	Emerald Dove		#	**nr**
Columba leucomela	White-headed Pigeon		#	**nr**
Columba livia	Rock Dove	*	#	#
Geopelia humeralis	Bar-shouldered Dove		#	**nr**
Lopholaimus antarcticus	Topknot Pigeon		#	**nr**
Macropygia amboinensis	Brown Cuckoo-Dove		#	**nr**
Ocyphaps lophotes	Crested Pigeon		#	**nr**
Streptopelia chinensis	Spotted Turtle-Dove	*	#	**nr**
PSITTACIFORMES	**COCKATOOS, PARROTS AND LORIKEETS**			
Cacatuidae	**Cockatoos**			
Cacatua galerita	Sulphur-crested Cockatoo		#	**nr**
Cacatua roseicapilla	Galah		#	**nr**
Cacatua sanguinea	Little Corella		#	**nr**
Cacatua tenuirostris	Long-billed Corella		#	**nr**
Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo		#	**nr**
Nymphicus hollandicus	Cockatiel		#	**nr**
Psittacidae	**Parrots and Lorikeets**			
Alisterus scapularis	King Parrot		#	**nr**
Glossopsitta pusilla	Little Lorikeet		#	**nr**
Platycercus adscitus	Pale-headed Rosella		#	**nr**
Platycercus eximius	Eastern Rosella		#	#
Psephotus haematonotus	Red-rumped Parrot		#	**nr**
Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet		#	**nr**
Trichoglossus haematodus	Rainbow Lorikeet		#	**nr**
CUCULIFORMES	**CUCKOOS AND COUCALS**			
Centropodidae	**Coucal**			
Centropus phasianinus	Pheasant Coucal		#	**nr**
Cuculidae	**Cuckoos**			
Cacomantis flabelliformis	Fan-tailed Cuckoo		#	**nr**
Cacomantis variolosus	Brush Cuckoo		#	**nr**
Chrysococcyx basalis	Horsfield's Bronze-Cuckoo		#	#
Chrysococcyx lucidus	Shining Bronze-Cuckoo		#	**nr**
Cuculus pallidus	Pallid Cuckoo		#	**nr**
Cuculus saturatus	Oriental Cuckoo	**M**	#	#
Eudynamys scolopacea	Common Koel		#	**nr**
Scythrops novaehollandiae	Channel-billed Cuckoo		#	**nr**
STRIGIFORMES	**OWLS**			
Strigidae	**Typical (Hawk) Owl**			
Ninox novaeseelandiae	Southern Boobook		#	**nr**
Tytonidae	**Barn Owls**			
Tyto alba	Barn Owl		#	**nr**

Scientific Name	Common Name	Status	Shortland	Kooragang
Tyto novaehollandiae	Masked Owl	**V2**	#	**nr**
CAPRIMULGIFORMES	**NIGHTJARS AND RELATIVES**			
Podargidae	**Frogmouths**			
Podargus strigoides	Tawny Frogmouth		#	**nr**
APODIFORMES	**SWIFTS**			
Apodidae	**Swifts**			
Hirundapus caudacutus	White-throated Needletail	**M**	#	**nr**
CORACIIFORMES	**KINGFISHERS, ROLLERS AND BEE-EATERS**			
Alcedinidae	**Water Kingfishers**			
Alcedo azurea	Azure Kingfisher		#	**nr**
Coraciidae	**Rollers**			
Eurystomus orientalis	Dollarbird		#	**nr**
Halcyonidae	**Tree Kingfishers**			
Dacelo novaeguineae	Laughing Kookaburra		#	#
Todiramphus macleayii	Forest Kingfisher		#	#
Todiramphus sanctus	Sacred Kingfisher		#	#
Meropidae	**Bee-eaters**			
Merops ornatus	Rainbow Bee-eater	**M**	#	**nr**
PASSERIFORMES	**SONGBIRDS**			
Artamidae	**Woodswallows, Magpies, Butcherbirds and Currawongs**			
Artamus leucorynchus	White-breasted Woodswallow		#	#
Cracticus nigrogularis	Pied Butcherbird		#	**nr**
Cracticus torquatus	Grey Butcherbird		#	**nr**
Gymnorhina tibicen	Australian Magpie		#	#
Strepera graculina	Pied Currawong		#	**nr**
Campephagidae	**Cuckoo-shrikes and Trillers**			
Coracina novaehollandiae	Black-faced Cuckoo-shrike		#	#
Lalage sueurii	White-winged Triller		#	#
Cinclosomatidae	**Whipbirds and Quail-thrushes**			
Psophodes olivaceus	Eastern Whipbird		#	**nr**
Climacteridae				
Cormobates leucophaeus	White-throated Treecreeper		**nr**	#
Corvidae	**Ravens and Crows**			
Corvus coronoides	Australian Raven		#	#
Dicaeidae	**Flowerpeckers**			
Dicaeum hirundinaceum	Mistletoebird		#	**nr**
Dicruridae	**Monarchs, Fantails, Magpielarks and Drongos**			
Dicrurus bracteatus	Spangled Drongo		#	**nr**
Grallina cyanoleuca	Magpie-lark		#	#
Monarcha melanopsis	Black-faced Monarch		#	**nr**
Myiagra inquieta	Restless Flycatcher		#	#
Myiagra rubecula	Leaden Flycatcher		#	**nr**
Rhipidura fuliginosa	Grey Fantail		#	#
Rhipidura leucophrys	Willie Wagtail		#	#

Scientific Name	Common Name	Status	Shortland	Kooragang
Rhipidura rufifrons	Rufous Fantail		#	**nr**
Fringillidae	**Finches**			
Carduelis carduelis	European Goldfinch	*	#	**nr**
Hirundinidae	**Swallows and Martins**			
Hirundo ariel	Fairy Martin		#	**nr**
Hirundo neoxena	Welcome Swallow		#	#
Hirundo nigricans	Tree Martin		#	**nr**
Hirundo rustica	Barn Swallow	**M**	#	**nr**
Maluridae	**Fairy-wrens**			
Malurus cyaneus	Superb Fairy-wren		#	#
Malurus lamberti	Variegated Fairy-wren		#	**nr**
Stipiturus malachurus	Southern Emu-wren		#	**nr**
Meliphagidae	**Honeyeaters**			
Acanthorhynchus tenuirostris	Eastern Spinebill		#	**nr**
Anthochaera carnunculata	Red Wattlebird		#	**nr**
Anthochaera chrysoptera	Little Wattlebird		#	**nr**
Epthianura albifrons	White-fronted Chat		**nr**	#
Lichenostomus chrysops	Yellow-faced Honeyeater		#	**nr**
Lichmera indistincta	Brown Honeyeater		#	#
Manorina melanocephala	Noisy Miner		#	**nr**
Melithreptus brevirostris	Brown-headed Honeyeater		#	**nr**
Melithreptus lunatus	White-naped Honeyeater		#	**nr**
Myzomela sanguinolenta	Scarlet Honeyeater		#	**nr**
Philemon citreogularis	Little Friarbird		#	**nr**
Philemon corniculatus	Noisy Friarbird		#	**nr**
Phylidonyris nigra	White-cheeked Honeyeater		#	**nr**
Phylidonyris novaehollandiae	New Holland Honeyeater		#	**nr**
Plectorhyncha lanceolata	Striped Honeyeater		#	#
Motacillidae	**Pipits and Wagtails**			
Anthus novaeseelandiae	Richard's Pipit		#	#
Motacilla flava	Yellow Wagtail	**M**	#	**nr**
Muscicapidae	**One World Warblers**			
Acrocephalus stentoreus	Clamorous Reed-Warbler		#	**nr**
Cincloramphus cruralis	Brown Songlark		**nr**	#
Cincloramphus mathewsi	Rufous Songlark		#	#
Cisticola exilis	Golden-headed Cisticola		#	#
Megalurus gramineus	Little Grassbird		#	#
Megalurus timoriensis	Tawny Grassbird		#	#
Turdus merula	Common Blackbird	*	#	**nr**
Oriolidae	**Orioles**			
Oriolus sagittatus	Olive-backed Oriole		#	**nr**
Sphecotheres viridis	Figbird		#	**nr**
Pachycephalidae	**Whistlers and Shrike-thrushes**			
Colluricincla harmonica	Grey Shrike-thrush		#	**nr**
Falcunculus frontatus	Crested Shrike-tit		#	**nr**
Pachycephala pectoralis	Golden Whistler		#	**nr**
Pachycephala rufiventris	Rufous Whistler		#	**nr**

Scientific Name	Common Name	Status	Shortland	Kooragang
Pardalotidae	**Pardalotes, Gerygones, Scrubwrens and Thornbills**			
Acanthiza chrysorrhoa	Yellow-rumped Thornbill		#	#
Acanthiza nana	Yellow Thornbill		#	#
Acanthiza pusilla	Brown Thornbill		#	**nr**
Acanthiza reguloides	Buff-rumped Thornbill		#	**nr**
Gerygone levigaster	Mangrove Gerygone		**nr**	#
Gerygone olivacea	White-throated Gerygone		#	**nr**
Pardalotus punctatus	Spotted Pardalote		#	**nr**
Pardalotus striatus	Striated Pardalote		#	**nr**
Sericornis frontalis	White-browed Scrubwren		#	**nr**
Passeridae	**House Sparrows and Grass Finches**			
Lonchura castaneothorax	Chestnut-breasted Mannikin		#	#
Neochmia temporalis	Red-browed Finch		#	**nr**
Passer domesticus	House Sparrow	*	#	**nr**
Taeniopygia bichenovii	Double-barred Finch		#	#
Taeniopygia guttata	Zebra Finch		#	#
Petroicidae	**Australasian Robins**			
Eopsaltria australis	Eastern Yellow Robin		#	**nr**
Petroica multicolor	Scarlet Robin		#	**nr**
Petroica rosea	Rose Robin		#	**nr**
Sturnidae	**Starlings**			
Acridotheres tristis	Common Myna	*	#	**nr**
Sturnus vulgaris	Common Starling	*	#	**nr**
Zosteropidae	**White-eyes**			
Zosterops lateralis	Silvereye		#	#

Appendix 2

Bird Species recorded breeding at the site

The following is a list of species recorded breeding at Shortland Wetlands (from Barden 2002), and indicates those species also known to occur at Kooragang Nature Reserve. Count data refers to Shortland only.

The Great Egret (*Ardea alba),* Intermediate Egret (*Ardea intermedia),* Little Egret (*Egretta garzetta*) and Cattle Egret (*Ardea ibis)* are seasonal migrants to the site from New Zealand. They arrive at Shortland during spring for their breeding season (Baxter 1994).

The numbers of White Ibis (*Threskiornis molucca)* at the site increase significantly over autumn and winter as migrants from inland breeding colonies come to the coast for non-breeding seasonal foraging (Maddock 2002).

Straw-necked Ibis *(Threskiornis spinicollis)* are very few in summer but large numbers migrate to the region during autumn and winter. Up to 7000 of these birds use the Melaleuca Swamp Forest for night roosting. The numbers start to drop during August as they set out on their return journey inland (Maddock 2002).

Nankeen Night Herons *(Nycticorax caledonicus)* use the site for night foraging and day roosting during the non-breeding season.

* Recorded at Kooragang Nature Reserve and Shortland Wetlands
\# Recorded at Shortland Wetlands only

Common Name	**Scientific Name**	**Count**
# Magpie Goose	*# Anseranas semipalmata*	over 100
# Wandering Whistling Duck	*# Dendrocygna arcuata*	30-50 (over 100 birds in 2000)
* Black Swan	* *Cygnus atratus*	6-20
* Australian Wood Duck	* *Chenonetta jubata*	20-50
* Pacific Black Duck	* *Anas superciliosa*	up to 100
* Grey Teal	* *Anas gracilis*	up to 100
* Chestnut Teal	* *Anas castanea*	up to 100
* Hardhead	* *Aythya australis*	20-40
* Australasian Grebe	* *Tachybaptus novaehollandiae*	10-30
* Little Black Cormorant	* *Phalacrocorax sulcirostris*	up to 100
* Little Pied Cormorant	* *Phalacrocorax melanoleucos*	up to 100
* White-faced Heron	* *Egretta novaehollandiae*	2-4 (up to 22)
* Little Egret	* *Egretta garzetta*	4-over 100
* Great Egret	* *Ardea alba*	40-400
* Intermediate Egret	* *Ardea intermedia*	20-900
* Cattle Egret	* *Ardea ibis*	200-1400

Common Name	Scientific Name	Count
* Australian White Ibis	* *Threskiornis molucca*	2-6 (over 1000 birds roosting)
* Nankeen Night Heron	* *Nycticorax caledonicus*	20-100
* Purple Swamphen	* *Porphyrio porphyrio*	10 - 100
* Dusky Moorhen	* *Gallinula tenebrosa*	10-100
* Eurasian Coot	* *Fulica atra*	10-40
* Black-fronted Dotterel	* *Elseyornis melanops*	6-18
* Red-kneed Dotterel	* *Erythrogonys cinctus*	2-10
* Masked Lapwing	* *Vanellus miles*	6-10
* Sacred Kingfisher	* *Todiramphus sanctus*	4-10
* Whistling Kite	* *Haliastur sphenurus*	2
# Brown Goshawk	# *Accipiter fasciatus*	2
# Barn Owl	# *Tyto alba*	2

Appendix 3

Mammals, Reptiles, Amphibians and Fish recorded at Shortland Wetlands

Species list compiled from observations made by Kevin Markwell over a period of several years and is supported by the Ecological Study of the State Highway No 23 – Shortland to Pacific Highway Corridor by Macdonald Wagner (1984). A species list for Kooragang is currently unavailable.

Key

V1 Listed as 'Vulnerable' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

E2 Listed as 'Endangered' under the NSW *Threatened Species Conservation Act 1995*

***** Introduced species

Scientific Name	Common Name	Status
MAMMALS		
Isoodon macrourus	Northern Brown Bandicoot	
Hydromys chrysogaster	Water Rat	
Mus musculus	House Mouse	*
Rattus rattus	Black Rat	*
Lepus capensis	Brown Hare	*
Oryctolagus cuniculus	European Rabbit	*
Vulpes vulpes	Red Fox	*
REPTILES		
Cheladina longicollis	Long-necked Tortoise	
Ctenotus robustus	Striped Skink	
Lampropholis delicata	Grass Skink	
L. mustelinum	Weasel Skink	
Saiphos equalis	Three-toed Skink	
Sphenomorphus quoyii	Eastern Water Skink	
Tiliqua casuarinae	She-oak Skink	
Hemiaspis signata	Swamp Snake	
Pseudechis porphyriacus	Red-bellied Black Snake	
AMPHIBIANS		
Litoria aurea	Green and Golden Bell Frog	V1,E2
Litoria dentata	Bleating Tree Frog	
Litoria fallax	Dwarf Green Tree Frog	
Litoria peroni	Peron's Tree Frog	
Litoria tyleri	Tyler's Tree Frog	
Litoria caerulea	Green Tree Frog	
Crinia signifera	Common Eastern Froglet	
Limnodynastes peroni	Striped Marsh Frog	
Lymnodynastes tasmaniensis	Spotted Grass Frog	
FISH		
Gobiomorphus coxii	Cox's Gudgeon	
Hypseleotris galii	Firetail Gudgeon	
Philypnodon grandiceps	Flathead Gudgeon	

Scientific Name	Common Name	Status
Philypnodon sp. Nov.	Gudgeon	
Anguilla australis	Short-finned Eel	
Gambusia holbrooki	Mosquito Fish	*

Appendix 4

Flora species recorded at Shortland Wetlands and Kooragang Nature Reserve

Shortland data relates to occurrence and abundance and is taken from Lightfoot (2000); Kooragang data relates to occurrence only and is taken from Winning (1996).

Key:
A – Abundant C – Common U – Uncommon R – Rare * - Exotic # - Planted
K – occurs at Kooragang

Scientific Name	Common Name	Shortland	Kooragang
DIVISION POLYPODIOPHYTA	**FERNS**		
Zamiaceae			
Macrozamia communis	Burrawang	U	
Azollaceae			
Azolla pinnata	Common Azolla	C	
Dennstaedtiaceae			
Pteridum esculentum	Bracken	U	
Sinopteridaceae			
Cheilanthes distans			K
Pellaea falcata			K
DIVISION PINOPHYTA	**CONIFERS**		
Podocarpaceae			
Podocarpus elatus			K
DIVISION MAGNOLIOPHYTA	**FLOWERING PLANTS**		
Acanthaceae			
Pseuderanthemum variabile	Pastel Flower	R	
Aizoaceae			
Tetragonia tetragonoides			K
Amaranthaceae			
Alternanthera denticulata	Lesser Joyweed	U	
**A. philoxeroides*	Alligator Weed	C	
**Ameranthus viridis*	Green Ameranth	C	
Apiaceae			
**Foeniculum vulgare*	Fennel	A	
**Hydrocotyle bonariensis*	Kurnell's Curse	A	
H. laxiflora	Stinking Pennywort	U	
Asclepiadaceae			
**Araujia hortorum*	Moth Plant	R	
Cynanchum elegans			K
**Gomphocarpus fruticosus*			K
Asteraceae			
**Ambrosia artemisiifolia*	Annual Ragweed	C	

Scientific Name	Common Name	Shortland	Kooragang
**Artemisia verlotiorum*	Mugwort	U	
**Aster subulatus*	Wild Aster	U	
**Bidens pilosa*	Pitchforks	U	
Cassinia quinquefaria	Biddy Bush	U	
**Chrysanthemoides monilifera var. rotundata*	Bitou Bush	U	
**Cirsium vulgare*	Spear Thistle	R	
**Conyza albida*	Tall Fleabane	C	
**Conyza bonariensis*			K
**Cotula coronopifolia*	Water Buttons	C	K
**Crepsis capillaris*	Smooth Hawksbeard	U	
**Galinsoga parviflora*		R	
**Hypochaeris radicata*	Flatweed	C	K
Senecio linearifolius	Fireweed Groundsel	C	
**S. madagascariensis*	Fireweed	C	K
**Xanthium occidentale*	Noogoora Burr	R	
Avicenniaceae			
Avicennia marina	Grey Mangrove	C	K
Brassicaceae			
**Capsella bursapastoris*	Shepherd's Purse	U	
**Lepidium campestre*	Field Cress	R	
Campanulaceae			
Wahlenbergia gracilis			K
Capparaceae			
Capparis arborea			K
Caprifoliaceae			
**Lonicera japonica*	Japanese Honeysuckle	U	
Cassythaceae			
Cassytha glabella			K
Cassytha pubescens			K
Casuarinaceae			
Casuarina glauca	Swamp She-Oak	C	K
Celastraceae			
Cassine australis			K
Celastrus australis			K
Celastrus subspicatus			K
Chenopodiaceae			
Atriplex australasica		U	
**Atriplex prostrata*			K
Einadia hastata			K
Sarcornia quinqueflora			K
Suaeda australis			K
Convolvulaceae			
Dichondra repens	Kidney Weed	C	K
Dilleniaceae			
Hibbertia scandens	Golden Guinea Flower	U	

Scientific Name	Common Name	Shortland	Kooragang
Ebenaceae			
Diospyros australis			K
Elaeocarpaceae			
#Elaeocarpus grandis		R	
#E. obovatus		R	K
Elatinaceae			
Elatine gratioloides			K
Euphorbiaceae			
Breynia oblongifolia			K
Croton verreauxii			K
**Euphorbia peplus*	Petty Spurge	C	K
Glochidion ferdinandi	Cheese Tree	C	
#Omalanthus populifolius	Bleeding Heart	R	
**Ricinus communis*	Castor Oil Plant	U	
Fabaceae/Caesalpinioideae			
**Senna pendula*	Winter Senna	U	
Fabaceae/Faboideae			
Glycine microphylla		R	
Hardenbergia violacea	False Sarsaparilla	R	
**Trifolium dubium,*	Yellow Suckling Clover	C	
**T. repens*	White Clover	C	K
**Vicia sativa*	Common Vetch	C	
Fabaceae/Mimosoldeae			
#Acacia baileyana	Cootamundra Wattle	R	
#A. elongata		R	
A. falcata	Falcate Wattle	R	
A. longifolia	Sydney Golden Wattle	A	
A. maidenii			K
A. parramattensis	Parramatta Green Wattle	U	
A. sophorae	Coastal Wattle	U	
Flacourtiaceae			
Scolopia braunii			K
Fumiariaceae			
**Fumaria bastardii*	Bastard's Fumitory	R	
Gentianaceae			
Centaurium spicatum			K
Geraniaceae			
Geranium solanderi var. solanderi	Native Geranium	U	
Lauraceae			
#Cryptocarya hypospodia		R	
Lobeliaceae			
Pratia purpurescens			K
Loranthaceae			
Amyena cambagei			K
Malvaceae			

Scientific Name	Common Name	Shortland	Kooragang
#Hibiscus tiliaceous	Cottonwood Hibiscus	R	
**H. trionum*	Bladder Ketmia	R	
**Modiola caroliniana*		C	K
**Sida rhombifolia*	Paddy's Lucerne	C	K
Meliaceae			
Dysoxylum fraserianum			K
Synoum glandulosum	Scentless Rosewood	U	
Toona ciliata	Red Cedar	R	
Menispermaceae			
Sarcopetalum harveyanum			K
Stephania japonica	Snake Vine	U	
Moraceae			
#Ficus coronata	Sandpaper Fig	R	
F. obliqua			K
#F. fraseri		R	
#F. racemosa		R	
F. rubiginosa			K
Maclura cochinchinensis			K
Streblus brunonianus			K
Myrsinaceae			
Aegiceras corniculatum			K
Myrtaceae			
#Acmena smithii	Lilly Pilly	R	
#Austromyrtus bidwillii	Python Tree	R	
Backhousia myrtifolia			K
#Callistemon citrinus	Crimson Bottlebrush	R	
Callistemon salignus			K
#Eucalyptus deanei	Mountain Blue Gum	R	
#E. gummifera	Red Bloodwood	R	
E. maculata	Spotted Gum	U	
#E. punctata	Grey Gum	R	
E. robusta	Swamp Mahogany	U	
#Leptospermum polygalifolium		U	
Melaleuca ericifolia	Swamp Paperbark	U	K
M. erubescens	Pink Honeymyrtle	R	
M. linariifolia	Snow-in-Summer	C	K
M. nodosa	Ball Honeymyrtle	R	
M. quinquenervia	Broad Leaved Paperbark	A	
M. sieberi			K
M. styphelioides	Prickly Leaved Paperbark	U	K
Syncarpia glomulifera	Turpentine	C	
#Syzygium australe	Brush Cherry	R	
#S. crebrinerve	Purple Cherry	R	
#S. leuhmannii	Riberry	R	
#S. paniculatum	Magenta Lilly pilly	R	

Scientific Name	**Common Name**	**Shortland**	**Kooragang**
#S. sp.		R	
#Waterhousea floribunda	Weeping Lilly pilly	R	
Oleaceae			
Jasminum volubile			K
**Ligustrum sinense*	Small-Leaved Privet	U	
Notelaea longifolia			K
Onagraceae			
Ludwigia peploides			K
**Oenothera spp.*			K
Passifloraceae			
**Passiflora edulis*	Common Passionfruit	U	
Phytolaccaceae			
**Phytolacca octandra*	Inkweed	R	
Pittosporaceae			
Bursaria spinosa	Blackthorn	R	
Citriobatus pauciflorus			K
Pittosporum revolutum			K
Pittosporum undulatum	Sweet Pittosporum	C	K
Plantaginaceae			
**Plantago lanceolata*	Plantain or Lamb's Tongues	C	K
**P. major*	Large Plantain	U	
Podocarpaceae			
#Podocarpus elatus	Plum Pine or Brown Pine	R	
Polygonaceae			
Muehlenbeckia gracillima		R	K
Persicaria decipiens	Slender Knotweed	U	
P. hydropiper			K
P. lapathifolia	Pale Knotweed	C	K
**Polygonum arenastrum*	Sandwireweed	U	
**Rumex crispus*	Curled Dock	C	
Portulaceae			
Portulaca oleracea	Pigweed	C	
Proteaceae			
#Banksia integrifolia	Coastal Banksia	R	
B. robur	Swamp Banksia	C	
Grevillea robusta	Silky Oak	R	
#Hakea salicifolia	Willow-Leaved Hakea	R	
#Stenocarpus salignus	Scrub Beefwood	R	
#S. sinuatus	Fire Tree	R	
Ranunculaceae			
Clematis aristata			K
Clematis glycinoides	Headache Vine	C	
Rosaceae			
**Rosa bracteata*			K
**Rubus fruticosus*	Blackberry	C	

Scientific Name	Common Name	Shortland	Kooragang
Rutaceae			
#Acronychia oblongifolia		R	
Geijera latifolia			K
#Melicope elleryana		R	
Sapindaceae			
Alectryon subcinereus			K
**Cardiospermum grandiflorum*	Balloon Vine	R	
#Cupaniopsis anarcardiodes	Tuckeroo	R	K
#Dipliglottis australis	Native Tamarind	R	
#Harpullia pendula	Tullipwood	R	
Rhysotoechia bifoliolata			K
Sapotaceae			
#Planchonella australis	Black Apple	R	
Scrophulariaceae			
Bacopa monnieri	Bacopa	C	
Solanaceae			
**Datura stramonium*	Common Thornapple	R	
**Solanum mauritianum*	Wild Tobacco Bush	U	
**S. nigrum*	Black-Berry Nightshade	C	
Sterculiaceae			
Commersonia fraseri	Brush Kurrajong	U	
Tropaeolaceae			
**Tropaeolum majus*	Nasturtium	R	
Urticaceae			
Dendrocnide photinophylla			K
Urtica incisa	Stinging Nettle	R	K
Verbenaceae			
Clerodendrum tomentosum			K
**Lantana camara*	Lantana	C	K
**Verbena bonariensis*	Purpletop	A	K
Violaceae			
Viola hederacea	Ivy-Leaved Violet	U	
Vitaceae			
Cayratia clematidea			K
Cissus antarctica			K
CLASS LILIOPSIDA	**MONOCOTYLEDONS**		
Alliaceae			
**Nothoscordum inodorum*	Onion Weed	R	
Amaryllidaceae			
**Narcissus jonquilla*	Jonquills	R	
Arecaceae			
#Livistona australis	Cabbage Tree Palm	U	K
Commelinaceae			
Commelina cyanea	Scurvy Weed	U	

Scientific Name	Common Name	Shortland	Kooragang
**Tradescantia albiflora*	Wandering Jew	U	
Cyperaceae			
Bolboschoenus caldwelli	Coast Clubrush	C	K
Carex inversa			K
Carex?pumila			K
**Cyperus eragrotis*	Umbrella Sedge	U	
C. odoratus	Fragrant Sedge	C	
**C. papyrus*	Papyrus	R	
C. polystachyos			K
C. tetraphyllus			K
Eleocharis acuta	Spike Rush	R	
Fimbristylis ferruginea			K
Schoenoplectus litoralis			K
Schoenoplectus validus	River Clubrush	U	
Hydrocharitaceae			
Vallisneria gigantea	Giant Ribbon Weed	C	
Iridaceae			
**Romulea rosea var. australis*	Onion Grass	C	
Juncaceae			
**Juncus acutus*	Spiny Rush	R	K
J. krausii	Sea Rush	C	K
J. polyanthemus			K
J. usitatus	Common Rush	C	K
Juncaginaceae			
Triglochin striatum			K
Triglochin multifructum	Water Ribbons	C	
Triglochin procerum			K
Liliaceae			
Blandfordia grandiflora	Christmas Bush	C	
Lomandraceae			
Lomandra longifolia	Spiny-Headed Mat Rush	C	
Philesiaceae			
Eustrephus latifolius			K
Geitonoplesium cymosum			K
Poaceae			
Agrostis avenaceae			K
Avena barbata			K
**Briza maxima*	Quaking Grass	C	
**B. minor*	Shivery Grass	C	K
Bromus uniloides			K
**Chloris gayana*	Rhodes Grass	C	
**Cortaderia selloana*	Pampas Grass	R	
Cynodon dactylon	Couch	C	K
Dichelachne micrantha			K
**Echinochloa crus-gali*	Barnyard grass	C	

Scientific Name	Common Name	Shortland	Kooragang
Ehrharta erecta			K
Isachne globosa	Swamp Millet	C	
Lolium spp.			K
**Lolium temulentum*	Darnel	C	
**Melinis repens*	Red Natal Grass	R	
Microlaena stipoides			K
Oplismenus imbecillis			K
**Panicum maximum*	Guinea Grass	C	
**Paspalum, dilatatum*	Paspalum	C	K
Paspalum vaginatum			K
P. Distichum	Water Couch	A	
**Pennisetum clandestinum*	Kikuyu Grass	A	K
Poa annua			K
Sporobolus indicus var. *africanus*			K
Sporobolus elongata			K
Sporobolus virginicus			K
Stenotaphrum secundatum			K
Ruppiaceae			
Ruppia ?polycarpa			K
Typhaceae			
Typha orientalis			K
Zannichelliaceae			
Zannichellia palustris			K

Information Sheet on Ramsar Wetlands

Categories approved by Recommendation 4.7 of the Conference of the Contracting Parties.

1. Date this sheet was completed/updated:
January 1998

FOR OFFICE USE ONLY.

DD	MM	YY

Designation date

Site Reference Number

2. Country: Australia

3. Name of wetland: Kooragang Nature Reserve

4. Geographical coordinates: Latitude: 32^0 51'S; Longitude: 151^0 46'E

5. Altitude: Less than 10 metres above mean sea level. **6. Area:** Approximately 2,926 hectares

7. Overview: Kooragang Nature Reserve lies in the estuarine section of the Hunter River. The Reserve and surrounding areas have become known as one of the most important bird study areas in New South Wales. The area is extremely important as both a feeding and roosting site for a large seasonal population of Palaearctic waders and as a waylay site for transient migrants. The site also supports a significant number of birds which over-winter.

8. Wetland Type:

marine-coastal:	A	B	C	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
inland:	L	M	N	O	P	Q	R	Sp	Ss	Tp	Ts
	U	Va	Vt	W	Xf	Xp	Y	Zg	Zk		
man-made:	1	2	3	4	5	6	7	8	9		

Please now rank these wetland types by listing them from the most to the least dominant:
Marine-coastal: I, F, H, G, J, K, E, D

9. Ramsar Criteria:

(1a) 1b 1c 1d | (2a) (2b) 2c 2d | 3a (3b) (3c) | 4a 4b

Please specify the most significant criterion applicable to the site: 2a

10. Map of site included? Please tick *yes* ☑ **-or-** *no* ☐

11. Name and address of the compiler of this form:

NSW National Parks and Wildlife Service
Conservation Assessment and Planning Division
PO BOX 1967
Hurstville NSW 2220
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phone: 02 9585 6477
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12. Justification of the criteria selected under point 9, on previous page. Kooragang Nature Reserve comprises a large area of productive estuarine wetland habitat. The area is ecologically diverse and represents a significant genetic pool for wetland species in the region.

The Hunter estuary has supported more than one percent of the Australian populations of sixteen migratory wading species (Smith 1991) and based on this criterion is ranked as the fifth most important site for shorebirds in Australia (Watkins 1993). Significant concentrations of migratory wading birds (more than 5000) have been recorded in the estuary (Gosper 1981).

13. General location: Kooragang Nature Reserve is located in the estuary of the Hunter River, approximately 7 km north of Newcastle on the coast of New South Wales.

The population of Newcastle in 1996 was 133 280. The administrative centre is located within the suburb of Newcastle.

14. Physical features: Kooragang Nature Reserve comprises two areas: Kooragang Island and Fullerton Cove. Both lie in the estuarine section of the Hunter River.

Kooragang Island originally consisted of several smaller islands or bars. Several attempts to control deposition and siltation of the Newcastle port area resulted in the agglomeration of these islands into a smaller number of larger units by the artificial filling of channels and the construction of training walls. Fullerton Cove is a large shallow embayment north of Kooragang Island. It has a maximum depth of two to three metres at its centre and at low tide large areas of mudflats are exposed.

The lower Hunter River is a barrier estuary formed by the deposition of sediments in swamps and flats lying between the inner and outer coastal barrier sands. The sediments on Kooragang Island and adjacent estuarine areas comprise black silty and highly saturated soft clays to a depth of about 2 metres which are underlain by a light grey and silty sand. Depending on their elevation above sea level, drainage pattern and susceptibility to freshwater flooding, these sediments may be more or less saline. Salinities may vary from as high as 70% in evaporative salt marsh areas to as low as 8% behind levees where the soil is generally more fertile and regularly flooded by fresh water.

Most soils of Kooragang Island are only slightly acidic, although small areas of sandy clays supporting brackish swamps can reach significantly low pH and create the potential for acid sulphates to occur, should they be permanently dried out or drained.

The tidal variation for Kooragang Island is 0.1m to 2m. Average annual rainfall at Williamtown (nearest gauging station) is 1088.28 mm. The mean maximum temperature is 22.7°C and the mean minimum temperature is 12.2°C.

15. Hydrological values: Kooragang Island originally consisted of seven islands that were mostly separated by narrow mangrove lined channels. One of the larger channels was Moscheto Creek which linked the north and south arms of the river. In the 1950's the islands were reclaimed and as a result the hydrological regime of what became "Kooragang Island" and the Hunter estuary was modified.

Restrictions in tidal, normal and flood river flows have resulted from the reclamation. Flows through the south arm of the Hunter River have increased. Moscheto was occluded at its southern end by an industrial railway to become tidal via the north arm only.

In 1970 a levee bank was built around Fullerton Cove in an effort to ameliorate flooding in low lying areas of Newcastle, downstream of Kooragang Island. Drains were installed to reclaim the significant wetland areas behind the levees for agriculture. This levee provides some protection to agricultural lands during minor floods but the levee is overtopped in major floods.

16. Ecological features: Kooragang Nature Reserve contains numerous wetland types. The area is ecologically diverse and represents a significant genetic pool for wetland species in the region.

Habitat types contained within Kooragang Nature Reserve include:

- Mangrove forests dominated by grey mangrove (*Avicennia marina*) with some river mangrove (*Aegceras corniculatum*);
- Saltmarsh dominated by samphire (*Sarcocornia sp.*) and saltwater couch (*Sporobolus virginicus*). The community of saltmarsh in the area to the west of Fullerton Cove was once the largest in the region (Moss 1983). However the present levee bank and drains have led to it being replaced with drier pasture grasses such as paspalum (*Paspalum vaginatum*), buffalo, kikuyu and couch (*Cynodon sp.*);
- Saline and freshwater pastures are dominated by couch and other agricultural grasses, sedges and introduced weeds;
- Swamp forests consisting of swamp oak (*Casuarina glauca*) and paperbarks (*Melaleuca spp.*) that are now limited. These forests once formed an intermediate stage in the succession of habitats from mangroves to forests in brackish water above the saline regime;
- Rainforest communities exist in remnants on Kooragang Island. Isolated individual trees, for example figs (*Ficus spp.*) and cabbage tree palms (*Livistona australis*), still occur;
- A small area of seagrass (*Ruppia spiralis*) is located in a large tide pool adjacent to the railway line south of the Reserve (Johnston 1992). This habitat type forms part of the proposed area additions to the Reserve;
- Brackish swamps and standing open water containing sedges (*Scirpus spp.*) and other aquatic species.

Other important habitats that exist include standing open water, mudflats, sandy beaches and rock training walls.

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17. Noteworthy flora: In 1982, (Anon) a survey was undertaken on Kooragang Island which identified 113 species of vascular plants. These plants form many distinct habitat types which are described above in “Ecological Features”. The mangrove and saltmarsh areas are particularly good examples of this type of plant community.

The estuarine herb (*Zannechellia palustris*) has been recorded immediately adjacent to the western end of the Reserve. This herb is only found in the Newcastle/Lake Macquarie area and along Ironbark Creek. The threatened rainforest vine *Cynanchum elegans* also occurs adjacent to the western boundary of the reserve and currently has only been recorded in 40 other sites in NSW.

The seagrass communities found in the proposed area additions are the only known communities in the Hunter estuary.

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18. Noteworthy fauna: The Hunter River estuary is renown for its birdlife, with over one hundred species of birds having been recorded throughout the area. Of particular importance is the occurrence of migratory waterbirds. In 1994, 6 440 migratory waders were recorded in the estuary. Approximately 36 migratory waders presently covered in the Japan-Australia and China-Australia Migratory Bird Agreements have been recorded in this wetland area (Anon 1983b).

Kooragang Nature Reserve provides habitat for numerous species listed as endangered or vulnerable under the *NSW Threatened Species Conservation Act 1995*. These include Freckled Duck (*Stictonetta naevosa*), Pied Oystercatcher (*Haematopus longirostris*), Mongolian Plover (*Charadrius mongolus*), Large Sandplover (*Charadrius lescenaultii*), Black-tailed Godwit (*Limosa limosa*), Terek Sandpiper (*Xenus cinereus*), Great Knot (*Calidris tenuirostris*), Broad-billed Sandpiper (*Limicola falcinellus*), Little Tern (*Sterna albifrons*) and Green and gold bell frog (*Litoria aurea*).

The Hunter estuary contains about 15 species of commercially important fish, crustacea and molluscs. The industry has been estimated at around a half a million dollars annually with major components being mullet, jewfish, prawn and oyster fisheries which together provide about 8% of the NSW annual catch.

19. Social and cultural values: Kooragang Nature Reserve and the surrounding areas have become known as one of the most important bird study areas in New South Wales. The Reserve is used for both research and recreational birdwatching. Limited recreational fishing is also undertaken within the Reserve.

The Worimi and Awabakal Aboriginal tribes were the earliest inhabitants of the lower Hunter estuary. There are numerous middens and campsites scattered throughout the lower Hunter but they occur particularly along the river banks and within the dunes along Stockton Bight. The nearest Aboriginal sites outside the reserve come from the dunes and coastal forests between Fullerton Cove and Stockton Bight where many and varied sites are known to occur.

There are a few European historic sites within Kooragang Nature Reserve. These include concrete footings of an old dairy on Sandy Island, a timber bridge, a mature Moreton Bay Fig associated with early farming and a half submerged timber drogher. The most significant structure on the island is the school teachers residence; however this lies outside the reserve.

20. Land tenure/ownership of: The Ramsar Site is dedicated as a Nature Reserve under the *New South Wales National Parks and Wildlife Act 1974*. Surrounding lands are Freehold.

21. Current land use: The Ramsar site is permanently dedicated as a Nature Reserve and is used as a nature conservation area. A substantial amount of ornithological, wetlands ecology and fisheries research together with bird watching is undertaken within the reserve. Surrounding areas are privately owned and used for heavy industry and pastoral activities.

Two areas adjoining Kooragang Nature Reserve have been rehabilitated (known as the Kooragang Island Rehabilitation Project) and are used for conservation purposes.

22. Factors (past, present or potential) adversely affecting the site's ecological character, including changes in land use and development projects:

Introduced animals are a moderate threat to the Reserve. Domestic dogs (*Canis familiaris*) and cats (*Felis cattus*) affect bird populations through direct disturbance and predation. Black Rat (*Rattus rattus*), Brown Rat (*Rattus norvegicus*) and House Mouse (*Mus musculus*) compete with native species in the area. Rats are also known to take both waterfowl eggs and their hatchlings as food. There are limited numbers of hares and rabbits in the Reserve, however they are a minor threat due to lack of suitable habitat.

Introduced weeds are a moderate threat to the Reserve. Four weeds are established within the Reserve and include Bitou bush (*Chrysanthemoides monilifera*), Alligator Weed (*Alternanthera philoxeroides*), Water hyacinth (*Eichornia crassipes*) and Pampas Grass (*Cortaderia selloana*). Sharp Rush (*Juncus acutus*) occurs in part of the Reserve but is considered a minor threat.

The lower catchment of the Hunter River is highly industrialised and urbanised. The mouth of the River has been developed as one of Australia’s most important ports. Land development continues near the Reserve and upstream along the Hunter River and this could accelerate soil erosion and water pollution in the vicinity of the Reserve. Soil erosion and water pollution are considered moderate threats.

Air pollution from nearby aluminium and steel industries is a minor threat. Oil spills are considered a major threat but to date none have occurred within the reserve.

23. Conservation measures taken:

Kooragang Nature Reserve was gazetted in March 1983. Since then 720 ha have been added to the Reserve which currently totals 2,926 ha. A draft Plan of Management for the Nature Reserve has been developed and it addresses numerous conservation and management initiatives to preserve and enhance the area for nature conservation. Management policies and practices are outlined for the following areas:

- Geology and soils;
- Hydrology, Water Quality and Catchment management;
- Native plants;

- Native animals including birds, invertebrates, mammals, reptiles and amphibians;
- Wetland rehabilitation;
- Cultural heritage;
- Introduced plants and animals;
- Fire management; and
- Use and promotion of the Nature Reserve.

Specific conservation measures undertaken recently include the following:

- Pampas grass control was undertaken in 1996;
- Vegetation mapping of the Nature Reserve was completed in 1996;
- An Alligator weed survey was completed in 1997 together with a management strategy for its control;
- The migratory shorebird habitat at Stockton sandspit has been rehabilitated; and
- Aerial survey of waterbirds every second month have been undertaken for two years running and were completed in 1997.

24. Conservation measures proposed but not yet implemented: Rehabilitation of wetlands areas within and adjacent to the Nature Reserve have been undertaken under the auspice of the Kooragang Rehabilitation Project. The Project aims to restore and/or enhance the habitat for migratory birds and waterfowl. To achieve this aim it is proposed that:

- Lands within Kooragang Nature Reserve previously reclaimed for agriculture and flood mitigation are to be rehabilitated to wetland;
- The hydrology created by artificial regulation devices on parts of Kooragang Island are to be modified; and
- Degraded vegetation communities in Kooragang Nature Reserve are to be rehabilitated.

Tidal regimes will be introduced into the Tomago buffer lands to increase the wetland habitat in the Nature Reserve.

25. Current scientific research and facilities: There are no research facilities within Kooragang Nature Reserve, however, the Shortland Wetlands Centre is located at Shortland less than 2km away. Research facilities are available at this centre.

Kooragang Island has been the subject of a number of ecological studies undertaken by a various parties including the University of Newcastle, Hunter Bird Observers Club, Shortland Wetlands Centre, Hunter Catchment Management Trust, Ironbark Creek Catchment Management Committee, Kooragang Wetland Rehabilitation Project, Hunter Water Corporation and various environmental consultancy companies.

Currently research is being undertaken in the following areas:

- Banding and plumage studies of wading birds, water bird counts, the success of water bird breeding and changes in migration patterns;
- Geomorphological changes to the Hunter River estuary;
- Water quality monitoring; and
- Alligator weed.

26. Current conservation education: Kooragang Nature Reserve offers significant opportunity for environmental education since it is readily accessible to a large number of people from Newcastle and the lower Hunter Valley.

The Shortland Wetlands Centre is located nearby and provides interpretation of the area. It also organises regular visits to the Nature Reserve for researchers and students of wetland conservation.

The Kooragang Wetland Rehabilitation Project has proposed to erect interpretation facilities and a model environmentally sustainable farm adjacent to the Nature Reserve. Erection of education facilities under Stockton Bridge are also proposed.

The NSW NPWS in cooperation with Environment Australia has erected signs that outline the principles of the Ramsar Convention and the conservation values of the Ramsar Site.

27. Current recreation and tourism: Kooragang Nature Reserve is not promoted as a tourist destination. Some limited low impact recreational uses are permitted within the Nature Reserve and include fishing, boating and bird watching. The Nature Reserve has approximately 5 000 visitors per year.

28. Jurisdiction:
Territorial: Government of New South Wales
Functional: New South Wales National Parks and Wildlife Service

29. Management authority:
NSW National Parks & Wildlife Service (Hunter District, Central Region, Sydney & Northern Zone)

Address:	District Manager
	P.O. Box 270
	Raymond Terrace, NSW 2334
	Australia.
Phone:	02 4987 3108
Fax:	02 4987 1031

30. Bibliographical references:

Anon (1978) *An Assessment of the Effects on the Environment of the Proposed Stage II Landfill Scheme at Kooragang Island, Newcastle.* NSW Department of Public Works.

Anon (1982) *An Investigation of the Natural Areas of Kooragang Island*. Insearch Ltd.

Anon (1983a) *Investigation of Natural Areas of Kooragang Island, Hunter River*. Department of Environment and Planning

Anon (1983b) *Results from the 1983 Summer Wader Counts*. Internal Report, National Parks and Wildlife Service.

Clarke, C.J. & van Gessel, F.W.C. (1983). Habitat evaluation. In Investigations of the natural areas of Kooragang Island. Field, C.D. and Associates and Insearch Ltd. NSW Department of Environment and Planning, Sydney.

Coffee, E.J., (1973) *Report of Findings of the Commissioner, Enquiry into Pollution from Kooragang Island*. State Pollution Control Commission.

Gosper, D.G., (1981) Survey of birds on floodplain-estuarine wetlands on the Hunter and Richmond Rivers in northern NSW. *Corella* 5: 1-18.

Hodges, S.L., (1980) *Kooragang Island/Fullerton Cove Proposed Nature Reserve, Investigation Report*. National Parks and Wildlife Service.

Holmes, G. (1970). A survey of wetlands of the Hunter River estuary, *Hunter Natural History* 2, 13-18.

Morris, A. K. (1975). The birds of Gosford, Wyong and Newcastle (County of Northumberland). *Australian Birds* 37-76.

Smith, P., (1991) *The biology and management of waders (Suborder Charadrii) in NSW*. NSW National Parks and Wildlife Service Species Management Report Number 9.

van Gessel, F. & Kendall, T. (1972a). A checklist of the birds of Kooragang Island. *Hunter Natural History* 4, 194-215.

van Gessel, F. & Kendall, T. (1972b). A checklist of the birds of Kooragang Island: Supplement No.1. *Hunter Natural History* 4, 256-260.

van Gessel, F. & Kendall, T. (1974). Trapping migratory waders at Kooragang Island, Newcastle, N.S.W. *The Australian Bird Bander* 12, 71-75.

Watkins, D. (1993). *A national plan for shorebird conservation in Australia*. Australian wader studies group.

Appendix 1: Waterbird species recorded in the Hunter Estuary. Records derived from Holmes (1970), van Gessel & Kendall (1972a&b, 1974); Morris (1975); Clarke and van Gessel (1983).

Common Name	Scientific Name
Australasian Grebe	*Tachybaptus novaehollandiae*
Hoary-headed Grebe	*Poliocephalus poliocephalus*
Great Crested Grebe	*Podiceps cristatus*
Australian Pelican	*Pelecanus conspicillatus*
Darter	*Anhinga melanogaster*
Great Cormorant	*Phalacrocorax carbo*
Pied Cormorant	*Phalacrocorax varius*
Little Black Cormorant	*Phalacrocorax sulcirostris*
Little Pied Cormorant	*Phalacrocorax melanoleucos*
Pacific Heron	*Ardea pacifica*
Great Egret	*Ardea alba*
Intermediate Egret	*Ardea intermedia*
White-faced Heron	*Ardea novaehollandiae*
Little Egret	*Ardea garzetta*
Striated Heron	*Ardea striata*
Cattle Egret	*Ardea ibis*
Rufous night Heron	*Nycticorax caledonicus*
Little Bittern	*Ixobrychus minutus*
Black Bittern	*Ixobrychus flavicollis*
Australasian Bittern	*Botaurus poiciloptilus*
Black-necked Stork	*Ephippiorhynchus asiaticus*
Glossy Ibis	*Plegadis falcinellus*
Australian White Ibis	*Threskiornis molucca*
Straw-necked Ibis	*Threskiornis spinicollis*
Royal Spoonbill	*Platalea regia*
Yellow-billed Spoonbill	*Platalea flavipes*
Plumed Whistling-duck	*Dendrocygna eytoni*
Musk Duck	*Biziura lobata*
Freckled Duck	*Stictonetta naevosa*
Black Swan	*Cygnus atratus*
Australian shelduck	*Tadorna tadornoides*
Maned Duck	*Chenonetta jubata*
Pink-eared Duck	*Malacorhynchus membranaceus*
Grey Teal	*Anas gracilis*
Chestnut Teal	*Anas castanea*
Pacific Black Duck	*Anas superciliosa*
Australasian Shoveler	*Anas rhynchotis*
Hardhead	*Aythya australis*
Buff-banded Rail	*Gallirallus philippensis*
Baillon's Crake	*Porzana pusilla*
Australian Crake	*Porzana fluminea*
Spotless Crake	*Porzana tabuensis*
Purple Swamphen	*Porphyrio porphyrio*
Dusky Moorhen	*Gallinula tenebrosa*
Eurasian Coot	*Fulica atra*
Painted Snipe	*Rostratula benghalensis*
Comb-crested Jacana	*Irediparra gallinacea*
Pied Oystercatcher	*Haematopus longirostris*
Sooty Oystercatcher	*Haematopus fuliginosus*
Black-winged Stilt	*Himantopus himantopus*
Banded Stilt	*Cladorhynchus leucocephalus*
Red-necked Avocet	*Recurvirostra novaehollandiae*
Pacific Golden Plover	*Pluvialis fulva*
Grey Plover	*Pluvialis squatarola*
Ringed Plover	*Charadrius hiaticula*
Red-capped Plover	*Charadrius ruficapillus*

Double-banded Plover	*Charadrius bicinctus*
Mongolian Plover	*Charadrius mongolus*
Large Sand Plover	*Charadrius lescenaultii*
Oriental Plover	*Charadrius veredus*
Black-fronted Plover	*Elsyornis melanops*
Red-kneed Dotterel	*Erythrogonys cinctus*
Banded Lapwing	*Vanellus tricolor*
Masked Lapwing	*Vanellus miles*
Latham's Snipe	*Gallinago hardwickii*
Black-tailed Godwit	*Limosa limosa*
Hudsonian Godwit	*Limosa haemastica*
Bar-tailed Godwit	*Limosa lapponica*
Little Curlew	*Numenius minutus*
Whimbrel	*Numenius phaeopus*
Eastern Curlew	*Numenius madagascariensis*
Marsh Sanpiper	*Tringa stagnatilis*
Common Greenshank	*Tringa nebularia*
Wood Sandpiper	*Tringa glareola*
Terek Sandpiper	*Actitis hypoleucos*
Grey-tailed Tattler	*Heteroscelus brevipes*
Wandering Tattler	*Heteroscelus incanus*
Ruddy Turnstone	*Arenaria interpres*
Asian Dowitcher	*Limnodromus semipalmatus*
Great Knot	*Calidris tenuirostris*
Red Knot	*Calidris canutus*
Sanderling	*Calidris alba*
Pectoral Sandpiper	*Calidris melanotus*
Sharp-tailed Sandpiper	*Calidris acuminata*
Curlew Sandpiper	*Calidris ferruginea*
Buff-breasted Sandpiper	*Tryngites subruficollis*
Broad-billed Sandpiper	*Limicola falcinellus*
Ruff	*Philomachus pugnax*
Oriental Pratincole	*Glareola maldivarum*
Kelp Gull	*Larus dominicanus*
Silver Gull	*Larus novaehollandiae*
Gull-billed Tern	*Sterna nilotica*
Caspian Tern	*Sterna caspia*
Crested Tern	*Sterna bergii*
White-fronted Tern	*Sterna striata*
Common Tern	*Sterna hirundo*
Artic Tern	*Sterna paradisea*
Little Tern	*Sterna albifrons*
Whiskered Tern	*Chlidonias hybridus*
White-winged Black Tern	*Chlidonias leucopterus*
Black Tern	*Chlidonia niger*

NUMBER 24:

NAME:

Kooragang Nature Reserve, New South Wales

DESIGNATED:

21 February 1984

GEOGRAPHICAL COORDINATES:

Latitude: 32^0 51'S
Longitude: 151^0 47'E

GENERAL LOCATION:

In the Hunter River catchment, approximately 7 km north of Newcastle, New South Wales.

AREA:

Approximately 2,206 hectares

WETLAND TYPE:

Marine and Coastal Wetlands - 4, 5, 6, 7, 8, 9, 10 & 11

Inland Wetlands - 7

ELEVATION:

Less than 10 metres above mean sea level.

OVERVIEW:

Kooragang Island lies in the estuarine section of the Hunter River and part of the Ramsar site is subject to tidal inundation. The island and surrounding habitat has become known as one of the most important bird study areas in New South Wales. The Ramsar site is extremely important as both a feeding and roosting site for a large seasonal population of palearctic waders and as a waylay site for transient migrants.

The site also supports a significant number of birds which over-winter.

PHYSICAL FEATURES:

Kooragang Island lies in the estuarine section of the Hunter River and is subject to tidal inundation by waters from the estuary. This water varies in salinity from about 1 part per thousand to 36 parts per thousand depending on ambient weather conditions.

Fullerton Cove is a large shallow embayment north of Kooragang Island. It has a maximum depth of two to three metres at its centre and, at low tide, large areas of mudflats are exposed.

Kooragang Island originally consisted of several smaller islands or bars. Several attempts to control deposition and siltation of the Newcastle port area resulted in the

agglomeration of these islands into a smaller number of larger units by the artificial filling of channels and the construction of training walls.

ECOLOGICAL FEATURES:

Numerous habitat types have been recognised within and surrounding the Nature Reserve. These comprise mangrove forest, saltmarsh, saline pastures, Casuarina forest, brackish and freshwater swamps, standing open water, mudflats, sandy beaches and rock training walls.

The conservation value of Kooragang Nature Reserve lies in the fact that it is a large area of numerous types of productive estuarine wetland habitat. The area is ecologically diverse and represents a significant genetic pool for wetland species in the region.

LAND TENURE:

The Nature Reserve is Crown Land dedicated under the New South Wales *National Parks and Wildlife Act 1974*. Surrounding lands are privately owned and used for heavy industry and pastoral activities.

CONSERVATION MEASURES TAKEN:

The Ramsar site is permanently dedicated as a nature reserve.

CONSERVATION MEASURES PROPOSED BUT NOT YET IMPLEMENTED:

The drafting of a Plan of Management for Kooragang Nature Reserve is programmed for commencement in 1993.

CURRENT LAND USE:

The Ramsar site is permanently dedicated as a nature reserve.

Ornithological research and bird watching are currently the primary uses of the Kooragang Nature Reserve.

DISTURBANCES/THREATS:

Existing problems are noxious plants and animals, easy public access for such illegal activities as rubbish dumping and trail bike riding. The water levels in the area west of Fullerton Cove will require active management.

HYDROLOGICAL AND PHYSICAL VALUES:

Part of the foreshore of Kooragang Island has been stabilised by the construction of rock training walls.

SOCIAL AND CULTURAL VALUES:

The Kooragang Island/Fullerton Cove area contains extensive areas of mangrove and is important for fisheries production.

NOTEWORTHY FAUNA:

The area is noted for its birdlife particularly migratory waders.

One hundred and ninety species of birds have been recorded, representing 25 percent of the species known in Australia.

The total number of waders recorded was 5,020 compared to 5,816 waders in the total Hunter River wetland (Anon 1983b). Overall, 38 of the 66 species of migratory waders presently covered in the Japan-Australia and China-Australia Migratory Bird Agreements occur in this wetland area (Anon 1983b).

Also of significance is the occurrence (1983) of 14.6 percent of the total observed population of the Lesser Golden Plover (*Charadrius hiaticula*) and 5.9 percent of the Eastern Curlew (*Numenius madagascariensis*).

The conservation value of Kooragang Nature Reserve lies in the fact that it is a large area of productive estuarine wetland habitats. The area is ecologically diverse and represents a significant genetic pool for wetland species in the region.

Of special interest is its international significance to waterbirds, particularly migratory species. The total wader population varies greatly because the area is a seasonal and permanent feeding and roosting site and it is also utilised by transient migrants. Several rare waders have been recorded in the reserve for example, the Ringed Plover (*Charadrius hiaticula*), Large Sand Plover (*Charadrius leschenaultii*), Little Curlew (*Numenius minutus*), Pectoral Sandpiper (*Calidris melanotus*) and Ruff (*Philomachus pugnax*).

NOTEWORTHY FLORA:

113 species of vascular plants were identified in a survey in 1982 (Anon, 1982). No rare or threatened species have been identified.

CURRENT SCIENTIFIC RESEARCH AND FACILITIES:

Extensive banding and plumage studies of wading birds is carried out in the Ramsar area.

CURRENT CONSERVATION EDUCATION:

The nearby Shortland Wetlands Centre is a renowned facility devoted to wetland research and education. The Ramsar area is visited regularly by researchers and by students of wetland conservation in association with the Shortland Wetlands Centre.

CURRENT RECREATION AND TOURISM:

Bird watching.

MANAGEMENT AUTHORITY:

New South Wales National Parks and Wildlife Service, P.O. Box 1967 Hurstville, NSW 2220 Australia.

JURISDICTION:

Government of New South Wales

REFERENCES:

Anon (1978) *An Assessment of the Effects on the Environment of the Proposed Stage II Landfill Scheme at Kooragang Island, Newcastle.* NSW Department of Public Works.

Anon (1982) *An Investigation of the Natural Areas of Kooragang Island*. Insearch Ltd.

Anon (1983a) *Investigation of Natural Areas of Kooragang Island, Hunter River*. Department of Environment and Planning

Anon (1983b) *Results from the 1983 Summer Wader Counts*. Internal Report, National Parks and Wildlife Service.

Coffee, E.J., (1973) *Report of Findings of the Commissioner, Enquiry into Pollution from Kooragang Island*. State Pollution Control Commission.

Hodges, S.L., (1980) *Kooragang Island/Fullerton Cove Proposed Nature Reserve, Investigation Report*. National Parks and Wildlife Service.

REASONS FOR INCLUSION:

1(b), 2(a), 2(b) and 3.

MAP:

Information Sheet on Ramsar Wetlands (RIS)

Categories approved by Recommendation 4.7 (1990), as amended by Resolution VIII.13 of the 8th Conference of the Contracting Parties (2002) and Resolutions IX.1 Annex B, IX.6, IX.21 and IX. 22 of the 9th Conference of the Contracting Parties (2005).

This Ramsar Information Sheet has been converted to meet the 2009 – 2012 format, but the RIS content has not been updated in this conversion. The new format seeks some additional information which could not yet be included. This information will be added when future updates of this Ramsar Information Sheet are completed. Until then, notes on any changes in the ecological character of the Ramsar site may be obtained from the Ecological Character Description (if completed) and other relevant sources.

---

1. Name and address of the compilers of this form:

The Wetlands Centre Ltd
PO Box 292, Wallsend NSW 2287
Phone: 02 4055 8673 Fax: 02 4950 0497
Contacts: Christine Prietto and Helen Aitchison

NSW National Parks and Wildlife Service
PO Box 1967, Hurstville NSW 2220
Phone: 02 9585 6692 Fax: 02 9585 6495
Contact: Penny Brett

NSW National Parks and Wildlife Service
Hunter Coast Area
Locked Bag 99, Nelson Bay NSW 2315
Phone: 02 4984 8200 Fax: 02 4981 5913
Contact: Mick Murphy

FOR OFFICE USE ONLY.

DD MM YY

Designation date   Site Reference Number

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2. Date this sheet was completed/updated:

October 2002

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3. Country:

Australia

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4. Name of the Ramsar site:

The precise name of the designated site in one of the three official languages (English, French or Spanish) of the Convention. Alternative names, including in local language(s), should be given in parentheses after the precise name.

Hunter Estuary Wetlands

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5. Designation of new Ramsar site or update of existing site:

Hunter Estuary Wetlands was designated on 21 February 1984.

The previous RIS was dated October 2002

This RIS is for (tick one box only)**:**

a) Designation of a new Ramsar site ❑; or

b) Updated information on an existing Ramsar site ❑

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6. For RIS updates only, changes to the site since its designation or earlier update:

a) Site boundary and area

The Ramsar site boundary and site area are unchanged: ❑

or
If the site boundary has changed:
i) the boundary has been delineated more accurately ❑; or
ii) the boundary has been extended ❑; or
iii) the boundary has been restricted** ❑

and/or

If the site area has changed:
i) the area has been measured more accurately ❑; or
ii) the area has been extended ❑; or
iii) the area has been reduced** ❑

** **Important note**: If the boundary and/or area of the designated site is being restricted/reduced, the Contracting Party should have followed the procedures established by the Conference of the Parties in the Annex to COP9 Resolution IX.6 and provided a report in line with paragraph 28 of that Annex, prior to the submission of an updated RIS.

b) Describe briefly any major changes to the ecological character of the Ramsar site, including in the application of the Criteria, since the previous RIS for the site:

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7. Map of site:
Refer to Annex III of the *Explanatory Note and Guidelines*, for detailed guidance on provision of suitable maps, including digital maps.

a) A map of the site, with clearly delineated boundaries, is included as:
i**) a hard copy** (required for inclusion of site in the Ramsar List): ❑;

ii**) an electronic format** (e.g. a JPEG or ArcView image) ☑;

iii) **a GIS file providing geo-referenced site boundary vectors and attribute tables** ❑.

b) Describe briefly the type of boundary delineation applied:
e.g. the boundary is the same as an existing protected area (nature reserve, national park, etc.), or follows a catchment boundary, or follows a geopolitical boundary such as a local government jurisdiction, follows physical boundaries such as roads, follows the shoreline of a waterbody, etc.

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8. Geographical coordinates (latitude/longitude, in degrees and minutes):
Provide the coordinates of the approximate centre of the site and/or the limits of the site. If the site is composed of more than one separate area, provide coordinates for each of these areas.

Kooragang: Latitude: 32º51'S; Longitude: 151º46'E
Shortland: Latitude: 32º53'S; Longitude: 151º41'E

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9. General location:
Include in which part of the country and which large administrative region(s) the site lies and the location of the nearest large town.

The Hunter Estuary Wetlands Ramsar site comprises Kooragang Nature Reserve (designated to the Ramsar list in 1984) and Shortland Wetlands. Although the sites are not contiguous they have significant linkages.

Kooragang Nature Reserve is located in the estuary of the Hunter River, approximately 7km north of Newcastle on the coast of New South Wales. Shortland Wetlands are located in the Ironbark Creek Catchment in the suburb of Shortland, 12km northwest of Newcastle and 2.5 km from Kooragang Nature Reserve. The Ironbark Creek Catchment, which also includes Hexham Swamp, is a sub catchment of the Hunter Estuary.

The two sites are linked hydrologically and by a wildlife corridor consisting of Ironbark Creek, the Hunter River and Ash Island (NPWS 1998). The sites are complementary as together they provide a representative range of wetland types found in coastal estuaries within the Sydney Basin biogeographic region. They provide habitat for a great diversity of flora and fauna species that are common to both sites and are highly used by numerous waterbird species for feeding and roosting.

The population of Newcastle in 2000 was over 140,000.

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10. Elevation: (in metres: average and/or maximum & minimum)
0-10m ASL

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11. Area: (in hectares)
Kooragang - 2,926 hectares; **Shortland** – 45 hectares

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12. General overview of the site:
Provide a short paragraph giving a summary description of the principal ecological characteristics and importance of the wetland.

The Hunter Estuary Wetlands Ramsar site comprises Kooragang Nature Reserve (designated to the Ramsar list in 1984) and Shortland Wetlands. The boundary of Shortland Wetlands is 2.5 km from Kooragang Nature Reserve and is connected to it by a wildlife corridor consisting of Ironbark Creek, the Hunter River and Ash Island.

Kooragang Nature Reserve lies in the estuarine section of the Hunter River. The Reserve and surrounding areas have become known as one of the most important bird study areas in New South Wales. The area is extremely important as both a feeding and roosting site for a large seasonal population of Palaearctic shorebirds and as a waylay site for transient migrants. The site also supports a significant number of birds that over-winter.

Shortland Wetlands is a small but unique complex of wetland types surrounded by urban development along three boundaries. Previously degraded, this urban wetland has been restored with the key objectives of wetland conservation, education and community involvement. The site provides habitat for a diverse range of wetland species, including waterbirds at a critical stage of their lifecycles and threatened species.

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13. Ramsar Criteria:
Tick the box under each Criterion applied to the designation of the Ramsar site. See Annex II of the *Explanatory Notes and Guidelines* for the Criteria and guidelines for their application (adopted by Resolution VII.11). All Criteria which apply should be ticked.

1	2	3	4	5	6	7	8	9
☑	❑	☑	☑	❑	☑	❑	❑	❑

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14. Justification for the application of each Criterion listed in 13 above:
Provide justification for each Criterion in turn, clearly identifying to which Criterion the justification applies (see Annex II for guidance on acceptable forms of justification).

Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
Shortland Wetlands is unique in that it has, within its 45ha site, a combination of high conservation value near-natural wetlands (Melaleuca Swamp Forest, freshwater reed marsh, coastal estuarine mangrove-lined creek) and high conservation value artificial wetlands (constructed freshwater lagoons, coastal estuarine Casuarina-lined channel, model farm dam). It is the only complex of this type found within the Sydney Basin biogeographic region. The Melaleuca Swamp Forest in particular represents a wetland type that, although once very widespread, is poorly represented in the Sydney Basin biogeographic region.

Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.
Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin biogeographic region. Winning (1996) identified 112 species of vascular plants at Kooragang Island (**Appendix 4**) which form many distinct habitat types (see Category 16). The Mangrove and Saltmarsh areas are particularly good examples of these plant communities.

The most significant wetland plant community at Shortland Wetlands is the Melaleuca Swamp Forest, dominated by Broad-leaved Paperbark *(Melaleuca quinquenervia*). The Swamp Forest is remnant of a plant community that was once very wide spread in this area and is now poorly represented in the Sydney Basin biogeographic region.

The Hunter Estuary Wetlands are also important for maintaining a high diversity of birds within the biogeographic region with over 250 species recorded (**Appendix 1**).

Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.
Kooragang Nature Reserve is widely recognised for its importance in the conservation of migratory birds (Geering 1995; NPWS 1998). At least 38 species of migratory birds recorded at Kooragang and 21 species of migratory birds at Shortland Wetlands are presently listed under International treaties including the Japan-Australia and China-Australia Migratory Bird Agreements (JAMBA and CAMBA) (**Appendix 1).**

In 2000, 4,800 migratory shorebirds were recorded in the Hunter Estuary (Straw 2000). Kooragang Nature Reserve regularly supports 15 species of migratory shorebird. Shortland Wetlands regularly provides habitat for at least seven species of migratory shorebird, particularly when muddy margins of the ponds become exposed (**Appendix 1).**

Kooragang and Shortland Wetlands also support a large number of species at a critical seasonal stage of their breeding cycle. Twenty-four of the 28 bird species recorded breeding at Shortland also occur at Kooragang (see **Appendix 2**).

The site provides refuge for a number of species during periods of critical inland drought. These species include Freckled Duck (*Stictonetta naevosa)*; Pink-eared Duck (*Malacorhynchus membranaceus)*; Australian Pelican (*Pelecanus conspicillatus)*; and Glossy Ibis (*Plegadis falcinellus)* (Albrecht and Maddock 1985). The site is also important for local resident ducks, herons and other waterbirds, with up to 2000 ducks recorded at Shortland Wetlands during dry periods (Winning 1989).

Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.
Kooragang Nature Reserve regularly supports between 2% and 5% of the East Asian-Australasian Flyway population of Eastern Curlew *(Numenius madagascariensis)*, with counts ranging from 320 to 900 birds between 1989 and 2000 (Straw 2000). The 1% population threshold for this species is 210 individuals (Rose and Scott 1997).

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15. Biogeography (required when Criteria 1 and/or 3 and /or certain applications of Criterion 2 are applied to the designation):
Name the relevant biogeographic region that includes the Ramsar site, and identify the biogeographic regionalisation system that has been applied.

a) biogeographic region:
Sydney Basin biogeographic region

b) biogeographic regionalisation scheme (include reference citation):
Interim Biogeographic Regionalisation for Australia (IBRA Version 5.1) (Thackway & Cresswell 1995, Environment Australia 2000)

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16. Physical features of the site:
Describe, as appropriate, the geology, geomorphology; origins - natural or artificial; hydrology; soil type; water quality; water depth, water permanence; fluctuations in water level; tidal variations; downstream area; general climate, etc.

Kooragang Nature Reserve
Kooragang Nature Reserve comprises Kooragang Island and Fullerton Cove, two areas that lie in the estuarine section of the Hunter River.

Kooragang Island originally consisted of several smaller islands or bars (NPWS 1998). Attempts to control deposition and siltation of the Newcastle port area resulted in the artificial filling of channels and the construction of training walls (NPWS 1998). Fullerton Cove is a large, shallow embayment north of Kooragang Island. It has a maximum depth of two to three metres at its centre and at low tide large areas of mudflats are exposed.

The lower Hunter River is a barrier estuary formed by the deposition of sediments in swamps and flats lying between the inner and outer coastal barrier sands (NPWS 1998). The sediments on Kooragang Island and adjacent estuarine areas comprise black silty and highly saturated soft clays to a depth of about 2m which are underlain by a light grey and silty sand (NPWS 1998). Salinities may vary from 70% in evaporative salt marsh areas to 8% behind levees where the soil is generally more fertile and regularly flooded by fresh water (NPWS 1998).

Most soils of Kooragang Island are only slightly acidic, although small areas of sandy clays supporting brackish swamps can reach significantly low pH and create the potential for acid sulfates to occur, should they be permanently dried out or drained (NPWS 1998).

The tidal variation for Kooragang Island is 0.1m to 2m. Average annual rainfall at Williamtown (nearest gauging station) is 1088 mm. The mean temperature ranges from 22.7°C to 12.2°C.

Shortland Wetlands
Shortland Wetlands is a restored and remnant wetland bounded on the south by the suburb of Shortland, on the east by a major arterial road, on the north by an old landfill site and on the west by Ironbark Creek and Hexham Swamp. There are strong ecological links between Hexham Swamp, Shortland Wetlands and the western end of Kooragang Nature Reserve (NPWS 1998).

Shortland Wetlands is situated on Quaternary estuarine/lacustrine sediments including silts and clays (Matthei 1995). The site consists of seven discreet but interconnected ponds and a freshwater channel.

Four of these ponds are natural and three are man-made. The man-made ponds have been constructed on old landfill sites that were subsequently used as sporting fields.

Water flows from adjacent urban areas into the wetlands and is controlled by various methods. It flows from south-east to north-west through the ponds and exits the site into Ironbark Creek. The average size of the ponds is $14m^2$ and each pond varies in depth from 0.4m to 1m (Bischof and Brown 1996). Most ponds are permanent, with varying water levels, although the Reed Marsh dries bi-annually. Water may be pumped into ponds from a nearby channel but this is rarely done. There is no tidal variation. The catchment area is not known but includes the urban suburbs of Shortland, Waratah West and Warabrook.

Water quality is consistent with natural, freshwater ponds. Abiotic measurements indicate that pH is generally between 6.2 and 7.9. Water temperature varies seasonally between 14°C and 24°C and turbidity is usually less than 10ntu. Salinity is less than 1% (Grace and Francesconi 1997).

The water flowing from Shortland Wetlands enters Ironbark Creek and subsequently the Hunter River. At peak flood times Shortland Wetlands becomes a storage area for approximately $42,000m^3$ of water (Sinlaparommard 1999).

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17. Physical features of the catchment area:
Describe the surface area, general geology and geomorphological features, general soil types, and climate (including climate type).

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18. Hydrological values:
Describe the functions and values of the wetland in groundwater recharge, flood control, sediment trapping, shoreline stabilization, etc.

Kooragang Nature Reserve
Kooragang Island originally consisted of seven islands that were mostly separated by narrow mangrove lined channels. One of the larger channels was Moscheto Creek which linked the north and south arms of the river. In the 1950s the islands were reclaimed and as a result the hydrological regime of what became "Kooragang Island" and the Hunter Estuary was modified (NPWS 1998). Restrictions in tidal, normal and flood river flows have resulted from the reclamation. Flows through the south arm of the Hunter River have increased. Moscheto was occluded at its southern end by an industrial railway to become tidal via the north arm only (NPWS 1998).

In 1970 a levee bank was built around Fullerton Cove in an effort to ameliorate flooding in low-lying areas of Newcastle, downstream of Kooragang Island (NPWS 1998). Drains were installed to reclaim the significant wetland areas behind the levees for agriculture. This levee provides some protection to agricultural lands during minor floods but the levee is overtopped in major floods (NPWS 1998).

Shortland Wetlands
Shortland Wetlands are a natural drainage depression, a remnant of extensive tidal and floodplain wetlands that once extended east of Ironbark Creek. Changes in the natural flow regime have been caused by the construction of floodgates on Ironbark Creek and a drainage canal from Sandgate Road to Ironbark Creek, the establishment of a garbage dump, the construction of a power transmission line and associated access roads and development as a sporting complex (Winning 1989). These actions restricted the entry of saline tidal water, changing the wetlands from a brackish to fresh water regime (Winning 1989). All of these actions pre-date the establishment of Shortland Wetlands as a Wetlands Centre.

Water flowing into Shortland Wetlands today is generated by local rainfall and run-off from nearby suburbs. Stormwater pipes and culverts collect stormwater from lands and suburbs to the south, east and north and deliver water to the Wetlands (NCC 2000).

Shortland Wetlands delivers water to Ironbark Creek or to a constructed channel via a series of drainage points along Ironbark Marsh and on the northern boundary of the site. However, the flow occurs only after periods of heavy rain or when Ironbark Marsh is at full capacity (Sinlaparommard 1999).

Shortland Wetlands is valuable for the storage of rainfall and stormwater which provide habitat for significant wetland fauna and flora species. The Wetlands enable the recycling of nutrients that enter the site in stormwater or through the activity of nesting birds.

19. Wetland Types

a) presence:

Circle or underline the applicable codes for the wetland types of the Ramsar "Classification System for Wetland Type" present in the Ramsar site. Descriptions of each wetland type code are provided in Annex I of the *Explanatory Notes & Guidelines*.

Marine/coastal: A • B • C • D • E • F • G • H • I • J • K • Zk(a)

Inland: L • M • N • O • P • Q • R • Sp • Ss • Tp • Ts • U • Va • Vt • W • Xf • Xp • Y • Zg • Zk(b)

Human-made: 1 • 2 • 3 • 4 • 5 • 6 • 7 • 8 • 9 • Zk(c)

b) dominance:

List the wetland types identified in a) above in order of their dominance (by area) in the Ramsar site, starting with the wetland type with the largest area.

Kooragang Nature Reserve: I, F, H, G, J, K, E, D
Shortland Wetlands: Ts, Ss, Xf, Type 2

20. General ecological features:

Provide further description, as appropriate, of the main habitats, vegetation types, plant and animal communities present in the Ramsar site, and the ecosystem services of the site and the benefits derived from them.

Kooragang Nature Reserve
Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin bioregion.

Habitat types mapped within the site (Briggs, Dames and Moore, Outhred and Buckney *in* NPWS 1998) include:

- Mangrove forests dominated by Grey Mangrove (*Avicennia marina*) and some River Mangrove (*Aegiceras corniculatum*);
- Saltmarsh dominated by Samphire (*Sarcocornia sp*.) and Saltwater Couch (*Sporobolus virginicus*). The saltmarsh community to the west of Fullerton Cove was once the largest in the region (Moss 1983). The present levee bank and drains have led to it being replaced with drier pasture grasses such as Paspalum (*Paspalum vaginatum*), Buffalo, Kikuyu (*Pennisetum clandestinum*) and Couch (*Cynodon sp*.);
- Saline and freshwater pastures are dominated by Couch and other agricultural grasses, sedges and introduced weeds;
- Swamp Forests consisting of Swamp She-oak (*Casuarina glauca*) and Paperbarks (*Melaleuca spp*.) that are now limited;
- Rainforest communities exist in remnants on Kooragang Island. Isolated individual Fig trees (*Ficus spp*.) and Cabbage Tree Palms (*Livistona australis*) occur;

- Brackish swamps and standing open water containing Sedges (*Scirpus spp*.) and other aquatic species; and
- Other important habitats include standing open water, mudflats, sandy beaches and rock retaining walls.

Shortland Wetlands
Shortland Wetlands were originally part of the estuarine wetlands of lower Ironbark Creek, with saltmarsh and mangroves extending well into the present site.

Today the site represents a remnant wetland that maintains its ecological connections to fresh, brackish and saline wetlands elsewhere in the estuary through its connection to Ironbark Creek. Although the floodgates on Ironbark Creek are still in place, their management is to be modified in the near future, allowing increased tidal flows into the creek system. This may enhance the brackish wetland values on the site.

The main habitats and vegetation types on the site include restored semi-permanent/seasonal freshwater ponds and marshes, natural semi-permanent/seasonal brackish ponds and marshes, freshwater swamp forests and a coastal estuarine creek.

Variations in water levels in the ponds result in a significant range of vegetation succession across the site annually, contributing to biodiversity values, especially in macro-invertebrate populations.

Over 150 flora species occur on the site (**Appendix 4**) within 22 vegetation communities (Beretta 1998). Floral communities include: Closed *Commersonia* Forest, Closed Mangrove Forest, Open Planted Rainforest, *Casuarina* Forest, Open *Melaleuca* Swamp Forest, Open Woodland, Wet Heath, *Banksia* Shrubland, *Acacia* Shrubland, Water Couch Wet Meadow, Closed *Typha* Rushland, Closed *Phragmites* Reed Swamp, *Juncus* Rushland and several large remnant Eucalypts.

The site contains a high diversity of original and rehabilitated plant communities and has undergone a committed landscaping effort (see Category 17).

Since 1996 over 32,000 trees have been planted on the site into four zones:
1. Visitor Centre Zone (native Australian plants);
2. Constructed Wetlands (plants native to the local region);
3. Natural Wetlands (plants native to the site); and
4. Rainforest Zone (a rehabilitated rainforest).

These plantings have significantly changed the landscape, enhancing natural processes on the site. The distribution and abundance of these plant communities create a stable and complex ecosystem that contributes to hydrologic processes, soil stabilisation and fauna diversity. The reedy margins provide breeding and feeding areas for waterfowl and vegetation in shallow pool margins provides foraging sites for shorebirds.

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21. Noteworthy flora:
Provide additional information on particular species and why they are noteworthy (expanding as necessary on information provided in 14, Justification for the application of the Criteria) indicating, e.g., which species/communities are unique, rare, endangered or biogeographically important, etc. *Do not include here taxonomic lists of species present – these may be supplied as supplementary information to the RIS.*

Kooragang Nature Reserve
A list of flora species compiled by Winning (1996) identified 112 species of vascular plants at Kooragang Island (**Appendix 4**) which form many distinct habitat types (see Category 16). The Mangrove and Saltmarsh areas are particularly good examples of these plant communities.

The estuarine herb *Zannechellia palustris* has been recorded immediately adjacent to the western end of the Reserve. This herb is only found in the Newcastle/Lake Macquarie area and along Ironbark Creek. The rainforest vine *Cynanchum elegans* is listed as Endangered under both State (TSC Act) and Commonwealth (EPBC Act) legislation. It occurs adjacent to the western boundary of the Reserve and has only been recorded in 40 other sites in NSW (NPWS 1998).

Shortland Wetlands
The most significant wetland plant community at Shortland Wetlands is the Melaleuca Swamp Forest, dominated by Broad-leaved Paperbark *(Melaleuca quinquenervia*). The Swamp Forest is remnant of a plant community that was once very wide spread in this area and is now poorly represented in the Sydney Basin bioregion.

Shortland Wetlands is significant for a range of plant communities that have been successfully re-introduced to the site, including:

- Open Rainforest developed around remnant rainforest species dominated by Turpentine (*Syncarpia glomulifera),* Lilly Pilly *(Acmena smithii),* Scentless Rosewood *(Synoum glandulosum)*, Cheese Tree *(Glochidion ferdinandi)* and Bleeding Heart *(Omalanthus populifolius*);
- Open Eucalypt woodland dominated by Swamp Mahogany (*Eucalyptus robusta*), Red Bloodwood (*Eucalyptus gummifera*) and Grey Gum (*Eucalyptus punctata*);
- Melaleuca Shrubland dominated by Ball Honeymyrtle (*Melaleuca nodosa*), Swamp Paperbark (*Melaleuca ericifolia*), Prickly-leaved Paperbark (*Melaleuca styphelioides*), and Swamp Millet (*Isachne globosa*);
- Acacia Shrubland dominated by Sydney Golden Wattle *(Acacia longifolia*);
- Wet Heath dominated by *Callistemon citrinus, Banksia robur* and Christmas Bells (*Blandfordia grandiflora*); and
- Casuarina Forest dominated by Swamp Oak (*Casuarina glauca*).

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22. Noteworthy fauna:
Provide additional information on particular species and why they are noteworthy (expanding as necessary on information provided in 14. Justification for the application of the Criteria) indicating, e.g., which species/communities are unique, rare, endangered or biogeographically important, etc., including count data. *Do not include here taxonomic lists of species present – these may be supplied as supplementary information to the RIS.*

The Hunter River Estuary is renowned for its birdlife. Over 250 species of birds have been recorded across the Hunter Estuary Wetlands site (**Appendix 1**). The occurrence of migratory waterbirds is of particular importance. In 2000, 4,800 migratory shorebirds were recorded in the Estuary (Straw 2000). At least 45 migratory species presently listed under the Japan-Australia Migratory Bird Agreement (JAMBA) and/or the China-Australia Migratory Bird Agreement (CAMBA) have been recorded at the site including 38 species at Kooragang and 21 species at Shortland, with 14 of these species common to both areas (**Appendix 1**).

The Estuary has supported more than one percent of the Australian populations of sixteen migratory wading species (Smith 1991) and based on this criterion has been ranked as the fifth most important site for shorebirds in Australia (Watkins 1993). It has also been recognised as the most important area for shorebirds in NSW (Smith 1991).

The site provides habitat for numerous threatened species listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act) (see **Appendix 1**). The Green and Golden Bell Frog (*Litoria aurea*) is also listed as vulnerable nationally under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). A project is currently underway to re-introduce the Bell Frog to Shortland Wetlands. The Australasian Bittern (*Botaurus poiciloptilus)* is also listed as vulnerable

globally (IUCN 2000) and the Red Goshawk (*Erythrotriorchis radiatus*) is vulnerable nationally (EPBC Act).

Threatened species (under the TSC Act) include Black-necked Storks (*Ephippiorhynchus asiaticus),* Australasian Bittern, Comb-crested Jacana (*Irediparra gallinacea)* and Magpie Geese (*Anseranas semipalmata)*. Black-necked Storks regularly use the site during their nomadic movements throughout the lower Hunter region. Australasian Bittern occur as a small, probably breeding population, but are rarely seen because of their secretive nature. Comb-crested Jacana is a rare species within the lower Hunter region. It has been reported at Kooragang Island and is a rare visitor to Shortland Wetlands. In 1987, the Wetlands Centre initiated a re-introduction of the locally extinct Magpie Goose and now supports a breeding population of more than 100 Geese. The Centre is one of four centres hosting a Freckled Duck captive-breeding program.

A total of seven mammal species have been recorded at Shortland Wetlands with only two of these being native. Several species of frogs, tortoise, skinks and snakes have been recorded at the site, all of which are common to the region (**Appendix 3**). Records for these species are currently not available for Kooragang.

The Hunter Estuary contains about 15 species of commercially important fish, crustacea and molluscs. The industry has been estimated at around a half a million dollars annually with major components being mullet, jewfish, prawn and oyster fisheries which together provide about 8% of the NSW annual catch (NPWS 1998).

Pond life at Shortland Wetlands is abundant. Six species of fish have been recorded (see **Appendix 3**). A wide diversity of macro-invertebrates is present including many sensitive insect larvae. Macro-invertebrate surveys routinely record molluscs, bloodworms, caddisfly larvae, gastropods, beetles, bugs, water fleas, seed shrimps, copepods and nymph forms of dragonfly, damselfly, stonefly and mayfly (Bischof and Brown 1996).

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23. Social and cultural values:

a) Describe if the site has any general social and/or cultural values e.g., fisheries production, forestry, religious importance, archaeological sites, social relations with the wetland, etc. Distinguish between historical/archaeological/religious significance and current socio-economic values:

Kooragang Nature Reserve

Kooragang Nature Reserve and the surrounding areas have become known as one of the most important bird study areas in New South Wales. The Reserve is used for both research and recreational birdwatching. Limited recreational fishing is also undertaken within the Reserve.

The Worimi and Awabakal Aboriginal tribes were the earliest inhabitants of the lower Hunter Estuary (NPWS 1998). There are numerous middens and campsites scattered throughout the lower Hunter but they occur particularly along the riverbanks and within the dunes along Stockton Bight. The nearest Aboriginal sites outside the Reserve come from the dunes and coastal forests between Fullerton Cove and Stockton Bight where many and varied sites are known to occur (NPWS 1998).

There are a few European historic sites within Kooragang Nature Reserve. These include concrete footings of an old munitions store on Sandy Island, a timber bridge, a mature Moreton Bay Fig associated with early farming and a half submerged timber drogher.

Shortland Wetlands

Historically the site now occupied by Shortland Wetlands would have been well-used by Aboriginal people as a food and materials source due to their productive and dynamic nature. The present site was occupied by the Pambalong people, a smaller tribe of the Awabakal People (Sokoloff 1974).

Shortland Wetlands contains a significant archaeological site that is believed to have been a factory site for the production of stone tools (Bangent 1990; Winning 1989).

Shortland Wetlands have retained their importance in the fabric of the local community since a community campaign to save and restore the wetlands. In 1984 the actions of the local conservation group gained support for the restoration of the degraded wetlands and the development of Shortland Wetlands Centre. This was a very ambitious project at that time. Now trading as The Wetlands Centre Australia, the Centre continues to attract strong community support and involvement.

The Wetlands Centre promotes wetland conservation and wise use through communication and education, passive recreation and community involvement and acts as a focal point for community-based environmental interest groups that represent valuable partnerships. The Hunter Bird Observers Club, Australian Plant Society and the Society for Frogs and Reptiles contribute expertise and resources to the sustainable management of the site. The successful restoration of Shortland Wetlands has been supported by the investment of many thousands of volunteer man-hours and valuable partnerships with relevant interest groups such as those mentioned above.

b) Is the site considered of international importance for holding, in addition to relevant ecological values, examples of significant cultural values, whether material or non-material, linked to its origin, conservation and/or ecological functioning?

If Yes, tick the box ❑ and describe this importance under one or more of the following categories:

i) sites which provide a model of wetland wise use, demonstrating the application of traditional knowledge and methods of management and use that maintain the ecological character of the wetland:

ii) sites which have exceptional cultural traditions or records of former civilizations that have influenced the ecological character of the wetland:

iii) sites where the ecological character of the wetland depends on the interaction with local communities or indigenous peoples:

iv) sites where relevant non-material values such as sacred sites are present and their existence is strongly linked with the maintenance of the ecological character of the wetland:

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24. Land tenure/ownership:

a) within the Ramsar site:

Kooragang Nature Reserve

The site is Crown Land dedicated as a Nature Reserve under the NSW *National Parks and Wildlife Act 1974*. Surrounding lands are a mixture of Freehold and other public authority managed lands.

Shortland Wetlands

The site is owned by Shortland Wetlands Centre, Ltd, trading as The Wetlands Centre Australia, a company limited by guarantee and owned by its (600) members. It operates as a not-for-profit conservation organisation and is managed by a volunteer Board of Directors.

b) in the surrounding area:

Land ownership in the surrounding area includes residential landholders, Newcastle City Council, Hunter Water Corporation, NSW Roads and Traffic Authority, Hunter Catchment Management Trust and NSW National Parks and Wildlife Service.

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25. Current land (including water) use:
a) within the Ramsar site:
Kooragang Nature Reserve
The site is permanently dedicated as a Nature Reserve and is used as a nature conservation area. A substantial amount of ornithological, wetlands ecology and fisheries research together with bird watching is undertaken within the Reserve. Surrounding areas are privately owned and used for heavy industry and pastoral activities.

Shortland Wetlands
The Shortland Wetlands site is used for wetland conservation, education and passive recreation. From 1984 the aim was to develop a wetland centre based on Slimbridge in the United Kingdom, to complement the restoration project. This project has matured alongside the restoration work. The site is well established as an education and eco-tourism destination. Providing public access for education purposes requires on-going management to assure that ecological values are not threatened.

b) in the surroundings/catchment:
Kooragang Nature Reserve
Two areas adjoining Kooragang Nature Reserve are being rehabilitated (known as the Kooragang Wetland Rehabilitation Project) and are used for conservation purposes.

Shortland Wetlands
The immediate surrounding area includes residential, water delivery infrastructure, a sports ground, roads, former local government landfill site, market gardens, railway line, a cemetery, as well as significant conservation areas adjacent to the site. It is important to note that approximately one-third of the Newcastle Local Government Area is classified as wetland. However, Newcastle also has an industrial economic base, including coal imports, a working port and small, medium and heavy manufacturing.

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26. Factors (past, present or potential) adversely affecting the site's ecological character, including changes in land (including water) use and development projects:
a) within the Ramsar site:
Kooragang Nature Reserve
Introduced animals are a moderate threat to the Reserve. Domestic dogs (*Canis familiaris*), foxes (*Vulpes vulpes*) and cats (*Felis cattus*) affect bird populations through direct disturbance and predation. Black Rat (*Rattus rattus*), Brown Rat (*Rattus norvegicus*) and House Mouse (*Mus musculus*) compete with native species in the area. Rats are also known to take both waterfowl eggs and their hatchlings as food. There are limited numbers of hares and rabbits in the Reserve, however they are a minor threat due to lack of suitable habitat.

Introduced weeds are a moderate threat to the Reserve. Four weeds are established within the Reserve and include Bitou bush (*Chrysanthemoides monilifera*), Alligator Weed (*Alternanthera philoxeroides*), Water hyacinth (*Eichornia crassipes*) and Pampas Grass (*Cortaderia selloana*). Sharp Rush (*Juncus acutus*) occurs in part of the Reserve but is considered a minor threat.

Shortland Wetlands
In 1971, floodgates were installed in Ironbark Creek. The purpose of this installation was to mediate flood control for surrounding areas. The Hunter Catchment Management Trust is proposing to open the floodgates in an attempt to re-introduce natural water flows and a tidal influence. Modeling suggests that this will have an insignificant impact on Shortland Wetlands although it may impact slightly on the western edge of the site. Currently, the Hunter Catchment Management Trust is conducting a trial by opening the floodgates in a limited way in order to monitor change.

Many exotic plant species occur at Shortland Wetlands (see **Appendix 4).** The spread of weeds may be enhanced by local residents who dump rubbish on the site, clear vegetation near their fences and plant exotic tree species. The most serious aquatic weed species include Alligator Weed (*Alternanthera philoxeroides),* Dock (*Rumex spp*.) and Pennywort (*Hydrocotyle bonariensis).*

Introduced animals that pose the most serious threat to native fauna at the site include the Black Rat (*Rattus rattus*), House Mouse (*Mus musculus*), Red Fox (*Vulpes vulpes*), domestic Cat (*Felis catus*), Common Myna (*Acridotheres tristus*), Common Starling (*Sturnus vulgaris*) and Mosquito Fish (*Gambusia holbrooki*).

The Black Rat poses a threat to shore-breeding birds, shorebirds, and the Long-necked Tortoise by predating eggs and nestlings. Red Foxes have been recorded preying on juveniles of Egrets and pose a threat to other species such as ground nesting and ground feeding birds. Rabbits may enhance the effects of soil erosion and Brown Hares pose a threat to the regeneration of vegetation. Predation by Mosquito Fish is listed as a key threatening process under the NSW *TSC Act 1995*. It is considered a threat to the Green and Golden Bell Frog (Morgan and Butterner *in* NPWS 2002b) as well as macro-invertebrate communities.

Some of the remnant natural wetlands on the site have exhibited signs of eutrophication, such as emission of odorous gases (e.g. Hydrogen sulphide), algal blooms and dominance by eutrophytes (e.g. *Triglochin procera, Spirodela pusilla, Azolla spp.*). Eutrophication may occur as a result of a concentration of nutrients, changes in water quality parameters such as pH, urban run-off and a build-up of bird faeces. The substrate of the artificial ponds may also increase eutrophication as it contains high nutrient material which was previously dumped on the site as fill.

b) in the surrounding area:

Kooragang Nature Reserve

The lower catchment of the Hunter River is highly industrialised and urbanised. The mouth of the River has been developed as one of Australia's most important ports. Further industrial expansion adjacent to the Reserve is proposed and potential impacts on the Ramsar values are currently being assessed. Land development continues near the Reserve and upstream along the Hunter River and this could accelerate soil erosion and water pollution in the vicinity of the Reserve. Soil erosion and water pollution are considered moderate threats.

Air pollution from nearby aluminum and steel industries is a minor threat. Oil spills are considered a major threat but to date none have occurred within the Reserve.

Shortland Wetlands

There is potential for development of the landfill site adjacent to Shortland Wetlands that is owned by Newcastle City Council and has been closed since 1992.

A proposed extension to the existing freeway to the east of the site could potentially impact on the wetland. There is, however, a buffer zone between the Ramsar site and the development proposal.

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27. Conservation measures taken:

a) List national and/or international category and legal status of protected areas, including boundary relationships with the Ramsar site:

In particular, if the site is partly or wholly a World Heritage Site and/or a UNESCO Biosphere Reserve, please give the names of the site under these designations.

Kooragang Nature Reserve was gazetted in 1983.

Shortland Wetlands was established as a **conservation reserve** in 1985.

b) If appropriate, list the IUCN (1994) protected areas category/ies which apply to the site (tick the box or boxes as appropriate):

Ia ❑;Ib ❑; II ❑; III ❑; IV ❑; V ❑; VI ❑

c) Does an officially approved management plan exist; and is it being implemented?:

Kooragang Nature Reserve

Since the gazettal of Kooragang Nature Reserve in 1983, 720ha have been added to the Reserve which currently totals 2,926ha. The Plan of Management (NPWS 1998) which aims to preserve and enhance the area for nature conservation has been implemented and includes:

- Water quality and catchment management;
- Management of native and introduced flora and fauna;
- Wetland rehabilitation;
- Cultural heritage;
- Fire management; and
- Use and promotion of the Nature Reserve.

Specific conservation measures currently being undertaken, or undertaken recently, include:

- Rehabilitation of Sandy Island for migratory shorebird roosting;
- Mangrove removal and ongoing management of the Stockton Sandspit for shorebird roosting;
- Artificial roost construction in Fullerton Cove;
- Monthly shorebird monitoring;
- Pampas grass control is anticipated in early 2003; and
- A management strategy for the control of Alligator weed.

Shortland Wetlands

The site was established as a conservation reserve in 1985. The site restoration has included the creation of two new ponds, development of tracks, building of structures and interpretation to support education uses. Management plans using a catchment management approach were developed and implemented to guide restoration work, on-going management and public access. A long-term revegetation plan has been implemented to improve degraded habitat and introduce new habitat types.

Management is under the direction of a volunteer site committee which meets quarterly and includes staff, volunteers and technical advisors.

Monitoring of a broad range of ecosystem functions and values has been intermittent. Monitoring of bird species, egret breeding and ibis roosting and recording of plant species have been maintained.

The Wetlands Centre is one of four centres hosting a Freckled Duck captive-breeding program. The program began with 17 ducks and since 1993, 52 ducklings have hatched and 36 have survived. Fifteen of these have been given to Tidbinbilla Nature Reserve as part of their captive-breeding program.

The restoration of the site has been used to promote broad conservation of all local wetlands. The involvement of the local community has played a major role in the restoration project, site management, project development, plantings, programs and administration.

d) Describe any other current management practices:

Some areas of Shortland Wetlands and Kooragang Nature Reserve (see **Map 2**) are covered by State Environmental Planning Policy 14, Coastal Wetlands (SEPP 14), which aims to ensure coastal wetlands are preserved and protected.

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28. Conservation measures proposed but not yet implemented:

e.g. management plan in preparation; official proposal as a legally protected area, etc.

Kooragang Nature Reserve

Rehabilitation of wetland areas within and adjacent to the Reserve have been undertaken under the auspice of the Kooragang Wetland Rehabilitation Project. The Project aims to restore and/or enhance the habitat for migratory birds and waterfowl and has proposed that:

- Lands within the Reserve previously reclaimed for agriculture and flood mitigation are to be rehabilitated to wetland;
- The hydrology created by artificial regulation devices on parts of Kooragang Island are to be modified; and
- Degraded vegetation communities in the Reserve are to be rehabilitated.

Tidal regimes will be introduced into the Tomago buffer lands to increase the wetland habitat in the Nature Reserve.

Shortland Wetlands

A Management Plan to guide the on-going management and wise use of Shortland Wetlands is currently being prepared. The Plan builds on and aims to enhance the management practices that have been in place since the start of the restoration project in 1984-85. The Plan is designed to accommodate the on-going involvement of local communities. The Wetlands Centre's focus on communication, education and public awareness has influenced the objectives and actions in the Plan. A key aim will be the development and implementation of a Monitoring Plan to identify changes in key factors relevant to the ecological character of the site.

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29. Current scientific research and facilities:

e.g., details of current research projects, including biodiversity monitoring; existence of a field research station, etc.

Kooragang Nature Reserve

The only research facility in the Nature Reserve is a small bird hide at Stockton Sandspit. Kooragang Island has been the subject of a number of ecological studies undertaken by various parties including the University of Newcastle, Hunter Bird Observers Club, Shortland Wetlands Centre, Hunter Catchment Management Trust, Ironbark Creek Catchment Management Committee, Kooragang Wetland Rehabilitation Project, Hunter Water Corporation and various environmental consultancy companies.

Currently research is being undertaken in the following areas:

- Banding and plumage studies of wading birds, water bird counts, the success of waterbird breeding and changes in migration patterns;
- Geomorphological changes to the Hunter River Estuary;
- Water quality monitoring; and
- Alligator weed.

Shortland Wetlands

There are no active research facilities currently operating on the site. However, there is a significant body of work about the site, its development and Centre activities that has been produced by students and by technical staff employed as consultants in past years. The Wetlands Centre has produced 37 scientific publications, 4 reports, poster papers at international conferences and contributed to three books. An extensive bibliographical list of publications relating to The Wetlands Centre (Burgess 2002) is held in the Wetlands Centre Library.

Research related to the site forms part of the Wetlands Centre Library collection. The library is extensive and unique. It has grown over the past 17 years to form a detailed collection of resources which describe local wetlands and environmental issues. The library is available to the public and is staffed by volunteers who respond to community needs.

There is good potential for the on-going involvement of research students from nearby Newcastle University in projects relevant to the management of the site.

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30. Current communications, education, participation and awareness (CEPA) activities related to or benefiting the site:

e.g. visitors' centre, observation hides and nature trails, information booklets, facilities for school visits, etc.

Kooragang Nature Reserve

Kooragang Nature Reserve offers significant opportunity for environmental education since it is readily accessible to a large number of people from Newcastle and the lower Hunter Valley.

Shortland Wetlands Centre provides interpretation of the area. It also organises regular visits to the Nature Reserve for researchers and students of wetland conservation.

The Kooragang Wetland Rehabilitation Project also has interpretation facilities and a model environmentally sustainable farm adjacent to the Nature Reserve. The erection of education facilities in the bird hide at the Stockton Sandspit are also proposed.

Signs that outline the principles of the Ramsar Convention and the conservation values of the Ramsar Site have been erected at the site.

Shortland Wetlands

The Wetlands Centre uses communication and education as key processes to promote wetland values, conservation and wise use management. Development on the site to support education includes the Visitors Centre, an extensive system of tracks, viewing platforms, decks, boardwalks and interpretation signs. An elevated bird hide provides access to nesting and roosting birds. Canoe facilities allow access to tidal creeks adjacent to the site.

The Visitors Centre is a large building containing an interpretation display with live and static displays, free-standing binoculars, information booklets and brochures, a souvenir shop, café, facilities and offices. Disabled access is available in the Centre and on some of the walks. A Sensory Trail provides access to the wetlands for visitors with sensory impairment.

The Wetlands Centre's school education program is underpinned by a valuable partnership with NSW Department of Education and Training (DET). The Wetlands Environmental Education Centre, a DET facility, manages the programs for approximately 8000 school visitors annually. Students from kindergarten to year 12 enjoy programs relevant to the NSW curriculum and their stage of schooling.

The Wetlands Centre programs and achievements have resulted in a greater understanding of wetlands in the Hunter region, increasing community support for other major wetland rehabilitation projects. This provides an excellent demonstration of the role education can play to build understanding of wetland values and functions.

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31. Current recreation and tourism:

State if the wetland is used for recreation/tourism; indicate type(s) and their frequency/intensity.

Kooragang Nature Reserve

Kooragang Nature Reserve is not promoted as a tourist destination. Some limited, low impact recreational uses are permitted within the Nature Reserve and include fishing, boating and bird watching. The Nature Reserve has approximately 5000 visitors per year.

Shortland Wetlands

Shortland Wetlands offer a range of outdoor recreation facilities with very easy access to high-conservation-value wetlands for visitors. Facilities include bush-walking trails, boardwalks, observation decks, elevated bird hide and canoes.

As an ecotourism facility, The Wetlands Centre complements other attractions in Newcastle and provides environment-focused tourism supported by environmental education.

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32. Jurisdiction:

Include territorial, e.g. state/region, and functional/sectoral, e.g. Dept of Agriculture/Dept. of Environment, etc.

Territorial: Government of New South Wales
Functional: NSW National Parks and Wildlife Service; Newcastle City Council.

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33. Management authority:

Provide the name and address of the local office(s) of the agency(ies) or organisation(s) directly responsible for managing the wetland. Wherever possible provide also the title and/or name of the person or persons in this office with responsibility for the wetland.

Shortland Wetlands Centre Ltd is responsible for management of **Shortland Wetlands:**

The Wetlands Centre Ltd
PO Box 292
Wallsend NSW 2287
Phone: 02 4951 6466

NSW National Parks and Wildlife Service is responsible for management of **Kooragang Nature Reserve**:

Manager
Hunter Coast Area
Locked Bag 99
Nelson Bay Delivery Centre NSW 2315
Phone: 02 4984 8200

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34. Bibliographical references:

Scientific/technical references only. If biogeographic regionalisation scheme applied (see 15 above), list full reference citation for the scheme.

Albrecht, G. and M. Maddock (1985). Avifauna of the Shortland Wetlands. *Wetlands* (*Australia*) **5**(2): 53-69.

Bangent, B. (1990). *Aboriginal Interpretation at Shortland Wetlands Centre*. Unpublished.

Barden, W. (2002). *Birds of the Wetlands Centre*. Unpublished.

Baxter , G.S. (1994). The location and status of egret colonies in coastal NSW. *Emu* **94**: 255-262.

Beretta, M. (1998). *Flora of the Shortland Wetlands, NSW*. University of Newcastle, NSW. Unpublished thesis.

Bischof, H. and N. Brown (1996). *Hydrology, water quality and macroinvertebrates of the Shortland Wetlands*. University of Newcastle, NSW. Unpublished thesis.

Burgess, B. (2002). *The Restoration and Development of Shortland Wetlands as a Centre for Wetland Conservation and Education: a Bibliography*. The Wetlands Centre, Newcastle, NSW.

Geering, D. (1995). *Ecology of migratory shorebirds in the Hunter River Estuary*. Shortland Wetlands Centre, NSW.

Grace, M. and N. Francesconi (1997). The Shortland Wetlands Centre. University of Newcastle, NSW. Unpublished thesis.

IUCN (2000). *IUCN Red List of Threatened Species.* IUCN, Gland, Switzerland and Cambridge, UK.

Lightfoot, P. (2000). *Tree planting at The Wetlands Centre at Shortland, Newcastle*. The Wetlands Centre, Shortland, NSW.

MacDonald Wagner (1984). *Ecological study of State Highway No. 23 (Shortland to Pacific Highway Corridor)*. Department of Main Roads, Hunter Division, NSW.

Maddock, M. (2002). Ibis in the Lower Hunter. *The Wetlander* **16**(2): 11-12.

Matthei, L.E. (1995). Soil Landscapes of the Newcastle 1:100 000 Sheet Map, Department of Land & Water Conservation, Sydney.

Moss, J. (1983). An Investigation of the Natural Areas of Kooragang Island, Hunter River. NSW Department of Environment and Planning.

NCC (2000). *Newcastle Stormwater Management Plan*. Newcastle City Council, Newcastle, NSW.

NPWS (1998). *Kooragang Nature Reserve and Hexham Swamp Nature Reserve Plan of Management*. NSW National Parks and Wildlife Service. Hurstville, NSW.

NPWS (2002a). Atlas of NSW Wildlife. Database of flora and fauna sightings in NSW. NSW National Parks and Wildlife Service. Hurstville, NSW.

NPWS (2002b). *Predation by* Gambusia holbrooki – *The Plague Minnow. Draft Threat Abatement Plan.* NSW National Parks and Wildlife Service. Hurstville, NSW.

Rose, P.M. and D.A. Scott (1997). *Waterfowl Population Estimates – Second edition*. Wetlands International Publ. 44, Wageningen, The Netherlands.

Sinlaparommard, J. (1999). Stormwater runoff quality at the Shortland Wetlands. Callaghan, NSW, University of Newcastle. Unpublished thesis.

Smith, P. (1991). *The biology and management of waders (Suborder Charadrii) in NSW*. NSW NPWS Species Management Report Number 9. NSW National Parks and Wildlife Service. Hurstville, NSW.

Sokoloff, B. (1974). *The Woromi: Hunter Gatherers at Port Stephens*. Part 1. Hunter Natural History, **6**(3): 166 – 169.

Straw, P. (2000). *Hunter Estuary Wader Habitat Investigation, Stage 2*. Unpublished report to NSW National Parks and Wildlife Service.

Watkins, D. (1993). *A national plan for shorebird conservation in Australia*. Australian Wader Studies Group.

Winning, G. (1989). *The Wetlands Centre: Site Management Plan 1990-1994*. The Wetlands Centre, Shortland, NSW. Unpublished.

Winning, G. (1996). *Vegetation of Kooragang Nature Reserve and Hexham Swamp Nature Reserve and adjoining land*. Report for NSW National Parks and Wildlife Service. The Wetlands Centre, Shortland, NSW.

Appendix 1. Bird species recorded at Shortland Wetlands and Kooragang Nature Reserve

Records for Shortland Wetlands from Barden (2002). Records for Kooragang derived from Holmes, van Gessel and Kendall, Morris, Clarke and van Gessel *in* NPWS 1998; and NPWS (2002a).

Key

V1 Listed as 'Vulnerable' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

V2 Listed as 'Vulnerable' under the NSW *Threatened Species Conservation Act 1995*

V3 Listed as 'Vulnerable' under the *IUCN Redlist of Threatened Species 2000*

E1 Listed as 'Endangered' under the EPBC Act

E2 Listed as 'Endangered' under the NSW *Threatened Species Conservation Act 1995*

M Migratory species listed under international treaties: Japan-Australia or China-Australia Migratory Bird Agreements (JAMBA or CAMBA)

***** Introduced species

\# Recorded at the site

nr Not recorded at the site

Scientific Name	Common Name	Status	Shortland	Kooragang
GALLIFORMES				
Phasianidae	**Old World Quail and Pheasant**			
Coturnix chinensis	King Quail		**nr**	#
Coturnix ypsilophora	Brown Quail		#	#
ANSERIFORMES	**WATERFOWL**			
Anatidae	**Ducks, Geese and Swans**			
Anas castanea	Chestnut Teal		#	#
Anas clypeata	Northern Shoveler	**M**	#	**nr**
Anas gracilis	Grey Teal		#	#
Anas platyrhynchos	Mallard		#	**nr**
Anas querquedula	Garganey	**M**	#	**nr**
Anas rhynchotis	Australasian Shoveler		#	#
Anas superciliosa	Pacific Black Duck		#	#
Aythya australis	Hardhead		#	#
Biziura lobata	Musk Duck		#	#
Chenonetta jubata	Australian Wood Duck		#	#
Cygnus atratus	Black Swan		#	#
Dendrocygna arcuata	Wandering Whistling-Duck		#	**nr**
Dendrocygna eytoni	Plumed Whistling-Duck		#	#
Malacorhynchus membranaceus	Pink-eared Duck		#	#
Oxyura australis	Blue-billed Duck	**V2**	#	**nr**
Stictonetta naevosa	Freckled Duck	**V2**	#	#
Tadorna tadornoides	Australian shelduck		**nr**	#
Anseranatidae	**Magpie Goose**			
Anseranas semipalmata	Magpie Goose	**V2**	#	**nr**

Scientific Name	Common Name	Status	Shortland	Kooragang
PODICIPEDIFORMES	**GREBES**			
Anhingidae	**Darters**			
Anhinga melanogaster	Darter		#	#
Pelecanidae	**Pelicans**			
Pelecanus conspicillatus	Australian Pelican		#	#
Phalacrocoracidae	**Cormorants**			
Phalacrocorax carbo	Great Cormorant		#	#
Phalacrocorax melanoleucos	Little Pied Cormorant		#	#
Phalacrocorax sulcirostris	Little Black Cormorant		#	#
Phalacrocorax varius	Pied Cormorant		#	#
Podicipedidae	**Grebes**			
Podiceps cristatus	Great Crested Grebe		**nr**	#
Poliocephalus poliocephalus	Hoary-headed Grebe		**nr**	#
Tachybaptus novaehollandiae	Australasian Grebe		#	#
CICONIIFORMES	**HERONS, STORKS AND IBIS**			
Ardeidae	**Herons and Egrets**			
Ardea alba	Great Egret	**M**	#	#
Ardea ibis	Cattle Egret	**M**	#	#
Ardea intermedia	Intermediate Egret		#	#
Ardea pacifica	White-necked Heron		#	#
Botaurus poiciloptilus	Australasian Bittern	**V2, V3**	#	#
Butorides striatus	Striated Heron		**nr**	#
Egretta garzetta	Little Egret		#	#
Egretta novaehollandiae	White-faced Heron		#	#
Ixobrychus flavicollis	Black Bittern	**V2**	**nr**	#
Ixobrychus minutus	Little Bittern		#	#
Nycticorax caledonicus	Nankeen Night Heron		#	#
Ciconiidae	**Storks**			
Ephippiorhynchus asiaticus	Black-necked Stork	**E2**	#	#
Threskiornithidae	**Ibis and Spoonbills**			
Platalea flavipes	Yellow-billed Spoonbill		#	#
Platalea regia	Royal Spoonbill		#	#
Plegadis falcinellus	Glossy Ibis	**M**	#	#
Threskiornis molucca	Australian White Ibis		#	#
Threskiornis spinicollis	Straw-necked Ibis		#	#
FALCONIORMES	**DIURNAL BIRDS OF PREY**			
Accipitridae	**Hawks, Eagles and Kites**			
Accipiter cirrocephalus	Collared Sparrowhawk		#	**nr**
Accipiter fasciatus	Brown Goshawk		#	**nr**
Accipiter novaehollandiae	Grey Goshawk		#	**nr**
Aquila audax	Wedge-tailed Eagle		#	**nr**
Aviceda subcristata	Pacific Baza		#	#
Circus approximans	Swamp Harrier		#	#
Circus assimilis	Spotted Harrier		#	**nr**
Elanus axillaris	Black-shouldered Kite		#	#
Erythrotriorchis radiatus	Red Goshawk	**V1, E2**	#	**nr**
Haliaeetus leucogaster	White-bellied Sea-Eagle	**M**	#	#
Haliastur indus	Brahminy Kite		#	**nr**
Haliastur sphenurus	Whistling Kite		#	#

Scientific Name	Common Name	Status	Shortland	Kooragang
Hieraaetus morphnoides	Little Eagle		#	**nr**
Lophoictinia isura	Square-tailed kite	**V2**	**nr**	#
Pandion haliaetus	Osprey	**M, V2**	#	**nr**
Falconidae	**Falcons**			
Falco berigora	Brown Falcon		#	**nr**
Falco cenchroides	Nankeen Kestrel		#	#
Falco longipennis	Australian Hobby		#	#
Falco peregrinus	Peregrine Falcon		#	#
Falco subniger	Black Falcon		**nr**	#
GRUIFORMES	**RAILS, CRANES AND BUSTARDS**			
Rallidae	**Rails, Crakes and Gallinules**			
Fulica atra	Eurasian Coot		#	#
Gallinula tenebrosa	Dusky Moorhen		#	#
Gallirallus philippensis	Buff-banded Rail		#	#
Porphyrio porphyrio	Purple Swamphen		#	#
Porzana fluminea	Australian Spotted Crake		#	#
Porzana pusilla	Baillon's Crake		#	#
Porzana tabuensis	Spotless Crake		#	#
Rallus pectoralis	Lewin’s Rail		**nr**	#
CHARADRIIFORMES				
Burhinidae				
Burhinus grallarius	Bush Stone Curlew	**E2**	**nr**	#
Charadriidae	**Plovers and Lapwings**			
Charadrius bicinctus	Double-banded Plover		**nr**	#
Charadrius hiaticula	Ringed Plover	**M**	**nr**	#
Charadrius lescenaultii	Greater Sand Plover	**M,V2**	**nr**	#
Charadrius mongolus	Mongolian Plover	**M,V2**	**nr**	#
Charadrius ruficapillus	Red-capped Plover		**nr**	#
Charadrius veredus	Oriental Plover	**M**	**nr**	#
Elseyornis melanops	Black-fronted Dotterel		#	#
Erythrogonys cinctus	Red-kneed Dotterel		#	#
Pluvialis dominica	Lesser Golden Plover	**M**	**nr**	#
Pluvialis fulva	Pacific Golden Plover		**nr**	#
Pluvialis squatarola	Grey Plover	**M**	**nr**	#
Vanellus miles	Masked Lapwing		#	#
Vanellus tricolor	Banded Lapwing		**nr**	#
Glareolidae				
Glareola maldivarum	Oriental Pratincole	**M**	**nr**	#
Haematopodidae	**Oystercatchers**			
Haematopus fuliginosus	Sooty Oystercatcher	**V2**	**nr**	#
Haematopus longirostris	Pied Oystercatcher	**V2**	**nr**	#
Jacanidae	**Jacanas**			
Irediparra gallinacea	Comb-crested Jacana	**V2**	#	#
Laridae	**Gulls, Terns and Skuas**			
Chlidonias hybridus	Whiskered Tern		#	#
Chlidonias leucopterus	White-winged Black Tern	**M**	#	#
Chlidonias niger	Black Tern	**M**	**nr**	#
Larus dominicanus	Kelp Gull		**nr**	#

Scientific Name	**Common Name**	**Status**	**Shortland**	**Kooragang**
Larus novaehollandiae	Silver Gull		#	#
Sterna albifrons	Little Tern	**M,E2**	**nr**	#
Sterna bergii	Crested Tern		**nr**	#
Sterna caspia	Caspian Tern	**M**	#	#
Sterna hirundo	Common Tern	**M**	**nr**	#
Sterna nilotica	Gull-billed Tern		**nr**	#
Sterna paradisea	Arctic Tern		**nr**	#
Sterna striata	White-fronted Tern		**nr**	#
Recurvirostridae	**Stilts and Avocets**			
Cladorhynchus leucocephalus	Banded Stilt		**nr**	#
Himantopus himantopus	Black-winged Stilt		#	#
Recurvirostra novaehollandiae	Red-necked Avocet		#	#
Rostratulidae	**Snipes**			
Rostratula benghalensis	Painted Snipe	**M**	**nr**	#
Scolopacidae	**Sandpipers**			
Actitis hypoleucos	Terek Sandpiper		**nr**	#
Arenaria interpres	Ruddy Turnstone		**nr**	#
Calidris acuminata	Sharp-tailed Sandpiper	**M**	#	#
Calidris alba	Sanderling	**M,V2**	**nr**	#
Calidris canutus	Red Knot	**M**	**nr**	#
Calidris ferruginea	Curlew Sandpiper	**M**	#	#
Calidris melanotus	Pectoral Sandpiper	**M**	**nr**	#
Calidris minuta	Little Stint		**nr**	#
Calidris ruficollis	Red-necked Stint	**M**	#	#
Calidris tenuirostris	Great Knot	**M,V2**	**nr**	#
Gallinago hardwickii	Latham's Snipe	**M**	#	#
Heteroscelus brevipes	Grey-tailed Tattler		**nr**	#
Heteroscelus incanus	Wandering Tattler		**nr**	#
Limicola falcinellus	Broad-billed Sandpiper	**M,V2**	**nr**	#
Limnodromus semipalmatus	Asian Dowitcher	**M**	**nr**	#
Limosa haemastica	Hudsonian Godwit		**nr**	#
Limosa lapponica	Bar-tailed Godwit	**M**	**nr**	#
Limosa limosa	Black-tailed Godwit	**M,V2**	**nr**	#
Numenius madagascariensis	Eastern Curlew	**M**	**nr**	#
Numenius minutus	Little Curlew	**M**	**nr**	#
Numenius phaeopus	Whimbrel	**M**	**nr**	#
Philomachus pugnax	Ruff	**M**	**nr**	#
Tringa glareola	Wood Sandpiper	**M**	#	#
Tringa nebularia	Common Greenshank	**M**	#	#
Tringa stagnatilis	Marsh Sandpiper	**M**	#	#
Tryngites subruficollis	Buff-breasted Sandpiper	**M**	**nr**	#
Xenus cinereus	Terek Sandpiper	**V2**	**nr**	#
COLUMBIFORMES	**PIGEONS AND DOVES**			
Columbidae	**Pigeons and Doves**			
Chalcophaps indica	Emerald Dove		#	**nr**
Columba leucomela	White-headed Pigeon		#	**nr**
Columba livia	Rock Dove	*	#	#
Geopelia humeralis	Bar-shouldered Dove		#	**nr**
Lopholaimus antarcticus	Topknot Pigeon		#	**nr**

Scientific Name	Common Name	Status	Shortland	Kooragang
Macropygia amboinensis	Brown Cuckoo-Dove		#	**nr**
Ocyphaps lophotes	Crested Pigeon		#	**nr**
Streptopelia chinensis	Spotted Turtle-Dove	*	#	**nr**
PSITTACIFORMES	**COCKATOOS, PARROTS AND LORIKEETS**			
Cacatuidae	**Cockatoos**			
Cacatua galerita	Sulphur-crested Cockatoo		#	**nr**
Cacatua roseicapilla	Galah		#	**nr**
Cacatua sanguinea	Little Corella		#	**nr**
Cacatua tenuirostris	Long-billed Corella		#	**nr**
Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo		#	**nr**
Nymphicus hollandicus	Cockatiel		#	**nr**
Psittacidae	**Parrots and Lorikeets**			
Alisterus scapularis	King Parrot		#	**nr**
Glossopsitta pusilla	Little Lorikeet		#	**nr**
Platycercus adscitus	Pale-headed Rosella		#	**nr**
Platycercus eximius	Eastern Rosella		#	#
Psephotus haematonotus	Red-rumped Parrot		#	**nr**
Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet		#	**nr**
Trichoglossus haematodus	Rainbow Lorikeet		#	**nr**
CUCULIFORMES	**CUCKOOS AND COUCALS**			
Centropodidae	**Coucal**			
Centropus phasianinus	Pheasant Coucal		#	**nr**
Cuculidae	**Cuckoos**			
Cacomantis flabelliformis	Fan-tailed Cuckoo		#	**nr**
Cacomantis variolosus	Brush Cuckoo		#	**nr**
Chrysococcyx basalis	Horsfield's Bronze-Cuckoo		#	#
Chrysococcyx lucidus	Shining Bronze-Cuckoo		#	**nr**
Cuculus pallidus	Pallid Cuckoo		#	**nr**
Cuculus saturatus	Oriental Cuckoo	**M**	#	#
Eudynamys scolopacea	Common Koel		#	**nr**
Scythrops novaehollandiae	Channel-billed Cuckoo		#	**nr**
STRIGIFORMES	**OWLS**			
Strigidae	**Typical (Hawk) Owl**			
Ninox novaeseelandiae	Southern Boobook		#	**nr**
Tytonidae	**Barn Owls**			
Tyto alba	Barn Owl		#	**nr**
Tyto novaehollandiae	Masked Owl	**V2**	#	**nr**
CAPRIMULGIFORMES	**NIGHTJARS AND RELATIVES**			
Podargidae	**Frogmouths**			
Podargus strigoides	Tawny Frogmouth		#	**nr**
APODIFORMES	**SWIFTS**			
Apodidae	**Swifts**			
Hirundapus caudacutus	White-throated Needletail	**M**	#	**nr**
CORACIIFORMES	**KINGFISHERS, ROLLERS AND BEE-EATERS**			
Alcedinidae	**Water Kingfishers**			
Alcedo azurea	Azure Kingfisher		#	**nr**
Coraciidae	**Rollers**			

Scientific Name	Common Name	Status	Shortland	Kooragang
Eurystomus orientalis	Dollarbird		#	**nr**
Halcyonidae	**Tree Kingfishers**			
Dacelo novaeguineae	Laughing Kookaburra		#	#
Todiramphus macleayii	Forest Kingfisher		#	#
Todiramphus sanctus	Sacred Kingfisher		#	#
Meropidae	**Bee-eaters**			
Merops ornatus	Rainbow Bee-eater	**M**	#	**nr**
PASSERIFORMES	**SONGBIRDS**			
Artamidae	**Woodswallows, Magpies, Butcherbirds and Currawongs**			
Artamus leucorynchus	White-breasted Woodswallow		#	#
Cracticus nigrogularis	Pied Butcherbird		#	**nr**
Cracticus torquatus	Grey Butcherbird		#	**nr**
Gymnorhina tibicen	Australian Magpie		#	#
Strepera graculina	Pied Currawong		#	**nr**
Campephagidae	**Cuckoo-shrikes and Trillers**			
Coracina novaehollandiae	Black-faced Cuckoo-shrike		#	#
Lalage sueurii	White-winged Triller		#	#
Cinclosomatidae	**Whipbirds and Quail-thrushes**			
Psophodes olivaceus	Eastern Whipbird		#	**nr**
Climacteridae	**Treecreepers**			
Cormobates leucophaeus	White-throated Treecreeper		**nr**	#
Corvidae	**Ravens and Crows**			
Corvus coronoides	Australian Raven		#	#
Dicaeidae	**Flowerpeckers**			
Dicaeum hirundinaceum	Mistletoebird		#	**nr**
Dicruridae	**Monarchs, Fantails, Magpielarks and Drongos**			
Dicrurus bracteatus	Spangled Drongo		#	**nr**
Grallina cyanoleuca	Magpie-lark		#	#
Monarcha melanopsis	Black-faced Monarch		#	**nr**
Myiagra inquieta	Restless Flycatcher		#	#
Myiagra rubecula	Leaden Flycatcher		#	**nr**
Rhipidura fuliginosa	Grey Fantail		#	#
Rhipidura leucophrys	Willie Wagtail		#	#
Rhipidura rufifrons	Rufous Fantail		#	**nr**
Fringillidae	**Finches**			
Carduelis carduelis	European Goldfinch	*	#	**nr**
Hirundinidae	**Swallows and Martins**			
Hirundo ariel	Fairy Martin		#	**nr**
Hirundo neoxena	Welcome Swallow		#	#
Hirundo nigricans	Tree Martin		#	**nr**
Hirundo rustica	Barn Swallow	**M**	#	**nr**
Maluridae	**Fairy-wrens**			
Malurus cyaneus	Superb Fairy-wren		#	#
Malurus lamberti	Variegated Fairy-wren		#	**nr**
Stipiturus malachurus	Southern Emu-wren		#	**nr**
Meliphagidae	**Honeyeaters**			
Acanthorhynchus tenuirostris	Eastern Spinebill		#	**nr**

Scientific Name	Common Name	Status	Shortland	Kooragang
Anthochaera carnunculata	Red Wattlebird		#	**nr**
Anthochaera chrysoptera	Little Wattlebird		#	**nr**
Epthianura albifrons	White-fronted Chat		**nr**	#
Lichenostomus chrysops	Yellow-faced Honeyeater		#	**nr**
Lichmera indistincta	Brown Honeyeater		#	#
Manorina melanocephala	Noisy Miner		#	**nr**
Melithreptus brevirostris	Brown-headed Honeyeater		#	**nr**
Melithreptus lunatus	White-naped Honeyeater		#	**nr**
Myzomela sanguinolenta	Scarlet Honeyeater		#	**nr**
Philemon citreogularis	Little Friarbird		#	**nr**
Philemon corniculatus	Noisy Friarbird		#	**nr**
Phylidonyris nigra	White-cheeked Honeyeater		#	**nr**
Phylidonyris novaehollandiae	New Holland Honeyeater		#	**nr**
Plectorhyncha lanceolata	Striped Honeyeater		#	#
Motacillidae	**Pipits and Wagtails**			
Anthus novaeseelandiae	Richard's Pipit		#	#
Motacilla flava	Yellow Wagtail	**M**	#	**nr**
Muscicapidae	**One World Warblers**			
Acrocephalus stentoreus	Clamorous Reed-Warbler		#	**nr**
Cincloramphus cruralis	Brown Songlark		**nr**	#
Cincloramphus mathewsi	Rufous Songlark		#	#
Cisticola exilis	Golden-headed Cisticola		#	#
Megalurus gramineus	Little Grassbird		#	#
Megalurus timoriensis	Tawny Grassbird		#	#
Turdus merula	Common Blackbird	*	#	**nr**
Oriolidae	**Orioles**			
Oriolus sagittatus	Olive-backed Oriole		#	**nr**
Sphecotheres viridis	Figbird		#	**nr**
Pachycephalidae	**Whistlers and Shrike-thrushes**			
Colluricincla harmonica	Grey Shrike-thrush		#	**nr**
Falcunculus frontatus	Crested Shrike-tit		#	**nr**
Pachycephala pectoralis	Golden Whistler		#	**nr**
Pachycephala rufiventris	Rufous Whistler		#	**nr**
Pardalotidae	**Pardalotes, Gerygones, Scrubwrens and Thornbills**			
Acanthiza chrysorrhoa	Yellow-rumped Thornbill		#	#
Acanthiza nana	Yellow Thornbill		#	#
Acanthiza pusilla	Brown Thornbill		#	**nr**
Acanthiza reguloides	Buff-rumped Thornbill		#	**nr**
Gerygone levigaster	Mangrove Gerygone		**nr**	#
Gerygone olivacea	White-throated Gerygone		#	**nr**
Pardalotus punctatus	Spotted Pardalote		#	**nr**
Pardalotus striatus	Striated Pardalote		#	**nr**
Sericornis frontalis	White-browed Scrubwren		#	**nr**
Passeridae	**House Sparrows and Grass Finches**			
Lonchura castaneothorax	Chestnut-breasted Mannikin		#	#
Neochmia temporalis	Red-browed Finch		#	**nr**
Passer domesticus	House Sparrow	*	#	**nr**
Taeniopygia bichenovii	Double-barred Finch		#	#

Scientific Name	Common Name	Status	Shortland	Kooragang
Taeniopygia guttata	Zebra Finch		#	#
Petroicidae	**Australasian Robins**			
Eopsaltria australis	Eastern Yellow Robin		#	**nr**
Petroica multicolor	Scarlet Robin		#	**nr**
Petroica rosea	Rose Robin		#	**nr**
Sturnidae	**Starlings**			
Acridotheres tristis	Common Myna	*	#	**nr**
Sturnus vulgaris	Common Starling	*	#	**nr**
Zosteropidae	**White-eyes**			
Zosterops lateralis	Silvereye		#	#

Appendix 2. Bird Species recorded breeding at the site

The following is a list of species recorded breeding at Shortland Wetlands (from Barden 2002), and indicates those species also known to occur at Kooragang Nature Reserve. Count data refers to Shortland only.

The Great Egret (*Ardea alba),* Intermediate Egret (*Ardea intermedia),* Little Egret (*Egretta garzetta*) and Cattle Egret (*Ardea ibis)* are seasonal migrants to the site from New Zealand. They arrive at Shortland during spring for their breeding season (Baxter 1994).

The numbers of White Ibis (*Threskiornis molucca)* at the site increase significantly over autumn and winter as migrants from inland breeding colonies come to the coast for non-breeding seasonal foraging (Maddock 2002).

Straw-necked Ibis *(Threskiornis spinicollis)* are very few in summer but large numbers migrate to the region during autumn and winter. Up to 7000 of these birds use the Melaleuca Swamp Forest for night roosting. The numbers start to drop during August as they set out on their return journey inland (Maddock 2002).

Nankeen Night Herons *(Nycticorax caledonicus)* use the site for night foraging and day roosting during the non-breeding season.

* Recorded at Kooragang Nature Reserve and Shortland Wetlands
\# Recorded at Shortland Wetlands only

Common Name	Scientific Name	Count
# Magpie Goose	# *Anseranas semipalmata*	over 100
# Wandering Whistling Duck	# *Dendrocygna arcuata*	30-50 (over 100 birds in 2000)
* Black Swan	* *Cygnus atratus*	6-20
* Australian Wood Duck	* *Chenonetta jubata*	20-50
* Pacific Black Duck	* *Anas superciliosa*	up to 100
* Grey Teal	* *Anas gracilis*	up to 100
* Chestnut Teal	* *Anas castanea*	up to 100
* Hardhead	* *Aythya australis*	20-40
* Australasian Grebe	* *Tachybaptus novaehollandiae*	10-30
* Little Black Cormorant	* *Phalacrocorax sulcirostris*	up to 100
* Little Pied Cormorant	* *Phalacrocorax melanoleucos*	up to 100
* White-faced Heron	* *Egretta novaehollandiae*	2-4 (up to 22)
* Little Egret	* *Egretta garzetta*	4-over 100
* Great Egret	* *Ardea alba*	40-400
* Intermediate Egret	* *Ardea intermedia*	20-900
* Cattle Egret	* *Ardea ibis*	200-1400
* Australian White Ibis	* *Threskiornis molucca*	2-6 (over 1000 birds roosting)
* Nankeen Night Heron	* *Nycticorax caledonicus*	20-100
* Purple Swamphen	* *Porphyrio porphyrio*	10 - 100
* Dusky Moorhen	* *Gallinula tenebrosa*	10-100
* Eurasian Coot	* *Fulica atra*	10-40

Common Name	Scientific Name	Count
* Black-fronted Dotterel	* *Elseyornis melanops*	6-18
* Red-kneed Dotterel	* *Erythrogonys cinctus*	2-10
* Masked Lapwing	* *Vanellus miles*	6-10
* Sacred Kingfisher	* *Todiramphus sanctus*	4-10
* Whistling Kite	* *Haliastur sphenurus*	2
# Brown Goshawk	# *Accipiter fasciatus*	2
# Barn Owl	# *Tyto alba*	2

Appendix 3. Mammals, Reptiles, Amphibians and Fish recorded at Shortland Wetlands

Species list compiled from observations made by Kevin Markwell over a period of several years and is supported by the Ecological Study of the State Highway No 23 – Shortland to Pacific Highway Corridor by Macdonald Wagner (1984). A species list for Kooragang is currently unavailable.

Key:

V1 Listed as 'Vulnerable' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

E2 Listed as 'Endangered' under the NSW *Threatened Species Conservation Act 1995*

***** Introduced species

Scientific Name	Common Name	Status
MAMMALS		
Isoodon macrourus	Northern Brown Bandicoot	
Hydromys chrysogaster	Water Rat	
Mus musculus	House Mouse	*
Rattus rattus	Black Rat	*
Lepus capensis	Brown Hare	*
Oryctolagus cuniculus	European Rabbit	*
Vulpes vulpes	Red Fox	*
REPTILES		
Cheladina longicollis	Long-necked Tortoise	
Ctenotus robustus	Striped Skink	
Lampropholis delicata	Grass Skink	
L. mustelinum	Weasel Skink	
Saiphos equalis	Three-toed Skink	
Sphenomorphus quoyii	Eastern Water Skink	
Tiliqua casuarinae	She-oak Skink	
Hemiaspis signata	Swamp Snake	
Pseudechis porphyriacus	Red-bellied Black Snake	
AMPHIBIANS		
Litoria aurea	Green and Golden Bell Frog	V1,E2
Litoria dentata	Bleating Tree Frog	
Litoria fallax	Dwarf Green Tree Frog	
Litoria peroni	Peron's Tree Frog	
Litoria tyleri	Tyler's Tree Frog	
Litoria caerulea	Green Tree Frog	
Crinia signifera	Common Eastern Froglet	
Limnodynastes peroni	Striped Marsh Frog	
Lymnodynastes tasmaniensis	Spotted Grass Frog	
FISH		
Gobiomorphus coxii	Cox's Gudgeon	
Hypseleotris galii	Firetail Gudgeon	
Philypnodon grandiceps	Flathead Gudgeon	
Philypnodon sp. Nov.	Gudgeon	
Anguilla australis	Short-finned Eel	
Gambusia holbrooki	Mosquito Fish	*

Appendix 4. Flora species recorded at Shortland Wetlands and Kooragang Nature Reserve

Shortland data relates to occurrence and abundance and is taken from Lightfoot (2000); Kooragang data relates to occurrence only and is taken from Winning (1996).

Key:
A – Abundant C – Common U – Uncommon R – Rare * - Exotic # - Planted
K – occurs at Kooragang

Scientific Name	Common Name	Shortland	Kooragang
DIVISION POLYPODIOPHYTA	**FERNS**		
Zamiaceae			
Macrozamia communis	Burrawang	U	
Azollaceae			
Azolla pinnata	Common Azolla	C	
Dennstaedtiaceae			
Pteridum esculentum	Bracken	U	
Sinopteridaceae			
Cheilanthes distans			K
Pellaea falcata			K
DIVISION PINOPHYTA	**CONIFERS**		
Podocarpaceae			
Podocarpus elatus			K
DIVISION MAGNOLIOPHYTA	**FLOWERING PLANTS**		
Acanthaceae			
Pseuderanthemum variabile	Pastel Flower	R	
Aizoaceae			
Tetragonia tetragonoides			K
Amaranthaceae			
Alternanthera denticulata	Lesser Joyweed	U	
**A. philoxeroides*	Alligator Weed	C	
**Ameranthus viridis*	Green Ameranth	C	
Apiaceae			
**Foeniculum vulgare*	Fennel	A	
**Hydrocotyle bonariensis*	Kurnell's Curse	A	
H. laxiflora	Stinking Pennywort	U	
Asclepiadaceae			
**Araujia hortorum*	Moth Plant	R	
Cynanchum elegans			K
**Gomphocarpus fruticosus*			K
Asteraceae			
**Ambrosia artemisiifolia*	Annual Ragweed	C	
**Artemisia verlotiorum*	Mugwort	U	
**Aster subulatus*	Wild Aster	U	
**Bidens pilosa*	Pitchforks	U	

Scientific Name	Common Name	Shortland	Kooragang
Cassinia quinquefaria	Biddy Bush	U	
**Chrysanthemoides monilifera var. rotundata*	Bitou Bush	U	
**Cirsium vulgare*	Spear Thistle	R	
**Conyza albida*	Tall Fleabane	C	
**Conyza bonariensis*			K
**Cotula coronopifolia*	Water Buttons	C	K
**Crepsis capillaris*	Smooth Hawksbeard	U	
**Galinsoga parviflora*		R	
**Hypochaeris radicata*	Flatweed	C	K
Senecio linearifolius	Fireweed Groundsel	C	
**S. madagascariensis*	Fireweed	C	K
**Xanthium occidentale*	Noogoora Burr	R	
Avicenniaceae			
Avicennia marina	Grey Mangrove	C	K
Brassicaceae			
**Capsella bursapastoris*	Shepherd's Purse	U	
**Lepidium campestre*	Field Cress	R	
Campanulaceae			
Wahlenbergia gracilis			K
Capparaceae			
Capparis arborea			K
Caprifoliaceae			
**Lonicera japonica*	Japanese Honeysuckle	U	
Cassythaceae			
Cassytha glabella			K
Cassytha pubescens			K
Casuarinaceae			
Casuarina glauca	Swamp She-Oak	C	K
Celastraceae			
Cassine australis			K
Celastrus australis			K
Celastrus subspicatus			K
Chenopodiaceae			
Atriplex australasica		U	
**Atriplex prostrata*			K
Einadia hastata			K
Sarcornia quinqueflora			K
Suaeda australis			K
Convolvulaceae			
Dichondra repens	Kidney Weed	C	K
Dilleniaceae			
Hibbertia scandens	Golden Guinea Flower	U	
Ebenaceae			
Diospyros australis			K
Elaeocarpaceae			
#Elaeocarpus grandis		R	

Scientific Name	Common Name	Shortland	Kooragang
#E. obovatus		R	K
Elatinaceae			
Elatine gratioloides			K
Euphorbiaceae			
Breynia oblongifolia			K
Croton verreauxii			K
**Euphorbia peplus*	Petty Spurge	C	K
Glochidion ferdinandi	Cheese Tree	C	
#Omalanthus populifolius	Bleeding Heart	R	
**Ricinus communis*	Castor Oil Plant	U	
Fabaceae/Caesalpinioideae			
**Senna pendula*	Winter Senna	U	
Fabaceae/Faboideae			
Glycine microphylla		R	
Hardenbergia violacea	False Sarsaparilla	R	
**Trifolium dubium,*	Yellow Suckling Clover	C	
**T. repens*	White Clover	C	K
**Vicia sativa*	Common Vetch	C	
Fabaceae/Mimosoldeae			
#Acacia baileyana	Cootamundra Wattle	R	
#A. elongata		R	
A. falcata	Falcate Wattle	R	
A. longifolia	Sydney Golden Wattle	A	
A. maidenii			K
A. parramattensis	Parramatta Green Wattle	U	
A. sophorae	Coastal Wattle	U	
Flacourtiaceae			
Scolopia braunii			K
Fumiariaceae			
**Fumaria bastardii*	Bastard's Fumitory	R	
Gentianaceae			
Centaurium spicatum			K
Geraniaceae			
Geranium solanderi var. solanderi	Native Geranium	U	
Lauraceae			
#Cryptocarya hypospodia		R	
Lobeliaceae			
Pratia purpurescens			K
Loranthaceae			
Amyena cambagei			K
Malvaceae			
#Hibiscus tiliaceous	Cottonwood Hibiscus	R	
**H. trionum*	Bladder Ketmia	R	
**Modiola caroliniana*		C	K
**Sida rhombifolia*	Paddy’s Lucerne	C	K
Meliaceae			
Dysoxylum fraserianum			K

Scientific Name	Common Name	Shortland	Kooragang
Synoum glandulosum	Scentless Rosewood	U	
Toona ciliata	Red Cedar	R	
Menispermaceae			
Sarcopetalum harveyanum			K
Stephania japonica	Snake Vine	U	
Moraceae			
#Ficus coronata	Sandpaper Fig	R	
F. obliqua			K
#F. fraseri		R	
#F. racemosa		R	
F. rubiginosa			K
Maclura cochinchinensis			K
Streblus brunonianus			K
Myrsinaceae			
Aegiceras corniculatum			K
Myrtaceae			
#Acmena smithii	Lilly Pilly	R	
#Austromyrtus bidwillii	Python Tree	R	
Backhousia myrtifolia			K
#Callistemon citrinus	Crimson Bottlebrush	R	
Callistemon salignus			K
#Eucalyptus deanei	Mountain Blue Gum	R	
#E. gummifera	Red Bloodwood	R	
E. maculata	Spotted Gum	U	
#E. punctata	Grey Gum	R	
E. robusta	Swamp Mahogany	U	
#Leptospermum polygalifolium		U	
Melaleuca ericifolia	Swamp Paperbark	U	K
M. erubescens	Pink Honeymyrtle	R	
M. linariifolia	Snow-in-Summer	C	K
M. nodosa	Ball Honeymyrtle	R	
M. quinquenervia	Broad Leaved Paperbark	A	
M. sieberi			K
M. styphelioides	Prickly Leaved Paperbark	U	K
Syncarpia glomulifera	Turpentine	C	
#Syzygium australe	Brush Cherry	R	
#S. crebrinerve	Purple Cherry	R	
#S. leuhmannii	Riberry	R	
#S. paniculatum	Magenta Lilly pilly	R	
#S. sp.		R	
#Waterhousea floribunda	Weeping Lilly pilly	R	
Oleaceae			
Jasminum volubile			K
**Ligustrum sinense*	Small-Leaved Privet	U	
Notelaea longifolia			K
Onagraceae			
Ludwigia peploides			K

Scientific Name	Common Name	Shortland	Kooragang
**Oenothera spp.*			K
Passifloraceae			
**Passiflora edulis*	Common Passionfruit	U	
Phytolaccaceae			
**Phytolacca octandra*	Inkweed	R	
Pittosporaceae			
Bursaria spinosa	Blackthorn	R	
Citriobatus pauciflorus			K
Pittosporum revolutum			K
Pittosporum undulatum	Sweet Pittosporum	C	K
Plantaginaceae			
**Plantago lanceolata*	Plantain or Lamb's Tongues	C	K
**P. major*	Large Plantain	U	
Podocarpaceae			
#Podocarpus elatus	Plum Pine or Brown Pine	R	
Polygonaceae			
Muehlenbeckia gracillima		R	K
Persicaria decipiens	Slender Knotweed	U	
P. hydropiper			K
P. lapathifolia	Pale Knotweed	C	K
**Polygonum arenastrum*	Sandwireweed	U	
**Rumex crispus*	Curled Dock	C	
Portulaceae			
Portulaca oleracea	Pigweed	C	
Proteaceae			
#Banksia integrifolia	Coastal Banksia	R	
B. robur	Swamp Banksia	C	
Grevillea robusta	Silky Oak	R	
#Hakea salicifolia	Willow-Leaved Hakea	R	
#Stenocarpus salignus	Scrub Beefwood	R	
#S. sinuatus	Fire Tree	R	
Ranunculaceae			
Clematis aristata			K
Clematis glycinoides	Headache Vine	C	
Rosaceae			
**Rosa bracteata*			K
**Rubus fruticosus*	Blackberry	C	
Rutaceae			
#Acronychia oblongifolia		R	
Geijera latifolia			K
#Melicope elleryana		R	
Sapindaceae			
Alectryon subcinereus			K
**Cardiospermum grandiflorum*	Balloon Vine	R	
#Cupaniopsis anarcardiodes	Tuckeroo	R	K
#Dipliglottis australis	Native Tamarind	R	
#Harpullia pendula	Tullipwood	R	

Scientific Name	Common Name	Shortland	Kooragang
Rhysotoechia bifoliolata			K
Sapotaceae			
#Planchonella australis	Black Apple	R	
Scrophulariaceae			
Bacopa monnieri	Bacopa	C	
Solanaceae			
**Datura stramonium*	Common Thornapple	R	
**Solanum mauritianum*	Wild Tobacco Bush	U	
**S. nigrum*	Black-Berry Nightshade	C	
Sterculiaceae			
Commersonia fraseri	Brush Kurrajong	U	
Tropaeolaceae			
**Tropaeolum majus*	Nasturtium	R	
Urticaceae			
Dendrocnide photinophylla			K
Urtica incisa	Stinging Nettle	R	K
Verbenaceae			
Clerodendrum tomentosum			K
**Lantana camara*	Lantana	C	K
**Verbena bonariensis*	Purpletop	A	K
Violaceae			
Viola hederacea	Ivy-Leaved Violet	U	
Vitaceae			
Cayratia clematidea			K
Cissus antarctica			K
CLASS LILIOPSIDA	**MONOCOTYLEDONS**		
Alliaceae			
**Nothoscordum inodorum*	Onion Weed	R	
Amaryllidaceae			
**Narcissus jonquilla*	Jonquills	R	
Arecaceae			
#Livistona australis	Cabbage Tree Palm	U	K
Commelinaceae			
Commelina cyanea	Scurvy Weed	U	
**Tradescantia albiflora*	Wandering Jew	U	
Cyperaceae			
Bolboschoenus caldwelli	Coast Clubrush	C	K
Carex inversa			K
Carex?pumila			K
**Cyperus eragrotis*	Umbrella Sedge	U	
C. odoratus	Fragrant Sedge	C	
**C. papyrus*	Papyrus	R	
C. polystachyos			K
C. tetraphyllus			K
Eleocharis acuta	Spike Rush	R	
Fimbristylis ferruginea			K

Scientific Name	Common Name	Shortland	Kooragang
Schoenoplectus litoralis			K
Schoenoplectus validus	River Clubrush	U	
Hydrocharitaceae			
Vallisneria gigantea	Giant Ribbon Weed	C	
Iridaceae			
**Romulea rosea var. australis*	Onion Grass	C	
Juncaceae			
**Juncus acutus*	Spiny Rush	R	K
J. krausii	Sea Rush	C	K
J. polyanthemus			K
J. usitatus	Common Rush	C	K
Juncaginaceae			
Triglochin striatum			K
Triglochin multifructum	Water Ribbons	C	
Triglochin procerum			K
Liliaceae			
Blandfordia grandiflora	Christmas Bush	C	
Lomandraceae			
Lomandra longifolia	Spiny-Headed Mat Rush	C	
Philesiaceae			
Eustrephus latifolius			K
Geitonoplesium cymosum			K
Poaceae			
Agrostis avenaceae			K
Avena barbata			K
**Briza maxima*	Quaking Grass	C	
**B. minor*	Shivery Grass	C	K
Bromus uniloides			K
**Chloris gayana*	Rhodes Grass	C	
**Cortaderia selloana*	Pampas Grass	R	
Cynodon dactylon	Couch	C	K
Dichelachne micrantha			K
**Echinochloa crus-gali*	Barnyard grass	C	
Ehrharta erecta			K
Isachne globosa	Swamp Millet	C	
Lolium spp.			K
**Lolium temulentum*	Darnel	C	
**Melinis repens*	Red Natal Grass	R	
Microlaena stipoides			K
Oplismenus imbecillis			K
**Panicum maximum*	Guinea Grass	C	
**Paspalum, dilatatum*	Paspalum	C	K
Paspalum vaginatum			K
P. Distichum	Water Couch	A	
**Pennisetum clandestinum*	Kikuyu Grass	A	K
Poa annua			K
Sporobolus indicus var. *africanus*			K

Scientific Name	Common Name	Shortland	Kooragang
Sporobolus elongata			K
Sporobolus virginicus			K
Stenotaphrum secundatum			K
Ruppiaceae			
Ruppia ?polycarpa			K
Typhaceae			
Typha orientalis			K
Zannichelliaceae			
Zannichellia palustris			K

APPENDIX B

Shorebird Data Analysis

HUNTER ESTUARY WETLANDS RAMSAR SITE – KOORAGANG COMPONENT

Formal Assessment of Change in Ecological Character – Shorebird Analysis

FINAL

April 2019

Australian Government
Department of the Environment and Energy

HUNTER ESTUARY WETLANDS RAMSAR SITE – KOORAGANG COMPONENT

Formal Assessment of Change in Ecological Character – Shorebird Analysis

FINAL

Prepared by
Umwelt (Australia) Pty Limited
on behalf of
Australian Government Department of the Environment and Energy

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1.0 Introduction

1.1 Limits of Acceptable Change

The limits of acceptable change (LAC) set for shorebirds as defined by the Ecological Character Description (ECD) (Brereton and Taylor-Wood 2010) for the Hunter Estuary Wetlands Kooragang Component is based on shorebird species diversity and five (5) consecutive years of counts for both the number of shorebirds and the number of the eastern curlew recorded in the Kooragang component of the Hunter Estuary Wetlands Ramsar site. Specifically, these are outlined in Table 6-1 of the ECD, which is represented below in **Table 1.1.**

Table 1.1 Limits of Acceptable Change for Critical Components and Processes for the Kooragang component of the Hunter Estuary Wetlands Ramsar site (Brereton and Taylor-Wood 2010)

Critical ecological components, processes and services	Baseline condition	LAC (based on baseline and natural variability)
Maximum number of species of migratory shorebirds recorded at site annually	There is median confidence in the maximum number of shorebirds species that regularly visited the Kooragang part of the Ramsar site around the time of listing. Data provided by the Hunter Bird Observers Club (Herbert 2007 and Herbert pers. comm. 2011), summarises all available records of bird counts from 1970 to 2007 from a range of sources (Van Gessel and Kendall 1974, Gosper 1981, AWSG, Phil Straw, Geering and Winning 1993, Kingsford et al, HBOC). It is noted that data count methods and sites may not be consistent across all these surveys. To establish a baseline for 1984, we have taken the median of the maximum annual counts of migratory shorebird species for the period 1970 to 1989. This is 18 species and the range was 17 to 18 species. Noting the maximum number of migratory species in the years 2003 to 2007 were 16, 17, 16, 16 and 13 species respectively.	No LAC has been set. It is not well understood what would constitute a substantial loss of diversity. LAC recommended to be set in future. No level of confidence identified.
Abundance of migratory shorebirds recorded at the site in summer	Maximum counts (n=6) either side of 1984 (1970-1989) of migratory shorebirds have been used to represent natural variability in abundance. In this period the range of maximum counts was between 10,000 migratory shorebirds in 1970 and 5000 migratory shorebirds in 1988 (Herbert 2007). The variability between these counts is considered to represent natural variability. There is no data to suggest that there were any major events in the estuary at the time of these counts that may have affected shorebird numbers. However, migratory shorebirds are exposed to factors outside the site at their breeding grounds and on their migration routes which may affect the abundance at the site. There is low confidence in the maximum counts of migratory shorebirds data because the methods that were used to carry out the surveys were not recorded in detail, including the extent of coverage of shorebird areas within	For any five consecutive years there will be no instance of all years recording a maximum summer annual count of migratory shorebirds of less than 5000 birds. This LAC is based on the range of variability shown in the counts between 1970 and 1989 and if there is consistently less than 5000 migratory shorebirds recorded in maximum summer counts this would indicate a change in

Critical ecological components, processes and services	Baseline condition	LAC (based on baseline and natural variability)
	the Hunter Estuary Ramsar site and the timing of the counts (i.e. did they coincide with the peak wader period in the year of the count). For the years 2003 to 2007 the maximum summer counts have been: 2003 – 3451 2004 – 3403 2005 – 3009 2006 – 3095 2007 – 3252.	ecological character. This estimate should be reviewed as better understanding of limits of acceptable change is derived. Low level of confidence in the LAC.
Eastern curlew	A maximum count of 900 eastern curlews was recorded for the Hunter estuary at the time of listing in 1984. Fourteen years before listing a maximum count of 600 eastern curlews was recorded in 1970 and thirteen years after listing in 1997 a maximum count of 900 eastern curlews was recorded (Herbert 2007). There is available data for the eastern curlew for 18 separate years in this 27 year period. The lowest recorded maximum count was 200 birds in 1973 and the highest recorded maximum count was 1000 eastern curlews in 1975 and 1996 and the lowest maximum counts were around 300 birds in 1971, 1989, and 1991 (Herbert 2007a). Three hundred eastern curlews have been adopted arbitrarily as the low point of natural variability around the time of Ramsar listing. The variability between these 18 counts is considered to represent natural variability. However, it is likely that the lower counts may have been a result of in-complete surveys and are therefore under-estimates (C. Herbert, pers. comm. March 2011). Herbert (pers.comm 2011) suggests 600 would be a more realistic low maximum count. There is no data to suggest that there were any major events in the estuary at the time of these counts that may have affected wader numbers. However, migratory shorebirds are exposed to factors outside the site at their breeding grounds and on their migration routes which may affect the abundance at the site. There is low confidence in the maximum counts of the eastern curlews data because the methods that were used to carry out the surveys were not recorded in detail, including the extent of coverage of wader areas within the Hunter Estuary Ramsar site and the timing of the counts (i.e. did they coincide with the peak wader period in the year of the count). However, counts of eastern curlews were carried out in most years in the 27 year period being considered around the time of listing which gives some level of confidence that natural variability is being detected.	For any five year period there will be no instance of all years recording a maximum summer annual count of eastern curlew for the Hunter estuary of less than 600 birds. This estimate should be reviewed as better understanding of limits of acceptable change is derived. Low level of confidence in the LAC.

1.2 Data Set

This appendix analyses long-term data collected at several locations within the Ramsar site to determine whether these LACs have been exceeded.

The data set consists of maximum count data for 27 migratory shorebird species recorded during monthly surveys conducted by the Hunter Bird Observers Club (HBOC). These bird species and status under the *Biodiversity Conservation Act 2016* (BC Act) and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) are listed in **Table 1.2**.

Table 1.2 Migratory Shorebird Species Data used in Analysis

Common name / *Scientific name*	BC Act listing	EPBC Act listing
Black-winged Stilt / *Himantopus himantopus*	-	M
Banded Stilt / *Cladorhynchus leucocephalus*	-	-
Pacific Golden Plover / *Pluvialis fulva*	-	B, C, J, K
Grey Plover / *Pluvialis squatarola*	-	M, B, C, J, K
Double-banded Plover / *Charadrius bicinctus*	-	M, B
Lesser Sand Plover / *Charadrius mongolus*	V	E, M, B, C, J, K
Latham's Snipe / *Gallinago hardwickii*	-	M, B, J, K
Black-tailed Godwit / *Limosa limosa*	V	M, B, C, J, K
Bar-tailed Godwit / *Limosa lapponica baueri*	-	V, M, B, C, J, K
Whimbrel / *Numenius phaeopus*	-	M, B, C, J, K
Eastern Curlew / *Numenius madagascariensis*	-	CE, M, B, C, J, K
Terek Sandpiper / *Xenus cinereus*	V	M, B, C, J, K
Common Sandpiper / *Actitis hypoleucos*	-	M, B, C, J, K
Grey-tailed Tattler / *Tringa brevipes*	-	M, B, C, K
Wandering Tattler / *Tringa incana*	-	M, B, J
Common Greenshank / *Tringa nebularia*	-	M, B, C, J, K
Marsh Sandpiper / *Tringa stagnatilis*	-	M, B, C, J, K
Ruddy Turnstone / *Arenaria interpres*	-	M, B, C, J, K
Great Knot / *Calidris tenuirostris*	V	CE, M, B, C, J, K
Red Knot / *Calidris canutus*	-	E, M, B, C, J, K
Red-necked Stint / *Calidris ruficollis*	-	M, B, C, J, K
Long-toed Stint / *Calidris subminuta*	-	M, B, C, J, K

Common name / *Scientific name*	BC Act listing	EPBC Act listing
Pectoral Sandpiper / *Calidris melanotos*	-	M, B, J, K
Sharp-tailed Sandpiper / *Calidris acuminata*	-	M, B, C, J, K
Curlew Sandpiper / *Calidris ferruginea*	E	CE, M, B, C, J, K
Broad-billed Sandpiper / *Limicola falcinellus*	V	M, B, C, J, K

Conservation Status in the *Biodiversity Conservation Act 2016* (BC Act) and/or *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act): V = Vulnerable; E = Endangered; CE = Critically Endangered; M = Marine
Migratory Treaties: B = Bonn; C = CAMBA; J = JAMBA; K = ROKAMBA

2.0 Methods

2.1 Bird Count Data

The maximum monthly counts of shorebird species (migratory and non-migratory) were recorded from April 1999 to December 2017 at seven sites within the Ramsar site (**Table 2.1**). Monthly surveys were conducted in a standardised manner with comparable survey effort (Roderick, M. pers. comms). As the LACs focus on summer counts, the 1999 data were omitted from analyses as only one month of summer survey was included for that year.

Table 2.1 Locations of Monthly Shorebird Surveys

Survey site	GPS coordinates	
	Easting	Northing
Stockton Sandspit	386919	6360999
Fern Bay	387176	6361217
Kooragang Dykes	385998	6361974
Fullerton Cove Beach	388277	6364957
Tomago	384206	6366296
Ash Island Teal Waders	379919	6363873
Ash Island Sharpies Flat	380491	6363880

2.2 Data analysis

To determine any limits of acceptable change of migratory shorebirds within the Kooragang component of the Hunter Estuary Wetland s Ramsar site, four response variables were developed. These included migratory shorebird species diversity, annual summer abundance of migratory shorebirds, annual summer abundance of the eastern curlew and annual summer abundance of other EPBC listed species including the Australasian bittern.

2.2.1 Species Diversity

Shorebird species diversity was calculated in three ways: 1) Richness; 2) Shannon's index; and 3) evenness.

Richness was calculated as the total number of species recorded at the site annually.

Shannon's index takes into account the abundances of each species when determining diversity. The Shannon index for each year was calculated using the following formula:

$$H = -\Sigma pi(log2\, pi)$$

Where pi is the proportion of the total sample belonging to species i

Evenness is another measure of biodiversity, which quantifies how even a community is as a mathematical value. The evenness of the community for each year was calculated using the following formulas:

$$J' = \frac{H'}{H'max}$$

Where H' is the number derived from the Shannon Wiener diversity index, and H'max is the maximum value of H', equal to:

$$H' \max = -\sum_{i=1}^{S} \frac{1}{S} In \frac{1}{S} = In\, S$$

Where S is the total number of species.

This calculates J', a value between 0 and 1, where the higher the value indicates a lower variation in communities.

Predictor variables: The three response variables for species diversity described above were analysed with a set of predictor variables. Predictor variables selected for the migratory shorebird data set included: mean minimum temperature (°C), mean maximum temperature (°C), local rainfall (mm), inland rainfall (mm) from the Murry-Darling Basin, inland rainfall (mm) from the Lake Eyre Basin, year and the southern oscillation index.

Monthly mean maximum and mean minimum temperature data and monthly mean local rainfall data were obtained from the weather station at the Newcastle University (061390) located approximately 4.6 kilometres from the Ramsar site. Where data were not recorded from the Newcastle University weather station, data were sourced from Nobby's Signal Station (061055) located approximately seven kilometres from site.

The monthly mean inland rainfall data were obtained from weather stations that represented the Murray-Darling Basin catchment and Lake Eyre Basin catchment. The most available data were obtained from weather stations at Quambone Station (051042) approximately 33 kilometres from the Macquarie Marshes, NSW and Moomba Airport (017123) approximately 250 kilometres from Lake Eyre and approximately 80 kilometres from Innamincka, SA. Inland rainfall included a lag of two months before summer in order to capture bird movements associated with inland rainfall events. All climatic data were obtained from the Bureau of Meteorology (BoM 2018a) website (accessed March 2018).

The monthly Southern Oscillation Index (SOI) data were also included as an explanatory variable to represent El Nino Southern Oscillation phases. SOI data were obtained from the Bureau of Meteorology (http://www.bom.gov.au/climate/current/soihtm1.shtml; accessed March 2018).

Models: To assess the effect environmental factors have on shorebird diversity over time, two complementary analyses were conducted.

Firstly, generalised linear models (GLMs) were developed to evaluate the relative importance of each of the explanatory variables on each of the three measures for shorebird diversity, separately. A full model including all variables was fitted before developing a reduced model with those variables that selected in a stepwise procedure.

Secondly, generalised additive models (GAMs) were developed to identify possible non-linear relationships among the explanatory variables and the three response variables. Cubic splines were used to identify any potential nonlinear relationship between the explanatory variables and response variables.

The model fit for the GLMs and GAMs were compared by performing ANOVAs and by comparing the Akaike Information Criterion (AIC) of each model. These tests were used to compare the final GLMs and GAMs in order to determine which model performed best. Multicollinearity was evaluated by comparing the pair-wise correlation among the explanatory variables.

Relationships between explanatory variables and the migratory shorebird species diversity variables were examined on a set of candidate models created from *a priori* hypotheses. The model-averaged parameter estimates over all the models in the candidate model set were calculated using the MuMIn R package (Bartoń 2013). The relative importance of each predictor variable was evaluated using multimodel inference based on information theory (Akaike's Information Criterion corrected for small sample sizes, AICc) (Burnham and Anderson 2002). The contribution of each model to the parameter estimates was determined by its weight, which depends on its delta AICc value. Model average estimates, associated unconditional standard errors (SE) and 95% confidence intervals (95% CI) were calculated to determine the importance of each variable in predicting the migratory shorebird species diversity variables.

All statistical analyses for migratory shorebirds data for the Kooragang component of the Hunter Estuary Wetlands Ramsar site were done in R 3.4.4 (R Development Core Team 2018), using the *gam* function in the package mgcv (Wood 2006) and the *dredge* and *model.avg* functions in the package MuMIn (Bartoń 2013).

2.2.2 Species Abundance

Species abundance was calculated as the **total number of shorebirds recorded during a summer period** (i.e. December, January and February) for each year of survey. This approach to measuring shorebird abundance was employed as avian abundance has been shown to correlate best with maximum rather than average abundance data from repeated surveys (Toms *et al.* 2006).

Models: The development of bird counts over time was analysed following the same method used for species diversity: first by developing GLMs and then using GAMs (GAM, Wood (2006). Models were used to describe the number of birds in relation to the explanatory variables used above for diversity. Cubic splines were used to identify any potential nonlinear relationship between the explanatory variables and response variables.

The model fit for the GLMs and GAMs were compared by performing ANOVAs and by comparing the Akaike Information Criterion (AIC) of each model. These tests were used to compare the final GLMs and GAMs in order to determine which model performed best. Multicollinearity was evaluated by comparing the pair-wise correlation among the explanatory variables. Sets of candidate models and associated model-averaged parameter estimates were created to determine the importance of each variable in predicting the migratory shorebird species diversity variables.

2.2.3 Eastern Curlew

The total summer abundance for the eastern curlew was analysed following the same methods described for species abundance above. This involved developing GLMs and GAMs in a stepwise manner to describe the number of eastern curlew in relation to the same explanatory variables used previously. Sets of candidate models and associated model-averaged parameter estimates were created to determine the importance of each variable in predicting the migratory shorebird species diversity variables.

2.2.4 Other Species

Analyses of the summer abundance of individual species compared with explanatory variables were undertaken using the methods outlined above for the eastern curlew. For any species data that exhibited a zero inflated distribution, these data were log +1 transformed.

3.0 Results

3.1 Species Diversity

3.1.1 Species richness

In the GLMs and GAMs, no explanatory variables were identified as significant predictors of migratory shorebird species richness at the Kooragang component. The explanatory variable 'year' was the closest variable tested in the GLMs to being significant (P = 0.056) for species richness.

The highest ranking model (AICc score) included the year (**Table 3.1**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included southern oscillation index, mean maximum temperature and rainfall at Lake Eyre. As the ΔAICc of the top six models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.1 Generalised additive model (GAM) candidates predicting migratory shorebird species richness

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
-204.2	√						3	62.7	0.00	0.188
-200.7	√					√	4	63.0	0.34	0.159
-3.76		√					3	63.9	1.19	0.104
17.61*							2	64.0	1.30	0.098
17.65						√	3	64.4	1.73	0.079
-200.9	√				√	√	5	64.7	1.99	0.070

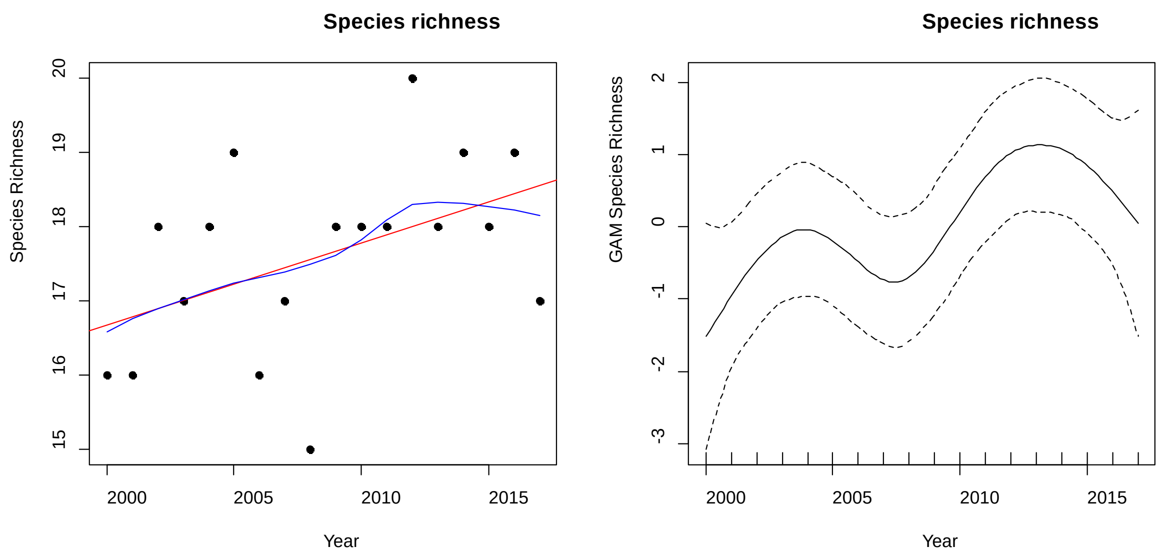
The models were ordered according to their correlated Akaike information criterion (AICc).
The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (W_i).
Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC).
√ indicates that a variable is included in the model; df denotes the degrees of freedom. * denotes intercept only.

Subsequent models formed the remaining explanatory variables, none of which explained migratory shorebird abundance (**Table 3.2**). The highest ranking model was just non-significant (F = 4.225, P = 0.0565), explaining 20.9% of the variance of the intercept (adjusted R^2 = 0.057).

Table 3.2 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the species richness of migratory shorebirds

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	-1.136^{+2}	1.351^{+2}	-3.875^{+2}, 1.603^{+2}	0.813	0.4164
Year	6.352^{-2}	6.886^{-2}	-7.594^{-2}, 2.029^{-1}	1.816	0.0694
SOI	-2.924^{-2}	4.944^{-2}	-1.294^{-1}, 7.092^{-2}	1.384	0.1663
MeanMaxTemp	1.598^{-1}	4.241^{-1}	-7.037^{-1}, 1.023	1.006	0.3143
LERain	5.006^{-4}	2.263^{-2}	-4.165^{-3}, 5.166^{-3}	0.582	0.5603

Although the explanatory variable 'year' was identified as being non-significant for predicting migratory shorebird species richness, there is a positive relationship associated between the two variables (**Figure 3.1**).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.1 Relationship between shorebird species richness over time and modelled GAM shorebird species richness over time

3.1.2 Shannon's Index

In the GLMs, the explanatory variable 'Lake Eyre rainfall' was identified as a significant predictor of the Shannon index of migratory shorebird species at the Kooragang component.

In the GAMs, "Lake Eyre rainfall' and 'year' were identified as significant predictors of the Shannon index of migratory shorebird species.

Comparison of the reduced GLM and GAM identified the GAM as being a better fit than the GLM (P = 0.075).

The highest ranking model (AICc score) included 'Lake Eyre rainfall', 'mean maximum temperature' and 'year' (**Table 3.3**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included 'Lake Eyre rainfall' and 'year'. As the ΔAICc of the top three models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.3 Generalised additive model (GAM) candidates predicting Shannon index of migratory shorebird species

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
30.230	√	√			√		5	-21.0	0.00	0.268
21.10	√				√		4	-20.8	0.28	0.234
1.907					√		3	-20.2	0.81	0.179

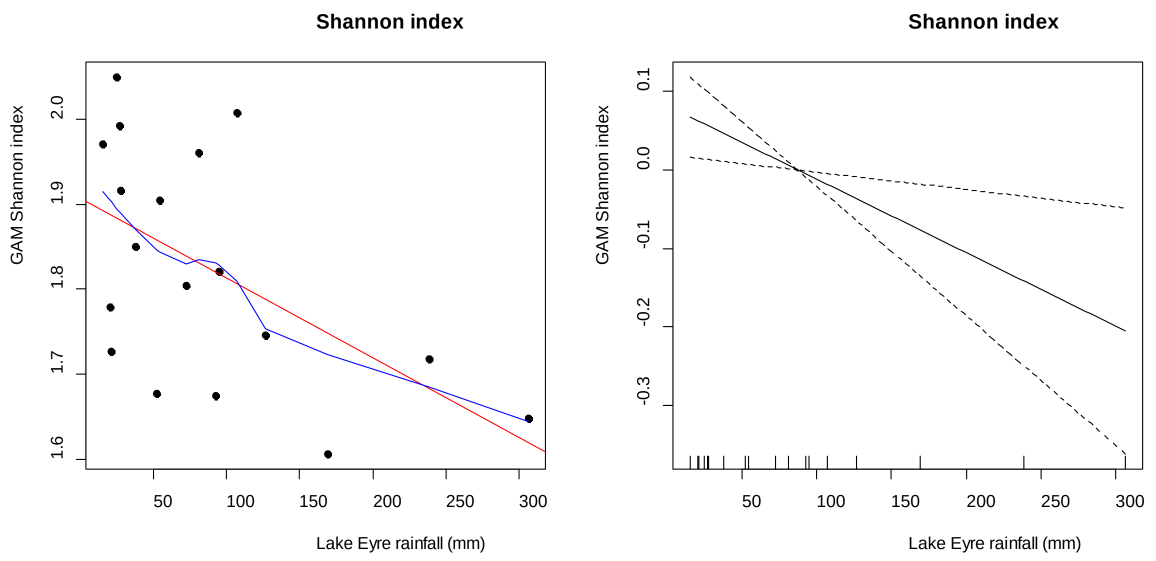
The models were ordered according to their correlated Akaike information criterion (AICc).
The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi).
Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC).
√ indicates that a variable is included in the model;
df denotes the degrees of freedom.

Subsequent models formed the remaining explanatory variables, none of which explained migratory shorebird abundance (**Table 3.4**). The highest ranking model was highly significant (F = 5.789, P = 0.0087), explaining 55.4% of the variance of the intercept (adjusted R^2 = 0.458).

Table 3.4 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the Shannon index of migratory shorebird species

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	1.633^{+1}	1.517^{+1}	-1.339^{+1}, 4.606^{+1}	1.077	0.2816
LERain	-6.850^{-4}	5.195^{-4}	-1.703^{-3}, 3.33^{-4}	2.265	0.0235
MeanMaxTemp	3.385^{-2}	6.197^{-2}	-8.760^{-2}, 1.553^{-1}	1.359	0.1742
Year	-7.590^{-3}	7.996^{-3}	-2.326^{-2}, 8.082^{-3}	1.821	0.0687

The explanatory variable 'Lake Eyre rainfall' was identified as being a significant predictor for the Shannon index of migratory shorebird species, which demonstrates a negative relationship associated between the two variables (**Figure 3.2**).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.2 Relationships between the Shannon index of migratory shorebird species and Lake Eyre rainfall, and modelled GAM Shannon index of migratory shorebird species and Lake Eyre rainfall.

3.1.3 Species Evenness

In the GLMs and GAMs, the explanatory variables 'Lake Eyre rainfall' and 'year' were identified as significant predictors of the evenness of migratory shorebird species. Comparison of the GLM and GAM identified neither model as being a better fit than the other (P = 0.15).

The highest ranking model (AICc score) included 'Lake Eyre rainfall' and 'year' (**Table 3.5**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included 'Lake Eyre rainfall', 'mean maximum temperature' and 'year'. As the ΔAICc of the top two models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.5 Generalised additive model (GAM) candidates predicting the evenness of migratory shorebird species

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
11.74	√				√		4	-64.4	0.00	0.461
13.88	√	√			√		5	-62.9	1.44	0.224

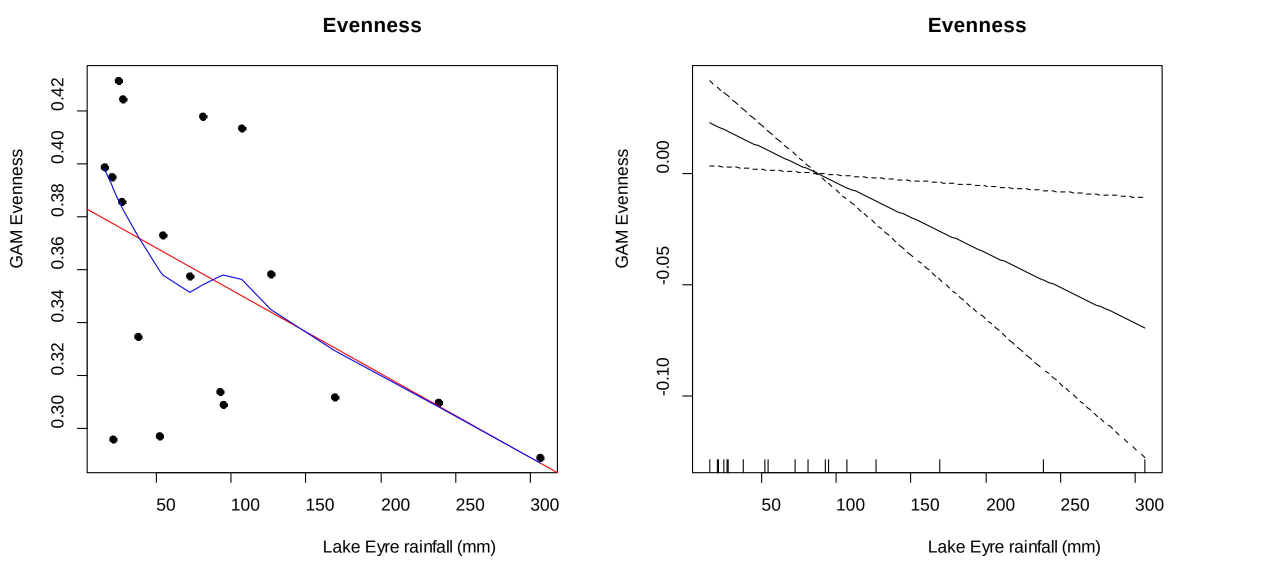
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

Subsequent models formed the remaining explanatory variables, none of which explained migratory shorebird abundance (**Table 3.6**). The highest ranking model was highly significant (F = 12.35, P = 0.0007), explaining 62.2% of the variance of the intercept (adjusted R^2 = 0.572).

Table 3.6 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the evenness of migratory shorebird species

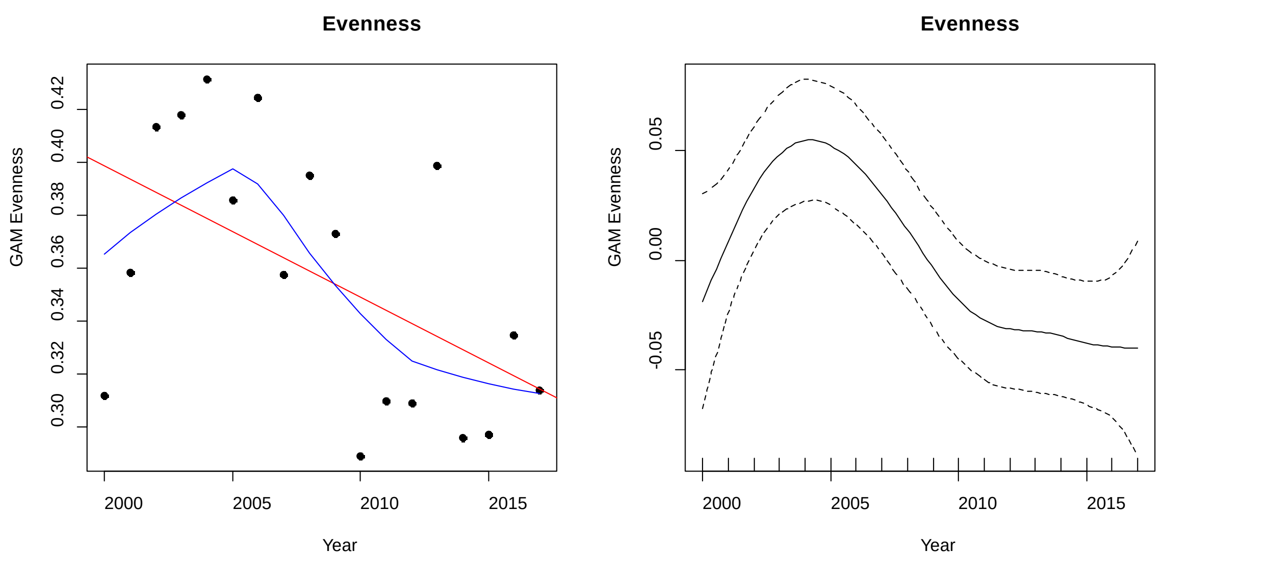
Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	1.266^{+1}	3.625	5.558, 19.769	3.493	0.0005
LERain	-3.589^{-4}	1.218^{-4}	-0.0006, - 1.202^{-4}	2.947	0.0032
Year	-6.225^{-3}	1.901^{-3}	-0.0099, -2.499^{-3}	3.274	0.0011
MeanMaxTemp	9.244^{-3}	1.715^{-2}	-0.024, 4.287^{-2}	0.539	0.5899

Although the explanatory variables 'Lake Eyre rainfall' and 'year' were identified as being significant predictors for the evenness of migratory shorebird species, both of which demonstrate a negative relationship associated between the two variables (**Figure 3.3** and **3.4**, respectively).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.3 Relationships between the evenness of migratory shorebird species and Lake Eyre rainfall, and modelled GAM evenness of migratory shorebird species and Lake Eyre rainfall



Dotted lines represent standard error.
Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.

Figure 3.4 Relationship between the evenness of migratory shorebird species over time, and modelled GAM evenness of migratory shorebird species over time

3.2 Species Abundance

In the GLMs, the explanatory variable 'mean SOI' was identified as a significant predictor of migratory shorebird abundance at the Kooragang component. This differed from the GAMs with 'mean SOI' and 'year' being identified as significant predictors of migratory shorebird abundance. Comparison of the GLM and GAM identified neither model as being a better fit than the other (P = 0.139).

The highest ranking model (AICc score) included the southern oscillation index and year (**Table 3.7**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the southern oscillation index. As the ΔAICc of the top two models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.7 Generalised additive model (GAM) candidates predicting migratory shorebird abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
-181300	√					√	4	307.4	0.00	0.390
4876						√	3	308.4	1.09	0.227

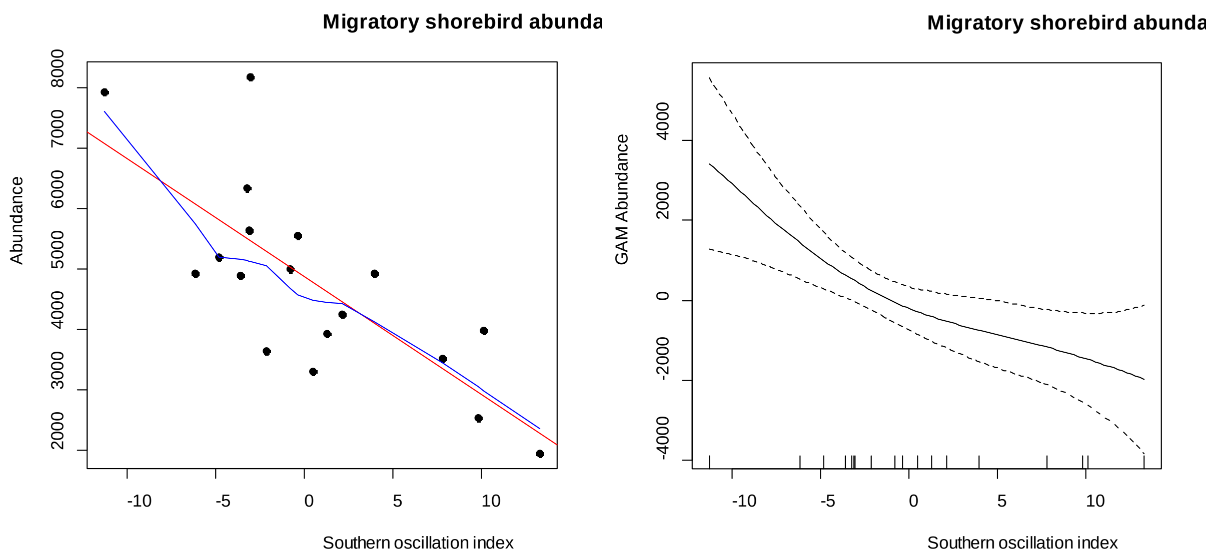
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

Subsequent models formed the remaining explanatory variables, none of which explained migratory shorebird abundance (**Table 3.8**). The highest ranking model was highly significant (F = 15.41, P = 0.0002), explaining 67.2% of the variance of the intercept (adjusted R^2 = 0.63).

Table 3.8 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of migratory shorebirds

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	-1.025^{+5}	1.146^{+5}	-3.349^{+5}, 12.9923.99	0.864	0.387
SOI	-1.836^{+2}	4.667^{+1}	-2.822^{+2}, -84.97	3.649	0.0003
Year	53.53	5.703^{+1}	-6.217^{+1}, 169.228	0.907	0.365

The southern oscillation index was identified as a significant explanatory variable predicting migratory shorebird abundance, which demonstrated a negative relationship to eastern curlew abundance (**Figure 3.5**).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.5 Relationship between migratory shorebird species abundance and the southern oscillation index, and the modelled GAM shorebird species abundance with the southern oscillation index

3.3 Eastern Curlew

In the GLMs, the explanatory variables 'year', 'mean maximum temperature' and 'rainfall' were identified as significant predictors of eastern curlew abundance at the Kooragang component. This differed from the GAMs with only 'year' being identified as significant predictors of bar-tailed godwit abundance. Comparison of the GLM and GAM identified neither model as being a better fit than the other (P = 0.754).

The highest ranking model (AICc score) included the year and local rainfall (**Table 3.9**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included year, local rainfall southern oscillation index. As the ΔAICc of the top three models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.9 Generalised additive model (GAM) candidates predicting the eastern curlew abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
105500	√		√				4	236.3	0.00	0.332
113200	√						3	237.4	1.07	0.194
104200	√		√			√	5	238.3	1.98	0.124

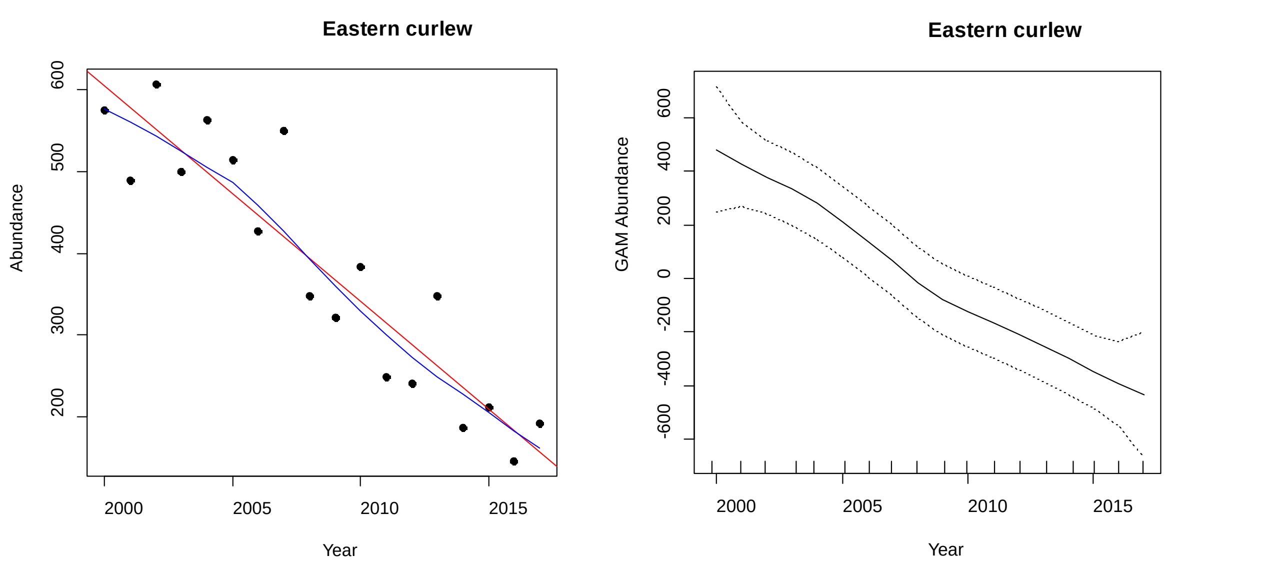
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

The subsequent models formed the remaining explanatory variables, none of which explained eastern curlew abundance (**Table 3.10**). The highest ranking model was highly significant (F = 41.73, P = 7.431^{-7}), explaining 84.8% of the variance of the intercept (adjusted R^2 = 0.83).

Table 3.10 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of eastern curlew

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	1.095^{+5}	1.457^{+4}	78661.40, 1.40^{+5}	6.961	2.0^{-16}
Year	-54.09	7.360	-69.65, -3.85	6.185	<0.001
Rainfall	-3.956^{-1}	4.025^{-1}	-1.212, 4.205^{-1}	0.950	0.342
SOI	-1.04	3.418	-8.073, 5.994	0.290	0.772

'Year' and 'Rainfall' were identified as significant explanatory variables predicting eastern curlew abundance with each variable demonstrating a negative relationship to eastern curlew abundance (**Figure 3.6**).



Dotted lines represent standard error.
Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.

Figure 3.6 Relationship between eastern curlew abundance over time and modelled GAM abundance over time

3.4 Other Species

Due to the large number of zero observations recorded for some species and the need for a single parsimonious model to make predictions for a large number of functional groups, a GAM was developed using a Poisson distribution. Those species data that were not zero inflated were fitted with a Gaussian distribution.

Data for the Australasian bittern were obtained from BioNet, which records positive counts (i.e. does not record zero counts). As such, it was assumed that where no records were made for a year, then the abundance for that year would be zero. The results of associated analyses need to take into consider the limitations of the data collection.

Results of the individual species analyses are described in subsequent sections. A summary of the relationships between each EPBC Act listed threatened species abundance and explanatory variables are provided in **Table 3.11**.

Table 3.11 Abundance trends over the period 2000 to 2017 for six shorebird species and the Australasian Bitter bittern

Common name *Scientific name*	Conservation listing (EPBC Act)	Evidence of Change	Prey Group/habitat	Significant Predictor
*Australasian bittern	Endangered	Data deficient	Benthic and pelagic/ freshwater wetlands	-
Bar-tailed godwit	Vulnerable	Decline	Benthic/ sandflats and mudflats	Year (-ve)
Black-tailed godwit	Migratory	Decline	Benthic/ sandflats and mudflats	Year (-ve)
Curlew sandpiper	Critically Endangered	Decline	Benthic/ mudflats	Year (-ve)
Great knot	Critically Endangered	Decline	Benthic/ sandflats and mudflats	Year (-ve)
*Lesser sand plover	Endangered	Data deficient	Benthic/ sandflats, mudflats and beaches	-
Red knot	Endangered	Decline	Benthic/ sandflats and mudflats	Year (-ve) and temperature (+ve)

*Poisson distribution fitted with log link

3.4.1 Bar-tailed godwit

The explanatory variables 'year', 'mean maximum temperature' and 'Lake Eyre rainfall' were identified as significant predictors of bar-tailed godwit abundance at the Kooragang within the GAMs. This differed from the GLMs with only 'year' and 'mean maximum temperature' being identified as significant predictors of bar-tailed godwit abundance. Comparison of the GLM and GAM identified the GAM as being the slightly better fitting model of the two (P = 0.014).

The highest ranking model (AICc score) included the year and Lake Eyre rainfall (**Table 3.12**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the year, Murry-Darling rainfall and Lake Eyre rainfall. As the ΔAICc of the top three models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.12 Generalised additive model (GAM) candidates predicting bar-tailed godwit abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
211400	√				√		4	265.3	0.00	0.318
218800	√						3	266.2	0.91	0.201
213000	√			√			4	267.1	1.88	0.124

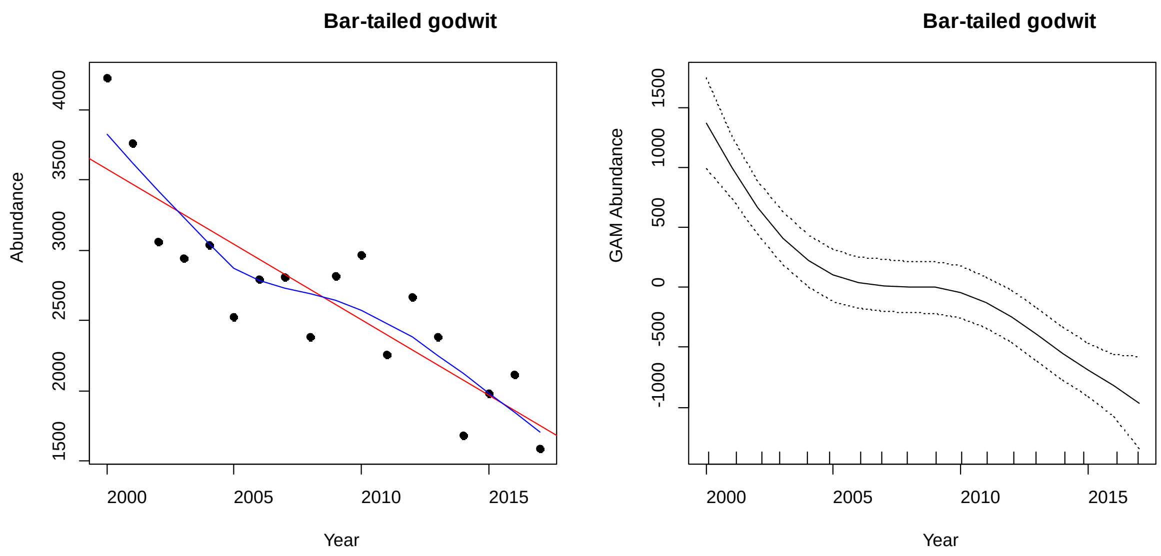
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

The subsequent models formed the remaining explanatory variables, none of which explained bar-tailed godwit abundance (**Table 3.13**). The model was highly significant (F = 31.41, P = 4.341^{-6}), explaining 80.7% of the variance of the intercept (adjusted R^2 = 0.78).

Table 3.13 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of bar-tailed godwit

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	2.139^{+5}	3.306^{+4}	149139.6, 278718.6	6.472	2.09^{16}
LERain	9.374^{-1}	1.225	-1.464, 3.338	0.765	0.444
Year	-1.052^{+2}	16.53	-1.376, -7.279	6.362	<0.001
MDRain	1.692^{-1}	4.623^{-1}	$-7.758-^{1}$, 1.114	0.351	0.726

'Year' was identified as a significant explanatory variable predicting bar-tailed godwit abundance. A negative relationship between bar-tailed godwit abundance and year is demonstrated in **Figure 3.7**.



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.7 Relationship between bar-tailed godwit abundance over time, and modelled GAM abundance over time

3.4.2 Lesser sand plover

No explanatory variables within the GLMs or GAMs were identified as significant predictors of lesser sand plover abundance at the Kooragang component of the Hunter Wetlands Estuary Ramsar site. Similarly, no explanatory variables were present in the highest ranking model (AICc score) (**Table 3.14**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the southern oscillation index and the rainfall for the Murry-Darling and Lake Eyre basins. As the ΔAICc of the top four models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.14 Generalised additive model (GAM) candidates predicting lesser sand plover abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
0.667							2	57.8	0.00	0.312
0.303					√		3	58.9	1.11	0.179
0.639						√	3	59.3	1.54	0.145
0.172				√			3	59.5	1.76	0.130

The models were ordered according to their correlated Akaike information criterion (AICc).
The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi).
Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC).
√ indicates that a variable is included in the model;
df denotes the degrees of freedom.

The subsequent models formed the remaining explanatory variables, none of which explained lesser sand plover abundance (**Table 3.15**). The highest ranked model only included the intercept. The second highest ranked model after the model contained the rainfall for Lake Eyre was not significant (F = 1.685, P = 0.213), explaining 0.1% of the variance of the intercept (adjusted R^2 = 0.04).

Table 3.15 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of lesser sand plover

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	0.321	38.43	-81.38, 82.02	0.008	0.994
LERain	0.001	2.521^{-3}	-0.004, 0.006	0.401	0.688
SOI	0.009	0.027	-0.047, 0.064	0.308	0.758
MDRain	3.62^{-4}	1.258^{-3}	-0.002, 0.003	0.273	0.785

3.4.3 Red knot

The explanatory variable 'year' was the only significant predictor of red knot abundance at the Kooragang component of the Hunter Wetlands Estuary Ramsar site identified within the GLMs and GAMs. Comparison of the GLM and GAM identified the GAM as being the slightly better fitting model of the two (P = 0.04).

The highest ranking model (AICc score) included the' year', 'local rainfall' and 'mean maximum temperature' (**Table 3.16**). The subsequent models formed the remaining explanatory variables, none of which explained red knot abundance (**Table 3.17**). The next ranked models were not within 2 AIC units (i.e. ΔAICc >2) and are therefore not considered to be supported (Burnham and Anderson 2002). The model was highly significant (F = 11.98, P = 0.0004), explaining 71.9% of the variance of the intercept (adjusted R^2 = 0.66).

Table 3.16 Generalised additive model (GAM) candidates predicting red knot abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
17150	√	√	√				5	180.9	0.00	0.77

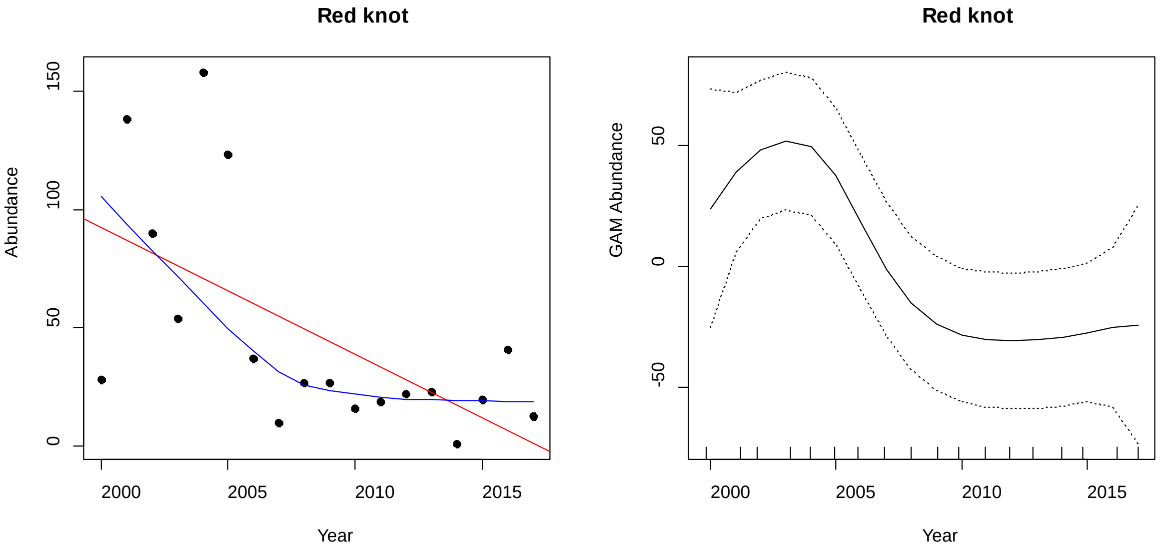
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

Table 3.17 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of red knot

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	1624^{+4}	3.421^{+3}	9723.25, 23357.28	4.413	1.02^{-5}
MeanMaxTemp	0.254	9.675	9.29, 44.08	2.472	0.0134
Rainfall	0.128	0.092	-0.037, 0.318	1.344	0.1789
Year	-8.437	1.79	-12.14, -5.075	4.392	1.12^{-5}

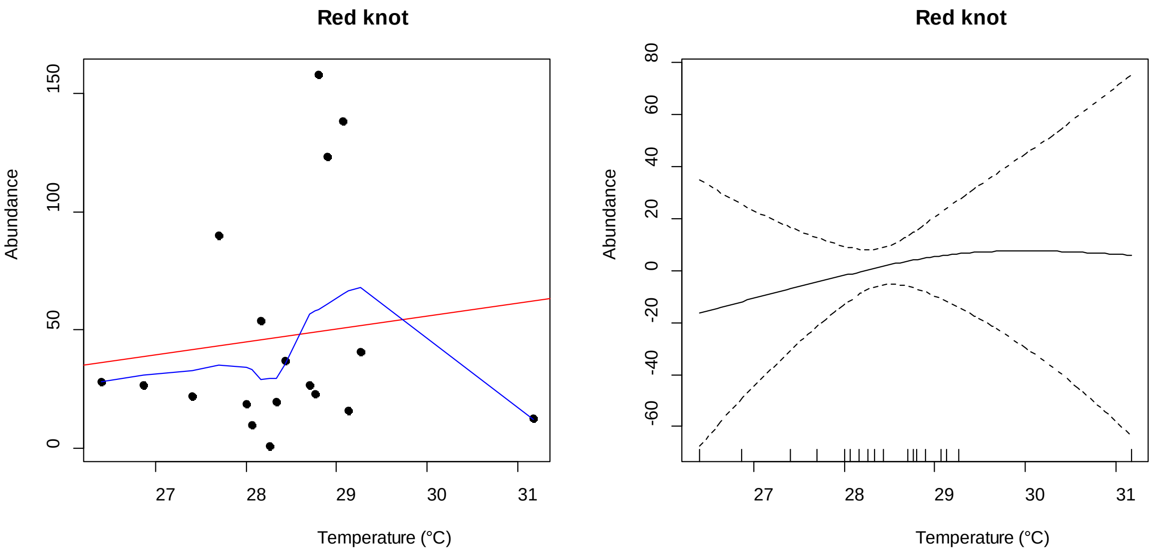
'Year' and 'mean maximum temperature' were identified as significant explanatory variables predicting red knot abundance. Red knot abundance showed a negative relationship over time (**Figure 3.8**).

The trend of red knot abundance and mean maximum temperature was slightly positive, although the spread of error should be considered when examining this trend (**Figure 3.9**).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.8 Relationship between red knot abundance over time, and modelled GAM abundance over time



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.9 Relationship between red knot abundance and the mean maximum temperature (°C), and the relationship between the modelled GAM abundance and the mean maximum temperature (°C)

3.4.4 Great knot

The explanatory variables 'year' and 'rainfall' were identified as significant predictors of great knot abundance at the Kooragang component within the GAMs. Only 'year' was identified as a significant predictor of great knot abundance in the GLMs suggesting a nonparametric effect of 'rainfall' in the data. Comparison of the GLM and GAM identified neither model as being a better fit than the other (P = >0.05).

The highest ranking model (AICc score) included the Murry-Darling rainfall (**Table 3.18**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the year and Murry-Darling rainfall. As the ΔAICc of the top two models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.18 Generalised additive model (GAM) candidates predicting great knot abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
3514				√			4	139.8	0.00	0.360
3281	√			√			3	140.7	0.87	0.233

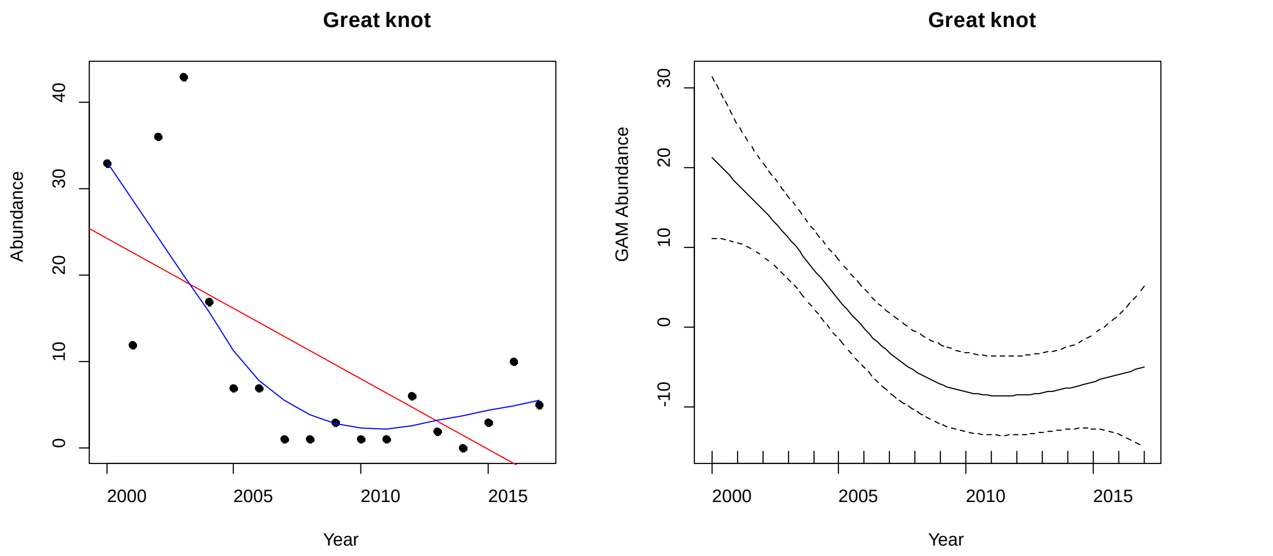
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

The subsequent models formed the remaining explanatory variables, none of which explained great knot abundance (**Table 3.19**). The model was highly significant (F = 9.14, P = 0.003), explaining 54.9% of the variance of the intercept (adjusted R^2 = 0.49). The explanatory variable 'Murry-Darling rainfall' did not explain great knot abundance based on AICc model-averaging.

Table 3.19 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of great knot

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	3.394^{+3}	958.7	1404.76, 5383.99	3.344	0.0008
Year	-1.681	0.467	-2.677, -0.685	3.308	0.0009
MDRain	-2.212^{-2}	2.522^{-2}	-0.073, 0.029	0.849	0.396

'Year' was identified as the only significant explanatory variable predicting great knot abundance, which demonstrates a negative relationship (**Figure 3.10**).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.10 Relationship between great knot abundance over time and modelled GAM abundance over time

3.4.5 Curlew sandpiper

The explanatory variable 'year' was identified as a significant predictor of curlew sandpiper abundance at the Kooragang component within the GLMs and GAMs. Comparison of the GLM and GAM identified the GAM to be the better fitting model (P = 3.775^{-5}).

The highest ranking model (AICc score) included the year and mean maximum temperature (**Table 3.20**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the year and Murry-Darling rainfall. As the ΔAICc of the top three models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.20 Generalised additive model (GAM) candidates predicting curlew sandpiper abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
99830	√	√					4	235.5	0.00	0.300
89280	√						3	236.4	0.86	0.195
92090	√			√			4	236.8	1.31	0.156

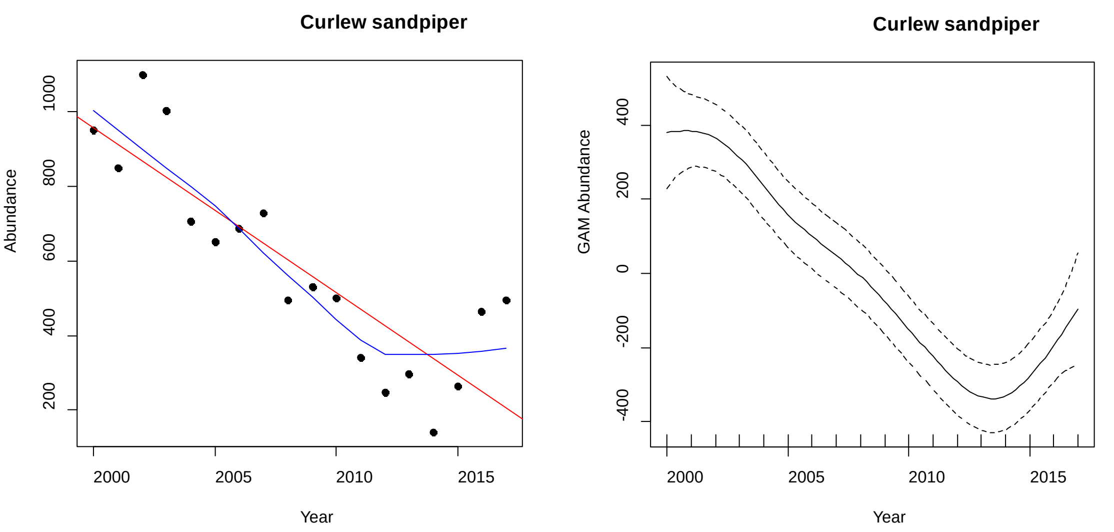
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

The subsequent models formed the remaining explanatory variables, none of which explained curlew sandpiper abundance (**Table 3.21**). The model was highly significant (F = 27.8, P = <0.05), explaining 78.8% of the variance of the intercept (adjusted R^2 = 0.73).

Table 3.21 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of curlew sandpiper

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	9.527^{+4}	1.444^{+4}	65290.49, 126948.1	6.12	< 0.01
MeanMaxTemp	33.87	4.300^{+1}	-53.208, 12.095	0.762	0.446
Year	-47.61	7.472	-63.359, -3.186	5.926	< 0.001
MDRain	-1.345^{-1}	2.617^{-1}	-0.666, 3.971^{-1}	0.496	0.620

'Year' was identified as the only significant explanatory variable predicting curlew sandpiper abundance, which demonstrates a negative relationship (**Figure 3.11**).



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.11 Relationship between curlew sandpiper abundance over time and modelled GAM abundance over time

3.4.6 Black-tailed godwit

The explanatory variable 'year' was identified as the significant predictor of black-tailed godwit abundance at the Kooragang component within the GLMs and GAMs. Comparison of the GLM and GAM identified the GAM as being the better fitting model of the two (P = <0.001).

The highest ranking model (AICc score) included the year (**Table 3.22**). The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the year and Murry-Darling rainfall. As the ΔAICc of the top three models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002).

Table 3.22 Generalised additive model (GAM) candidates predicting black-tailed godwit abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
211400	√						3	226.5	0.00	0.425
218800	√			√			4	228.1	1.60	0.191

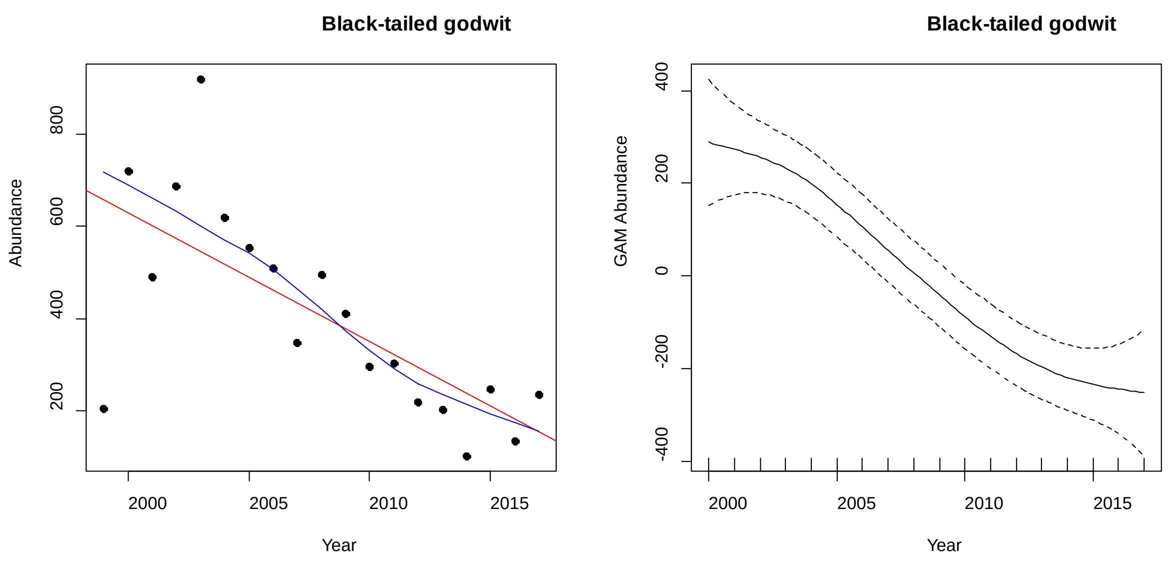
The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

The subsequent models formed the remaining explanatory variables, none of which explained black-tailed godwit abundance (**Table 3.23**). The model was highly significant (F = 52.79, P = 1.89^{-6}), explaining 76.7% of the variance of the intercept (adjusted R^2 = 0.753).

Table 3.23 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of black-tailed godwit

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI	z value	P (>|z|)
Intercept	7.493^{+4}	1.051^{+4}	52560.25, 97300.02	6.565	2.09^{16}
MDRain	-6.866^{-2}	1.643^{-1}	-0.405, 0.268	0.400	0.689
Year	-3.710^{+1}	5.254	-48.278, -25.916	6.503	<0.001

'Year' was identified as a significant explanatory variable predicting black-tailed godwit abundance. A negative relationship between black-tailed godwit abundance and year is demonstrated in **Figure 3.12**.



Red line represents line of best fit.
Blue line represents locally weighted scatterplot smoothing (LOWESS) line.
Dotted lines in the GAM model represent standard error.

Figure 3.12 Relationship between black-tailed godwit abundance over time and modelled GAM abundance over time.

3.4.7 Australasian bittern

No explanatory variables were identified that explained the variance for the abundance of Australasian bittern at the Kooragang component. The highest ranking model did not include any of the explanatory variables (**Table 3.24**).

Table 3.24 Generalised additive model (GAM) candidates predicting Australasian bittern abundance

Intercept	Explanatory variables						df	AICc	ΔAICc	W_i
	Year	MeanMaxTemp	Rainfall	MDRain	LERain	SOI				
0.74							2	76.9	0.00	0.373
0.66						√	3	78	1.02	0.224
-13.24		√					3	78.7	1.78	0.153
3.02			√				3	78.8	1.82	0.150

The models were ordered according to their correlated Akaike information criterion (AICc). The difference between each model and the most parsimonious model (ΔAICc) is used to calculate the Akaike weights (Wi). Models are ranked within each measure of species richness in ascending order according to Akaike's Information Criterion (AIC). √ indicates that a variable is included in the model; df denotes the degrees of freedom.

The next ranked models within 2 AIC units (i.e. ΔAICc ≤2) included the southern oscillation index, local rainfall and the mean maximum temperature. As the ΔAICc of the top four models is ≤2, they cannot be distinguished and are considered to be highly supported (Burnham and Anderson 2002). The subsequent models formed the remaining explanatory variables, none of which explained Australasian bittern abundance (**Table 3.25**). The highest ranked model only included the intercept. The second highest ranked model after the model contained the southern oscillation index and was identified as being non-significant (F = 1.716, P = 0.208), explaining 0.1% of the variance of the intercept (adjusted R^2 = 0.04).

Table 3.25 Model-averaged estimates, unconditional standard errors and unconditional 95% confidence intervals for the best-supported variables in models of the abundance of Australasian bittern

Predictor	Model averaged estimates	Unconditioned SE	Unconditional 95% CI (lower, upper)	z value	P (>|z|)
Intercept	7.242	59.795	-117.7, 132.2	0.114	0.910
MeanSOI	0.077	0.050	-0.05, 0.21	0.481	0.631
MeanMaxTemp	0.569	0.360	-0.68, 1.82	0.325	0.745
Rainfall	-0.024	0.016	-0.08, 0.03	0.333	0.739

4.0 Discussion and Summary

4.1 Species Diversity

Three measures of migratory shorebird species diversity (richness, Shannon's index and evenness) were used to assess relationships with a selection of potential predictor variables.

- There was a slight, albeit non-significant, relationship between spices richness and year with the number of migratory shorebird species increasing during the 2000 to 2017 period. Richness remained relatively stable during this time with minor variation (i.e. to the magnitude of one to six species).
- The Shannon's index and species evenness measures of diversity provide a more realistic indicator of changes in diversity as they account for species abundance.
  - Shannon's index and evenness of migratory shorebirds identified the amount of rainfall recorded at Lake Eyre as being a significant predictor of these variables; both showing a negative relationship.
  - Additionally, a significant negative relationship was identified for species evenness and year.
  - Both Shannon index and evenness measures recorded a drop with high levels of rainfall at Lake Eyre in 2010/2011; with an inverse observed in 2004 and 2013 where both diversity indices increased when rainfall was lowest (**Figures 4.1** and **4.2**). Migratory shorebird diversity and abundance has shown to increase at Lake Eyre during periods of inland inundation (Kingsford, Bino and Porter 2013). As many species of migratory shorebirds move from traditional coastal habitats to various inland wetlands that have formed during heavy rainfall events (Kingsford and Porter, 1993), it can be expected that the diversity of shorebird species will undergo a decline from the Kooragang component during these times.

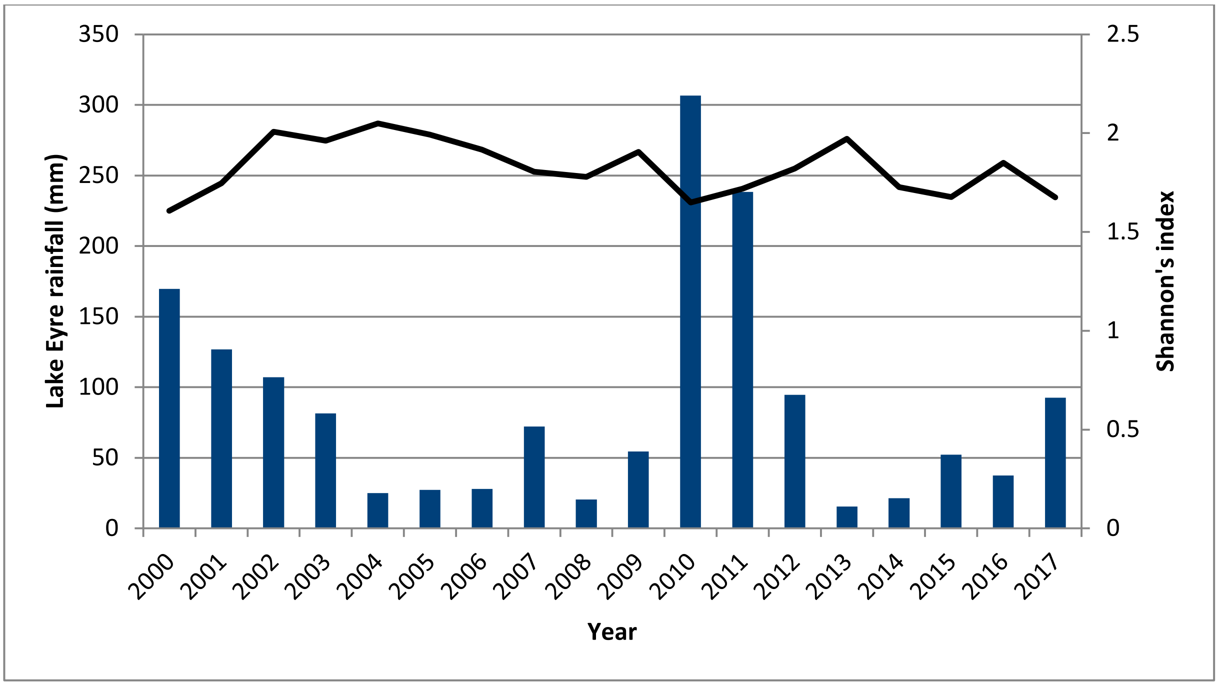


Figure 4.1 The relationship between the Shannon's index (line) of diversity for migratory shorebird species recorded at the Kooragang component of the Hunter Wetlands Estuary Ramsar site and the rainfall at Lake Eyre (bars) from 2000 to 2017

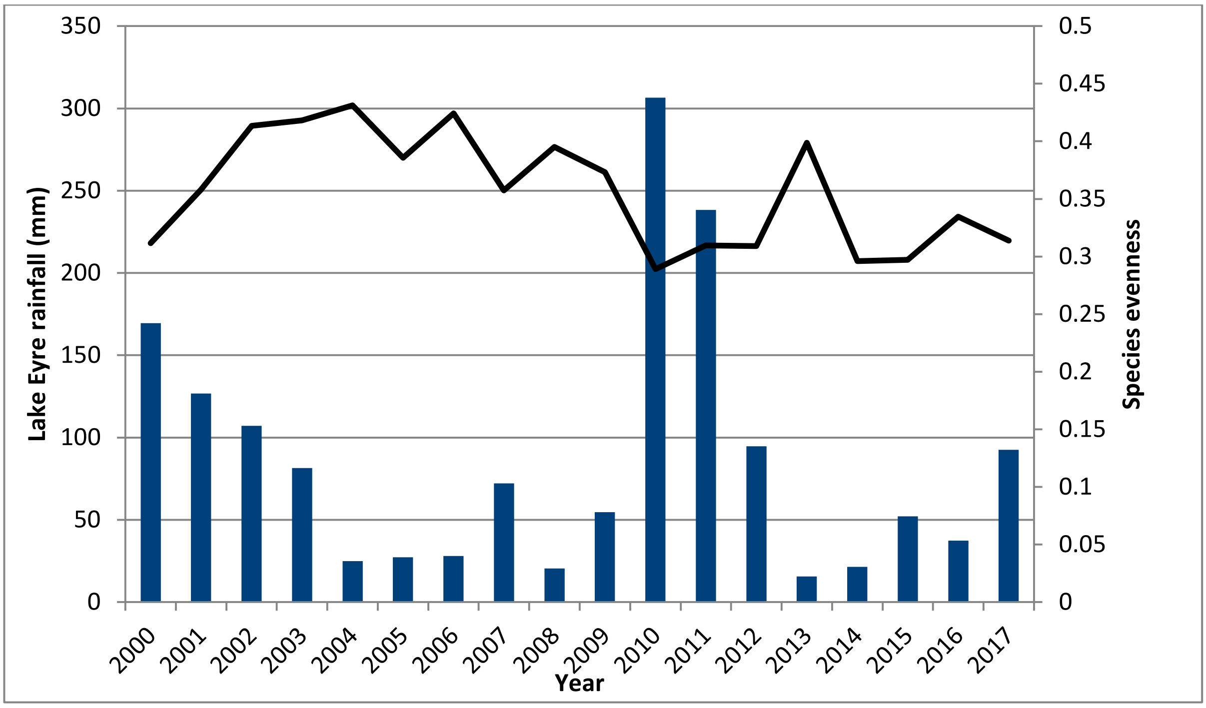


Figure 4.2 The relationship between the migratory shorebird species evenness (line) recorded at the Kooragang component of the Hunter Wetlands Estuary Ramsar site and the rainfall at Lake Eyre (bars) from 2000 to 2017

4.2 Species Abundance

Migratory shorebird summer abundance was shown to significantly decrease as southern oscillation index increased, which may be attributed to rainfall events.

The influence that the southern oscillation index has on Australian rainfall variability, prevalence and severity has been well established (Simmonds and Hope 1997; McBride and Nicholls 1983; Whitting *et al* 2003; and Power *et al* 1999; and Cai *et al* 2011). This can result in lower than average rainfall or higher than average rainfall influencing periods of flood and drought. In particular, strong peaks of positive southern oscillation index have been shown to correspond with flood periods in the Lake Eyre and Murry-darling basins (Puckridge et al 2000); flooding that is critical for the inundation of wetland habitats. The availability of inland wetlands varies considerably by the influences of stochastic rainfall and river flows (Roshier et al., 2001). When inland wetlands become available, the habitat created provide important foraging grounds for migratory shorebirds, with many species recorded moving from traditional coastal habitats to various inland wetlands that have formed due to inundation (Kingsford and Porter, 1993). It is possible that the summer abundance of migratory shorebirds at the Kooragang component follows this trend, with clear patterns associated with the southern oscillation index (**Figure 4.3**).

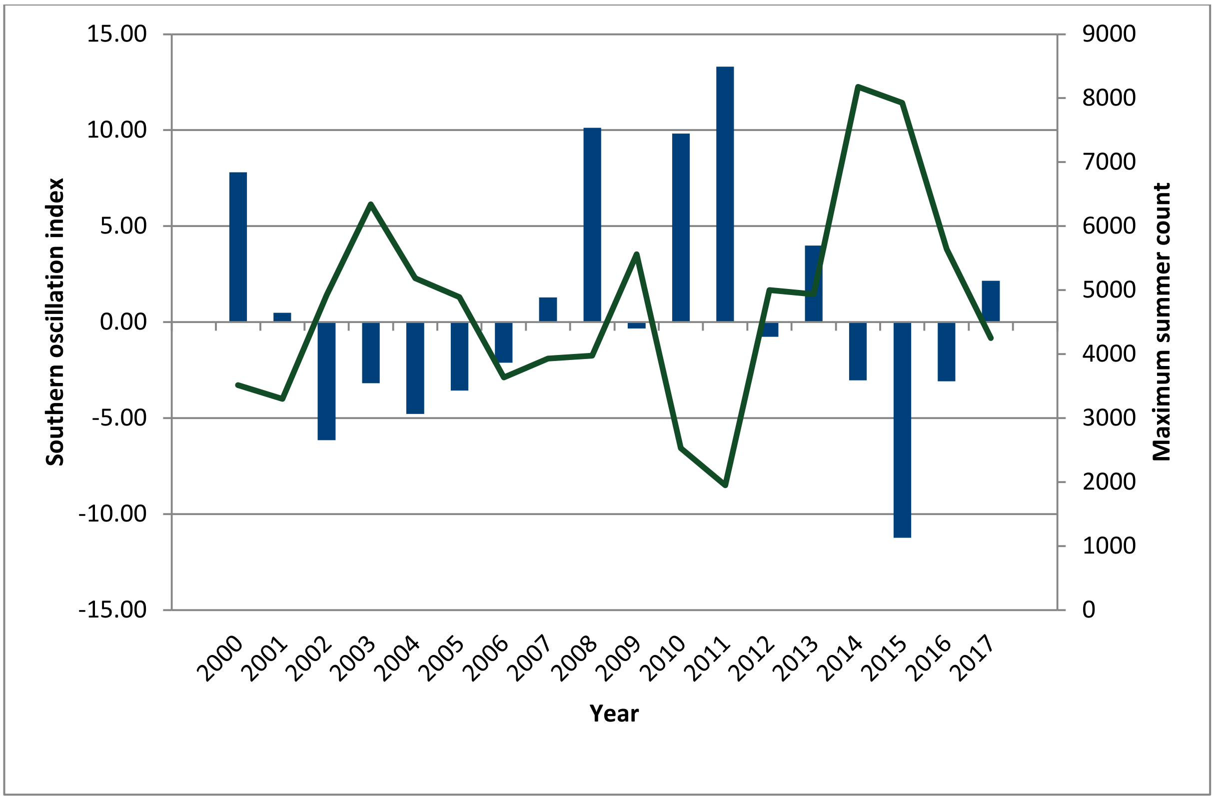


Figure 4.3 The relationship between the migratory shorebird abundance (line) recorded at the Kooragang component of the Hunter Wetlands Estuary Ramsar site and southern oscillation index (bars) from 2000 to 2017

The low abundance of shorebirds in 2010/2011 reflects large positive southern oscillation indices for those years and corresponds with a La Nińa event that broke one of the longest droughts across the Murray-Darling basin that saw significantly higher than average rainfall (BoM 2018b). This corresponded with the lowest number of migratory shorebirds recorded at the Ramsar site, being 4745 birds indicating that the birds had moved to exploit the newly created inland resources. Variations in the abundance of migratory shorebirds associated with episodic inland flooding events have been demonstrated in other coastal habitats areas. For example, declines in sharp-tailed sandpipers and banded stilts occurred at the coastal habitat at Gulf St Vincent in South Australia during 2010/2011 with birds moving to the inland Lake Torrens in response to sudden flooding events (Purnell, Peter and Clemens 2011).

In contrast, the largest number of shorebirds recorded at the site occurred over 2014/2015, which corresponded with a strong El Niño event that resulted in inland rainfall deficiencies (BoM 2015). This likely resulted in migratory shorebirds remaining at reliable coastal habitats such as the Kooragang component of the Hunter Wetlands Estuary Ramsar site.

4.3 Eastern Curlew

The eastern curlew abundance demonstrated a pattern of decline over time. In particular, these declines appear more pronounced since 2008 (**Figure 4.4**). Prior to 2008, surveys conducted from 1999 to 2007 also showed a slight decline, but numbers remained within the LAC (i.e. less than 600 birds) with regular counts of 400 to 600 individuals recorded (Herbert 2007a). At a local scale, these observed declines may be a result of local movement patterns or temporary emigrations (Warnock et al., 1995; Butler et al., 2002).

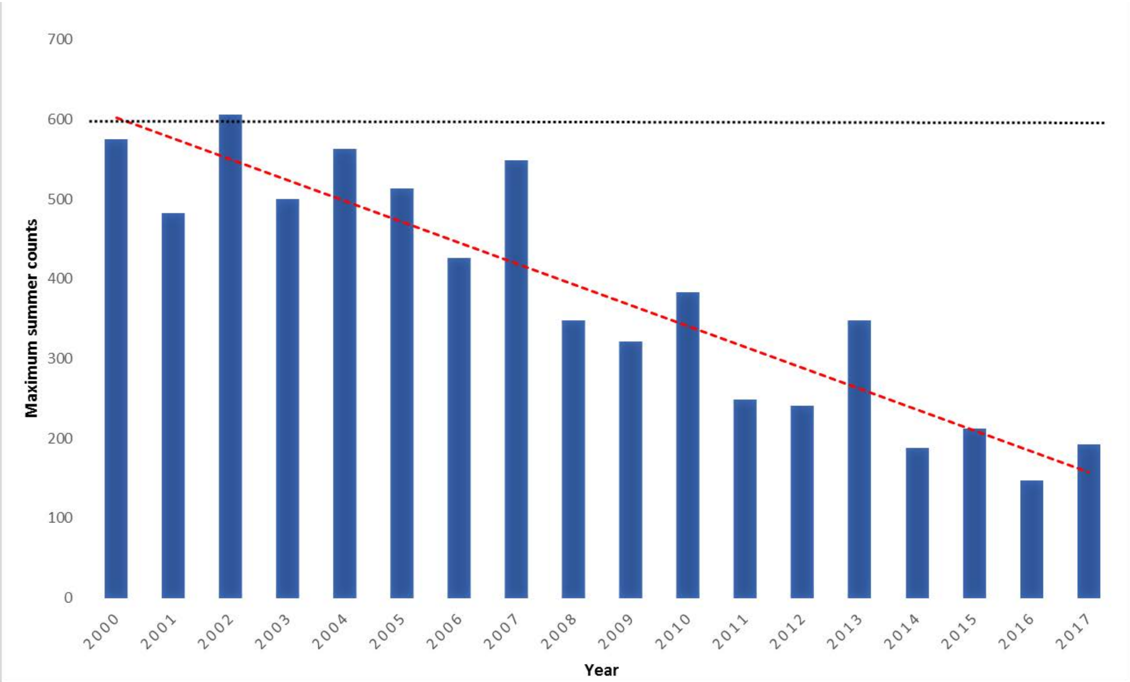


Figure 4.4 The eastern curlew abundance recorded at the Kooragang component of the Hunter Wetlands Estuary Ramsar site from 2000 to 2017. Red line represents line of best fit. Black line represents the LAC threshold of 600 birds

At a national level, localised declines in eastern curlews have been documented (Bamford et al 2008, Hansen et al., 2016; Clemens et al 2016). Globally, it is uncertain whether the results from this report are reflecting the eastern curlew abundance at a global level particularly as this species, like many migratory shorebirds, can experience impacts from factors at their overseas breeding grounds and on their migration routes, which may affect the abundances recorded at the Kooragang estuary.

4.4 Summary

The results of the migratory shorebird analyses in relation to the critical ecological components, processes and services and their limits of acceptable changes and whether these LACs have been exceeded are detailed in **Table 4.1**.

Table 4.1 Summary of the outcomes of migratory shorebird analyses relating to the Limits of Acceptable Change

Critical ecological components, processes and services	Limits of acceptable change (based on baseline and natural variability)	Evidence of LACs exceeding
Maximum number of species of migratory shorebirds recorded at site annually	No LAC has been set, however baseline migratory shorebird species richness was set at 18 species. It is not well understood what would constitute a substantial loss of diversity and the ECD recommended that this LAC be set in future. No confidence level was identified for the LAC.	Species richness from reliable survey data collected from 2000 to 2017 recorded seven years where species richness was less than 18 species. These were in 2000, 2001, 2006, 2007, 2008 and 2017. The lowest recorded species number was 15 in 2008. While year demonstrated a positive pattern of species richness over time, this was not identified as a significant predictor variable in the statistical analyses. The only significant predictor of species richness from the GAMs was the total amount of rainfall at Lake Eyre. Additional analyses using Shannon index and evenness measures that account for the abundance of shorebirds. For the Shannon index, the explanatory variables year and the total lagged summer rainfall at Lake Eyre were identified as being significant predictors for Shannon index in the GAM. For the evenness, year and the total lagged summer rainfall at Lake Eyre were identified as being significant predictors of evenness. When determining the importance of each variable in predicting the migratory shorebird species diversity variables using model-averaging, the most parsimonious models for predicting species richness included the year, mean maximum temperature, southern oscillation index and Lake Eyre rainfall, however none of these variable were significant. The most parsimonious models predicting Shannon index included the year, mean maximum temperature and Lake Eyre rainfall, with Lake Eyre rainfall being significant. Similarly, the most parsimonious models predicting evenness included the year, mean maximum temperature and Lake Eyre rainfall, with year and Lake Eyre rainfall being significant.

Critical ecological components, processes and services	Limits of acceptable change (based on baseline and natural variability)	Evidence of LACs exceeding
Abundance of migratory shorebirds recorded at the site in summer	For any five consecutive years there will be no instance of all years recording a maximum summer annual count of migratory shorebirds of less than 5000 birds. This LAC is based on the range of variability shown in the counts between 1970 and 1989 and if there is consistently less than 5000 migratory shorebirds recorded in maximum summer counts this would indicate a change in ecological character. This estimate should be reviewed as better understanding of limits of acceptable change is derived. Confidence level was low.	The annual summer abundance was less than 5000 individuals for the year 2000, 2001, 2002, 2005, 2006, 2007, 2008, 2010, 2011, 2013 and 2017. However, there was no instance for all years within any given five consecutive year period where the maximum summer annual count of migratory shorebirds was less than 5000. Therefore, the change has not exceeded the LAC. The explanatory variables year and the southern oscillation index were identified as being significant predictors for the migratory shorebird summer abundance in the GAM. When determining the importance of each variable in predicting the migratory shorebird species diversity variables using model-averaging, the most parsimonious models for predicting the migratory shorebird summer abundance included the southern oscillation index, rainfall and Lake Eyre rainfall, with the southern oscillation index being significant.
Eastern curlew	For any five year period there will be no instance of all years recording a maximum summer annual count of eastern curlew for the Hunter estuary of less than 600 birds. This estimate should be reviewed as better understanding of limits of acceptable change is derived. Confidence level was low.	According to the survey data from 2000 to 2017, the maximum summer annual counts recorded for the eastern curlew has been less than 600 birds since 2002. Since 2002, the range of maximum summer count has been 188 to 563 birds, with a mean of 346 individuals. While this analysis would indicate that the LAC for the eastern curlew has been exceeded, it is noted that there is a low level of confidence in the LAC. Further, this declining trend of the eastern curlew abundance is reported both nationally and globally (Hansen et al., 2016; Clemens et al 2016), that is the decline is not likely to be limited to local factors. Further the national decline has been recognised in the initial listing of the species as 'critically endangered' under the EPBC Act in 2015. Year and the rainfall at Lake Eyre were identified as significant predictors of eastern curlew abundance in the GAM. When determining the importance of each variable in predicting the migratory shorebird species diversity variables using model-averaging, the most parsimonious models for predicting eastern curlew abundance included the year, local rainfall and southern oscillation index, with the year being the only significant predictor.

5.0 References

Bamford M., Watkins D., Bancroft, W., Tischler, G. and Wahl, J. (2008) Migratory Shorebirds of the East Asian - Australasian Flyway; Population Estimates and Internationally Important Sites. Wetlands International - Oceania. Canberra, Australia.

Bartoń, K. 2013. MuMIn: Multi-model inferences. R package version 1.40.4. http://CRAN.R-project.org/package=MuMIn Accessed March 2018.

Butler, R.W., Shepherd, P.C.F. and Lemon, M.J.F. (2002) Site fidelity and local movements of migrating Western Sandpipers on the Fraser River estuary. Wilson Bulletin 114, 485-490.

Bureau of Meteorology (BoM). (2018a) Climate data online. http://www.bom.gov.au/climate/data/index.shtml?bookmark=200 Accessed March 2018.

Bureau of Meteorology (BoM). (2018b) Record rainfall and widespread flooding. http://www.bom.gov.au/climate/enso/history/ln-2010-12/rainfall-flooding.shtml Accessed April 2018.

Bureau of Meteorology (BoM). (2015) Rainfall deficiencies continue after drier-than-average month for much of South Australia and the east. http://www.bom.gov.au/climate/drought/archive/20150408.shtml Accessed April 2018.

Burnham, K. P. and Anderson, D. R. (2002) Model selection and multimodel inference: a practical information-theoretic approach. 2nd ed. New York, Springer-Verlag.

Brereton, R. and Taylor-Wood, E. (2010) Ecological Character Description of the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site. Report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPAC), Canberra.

Cai, W., Van Rensch, P., Cowan, T. and Hendon, H. (2011) Teleconnection Pathways of ENSO and the IOD and the mechanisms for Impacts on Australian Rainfall. Journal of Climate, 24: 3910-3923.

Clemens, R.S., Rogers, D.I., Hansen, B.D., Gosbell, K., Minton, C.D.T., Straw, P., Bamford, M., Woehler, E.J., Milton, D.A., Weston, M.A., Venables, B., Weller, D.R., Hassell, C., Rutherford, B., Onton, K., Herrod, A., Studds, C.E., Choi, C.Y., Dhanjal-Adams, K.L., Murray, N.J., Skilleter, G., and Fuller, R.A., 2016. Continental-scale decreases in shorebird populations in Australia. *Emu*. 116:119-135.

Hansen, B.D., Fuller, R.A., Watkins, D., Rogers, D.I., Clemens, R.S., Newman, M., Woehler, E.J., and Weller, D.R, 2016. Revision of the East Asian-Australasian Flyway Population Estimates for 37 listed Migratory Shorebird Species. Unpublished report for the Department of the Environment. BirdLife Australia, Melbourne.

Kingsford, R. and Porter, J. (1993) Waterbirds of Lake Eyre, Australia. Biological Conservation 65:141-151.

Kingsford, R. T., Bino, G. and Porter, J. L. (2013) Waterbirds in the Lake Eyre Basin (1983-2012) – an assessment of wetland condition at different spatial scales. Report for the Lake Eyre Basin Rivers Assessment – April 2013.

McBride, J.L. and Nicholls, N. (1983) Seasonal relationships between Australian rainfall and the southern oscillation. Monthly Weather Review 111: 1998–2004.

Power, S., Casey, T., Folland, C., Colman, A. and Mehta, V. (1999) Inter-decadal modulation of the impact of ENSO on Australia. Climate Dynamics 15: 319–324.

Puckridge, J., Walker K. F. and Costelloe J. (2000) Hydrological persistence and the ecology of dryland rivers. Regulated Rivers: Research & Management 16: 385- 402.

Purnell, C., Peter, J., Clemens, R. (2011) Shorebird Population Monitoring within the Gulf of St Vincent: July 2010 to June 2011 Annual Report. Birds Australia report for the.Adelaide and Mount Lofty Ranges Natural Resources Management Board and the Department of the Environment, Water, Heritage and the Arts.

R Core Team. (2018) R: A language and environment for statistical computing. R Foundation for statistical Computing, Vienna, Austria. https://www.R-project.org/

Roshier, D., Robertson, A., Kingsford, R. and Green, D. (2001) Continental-scale interactions with temporary resources may explain the paradox of large populations of desert waterbirds in Australia. Landscape Ecology 16:547-556.

Simmonds, I. and Hope, P. (1997) Persistence characteristics of Australian rainfall anomalies. International Journal of Climatology 17: 597–613

Toms, J.D., Schmiegelow, F.K.A., Hannon, S.J. and Villard, M.A. (2006) Are point counts of boreal songbirds reliable proxies for more intensive abundance estimators? *Auk* 123, 438–454.

Verdon, D. and Wyatt, A., (2004) Multidecadal variability of rainfall and streamflow: Eastern Australia. Water Resources Research, 40 (W10201): 1-8

Warnock, N., Page, G.W. and Stenzel, L.E. (1995) Non-migratory movements of Dunlins on their California wintering grounds. Wilson Bulletin 107, 131-139.

Whiting, J.P., Lambert, M.F. and Metcalfe, A.V. (2003) Modelling persistence in annual Australian point rainfall. Hydrology and Earth System Sciences 7(2): 197–211.

Wood, S.N. (2006) Generalized additive models: an introduction with R. Florida: Chapman and Hall/ CRC. 410 p.

Wood, S. (2018) mgcv: Mixed GAM Computation Vehicle with Automatic Smoothness Estimation and GAMs by REML/PQL. R package version 1.8-23 http://CRAN.R-project.org/package=mgcv Accessed March 2018.

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APPENDIX C

Mapped Vegetation Communities & Conservation Status

Figure C: Vegetation Communities in the Kooragang Component of the Hunter Estuary Wetlands Ramsar Site at the time of listing in 1984.

Appendix C - Vegetation Communities Mapped in Kooragang component in 1983, 2016 and their current Conservation Status

1983 Vegetation Mapping[1]		2016 Vegetation Mapping[2]		Conservation Status[3]
Dry Sclerophyll Forest				
Not mapped	-	Coastal Sand Scrub	3.45	-
Not mapped	-	Dry Sclerophyll Forest	4.97	-
Freshwater Wetlands				
Brackish Swamp	23.8	Brackish Sedgeland/Grassland	17.13	Freshwater Wetlands on Coastal Floodplains of the NSW North Coast, Sydney basin and south east corner bioregion EEC (NSW BC Act)
		Freshwater Reedland	62.66	
		Freshwater Sedgeland/Rushland	39.35	
		Freshwater Ponds	1.85	-
Forest Wetlands				
Casuarina glauca woodland	3.4	Swamp Oak Forest	76.67	Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions EEC (NSW BC Act) Coastal Swamp Oak (*Casuarina glauca*) Forest of New South Wales and South East Queensland EEC (Coastal Swamp Oak Forest) (EPBC Act)
Not mapped	-	Swamp Mahogany/Paperbark-Forest	8.08	Swamp Sclerophyll Forest on coastal floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions EEC (NSW BC Act)

1983 Vegetation Mapping[1]		2016 Vegetation Mapping[2]		Conservation Status[3]
Saline Wetlands				
Vigorous mangroves, mangroves lacking vigour	1127.9	Mangroves	1390.05	
Sarcocornia saltmarsh, *Sporobolus* saltmarsh	570.1	Saltmarsh - *Sarcocornia*	258.65	Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions EEC (NSW BC Act) Subtropical and Temperate Coastal Saltmarsh VEC (EPBC Act)
		Saltmarsh - Degraded	20.78	
Juncus saltmarsh	7.5	Saltmarsh - Saline Rushland	9.23	
Open water Bare ground	1325.9	Intertidal mudflats and shallow ponds	94.54	-
		Channels and Estuarine waters	1265.91	-
Others				
Not mapped	-	Planted Native Vegetation	0.55	-
Saline pasture, saline pasture and saltmarsh, *Sarcocornia/ Sporobolus* saltmarsh/saline pasture	233.2	Exotic vegetation	91.84	-

1. Outhred and Buckney (1983) The Vegetation of Kooragang Island, NSW;

2. Kleinfelder (2016) Lower Hunter Estuary Vegetation Mapping of Hunter Wetlands National Park

3. Conservation Status: *Biodiversity Conservation Act 2016* (BC Act) and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), EEC = Endangered Ecological Community; VEC = Vulnerable Ecological Community

APPENDIX D

Threatened Fauna Species of the Ramsar Site

Appendix D - Threatened Fauna Species at the Kooragang component of the Hunter Estuary Wetlands Ramsar Site

Scientific Name	Common Name	Conservation Status				Hunter Region (Roderick and Stuart, 2016)	
Frogs							
Litoria aurea	green and golden bell frog	E	V	-		-	-
Birds							
Botaurus poilcilptilus	Australasian bittern	E	E	-	E	Rare resident	Possibly declining with reduction in freshwater habitat at Tomago wetlands and Hexham Swamp
Burhinus grallarius	bush stone-curlew	E	-	-	LC	Uncommon resident	Population focused in Port Stephens
Calidris canutus	red knot	-	E, Mi	C, J, R	NT	Summer migrant	Numbers declining
Calidris ferruginea	**curlew sandpiper**	**E**	**CE, Mi**	**C, J, R**	**NT**	**Summer migrant**	**Declining numbers. Peak numbers approx. 50% of those recorded in 2010**
Calidris tenuirostris	great knot	V	CE, Mi	C, J, R	E	Uncommon summer migrant	For decades numbers have usually been low
Charadrius leschenaultii	greater sand-plover	V	V, Mi	C, J, R	LC	Accidental summer migrant	Recent records only 1-2 birds for (short periods) in 2012, 2013 and 2016.

Scientific Name	Common Name	Conservation Status				Hunter Region (Roderick and Stuart, 2016)	
Charadrius mongolus	**lesser sand-plover**	**V**	**E, Mi**	**C, J, R**	**LC**	**Uncommon summer migrant**	**Small numbers typically 1 to 5 birds**
Ephippoiorhynchus asiaticus	black-necked stork	E	-		NT	Rare resident	Small regional population
Epthianura albifrons	white-fronted chat	V, EP	-	-	LC	Resident	Populations at Tomago wetlands and Hexham Swamp. Both increasing.
Esacus magnirostris	beach stone-curlew	CE	-	-	NT	Rare resident	Increasing in Hunter region.
Ixobrychus flavicollis	black bittern	V	-	-	LC	Rare resident	Small regional population probably stable
Haematopus fuliginosus	sooty oystercatcher	V	-	-	LC	Resident	Non-breeding population increasing. Breeding population stable uncertain as occurs on offshore islands.
Haematopus longirostris	pied oystercatcher	E	-	-	LC	Resident	Non-breeding population increasing. Small breeding population stable.
Haliaeetus leucogaster	white-bellied sea-eagle	V	Mi	-		Resident	-
Limicola falcinellus	broad-billed sandpiper	V	Mi	C, J, R		Rare summer migrant	Several records from Hunter estuary over 2012-2014.

Scientific Name	Common Name	Conservation Status				Hunter Region (Roderick and Stuart, 2016)	
Limosa lapponica baueri	**bar-tailed godwit (baueri)**	**-**	**V, Mi**	**C, J, R**	**-**	**Common summer migrant**	**Numbers in Hunter estuary declining. Many juveniles over winter.**
Limosa limosa	**black-tailed godwit**	**V**	**Mi**	**C, J, R**	**NT**	**Summer migrant**	**Declining. Now only occurs in Hunter estuary. Numbers now 85-90% lower than in the 1970s**
Lophoictinia isura	square-tailed kite	V	-	-	LC	Uncommon resident	Most records Maitland/Cessnock or Coopernook/Harrington.
Numenius madagascariensis	**eastern curlew**	**-**	**CE, Mi**	**C, J, R**	**E**	**Common summer migrant**	**Numbers reasonably stable 2010-2013 declining since 2014.**
Pandion cristatus	eastern osprey	V	Mi	-	LC	Resident	More than 25 breeding pairs in region none in Hunter estuary.
Rostratula australis	Australian painted snipe	E	E	--	E	Rare summer migrant	Uncertain. No records since 2014 though hard to detect.
Sternula albifrons	little tern	E	Mi	C, J, R	LC	Summer migrant	Major breeding colony Manning estuary. Others at Fern Bay (Newcastle Bight), Winda Woppa and Swansea.
Stictonetta naevosa	freckled duck	V	-	-	LC	Uncommon visitor	Predominantly inland bird, Hunter region is a drought refuge
Tyto longimembris	eastern grass owl	V	-	-	LC	Rare resident	Uncertain. Occasional reports within Hunter estuary

Scientific Name	Common Name	Conservation Status				Hunter Region (Roderick and Stuart, 2016)	
Xenus cinereus	**terek sandpiper**	**V**	**Mi**	**C, J, R**	**LC**	**Uncommon summer migrant**	**Very few records outside of Hunter Estuary. Numbers declining. Peak counts fewer than 15.**
Fish							
Dasyatis fluviorum	estuary stingray	-	-	-	V	-	-
Mammals							
Chalinolobus dwyeri	large-eared pied bat	V	V	-		-	-
Falsistrellus tasmaniensis	eastern false pipistrelle	V	-	-		-	-
Miniopterus australis	little bentwing-bat	V	-	-		-	-
Miniopterus schreibersii oceanensis	eastern bentwing-bat	V	-	-		-	-
Mormopterus norfolkensis	eastern freetail-bat	V	-	-		-	-
Myotis macropus	southern myotis	V	-	-		-	-
Pteropus poliocephalus	grey-headed flying-fox	V	V	-		-	-
Saccolaimus flaviventris	yellow-bellied sheath-tail bat	V	-	-		-	
Scoteanax rueppellii	greater broad-nosed bat	V	-	-		-	-

Scientific Name	Common Name	Conservation Status	Hunter Region (Roderick and Stuart, 2016)

Bold text indicates EAAF shorebirds identified by Clemens et al (2016) as showing strong evidence of declines in numbers in Australia

Conservation status: *Biodiversity Conservation Act 2016* (BC Act), *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) where CE = Critically Endangered; E = Endangered; EP = Endangered Population; V = Vulnerable; Mi = migratory species

Treaties: Migratory Bird Listing where: C = China-Australia Migratory Bird Agreement 1988 (CAMBA); J = Japan–Australia Migratory Bird Agreement 1981 (JAMBA) and R = Republic of Korea–Australia Migratory Bird Agreement 2006 (ROKAMBA).

International Union for Conservation of Nature (IUCN): E = endangered; V = vulnerable; NT = near threatened; LC = least concern.

APPENDIX E

Critical Ecological Components, Processes and Services (CPS)

Appendix E- Summary of findings relating to the potential change in ecological character of the Kooragang Component of the Hunter Estuary Wetlands Ramsar site

Critical ecological components, processes and services	Potential impacts: pathways of chemical contamination	Current Limit Of Acceptable Changes [Confidence level]	Has Change Occurred?	Other comments
Migratory shorebirds: Number of species of migratory shorebirds recorded at site annually	Heavy metals (lead) and PFAS: Bioaccumulation through the food chain and direct toxic effects via ingestion of algae, benthic organisms and small fish In-direct impacts from poor water quality (e.g. low oxygen, algal blooms).	No limit of acceptable change has been set, however baseline migratory shorebird species richness was set at 18 species. It is not well understood what would constitute a substantial loss of diversity. [Confidence level: Not applicable]	Unknown	Species richness from reliable survey data collected from 2000 to 2017 recorded seven years where species richness was less than 18 species. These were in 2000, 2001, 2003, 2006, 2007, 2008 and 2017. The lowest recorded species number was 15 in 2008. Limit of acceptable change recommended to be set in future. This may be related to loss of guilds rather than individual species.
Migratory shorebirds: Abundance of migratory shorebirds recorded at the site in summer		For any five consecutive years there will be no instance of all years recording a maximum summer annual count of migratory shorebirds of less than 5000 birds. [Confidence level: Low]	Change does not exceed the limit of acceptable change	Both a more robust limit of acceptable change and improved monitoring protocols are needed for greater certainty and analytical capacity
Migratory shorebirds: Number of migratory shorebird roost sites		The limit of acceptable change for this critical component is linked to vegetation changes and as such an indirect limit of acceptable change is specified. See limit of acceptable change for saltmarsh.	Unknown.	Five regularly used roost sites are known for the time of listing: Stockton Sandspit (bare ground), Fern Bay, Kooragang Dykes, Fullerton Cove Beach and Windeyers Reach Nocturnal Roost (Herbert 2007a). A review of the limit of acceptable change is recommended as the current limit is linked to saltmarsh, yet roost sites in the Ramsar site also include bare ground and rocky substrate. This review should be developed in consultation with

Critical ecological components, processes and services	Potential impacts: pathways of chemical contamination	Current Limit Of Acceptable Changes [Confidence level]	Has Change Occurred?	Other comments
				HBOC and specialists and informed by further investigations into nocturnal roost sites.
Eastern curlew (critically endangered)	Heavy metals (lead) and PFAS: Bioaccumulation through the food chain and direct toxic effects via ingestion of algae, benthic organisms and small fish.	For any five year period there will be no instance of all years recording a maximum summer annual count of eastern curlew for the Hunter estuary of less than 600 birds. [Confidence level: Low]	Unknown	While analysis has identified a decline in the abundance of eastern curlew locally since 2000 to 2017 this decline is also evident nationally and globally. Accordingly, the decline is not likely to be limited to local factors. A review of the limit of acceptable change is recommended. This may include links to global numbers.
Green and golden bell frog (endangered)	Unknown. Possibly direct toxic effects associated with exposure to heavy metals and PFAS, although there is evidence of frogs existing and breeding in ponds with significant heavy metal contamination.	There are no more than two years between successful breeding events (defined as the presence of a first year adult cohort) in at least one of the three known populations. [Confidence level: Low]	Change may be occurring, but site specific data is limited and long-term breeding data within the Ramsar site is absent	Surveys are required to identify potential habitat, distribution and breeding events with a particular focus on the western end the Kooragang component. The findings of these surveys would inform a review of whether it is appropriate to include the green and golden bell frog as a critical component for the Ramsar site, and a review of the limit of acceptable change.
Saltmarsh community	Nutrients: Facilitating spread of salt tolerant weeds	The areal extent of saltmarsh does not fall below 466 ha (i.e. the areal extent at time of listing (582 ha) minus a 20% mapping error). [Confidence level: Low]	Possible that change has exceeded the limit of acceptable change, but unlikely to represent a change in ecological character. Rehabilitation works have	The areal extent of saltmarsh has been recently (2016) determined as 289 ha. This is approximately 293 ha (or 50%) less than the estimated area at the time of listing. However the majority of this loss occurred before 1994 and the decline over the last 22 years has slowed with only 50 ha lost, with this loss likely to be largely due to mangrove encroachment and a lag in the response to the installation of the flood mitigation and drainage works. While this may be due to local pressures, mangrove encroachment into saltmarsh is also a phenomenon that has been reported in Australia and globally.

Critical ecological components, processes and services	Potential impacts: pathways of chemical contamination	Current Limit Of Acceptable Changes [Confidence level]	Has Change Occurred?	Other comments
			largely addressed declines.	Further restoration projects have commenced in the Ramsar site and these are aimed at restoring saltmarsh habitat. A lag in the area of saltmarsh in the restoration area should be included in the revised limit of acceptable change.
Food webs	Refer to birds, frogs, saltmarsh and intertidal mudflats.	This critical service is linked to changes in the presence of migratory shorebirds. Therefore no direct limit of acceptable change has been developed and instead the critical service will be assessed indirectly through changes in the abundance and diversity of migratory shorebirds. See limit of acceptable change for shorebirds.	Possibly as there may be a change that is not yet evident in shorebirds. .	Research is required to better understand intertidal mudflats and the food web for invertebrates and shorebirds in the Kooragang component.
Biodiversity	Refer to birds, frogs and saltmarsh.	Migratory shorebirds, saltmarsh and the intertidal mudflats have also been identified as critical components and limit of acceptable changes have been developed for them. See limit of acceptable changes for shorebirds, saltmarsh and intertidal mudflats	See changes for shorebirds, saltmarsh and intertidal mudflats	See limit of acceptable changes for shorebirds, saltmarsh and intertidal mudflats
Threatened wetland species, habitats and ecosystems	Heavy metals (lead) and PFAS: Bioaccumulation through the food chain and direct toxic effects via ingestion of algae, benthic organisms and small fish.	The green and golden bell frog has been identified as a critical component and a limit of acceptable change has been developed for it (see above). There is no limits set for other threatened species.	Unknown	Monitoring being undertaken by BirdLife Australia into the Australasian bittern should be supported and reviewed to identify whether there has been a change in the population of the bittern. This would inform the setting of limits of acceptable change for this species as an indicator for freshwater wetland habitat and would also inform management of habitats.
Intertidal mudflats	Intertidal mud flats are likely to be affected by	As this critical component is linked to changes in the presence of migratory	Unknown	Research is required to better understand intertidal mudflats and the food web for

Critical ecological components, processes and services	Potential impacts: pathways of chemical contamination	Current Limit Of Acceptable Changes [Confidence level]	Has Change Occurred?	Other comments
	PFOS and heavy metal contamination in sediments. One study has suggested that heavy metal contamination may result in reduced diversity of in-fauna. This would in turn result in reduced food sources for waterbirds. Possible indirect effects of nutrient contamination resulting in low dissolved oxygen levels.	shorebirds, no direct limit of acceptable change has been developed. See limit of acceptable changes for migratory shorebirds abundance and diversity.		invertebrates and shorebirds in the Kooragang component.
Tidal range	None	As this critical process is linked to changes in saltmarsh coverage, no direct limit of acceptable change has been developed and instead will be assessed indirectly through changes in saltmarsh coverage. See saltmarsh limit of acceptable change.	Unknown	Research is required to better understand tidal range and contributions of change due to climate change relative to anthropogenic change. It is considered likely that changes in tidal range, associated with climate change may be the cause of the increased mangrove incursion into saltmarsh. This needs to be considered in a review of the limit of acceptable change for this critical process.
Freshwater inflow	None	As this critical process is linked to changes in saltmarsh coverage, no direct limit of acceptable change has been developed and instead will be assessed indirectly through changes in saltmarsh coverage. See saltmarsh limit of acceptable change.	Unknown	It is noted that alterations in tidal inundation are resulting in reduction in freshwater habitats in Tomago wetlands and the nearby Hexham Swamps. This is reducing habitat for the threatened Australasian bittern. This needs to be considered in planning of further restoration works and a review of the limit of acceptable change for this critical process. Further consideration of the future management of the site to make it resilient to climate change is required. This may result in changes between the

Critical ecological components, processes and services	Potential impacts: pathways of chemical contamination	Current Limit Of Acceptable Changes [Confidence level]	Has Change Occurred?	Other comments
				freshwater and saltwater balance and will influence the setting of appropriate limits of acceptable change.

Change that has occurred

As indicated by the information presented above and based on the best available scientific evidence, the Kooragang component is likely to have undergone a change in ecological character since the time of listing in 1984, with changes related to:

- the extent of saltmarsh
- the abundance of the eastern curlew (possibly).

The decline in saltmarsh was occurring prior to and at the time of listing of the Ramsar site largely due to development in the catchment, deltaic island reclamation, flood mitigation works and industrial development. Post listing the decline was most marked in the Tomago and Fullerton Cove area of the Kooragang component in response to flood mitigation works that occurred prior to listing.

Change in this critical component has been recognised and since 1993 a number of restoration projects have commenced in the Hunter estuary on Stockton Sandspit, Kooragang Island, Tomago Wetlands and Hexham Swamp under the Kooragang Wetland Rehabilitation Project (KWRP). The works on Kooragang Island, Tomago Wetlands and in Hexham Swamp are aimed at reinstate tidal inundation, restoring saltmarsh providing shorebird habitat and fish habitat largely through modifications to flood mitigation works. Confounding this is the expansion of mangroves into the saltmarsh. The decline in saltmarsh in the Kooragang component is consistent with the findings of Saintilan and Williams (1999) who found that there has been a general decline in saltmarsh in south east Australia since the 1940s. Mangrove expansion within estuaries is a near ubiquitous trend in south eastern Australia (Saintilan and Williams, 1999) attributed to a range of causes including including increases in rainfall, revegetation of areas cleared for agriculture, altered tidal regimes or estuary water levels, and increases in nutrient levels and sedimentation.

The decline in Eastern Curlew at this site is consistent national and global declines. Accordingly, the decline is not likely to be limited to local factors.

APPENDIX F

OEH Stormwater Chemistry Data

	201500667	201500668	201500669	201500670	201500671	201500672
Phenol	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
2-Chlorophenol	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
1,4-Dichlorobenzene	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
1,2-Dichlorobenzene	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
2-Methylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
3+4-Methylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Nitrobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2-Nitrophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4-Dimethylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4-Dichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
1,2,4-Trichlorobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Naphthalene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2,6-Dichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
4-Chloro-3-methylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
1,2,4,5-Tetrachlorobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4,6-Trichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4,5-Trichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Acenaphthylene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Acenaphthene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2,4-Dinitrophenol	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L
Pentachlorobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
4-Nitrophenol	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
2,4-Dinitrotoluene	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
2,3,4,6-Tetrachlorophenol	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
Fluorene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2-Methyl-4,6-dinitrophenol	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
alpha-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Hexachlorobenzene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Pentachloronitrobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Pentachlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
beta-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
gamma-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Phenanthrene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Anthracene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
delta-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Heptachlor	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Dibutyl phthalate	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L
Chlorpyrifos	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Aldrin	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Isodrin	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Heptachlor epoxide	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Fluoranthene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
gamma-Chlordane	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
alpha-Chlordane	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Endosulfan I	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
pp'-DDE	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Dieldrin	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Endrin	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
pp'-DDD	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Endosulfan II	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Endrin aldehyde	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L
Bis-2-ethyl hexyl adipate	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L
pp'-DDT	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Endosulfan sulfate	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Methoxychlor	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Bis-2-ethyl hexyl phthalate	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L
Endrin ketone	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Benzo (a) anthracene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Chrysene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (b) fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (k) fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (a) pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Perylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Indeno (123cd) pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Dibenzo (ah) anthracene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (ghi) perylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
GC/MS scan	The GC/MS scan tentatively identified the presence of the following non-target semivolatile organic compounds using the NIST 2					
Aroclor 1016 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1221 (Screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1232 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1242 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1248 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1254 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1260 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L

201500673	201500674	201500675	201500676	201500677	201500678	201500679	201500680
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L
<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L
<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L

)08 reference mass spectral library. The concentrations are estimates and calculated against internal standards (1,4-dichloroben -

<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L

Hunter Event 2 - 201500104
Sampled 20/04/15
Results are presented as Limits of Detection

Client ID	*W1*	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*	*W8*	*W9*	*W10*	*W11*	***W12***	***W13***	***W14***
Laboratory ID	*201500731*	*201500732*	*201500733*	*201500734*	*201500735*	*201500736*	*201500737*	*201500738*	*201500739*	*201500740*	*201500741*	***201500742***	***201500743***	***201500744***
Analyte														
Phenol	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
2-Chlorophenol	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
1,4-Dichlorobenzene	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
1,2-Dichlorobenzene	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
2-Methylphenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
3+4-Methylphenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Nitrobenzene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2-Nitrophenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2,4-Dimethylphenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2,4-Dichlorophenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
1,2,4-Trichlorobenzene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Naphthalene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2,6-Dichlorophenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
4-Chloro-3-methylphenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
1,2,4,5-Tetrachlorobenzene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2,4,6-Trichlorophenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2,4,5-Trichlorophenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Acenaphthylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Acenaphthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2,4-Dinitrophenol	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L
Pentachlorobenzene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
4-Nitrophenol	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L
2,4-Dinitrotoluene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2,3,4,6-Tetrachlorophenol	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Fluorene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
2-Methyl-4,6-dinitrophenol	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L	<0.0006 mg/L
alpha-BHC	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Hexachlorobenzene	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L	<0.00004 mg/L
Pentachloronitrobenzene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Pentachlorophenol	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
beta-BHC	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
gamma-BHC	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Phenanthrene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Anthracene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
delta-BHC	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Heptachlor	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Dibutyl phthalate	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Chlorpyrifos	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Aldrin	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Isodrin	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Heptachlor epoxide	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0002 mg/L**	**0.0005 mg/L**
gamma-Chlordane	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L	<0.00002 mg/L
alpha-Chlordane	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Endosulfan I	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0002 mg/L**	**0.0005 mg/L**
pp'-DDE	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
Dieldrin	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
Endrin	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
pp'-DDD	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
Endosulfan II	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Endrin aldehyde	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L	<0.0008 mg/L
Bis-2-ethyl hexyl adipate	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L	<0.0024 mg/L
pp'-DDT	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
Endosulfan sulfate	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Methoxychlor	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L	<0.00006 mg/L
Bis-2-ethyl hexyl phthalate	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L	<0.0012 mg/L
Endrin ketone	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (a) anthracene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0002 mg/L**
Chrysene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0002 mg/L**
Benzo (b) fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0002 mg/L**	**0.0005 mg/L**
Benzo (k) fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0002 mg/L**
Benzo (a) pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0001 mg/L**	**0.0003 mg/L**
Perylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0001 mg/L**
Indeno (123cd) pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0001 mg/L**	**0.0004 mg/L**
Dibenzo (ah) anthracene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (ghi) perylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	**0.0001 mg/L**	**0.0004 mg/L**
Aroclor 1016 (screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1221 (Screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1232 (screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1242 (screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1248 (screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1254 (screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1260 (screen)	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L	<0.00008 mg/L
Non-target compounds (estimated concentrations)														
2-(2-ethoxyethoxy)-ethanol	ND	0.5 µg/L	ND	0.9 µg/L	0.8 µg/L	0.7 µg/L	0.8 µg/L	ND	0.6 µg/L	0.5 µg/L	0.9 µg/L	0.9 µg/L	0.8 µg/L	0.8 µg/L
1-methyl-2-pyrrolidinone	ND	0.8 µg/L	ND	0.7 µg/L	0.6 µg/L	0.7 µg/L	0.7 µg/L	0.5 µg/L	0.7 µg/L	ND	0.7 µg/L	0.7 µg/L	0.8 µg/L	ND
Hexadecane	ND	0.9 µg/L	0.8 µg/L	ND	ND	0.8 µg/L	0.5 µg/L	ND	0.9 µg/L	ND	ND	0.6 µg/L	ND	ND
Octadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.7 µg/L
7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	ND	0.5 µg/L	ND	ND	ND	ND	ND	ND	ND	0.4 µg/L	ND	ND	ND	ND
Hexanoic acid	ND	7.7 µg/L	23 µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptanoic acid	ND	ND	0.7 µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Octanoic acid	ND	ND	0.6 µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzeneacetic acid	ND	ND	1.5 µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzenepropanoic acid	ND	ND	2.3 µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexadecanoic acid	ND	ND	8.4 µg/L	8.2 µg/L	ND	ND	ND	8.8 µg/L	ND	ND	ND	ND	ND	ND
Octadecanoic acid	1.3 µg/L	7.3 µg/L	8.2 µg/L	8.0 µg/L	1.2 µg/L	1.4 µg/L	0.9 µg/L	8.0 µg/L	0.8 µg/L	0.4 µg/L	0.5 µg/L	0.3 µg/L	2.7 µg/L	4.7 µg/L
Squalene	ND	ND	11 µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Eicosane	ND	ND	ND	ND	ND	ND	ND	0.4 µg/L	ND	ND	ND	ND	ND	0.8 µg/L
Tetracosane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.5 µg/L
Pentacosane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.0 µg/L

	201500731	201500732	201500733	201500734	201500735	201500736	201500737	201500738	201500739	201500740	201500741	201500742	201500743	201500744
Phenol	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
2-Chlorophenol	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
1,4-Dichlorobenzene	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
1,2-Dichlorobenzene	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
2-Methylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
3+4-Methylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Nitrobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2-Nitrophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4-Dimethylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4-Dichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
1,2,4-Trichlorobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Naphthalene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2,6-Dichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
4-Chloro-3-methylphenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
1,2,4,5-Tetrachlorobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4,6-Trichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
2,4,5-Trichlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Acenaphthylene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Acenaphthene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2,4-Dinitrophenol	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L
Pentachlorobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
4-Nitrophenol	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
2,4-Dinitrotoluene	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
2,3,4,6-Tetrachlorophenol	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
Fluorene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
2-Methyl-4,6-dinitrophenol	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
alpha-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Hexachlorobenzene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Pentachloronitrobenzene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Pentachlorophenol	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
beta-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
gamma-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Phenanthrene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
Anthracene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L
delta-BHC	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Heptachlor	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Dibutyl phthalate	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L	<0.002 mg/L
Chlorpyrifos	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Aldrin	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Isodrin	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Heptachlor epoxide	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Fluoranthene	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	0.0005 mg/L
gamma-Chlordane	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
alpha-Chlordane	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Endosulfan I	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0002 mg/L	0.0005 mg/L
pp'-DDE	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Dieldrin	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Endrin	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
pp'-DDD	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Endosulfan II	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Endrin aldehyde	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L	<0.004 mg/L
Bis-2-ethyl hexyl adipate	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L	<0.012 mg/L
pp'-DDT	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L
Endosulfan sulfate	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Methoxychlor	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L	<0.0003 mg/L

Bis-2-ethyl hexyl phthalate	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L	<0.006 mg/L
Endrin ketone	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L	<0.0005 mg/L
Benzo (a) anthracene	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	<0.0002 mg/L	0.0002 mg/L
Chrysene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0002 mg/L
Benzo (b) fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0002 mg/L	0.0005 mg/L
Benzo (k) fluoranthene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0002 mg/L
Benzo (a) pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0001 mg/L	0.0003 mg/L
Perylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0001 mg/L
Indeno (123cd) pyrene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0001 mg/L	0.0004 mg/L
Dibenzo (ah) anthracene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L
Benzo (ghi) perylene	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	<0.0001 mg/L	0.0001 mg/L	0.0004 mg/L
Aroclor 1016 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1221 (Screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1232 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1242 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1248 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1254 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L
Aroclor 1260 (screen)	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L	<0.0004 mg/L

Hunter Event 3 - 201500176
Sampled 17/06/15
Results are presented as Limits of Detection

Client ID	*W13*	*W14*
Laboratory ID	*201501205*	*201501206*
Analyte		
Phenol	<0.00006 mg/L	<0.00006 mg/L
2-Chlorophenol	<0.00006 mg/L	<0.00006 mg/L
1,4-Dichlorobenzene	<0.00006 mg/L	<0.00006 mg/L
1,2-Dichlorobenzene	<0.00006 mg/L	<0.00006 mg/L
2-Methylphenol	<0.0001 mg/L	<0.0001 mg/L
3+4-Methylphenol	<0.0001 mg/L	<0.0001 mg/L
Nitrobenzene	<0.0001 mg/L	<0.0001 mg/L
2-Nitrophenol	<0.0001 mg/L	<0.0001 mg/L
2,4-Dimethylphenol	<0.0001 mg/L	<0.0001 mg/L
2,4-Dichlorophenol	<0.0001 mg/L	<0.0001 mg/L
1,2,4-Trichlorobenzene	<0.0001 mg/L	<0.0001 mg/L
Naphthalene	<0.0001 mg/L	<0.0001 mg/L
2,6-Dichlorophenol	<0.0001 mg/L	<0.0001 mg/L
4-Chloro-3-methylphenol	<0.0001 mg/L	<0.0001 mg/L
1,2,4,5-Tetrachlorobenzene	<0.0001 mg/L	<0.0001 mg/L
2,4,6-Trichlorophenol	<0.0001 mg/L	<0.0001 mg/L
2,4,5-Trichlorophenol	<0.0001 mg/L	<0.0001 mg/L
Acenaphthylene	<0.0001 mg/L	<0.0001 mg/L
Acenaphthene	<0.0001 mg/L	<0.0001 mg/L
2,4-Dinitrophenol	<0.004 mg/L	<0.004 mg/L
Pentachlorobenzene	<0.0001 mg/L	<0.0001 mg/L
4-Nitrophenol	<0.0006 mg/L	<0.0006 mg/L
2,4-Dinitrotoluene	<0.0002 mg/L	<0.0002 mg/L
2,3,4,6-Tetrachlorophenol	<0.0002 mg/L	<0.0002 mg/L
Fluorene	<0.0001 mg/L	<0.0001 mg/L
2-Methyl-4,6-dinitrophenol	<0.0006 mg/L	<0.0006 mg/L
alpha-BHC	<0.0001 mg/L	<0.0001 mg/L
Hexachlorobenzene	<0.00004 mg/L	<0.00004 mg/L
Pentachloronitrobenzene	<0.0001 mg/L	<0.0001 mg/L
Pentachlorophenol	<0.0001 mg/L	<0.0001 mg/L
beta-BHC	<0.0001 mg/L	<0.0001 mg/L
gamma-BHC	<0.0001 mg/L	<0.0001 mg/L
Phenanthrene	<0.0002 mg/L	<0.0002 mg/L
Anthracene	<0.0002 mg/L	<0.0002 mg/L
delta-BHC	<0.0001 mg/L	<0.0001 mg/L
Heptachlor	<0.0001 mg/L	<0.0001 mg/L
Dibutyl phthalate	<0.0004 mg/L	<0.0004 mg/L
Chlorpyrifos	<0.0001 mg/L	<0.0001 mg/L
Aldrin	<0.0001 mg/L	<0.0001 mg/L
Isodrin	<0.0001 mg/L	<0.0001 mg/L
Heptachlor epoxide	<0.0001 mg/L	<0.0001 mg/L
Fluoranthene	**0.0001 mg/L**	**0.0004 mg/L**
gamma-Chlordane	<0.00002 mg/L	<0.00002 mg/L
alpha-Chlordane	<0.0001 mg/L	<0.0001 mg/L
Endosulfan I	<0.0001 mg/L	<0.0001 mg/L
Pyrene	**0.0001 mg/L**	**0.0004 mg/L**
pp'-DDE	<0.00006 mg/L	<0.00006 mg/L
Dieldrin	<0.00006 mg/L	<0.00006 mg/L
Endrin	<0.0001 mg/L	<0.0001 mg/L
pp'-DDD	<0.00006 mg/L	<0.00006 mg/L
Endosulfan II	<0.0001 mg/L	<0.0001 mg/L
Endrin aldehyde	<0.0008 mg/L	<0.0008 mg/L
Bis-2-ethyl hexyl adipate	<0.0024 mg/L	<0.0024 mg/L
pp'-DDT	<0.00006 mg/L	<0.00006 mg/L
Endosulfan sulfate	<0.0001 mg/L	<0.0001 mg/L
Methoxychlor	<0.00006 mg/L	<0.00006 mg/L
Bis-2-ethyl hexyl phthalate	<0.0012 mg/L	**0.0018 mg/L**
Endrin ketone	<0.0001 mg/L	<0.0001 mg/L
Benzo (a) anthracene	<0.0001 mg/L	**0.0002 mg/L**
Chrysene	<0.0001 mg/L	**0.0002 mg/L**
Benzo (b) fluoranthene	<0.0001 mg/L	**0.0003 mg/L**
Benzo (k) fluoranthene	<0.0001 mg/L	**0.0001 mg/L**
Benzo (a) pyrene	<0.0001 mg/L	**0.0003 mg/L**
Perylene	<0.0001 mg/L	**0.0001 mg/L**
Indeno (123cd) pyrene	<0.0001 mg/L	**0.0003 mg/L**
Dibenzo (ah) anthracene	<0.0001 mg/L	<0.0001 mg/L
Benzo (ghi) perylene	<0.0001 mg/L	**0.0003 mg/L**
Aroclor 1016 (screen)	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1221 (Screen)	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1232 (screen)	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1242 (screen)	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1248 (screen)	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1254 (screen)	<0.00008 mg/L	<0.00008 mg/L
Aroclor 1260 (screen)	<0.00008 mg/L	<0.00008 mg/L
Non-target compounds (estimated concentrations)		
Hexadecane	1.3 µg/L	1.1 µg/L

	201501205	201501206
Phenol	<0.0006 mg/L	<0.0006 mg/L
2-Chlorophenol	<0.0006 mg/L	<0.0006 mg/L
1,4-Dichlorobenzene	<0.0006 mg/L	<0.0006 mg/L
1,2-Dichlorobenzene	<0.0006 mg/L	<0.0006 mg/L
2-Methylphenol	<0.001 mg/L	<0.001 mg/L
3+4-Methylphenol	<0.001 mg/L	<0.001 mg/L
Nitrobenzene	<0.001 mg/L	<0.001 mg/L
2-Nitrophenol	<0.001 mg/L	<0.001 mg/L
2,4-Dimethylphenol	<0.001 mg/L	<0.001 mg/L
2,4-Dichlorophenol	<0.001 mg/L	<0.001 mg/L
1,2,4-Trichlorobenzene	<0.001 mg/L	<0.001 mg/L
Naphthalene	<0.0004 mg/L	<0.0004 mg/L
2,6-Dichlorophenol	<0.001 mg/L	<0.001 mg/L
4-Chloro-3-methylphenol	<0.001 mg/L	<0.001 mg/L
1,2,4,5-Tetrachlorobenzene	<0.001 mg/L	<0.001 mg/L
2,4,6-Trichlorophenol	<0.001 mg/L	<0.001 mg/L
2,4,5-Trichlorophenol	<0.001 mg/L	<0.001 mg/L
Acenaphthylene	<0.0004 mg/L	<0.0004 mg/L
Acenaphthene	<0.0004 mg/L	<0.0004 mg/L
2,4-Dinitrophenol	<0.04 mg/L	<0.04 mg/L
Pentachlorobenzene	<0.001 mg/L	<0.001 mg/L
4-Nitrophenol	<0.006 mg/L	<0.006 mg/L
2,4-Dinitrotoluene	<0.002 mg/L	<0.002 mg/L
2,3,4,6-Tetrachlorophenol	<0.002 mg/L	<0.002 mg/L
Fluorene	<0.0004 mg/L	<0.0004 mg/L
2-Methyl-4,6-dinitrophenol	<0.006 mg/L	<0.006 mg/L
alpha-BHC	<0.001 mg/L	<0.001 mg/L
Hexachlorobenzene	<0.0004 mg/L	<0.0004 mg/L
Pentachloronitrobenzene	<0.001 mg/L	<0.001 mg/L
Pentachlorophenol	<0.001 mg/L	<0.001 mg/L
beta-BHC	<0.001 mg/L	<0.001 mg/L
gamma-BHC	<0.001 mg/L	<0.001 mg/L
Phenanthrene	<0.0004 mg/L	<0.0004 mg/L
Anthracene	<0.0004 mg/L	<0.0004 mg/L
delta-BHC	<0.001 mg/L	<0.001 mg/L
Heptachlor	<0.001 mg/L	<0.001 mg/L
Dibutyl phthalate	<0.004 mg/L	<0.004 mg/L
Chlorpyrifos	<0.001 mg/L	<0.001 mg/L
Aldrin	<0.001 mg/L	<0.001 mg/L
Isodrin	<0.001 mg/L	<0.001 mg/L
Heptachlor epoxide	<0.001 mg/L	<0.001 mg/L
Fluoranthene	<0.001 mg/L	<0.001 mg/L
gamma-Chlordane	<0.0002 mg/L	<0.0002 mg/L
alpha-Chlordane	<0.001 mg/L	<0.001 mg/L
Endosulfan I	<0.001 mg/L	<0.001 mg/L
Pyrene	<0.0002 mg/L	0.0004 mg/L
pp'-DDE	<0.0006 mg/L	<0.0006 mg/L
Dieldrin	<0.0006 mg/L	<0.0006 mg/L
Endrin	<0.001 mg/L	<0.001 mg/L
pp'-DDD	<0.0006 mg/L	<0.0006 mg/L
Endosulfan II	<0.001 mg/L	<0.001 mg/L
Endrin aldehyde	<0.007 mg/L	<0.007 mg/L
Bis-2-ethyl hexyl adipate	<0.024 mg/L	<0.024 mg/L
pp'-DDT	<0.0006 mg/L	<0.0006 mg/L
Endosulfan sulfate	<0.001 mg/L	<0.001 mg/L
Methoxychlor	<0.0006 mg/L	<0.0006 mg/L
Bis-2-ethyl hexyl phthalate	<0.012 mg/L	<0.012 mg/L
Endrin ketone	<0.001 mg/L	<0.001 mg/L
Benzo (a) anthracene	<0.0004 mg/L	<0.0004 mg/L
Chrysene	<0.0002 mg/L	<0.0002 mg/L
Benzo (b) fluoranthene	<0.0002 mg/L	0.0003 mg/L
Benzo (k) fluoranthene	<0.0002 mg/L	<0.0002 mg/L
Benzo (a) pyrene	<0.0002 mg/L	0.0003 mg/L
Perylene	<0.0002 mg/L	<0.0002 mg/L
Indeno (123cd) pyrene	<0.0002 mg/L	0.0003 mg/L
Dibenzo (ah) anthracene	<0.0002 mg/L	<0.0002 mg/L
Benzo (ghi) perylene	<0.0002 mg/L	0.0003 mg/L
Aroclor 1016 (screen)	<0.0008 mg/L	<0.0008 mg/L
Aroclor 1221 (Screen)	<0.0008 mg/L	<0.0008 mg/L
Aroclor 1232 (screen)	<0.0008 mg/L	<0.0008 mg/L
Aroclor 1242 (screen)	<0.0008 mg/L	<0.0008 mg/L
Aroclor 1248 (screen)	<0.0008 mg/L	<0.0008 mg/L
Aroclor 1254 (screen)	<0.0008 mg/L	<0.0008 mg/L
Aroclor 1260 (screen)	<0.0008 mg/L	<0.0008 mg/L

UNIVERSITY OF CANBERRA
ECOCHEMISTRY LABORATORY

SaltWater samples

Sample as received **9th April 2015** **From:- Rebecca Swanson** **NSW Office of Environment and Heritage**

Majors and Trace elements

Sample No	Total	Lab No.	Li ug/L	Be ug/L	B ug/L	Na ug/L	Mg ug/L	Al ug/L	Si ug/L	P ug/L	K ug/L	Ca ug/L	Ti ug/L	V ug/L	Cr ug/L	Fe ug/L	Mn ug/L	Co ug/L	Ni ug/L
W1	digested	C150184	192	1	3169	8192757	995751	241	720	164	301159	265492	101	<0.1	1	<0.1	12	1	20
W2		C150185	197	1	3288	8527250	1019661	471	1123	189	310878	276799	121	<0.1	1	341	21	1	19
W3		C150186	192	1	3216	8369948	1003320	508	1122	177	311367	271538	120	1	1	266	20	1	18
W4		C150187	187	1	3054	7900550	942771	940	2071	186	285981	254790	175	2	2	888	33	2	19
W6		C150188	118	1	2080	4455912	507467	727	1938	182	168426	139855	98	5	2	754	100	1	12
W7		C150189	146	1	2333	5524662	668215	626	2084	205	203821	182100	100	7	2	915	45	1	16
W8		C150190	142	1	2707	5227680	624620	534	2800	178	187521	219043	104	5	3	319	64	1	16
W9		C150191	174	1	2824	6851363	824192	1325	2905	237	248061	221828	154	5	4	1497	76	2	19
W10		C150192	204	1	3421	8477506	1012683	385	849	183	301600	268961	126	1	2	199	14	1	22
W11		C150193	217	1	3462	9028964	1082908	384	898	187	324094	293561	155	3	2	314	14	1	21
W13		C150194	155	1	2543	5753082	684578	430	2544	198	203271	189266	100	7	2	308	59	1	15
W12		C150195	194	1	3085	7597848	907235	313	1141	187	273550	245767	122	3	2	51	18	1	19
W14		C150196	104	1	1565	3216700	390505	571	4493	193	117742	113151	69	4	2	377	87	1	10
Unfiltered blank		C150197	36	1	51	8197	528	278	178	132	233	211	8	<0.1	<0.1	8	1	<0.1	<0.1
W1	Dissolved	C150198	202	1	2934	7644943	897810	115	552	<10.0	284360	246218	80	<0.1	2	<0.1	6	<0.1	13
W2		C150199	204	1	2976	7782896	931560	118	552	<10.0	293666	252416	86	<0.1	2	<0.1	6	<0.1	13
W3		C150200	204	1	2934	7675249	909099	117	647	<10.0	288438	250641	87	1	2	<0.1	9	<0.1	13
W4		C150201	200	1	2899	7186733	862749	119	746	<10.0	272788	239540	87	4	2	<0.1	11	<0.1	13
W5		C150202	182	1	2625	6267448	747919	127	1052	<10.0	233920	202891	82	4	2	<0.1	11	<0.1	11
W6		C150203	126	1	2015	3907374	447221	120	1110	<10.0	152987	123517	51	4	1	<0.1	83	<0.1	7
W7		C150204	158	1	2305	4970312	594151	125	1420	<10.0	182316	165036	66	4	1	<0.1	24	<0.1	10
W8		C150205	153	1	2619	4619822	557219	125	2386	<10.0	175483	199919	74	4	2	<0.1	48	<0.1	10
W9		C150206	186	1	2694	6132385	753369	122	1115	<10.0	235078	205805	74	2	2	<0.1	10	<0.1	11
W10		C150207	218	1	3142	7814946	951821	122	506	<10.0	299832	264465	105	1	2	<0.1	6	<0.1	14
W11		C150208	218	1	3141	7769788	944298	122	516	<10.0	294226	260088	107	3	2	<0.1	6	<0.1	14
W13		C150209	168	1	2436	5320982	640584	135	2142	<10.0	197588	179002	76	6	1	<0.1	53	<0.1	10
W12		C150210	198	1	2917	6856868	825205	125	888	<10.0	257133	231191	88	5	2	<0.1	13	<0.1	13
W14		C150211	110	1	1505	2936241	354204	162	3822	<10.0	109840	103651	46	4	1	<0.1	79	<0.1	5
Filtered blank		C150212	34	1	50	270	36	178	90	<10.0	6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Cu ug/L	Zn ug/L	Ga ug/L	Ge ug/L	As ug/L	Se ug/L	Rb ug/L	Sr ug/L	Zr ug/L	Nb ug/L	Mo ug/L	Ru ug/L	Ag ug/L	Pd ug/L	Cd ug/L	Sn ug/L	Sb ug/L	Te ug/L	Cs ug/L	Ba ug/L	La ug/L	Ce ug/L	Pr ug/L	Nd ug/L	Sm ug/L
63	73	0	<0.1	<0.1	<0.1	77	4719	<0.1	<0.1	7	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7	<0.1	<0.1	<0.1	<0.1	<0.1
66	78	1	<0.1	<0.1	<0.1	81	4903	<0.1	<0.1	8	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7	<0.1	0	<0.1	0	<0.1
65	69	1	<0.1	<0.1	<0.1	79	4766	<0.1	<0.1	6	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8	<0.1	0	<0.1	0	<0.1
64	68	1	<0.1	<0.1	<0.1	77	4628	<0.1	<0.1	8	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10	1	1	<0.1	1	<0.1
42	45	1	<0.1	<0.1	<0.1	47	2636	<0.1	<0.1	3	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11	0	0	<0.1	0	<0.1
54	63	1	<0.1	<0.1	<0.1	57	3406	<0.1	<0.1	4	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	17	0	1	<0.1	0	<0.1
47	102	1	<0.1	1	<0.1	57	3198	<0.1	<0.1	4	0	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	17	<0.1	0	<0.1	<0.1	<0.1
61	82	1	<0.1	2	<0.1	69	4128	<0.1	<0.1	5	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	13	1	2	<0.1	1	<0.1
74	81	1	<0.1	1	<0.1	84	4905	<0.1	<0.1	8	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6	<0.1	<0.1	<0.1	<0.1	<0.1
76	79	1	<0.1	2	<0.1	87	5225	<0.1	<0.1	8	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7	<0.1	<0.1	<0.1	<0.1	<0.1
57	76	1	<0.1	2	<0.1	61	3511	<0.1	<0.1	4	0	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	17	<0.1	0	<0.1	<0.1	<0.1
68	69	1	<0.1	2	<0.1	75	4453	<0.1	<0.1	6	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10	<0.1	<0.1	<0.1	<0.1	<0.1
37	71	1	<0.1	1	<0.1	36	2087	<0.1	<0.1	0	0	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	28	<0.1	0	<0.1	0	<0.1
1	7	0	0	<0.1	<0.1	<0.1	4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
59	68	<0.1	<0.1	<0.1	<0.1	80	4613	<0.1	<0.1	9	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8	<0.1	<0.1	<0.1	<0.1	<0.1
63	78	<0.1	<0.1	<0.1	<0.1	81	4641	<0.1	<0.1	9	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8	<0.1	<0.1	<0.1	<0.1	<0.1
63	69	<0.1	<0.1	<0.1	<0.1	80	4492	<0.1	<0.1	8	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	9	<0.1	<0.1	<0.1	<0.1	<0.1
62	66	<0.1	<0.1	1	<0.1	78	4325	<0.1	<0.1	9	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10	<0.1	<0.1	<0.1	<0.1	<0.1
55	58	<0.1	<0.1	1	<0.1	68	3802	<0.1	<0.1	6	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	13	<0.1	<0.1	<0.1	<0.1	<0.1
37	38	<0.1	<0.1	<0.1	<0.1	45	2397	<0.1	<0.1	3	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11	<0.1	<0.1	<0.1	<0.1	<0.1
46	52	<0.1	<0.1	0	<0.1	57	3184	<0.1	<0.1	5	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	17	<0.1	<0.1	<0.1	<0.1	<0.1
42	83	<0.1	<0.1	1	<0.1	56	2955	<0.1	<0.1	5	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	17	<0.1	<0.1	<0.1	<0.1	<0.1
55	59	<0.1	<0.1	1	<0.1	69	3810	<0.1	<0.1	7	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	12	<0.1	<0.1	<0.1	<0.1	<0.1
68	72	<0.1	<0.1	0	<0.1	85	4697	<0.1	<0.1	9	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7	<0.1	<0.1	<0.1	<0.1	<0.1
69	73	<0.1	<0.1	0	<0.1	84	4616	<0.1	<0.1	9	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8	<0.1	<0.1	<0.1	<0.1	<0.1
49	57	<0.1	<0.1	2	<0.1	60	3283	<0.1	<0.1	5	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	17	<0.1	<0.1	<0.1	<0.1	<0.1
63	66	<0.1	<0.1	1	<0.1	75	4058	<0.1	<0.1	7	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11	<0.1	<0.1	<0.1	<0.1	<0.1
29	48	<0.1	<0.1	1	<0.1	34	1901	<0.1	<0.1	1	0	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	28	<0.1	<0.1	<0.1	0	<0.1
<0.1	4	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Eu ug/L	Gd ug/L	Dy ug/L	Er ug/L	Tm ug/L	Yb ug/L	Lu ug/L	Hf ug/L	Ta ug/L	Re ug/L	Ir ug/L	Pt ug/L	Au ug/L	Hg ug/L	Tl ug/L	Tl ug/L	Pb ug/L	Bi ug/L	Th ug/L	U ug/L
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

ANZECC guidelines	protection of marine ecosystem	CrVI		Mn			Cu	Zn	As III	Se		Cd		Hg	Pb
	99%	0.14		80*			0.3	7	ID	ID		0.7		0.1	2.2
	95%	4.4		80*			1.3	15	ID	ID		5.5		0.4	4.4
	90%	6.6		80*			3	23	ID	ID		14		0.7	6.6
	80%	12		80*			8	43	ID	ID		36		1.4	12
Sample No		**Cr ug/L**	**Fe ug/L**	**Mn ug/L**	**Co ug/L**	**Ni ug/L**	**Cu ug/L**	**Zn ug/L**	**As ug/L**	**Se ug/L**	**Ag ug/L**	**Cd ug/L**	**Sn ug/L**	**Hg ug/L**	**Pb ug/L**
W1	**Total digested**	1	<0.1	11	1	20	**62**	**66**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W2		1	333	20	1	19	**65**	**71**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W3		1	258	19	1	18	**64**	**62**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W4		2	880	32	2	19	**63**	**61**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W6		2	746	**99**	1	12	**41**	**38**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W7		2	907	44	1	16	**53**	**56**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W8		3	311	63	1	16	**46**	**95**	1	<0.1	<0.1	<0.1	<0.1	<0.1	1
W9		4	1489	75	2	19	**60**	**75**	2	<0.1	<0.1	<0.1	<0.1	<0.1	1
W10		2	191	13	1	22	**73**	**74**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W11		2	306	13	1	21	**75**	**72**	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W13		2	300	58	1	15	**56**	**69**	2	<0.1	<0.1	<0.1	<0.1	<0.1	1
W12		2	43	17	1	19	**67**	**62**	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W14		2	369	**86**	1	10	**36**	**64**	1	<0.1	<0.1	<0.1	<0.1	<0.1	0
W1	**Dissolved**	2	<0.1	6	<0.1	13	**59**	**64**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W2		2	<0.1	6	<0.1	13	**63**	**74**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W3		2	<0.1	9	<0.1	13	**63**	**65**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W4		2	<0.1	11	<0.1	13	**62**	**62**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W5		2	<0.1	11	<0.1	11	**55**	**54**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W6		1	<0.1	**83**	<0.1	7	**37**	**34**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W7		1	<0.1	24	<0.1	10	**46**	**48**	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W8		2	<0.1	48	<0.1	10	**42**	**79**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W9		2	<0.1	10	<0.1	11	**55**	**55**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W10		2	<0.1	6	<0.1	14	**68**	**68**	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W11		2	<0.1	6	<0.1	14	**69**	**69**	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W13		1	<0.1	53	<0.1	10	**49**	**53**	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W12		2	<0.1	13	<0.1	13	**63**	**62**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W14		1	<0.1	**79**	<0.1	5	**29**	**44**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W1	**% Diss of total**	267	NA	54	NA	67	95	97	NA	NA	NA	NA	NA	NA	NA
W2		147	NA	30	NA	69	97	103	NA	NA	NA	NA	NA	NA	NA
W3		149	NA	47	NA	73	98	105	NA	NA	NA	NA	NA	NA	NA
W4		85	NA	33	NA	66	97	102	NA	NA	NA	NA	NA	NA	NA
W6		71	NA	84	NA	56	89	90	NA	NA	NA	NA	NA	NA	NA
W7		79	NA	54	NA	62	86	85	NA	NA	NA	NA	NA	NA	NA
W8		70	NA	76	NA	62	91	83	91	NA	NA	NA	NA	NA	NA
W9		51	NA	13	NA	60	92	74	49	NA	NA	NA	NA	NA	NA
W10		105	NA	49	NA	65	94	91	92	NA	NA	NA	NA	NA	NA
W11		105	NA	45	NA	66	92	95	2	NA	NA	NA	NA	NA	NA
W13		79	NA	91	NA	69	88	77	81	NA	NA	NA	NA	NA	NA
W12		103	NA	73	NA	66	95	99	34	NA	NA	NA	NA	NA	NA
W14		61	NA	92	NA	56	81	68	92	NA	NA	NA	NA	NA	NA

blanks were substracted from sample concentrations (most were zero or <0.1)
* Indicative interim working level
ID = insufficient data
bold data exceeds guidelines at the protection level indicated by colour of text (80% protection level is being exceeded in all cases shown in this dataset)
large majority of copper (>80%) and zinc (>68%) is dissolved.
Copper - over 90% total Cu is dissolved Cu at all sites except for W6 (89%), W7 (86%), W13 (88%) and W14 (81%)
Zinc - all zinc at W1-4 is dissolved Zn. Over 90% is dissolved Zn at W6, W10, W11, W12. Other sites- W7 (85%), W8 (83%), W9 (74%), W13 (77%) and W14 (68%)
Manganese - W6 and W14 had levels above interim working level. I suspect persistent low concs but high loads are leaching from and/or discharged from Kooragang Is.

ANZECC guidelines	protection of marine ecosystem	CrVI		Mn			Cu	Zn	As III	Se		Cd		Hg	Pb
	99%	**0.14**		**80***			**0.3**	**7.0**	ID	ID		0.7		0.1	2.2
	95%	**4.4**		**80***			**1.3**	**15.0**	ID	ID		5.5		0.4	4.4
	90%	**6.6**		**80***			**3.0**	**23.0**	ID	ID		14		0.7	6.6
	80%	**12**		**80***			**8.0**	**43.0**	ID	ID		36		1.4	12
Sample No		**Cr ug/L**	**Fe ug/L**	**Mn ug/L**	**Co ug/L**	**Ni ug/L**	**Cu ug/L**	**Zn ug/L**	**As ug/L**	**Se ug/L**	**Ag ug/L**	**Cd ug/L**	**Sn ug/L**	**Hg ug/L**	**Pb ug/L**
W1	**Dissolved**	2	<0.1	6	<0.1	13	**7.4**	**8.2**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W2		2	<0.1	6	<0.1	13	**7.4**	**9.4**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W3		2	<0.1	9	<0.1	13	**7.8**	**7.7**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W4		2	<0.1	11	<0.1	13	**7.3**	**8.0**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W5		2	<0.1	11	<0.1	11	**6.5**	**7.6**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W6		1	<0.1	**83**	<0.1	7	**3.5**	**6.2**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W7		1	<0.1	24	<0.1	10	**4.8**	**9.0**	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W8		2	<0.1	48	<0.1	10	**4.8**	**44.2**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W9		2	<0.1	10	<0.1	11	**6.2**	**8.3**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W10		2	<0.1	6	<0.1	14	**8.1**	**9.3**	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W11		2	<0.1	6	<0.1	14	**7.7**	**9.2**	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W13		1	<0.1	53	<0.1	10	**5.1**	**13.8**	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W12		2	<0.1	13	<0.1	13	**6.9**	**10.2**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W14		1	<0.1	**79**	<0.1	5	**3.0**	**22.6**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W1	**Total**	1	<0.1	11	1	20	**6.6**	**9.0**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W2	**digested**	1	333	20	1	19	**7.9**	**11.6**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W3		1	258	19	1	18	**8.4**	**9.5**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W4		2	880	32	2	19	**8.2**	**11.8**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W6		2	746	**99**	1	12	**3.7**	**6.8**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W7		2	907	44	1	16	**5.7**	**14.2**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W8		3	311	63	1	16	**5.6**	**64.8**	1	<0.1	<0.1	<0.1	<0.1	<0.1	1
W9		4	1489	75	2	19	**7.9**	**20.5**	2	<0.1	<0.1	<0.1	<0.1	<0.1	1
W10		2	191	13	1	22	**8.7**	**10.6**	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W11		2	306	13	1	21	**8.3**	**9.3**	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W13		2	300	58	1	15	**7.0**	**20.7**	2	<0.1	<0.1	<0.1	<0.1	<0.1	1
W12		2	43	17	1	19	**7.4**	**10.6**	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W14		2	369	**86**	1	10	**5.4**	**29.9**	1	<0.1	<0.1	<0.1	<0.1	<0.1	0
W1	**% Diss**	267	NA	54	NA	67	*113.0*	*90.7*	NA	NA	NA	NA	NA	NA	NA
W2	**of total**	147	NA	30	NA	69	*93.8*	*81.2*	NA	NA	NA	NA	NA	NA	NA
W3		149	NA	47	NA	73	*93.6*	*80.7*	NA	NA	NA	NA	NA	NA	NA
W4		85	NA	33	NA	66	*88.9*	*67.6*	NA	NA	NA	NA	NA	NA	NA
W6		71	NA	84	NA	56	*94.2*	*90.9*	NA	NA	NA	NA	NA	NA	NA
W7		79	NA	54	NA	62	*84.6*	*63.5*	NA	NA	NA	NA	NA	NA	NA
W8		70	NA	76	NA	62	*85.5*	*68.2*	91	NA	NA	NA	NA	NA	NA
W9		51	NA	13	NA	60	*78.0*	*40.6*	49	NA	NA	NA	NA	NA	NA
W10		105	NA	49	NA	65	*93.1*	*88.4*	92	NA	NA	NA	NA	NA	NA
W11		105	NA	45	NA	66	*92.3*	*98.8*	2	NA	NA	NA	NA	NA	NA
W13		79	NA	91	NA	69	*73.4*	*66.8*	81	NA	NA	NA	NA	NA	NA
W12		103	NA	73	NA	66	*93.3*	*95.9*	34	NA	NA	NA	NA	NA	NA
W14		61	NA	92	NA	56	*56.3*	*75.6*	92	NA	NA	NA	NA	NA	NA

blanks were substracted from sample concentrations (most were zero or <0.1)

* Indicative interim working level

ID = insufficient data

bold data exceeds guidelines at the protection level indicated by colour of text (80% protection level is being exceeded in all cases shown in this dataset

large majority of copper (>80%) and zinc (>68%) is dissolved.

Copper - over 90% total Cu is dissolved Cu at all sites except for W6 (89%), W7 (86%), W13 (88%) and W14 (81%)

Zinc - all zinc at W1-4 is dissolved Zn. Over 90% is dissolved Zn at W6, W10, W11, W12. Other sites- W7 (85%), W8 (83%), W9 (74%), W13 (77%) and W14 (68%)

Manganese - W6 and W14 had levels above interim working level. I suspect persistent low concs but high loads are leaching from and/or discharged from Kooragang Is.

UNIVERSITY OF CANBERRA
ECOCHEMISTRY LABORATORY

SaltWater samples

Sample as received **20th May 2015** **From:- Rebecca Swanson** **NSW Office of Environment**

Majors and Trace elements

EVENT 2 - TOTAL and DISSOLVED metal results

			Li	Be	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Fe	Mn
W1	Total	C150298	150.4	0.4	3263.9	8217472.8	1000417.5	448.0	703.1	290.3	307330.7	269326.2	52.7	1.8	3.4	<0.1	14.9
W2	digested	C150299	93.5	0.7	2006.2	4569753.7	565517.2	895.7	1397.2	763.8	173467.6	166956.8	31.3	9.6	1.1	231.9	42.6
W3		C150300	95.3	0.2	2245.8	4474613.7	553332.0	414.8	1030.5	505.2	169410.0	149155.0	30.4	7.0	1.2	260.8	35.2
W4		C150301	164.0	0.8	3843.4	8066868.7	985489.6	524.7	996.4	<10.0	303787.0	265041.3	49.9	3.2	0.5	210.8	28.5
W5		C150302	130.1	0.5	3198.4	6288871.8	778765.7	1180.0	704.0	4571.6	242558.4	214266.2	46.1	6.3	2.1	161.3	29.6
W6		C150303	169.7	0.8	4153.0	9102372.9	1123685.3	146.2	637.8	<10.0	349251.6	300641.7	55.7	<0.1	<0.1	<0.1	11.7
W7		C150304	176.6	0.8	4240.2	8825934.1	1090160.2	76.8	469.6	<10.0	338738.3	291606.4	63.0	0.6	<0.1	<0.1	9.6
W8		C150305	125.7	0.7	3580.7	6205402.9	766555.4	86.2	1858.1	<10.0	239654.1	265815.0	62.0	9.6	5.8	16.3	44.7
W9		C150306	145.8	0.6	3572.1	7585699.1	926792.4	76.8	1060.2	<10.0	291090.1	247956.6	49.4	10.3	0.8	41.4	79.9
W10		C150307	170.1	0.5	4112.1	9500962.7	1164787.1	83.7	479.6	<10.0	365859.7	314233.6	75.8	5.4	3.4	<0.1	7.7
W11		C150308	145.4	0.3	3453.3	7856033.4	965577.4	536.6	581.5	<10.0	304228.1	260245.2	59.2	8.7	4.3	85.2	11.2
W12		C150309	167.8	0.5	3855.3	9427879.8	1159802.8	57.5	450.3	<10.0	365367.1	313998.1	70.0	7.3	0.2	<0.1	5.2
W13		C150310	97.9	0.4	2561.7	5678430.5	700544.6	209.0	2006.2	18.9	220025.3	193866.0	42.9	13.8	2.3	123.8	39.8
W14		C150311	3.5	<0.1	118.9	149886.4	20801.4	357.3	1837.1	48.0	8374.2	10176.0	3.4	4.7	8.6	489.4	39.5
Unfiltered blank		C150312	<0.1	<0.1	<0.1	160.0	70.8	<0.1	<0.1	<10.0	97.7	220.8	<0.1	<0.1	<0.1	<0.1	<0.1
W1	Dissolved	C150313	138.1	<0.1	3149.7	8965980.6	1097799.9	546.2	629.4	294.6	348562.7	301453.7	55.4	<0.1	<0.1	<0.1	7.3
W2		C150314	79.8	<0.1	1976.0	4738634.4	576776.2	<0.1	1205.6	617.3	184291.0	172894.0	42.2	11.3	<0.1	<0.1	12.9
W3		C150315	76.2	<0.1	1933.4	4740911.8	577297.2	<0.1	773.2	393.2	184253.3	159787.9	49.1	9.8	<0.1	13.3	16.5
W4		C150316	133.2	<0.1	2983.1	8483754.5	1029422.1	<0.1	435.2	14.5	326130.4	284120.1	125.4	4.7	<0.1	<0.1	9.2
W5		C150317	105.6	<0.1	2569.7	6673193.5	818868.6	<0.1	374.0	4458.2	262280.0	228463.1	128.3	9.8	0.6	<0.1	13.3
W6		C150318	144.8	<0.1	3303.8	9456718.7	1145168.4	<0.1	460.7	<10.0	365331.1	317150.9	181.5	0.3	0.6	<0.1	6.6
W7		C150319	144.4	<0.1	3424.9	9675413.0	1187327.2	<0.1	387.9	<10.0	374688.7	331451.4	200.2	7.9	<0.1	<0.1	4.9
W8		C150320	103.5	<0.1	2989.8	6406140.9	786247.6	<0.1	1839.3	14.0	251093.2	285964.9	155.4	12.8	1.8	<0.1	30.0
W9		C150321	126.9	<0.1	3074.1	7889587.0	965121.9	<0.1	1107.1	<10.0	308956.2	273181.1	178.3	8.5	0.6	<0.1	14.4
W10		C150322	148.7	<0.1	3512.3	9560476.8	1174292.8	<0.1	358.0	<10.0	377382.5	337088.1	211.0	6.1	1.5	<0.1	3.5
W11		C150323	132.2	<0.1	3197.7	8039055.4	990419.2	<0.1	289.9	<10.0	318690.2	285267.6	188.4	12.4	3.7	<0.1	5.0
W12		C150324	152.2	<0.1	3578.8	9487174.2	1158252.9	<0.1	400.7	<10.0	373312.4	335375.8	200.9	11.0	4.8	<0.1	3.3
W13		C150325	93.7	<0.1	2517.5	5651040.1	693714.7	283.0	1862.9	17.5	222644.1	204568.5	136.8	15.8	6.6	16.9	33.1
W14		C150326	5.5	<0.1	143.3	154186.1	21483.1	<0.1	1660.5	40.9	9138.6	10881.9	23.6	3.4	7.1	57.2	12.4
W3 drain		C150327	5.3	<0.1	106.7	26308.6	2182.5	96.1	1325.0	1124.2	3123.5	5060.0	9.8	6.2	5.1	194.6	30.6
W5 drain		C150328	3.2	<0.1	48.1	39321.5	6588.6	43.5	590.5	18126.9	6841.5	12664.8	4.7	3.9	2.5	46.4	48.1
Filtered blank		C150329	<0.1	<0.1	<0.1	589.7	103.4	<0.1	<0.1	<10.0	149.4	210.6	<0.1	<0.1	<0.1	<0.1	<0.1

and Heritage

Co	Ni	Cu	Zn	Ga	Ge	As	Se	Rb	Sr	Zr	Nb	Mo	Ru	Ag	Pd	Cd	Sn	Sb	Te	Cs	Ba	La
1.2	<0.1	9.1	13.1	<0.1	<0.1	0.6	<0.1	19.4	3907.3	<0.1	<0.1	5.2	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.5	<0.1
0.9	3.2	6.6	21.0	<0.1	<0.1	3.0	6.1	22.5	2487.5	<0.1	<0.1	6.0	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5.5	<0.1
1.0	3.5	8.2	48.9	<0.1	<0.1	1.7	4.0	20.9	2344.3	<0.1	<0.1	5.7	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.1	<0.1
1.6	0.4	8.2	14.7	<0.1	<0.1	1.3	5.5	31.0	3572.0	<0.1	<0.1	5.5	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.7	<0.1
1.0	2.2	6.5	33.7	<0.1	<0.1	0.6	4.5	25.7	2964.3	<0.1	<0.1	6.8	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.6	<0.1
1.2	0.9	6.8	3.2	<0.1	<0.1	0.8	1.3	31.3	3798.1	<0.1	<0.1	6.3	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.5	<0.1
1.1	0.2	7.6	4.0	<0.1	<0.1	0.9	4.4	33.0	3761.3	<0.1	<0.1	6.2	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.4	<0.1
1.0	9.3	6.0	76.4	<0.1	<0.1	1.9	9.2	26.2	2791.8	<0.1	<0.1	5.8	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6.3	<0.1
1.1	2.2	6.4	2.8	<0.1	<0.1	1.0	5.7	28.3	3221.8	<0.1	<0.1	5.5	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.8	<0.1
1.2	3.1	7.3	8.1	<0.1	<0.1	1.0	8.2	32.7	3712.0	<0.1	<0.1	7.0	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.9	<0.1
1.0	4.4	29.3	126.2	<0.1	<0.1	1.0	2.8	28.7	3221.4	<0.1	<0.1	6.0	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1
1.1	1.5	7.6	2.8	<0.1	<0.1	0.5	7.1	32.3	3639.0	<0.1	<0.1	6.6	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.1	<0.1
0.8	5.3	6.6	25.7	<0.1	<0.1	1.5	2.6	20.3	2387.0	<0.1	<0.1	3.5	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.4	<0.1
0.4	7.1	6.9	76.1	<0.1	<0.1	0.9	<0.1	<0.1	108.5	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	9.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0.9	<0.1	6.6	5.4	<0.1	<0.1	<0.1	1.2	26.4	3197.1	<0.1	<0.1	4.8	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.7	<0.1
0.6	1.8	5.0	3.5	<0.1	<0.1	2.1	1.1	15.7	1927.5	<0.1	<0.1	3.0	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.4	<0.1
0.7	2.5	5.6	21.1	<0.1	<0.1	1.7	2.0	15.9	1876.9	<0.1	<0.1	3.0	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.6	<0.1
1.1	<0.1	6.6	7.2	<0.1	<0.1	<0.1	2.1	25.6	3022.8	<0.1	<0.1	4.5	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.1	<0.1
0.8	2.1	6.4	7.2	<0.1	<0.1	2.1	0.5	21.6	2491.1	<0.1	<0.1	4.9	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.1	<0.1
1.0	0.7	6.8	1.0	<0.1	<0.1	0.8	5.0	27.5	3264.6	<0.1	<0.1	5.1	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.5	<0.1
1.1	<0.1	8.5	2.6	<0.1	<0.1	<0.1	10.2	28.5	3261.5	<0.1	<0.1	5.2	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.1	<0.1
1.0	7.6	5.9	58.0	<0.1	<0.1	2.0	5.3	23.0	2333.9	<0.1	<0.1	3.9	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.0	<0.1
0.9	1.3	27.9	12.8	<0.1	<0.1	1.7	5.3	25.2	2780.7	<0.1	<0.1	4.6	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	4.9	<0.1
1.0	2.4	7.4	1.4	<0.1	<0.1	1.5	5.7	30.1	3228.0	<0.1	<0.1	5.6	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.9	<0.1
1.0	3.6	11.3	76.1	<0.1	<0.1	1.7	8.1	26.0	2776.8	<0.1	<0.1	4.8	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.3	<0.1
1.0	4.9	8.4	2.5	<0.1	<0.1	2.0	1.3	30.8	3141.2	<0.1	<0.1	5.5	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.8	<0.1
0.7	6.7	6.2	14.8	<0.1	<0.1	2.7	10.0	20.0	2036.3	<0.1	<0.1	3.6	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.5	<0.1
0.2	4.9	0.7	21.5	<0.1	<0.1	0.6	<0.1	<0.1	99.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6.2	<0.1
0.4	5.3	6.3	80.4	<0.1	<0.1	1.1	<0.1	<0.1	8.4	<0.1	<0.1	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.5	<0.1
0.4	5.1	5.1	33.0	<0.1	<0.1	0.8	<0.1	<0.1	48.9	0.4	<0.1	5.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Ce	Pr	Nd	Sm	Eu	Gd	Dy	Er	Tm	Yb	Lu	Hf	Ta	Re	Ir	Pt	Au	Hg	Tl	Pb	Bi	Th	U
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.9	<0.1	<0.1	0.9
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.3	<0.1	<0.1	0.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.3	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.9	<0.1	<0.1	0.9
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.9	<0.1	1.4	<0.1	<0.1	3.7
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	1.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	1.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.3	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	0.7
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	114.3	<0.1	<0.1	0.8
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.7	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	13.2	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.9
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.4
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.5
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.3	<0.1	<0.1	0.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10.4	<0.1	<0.1	0.5
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	0.7
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.9	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.7	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.7	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

UNIVERSITY OF CANBERRA
ECOCHEMISTRY LABORATORY

Salt Water samples

Sample as received **19th June 2015** **From:- Rebecca Swanson** **NSW Office of Environment and Heritage**

Majors and Trace elements

			Li	Be	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Fe	Mn	Co	Ni	Cu	Zn	Ga	Ge
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
W1	Dissolved	C150375	172.2	0.3	2661.7	8048940.0	948150.0	80.5	703.9	<0.1	238920.0	216870.0	<0.1	1.8	0.3	<0.1	12.8	1.1	<0.1	5.5	10.6	<0.1	<0.1
W2		C150376	166.3	0.1	2796.9	8301340.0	996650.0	72.9	866.5	70.9	252490.0	203290.0	<0.1	11.7	0.5	<0.1	13.8	1.1	<0.1	6.7	9.8	<0.1	<0.1
W3		C150377	122.6	<0.1	2019.5	5048400.0	650980.0	106.3	838.8	585.3	185110.0	149100.0	<0.1	19.2	<0.1	16.2	22.7	1.1	0.9	6.8	19.8	<0.1	<0.1
W4		C150378	121.6	0.1	2029.4	5229270.0	685500.0	69.6	2200.6	49.8	188260.0	180390.0	9.4	14.0	<0.1	<0.1	59.1	1.3	2.6	4.5	6.5	<0.1	<0.1
W5		C150379	43.1	<0.1	514.2	1015980.0	138040.0	92.0	745.6	21555.5	40650.0	32710.0	6.2	19.1	0.3	9.0	21.6	1.1	2.8	2.4	11.7	<0.1	<0.1
W6		C150380	138.3	0.3	2294.1	6767000.0	761800.0	74.9	1339.8	3.5	180540.0	160320.0	27.5	11.5	0.1	<0.1	41.9	1.1	1.1	5.1	5.6	<0.1	<0.1
W7		C150381	138.7	<0.1	2280.3	5794790.0	691500.0	78.7	1859.3	<0.1	196030.0	172720.0	38.7	14.4	<0.1	<0.1	31.6	1.1	1.2	5.0	5.7	<0.1	<0.1
W8		C150382	90.2	<0.1	1779.2	3118600.0	395560.0	90.9	2764.1	18.0	113170.0	145030.0	31.0	19.6	<0.1	0.3	60.2	1.1	6.7	3.4	96.9	<0.1	<0.1
W9		C150383	148.2	0.2	2559.5	6305930.0	763980.0	86.2	822.0	<0.1	225440.0	185350.0	34.4	15.4	<0.1	<0.1	11.2	1.1	1.3	5.2	6.3	<0.1	<0.1
W10		C150384	178.6	0.3	2998.4	8395980.0	997050.0	88.1	571.3	<0.1	234000.0	212480.0	46.0	21.8	<0.1	<0.1	9.7	1.2	1.3	6.1	7.5	<0.1	<0.1
W11		C150385	183.5	0.3	3071.2	8513820.0	1018990.0	91.6	474.0	<0.1	277020.0	231720.0	47.4	26.6	<0.1	<0.1	7.3	1.2	1.4	6.6	16.5	<0.1	<0.1
W12		C150386	167.1	0.4	2844.1	7578340.0	883250.0	96.6	817.0	<0.1	243060.0	216060.0	42.6	28.2	<0.1	<0.1	14.0	1.2	2.4	6.0	7.8	<0.1	<0.1
W13		C150387	91.6	<0.1	1518.5	3829600.0	447890.0	115.6	1804.2	<0.1	109640.0	91680.0	29.0	25.4	<0.1	6.1	25.7	1.1	3.0	3.7	22.0	<0.1	<0.1
W14		C150388	69.4	<0.1	1059.0	2662580.0	310340.0	125.2	2307.2	<0.1	73630.0	61730.0	17.3	21.8	<0.1	17.7	26.3	1.1	3.2	3.8	36.0	<0.1	<0.1
W5 drain		C150389	23.1	<0.1	85.8	59900.0	10620.0	138.7	775.0	21991.4	1100.0	1080.0	5.5	16.2	0.4	24.6	17.4	1.1	3.1	2.3	18.3	<0.1	<0.1
BIA 1		C150390	157.1	0.2	2514.4	6979910.0	902300.0	99.4	2084.7	1.9	246830.0	204050.0	24.2	18.4	<0.1	<0.1	97.1	1.1	2.3	4.5	4.9	<0.1	<0.1
BIA 2		C150391	166.1	0.2	2772.6	7661720.0	856890.0	103.6	1038.3	<0.1	239490.0	210310.0	39.2	21.4	<0.1	<0.1	30.7	1.1	2.7	5.1	5.3	<0.1	<0.1
BIA 3		C150392	163.6	0.2	2771.0	8280500.0	985820.0	107.0	795.0	<0.1	260140.0	214820.0	38.9	25.4	<0.1	<0.1	18.4	1.1	2.9	5.4	6.3	<0.1	<0.1
BIA 1/4		C150393	135.0	<0.1	2018.1	5581980.0	651840.0	127.8	3673.9	39.2	158970.0	139750.0	37.8	25.7	<0.1	634.6	281.7	1.1	3.9	3.7	5.1	<0.1	<0.1
BIA 1/2		C150394	89.8	<0.1	661.5	121610.0	34340.0	110.1	8921.1	27.2	16720.0	32330.0	27.3	10.7	<0.1	1165.5	933.7	1.0	3.5	0.5	0.5	<0.1	0.4
BIA DS		C150395	153.5	<0.1	2484.3	7804050.0	874020.0	108.0	1015.0	<0.1	211920.0	196470.0	26.3	19.5	<0.1	<0.1	17.4	1.1	2.5	4.3	4.0	<0.1	<0.1
BIA US		C150396	103.1	<0.1	1394.7	2784470.0	354610.0	129.6	7801.0	4.1	109220.0	85190.0	33.2	24.2	0.7	13.1	126.6	1.0	2.6	2.5	1.3	<0.1	<0.1
Filtered blank		C150397	21.5	<0.1	53.6	<0.1	360.0	1238.2	78.6	<0.1	<0.1	<10	1.1	8.6	1.9	<0.1	<0.1	0.9	3.5	<0.1	<0.1	<0.1	<0.1
W1	Total	C150398	189.1	0.3	3005.2	7083750.0	892925.0	320.5	1036.9	155.9	249112.5	265262.5	45.1	27.5	<0.1	353.4	18.5	1.3	3.9	4.8	9.6	<0.1	<0.1
W2	digested	C150399	187.3	0.1	2853.3	6632525.0	876975.0	300.2	1120.7	326.9	243675.0	216525.0	62.0	30.7	0.3	404.3	21.6	1.4	4.9	7.2	11.8	<0.1	<0.1
W3		C150400	142.7	0.2	2066.1	5299000.0	640312.5	617.3	1597.2	1278.0	177887.5	161550.0	70.0	33.1	1.7	837.8	49.0	1.7	5.4	9.1	43.2	<0.1	<0.1
W4		C150401	147.8	<0.1	2125.6	5821112.5	739750.0	304.9	2669.1	217.8	177875.0	176887.5	60.5	28.7	<0.1	467.0	76.1	1.8	7.4	4.1	5.6	<0.1	<0.1
W5		C150402	55.3	<0.1	611.7	1154275.0	150412.5	921.0	1029.1	21300.3	36325.0	34037.5	48.7	26.6	11.2	985.6	54.1	1.5	4.7	4.2	119.0	<0.1	<0.1
W6		C150403	156.2	0.2	2245.1	6325337.5	708925.0	328.3	1679.8	157.5	191625.0	181350.0	50.9	25.1	<0.1	495.4	47.6	1.5	4.9	4.5	10.3	<0.1	<0.1
W7		C150404	152.9	<0.1	2263.3	5535137.5	723012.5	308.5	2191.0	157.4	191900.0	173600.0	54.8	27.1	0.2	532.9	38.9	1.5	4.9	4.4	5.2	<0.1	<0.1
W8		C150405	104.2	<0.1	1722.9	3357500.0	423975.0	304.0	2984.0	166.1	101137.5	139150.0	55.3	26.4	7.9	595.0	77.2	1.6	12.3	4.7	117.5	<0.1	<0.1
W9		C150406	163.8	<0.1	2355.2	7115362.5	851525.0	321.6	1160.5	143.3	212012.5	180562.5	57.0	26.3	<0.1	487.1	20.9	1.3	4.7	5.0	6.3	<0.1	<0.1
W10		C150407	180.7	<0.1	2644.9	8798800.0	1085437.5	280.4	862.3	126.5	275150.0	228075.0	54.8	26.9	0.1	361.6	13.8	1.3	4.2	6.1	6.7	<0.1	<0.1
W11		C150408	186.9	0.6	2714.6	9302850.0	1074462.5	254.8	664.9	120.7	262037.5	205237.5	45.3	28.4	<0.1	332.5	9.9	1.3	4.3	6.4	15.1	<0.1	<0.1
W12		C150409	179.3	<0.1	2598.9	8078500.0	933362.5	245.5	1030.0	126.9	221262.5	184900.0	56.5	29.7	<0.1	330.2	16.8	1.3	4.7	5.5	7.8	<0.1	<0.1
W13		C150410	132.3	<0.1	1276.0	3352975.0	418412.5	278.5	1134.1	157.4	95062.5	81125.0	5.2	45.5	3.0	389.6	22.0	1.2	6.5	2.3	22.9	<0.1	<0.1
W14		C150411	118.8	<0.1	960.2	2459400.0	287687.5	368.4	1602.3	202.0	62437.5	55012.5	25.3	22.8	<0.1	488.4	27.3	1.3	6.3	4.0	38.3	<0.1	<0.1
W5 drain		C150412	78.2	0.3	31.4	<0.1	1462.5	927.5	449.2	15591.1	<0.1	25.0	44.7	11.1	13.0	1062.6	65.0	1.4	6.1	4.9	122.5	<0.1	<0.1
BIA 1		C150413	174.6	<0.1	2034.7	6824950.0	856237.5	319.0	970.1	60.6	229675.0	192712.5	6.7	18.1	<0.1	302.1	75.8	1.2	4.5	2.6	8.3	<0.1	<0.1
BIA 2		C150414	173.3	<0.1	2093.4	8172962.5	972187.5	200.6	460.0	54.8	224487.5	185862.5	12.7	6.4	<0.1	209.9	27.4	1.2	4.8	2.8	6.5	<0.1	<0.1
BIA 3		C150415	173.5	<0.1	2047.8	8352237.5	968312.5	202.9	354.0	18.6	230025.0	225637.5	37.3	7.7	<0.1	196.4	17.1	1.2	7.3	3.6	16.2	<0.1	<0.1
BIA 1/4		C150416	152.3	<0.1	1610.7	5842850.0	691487.5	235.6	3070.6	147.6	168287.5	145637.5	54.0	8.0	0.8	1386.4	220.1	1.3	7.8	10.2	10.0	<0.1	<0.1
BIA 1/2		C150417	128.5	<0.1	545.5	117587.5	35437.5	198.1	7837.3	266.1	14887.5	34450.0	50.1	11.2	1.8	1723.6	768.5	1.4	5.0	<0.1	<0.1	<0.1	0.1
BIA DS		C150418	157.4	<0.1	1882.4	7100137.5	828650.0	193.6	174.5	3.5	221625.0	206500.0	8.9	13.8	<0.1	141.4	17.0	1.3	5.7	2.4	5.8	<0.1	<0.1
BIA US		C150419	130.4	<0.1	1330.0	2759262.5	318112.5	214.9	6243.9	126.5	85137.5	77775.0	37.5	12.2	1.1	258.9	94.3	1.3	5.7	1.2	2.4	<0.1	<0.1
Unfiltered blank		C150420	16.1	<0.1	10.5	<0.1	225.0	194.1	<0.1	174.4	<0.1	214.9	88.6	10.9	1.3	347.5	3.8	1.0	18.9	5.3	0.1	<0.1	<0.1

As ug/L	Se ug/L	Rb ug/L	Sr ug/L	Zr ug/L	Nb ug/L	Mo ug/L	Ru ug/L	Ag ug/L	Pd ug/L	Cd ug/L	Sn ug/L	Sb ug/L	Te ug/L	Cs ug/L	Ba ug/L	La ug/L	Ce ug/L	Pr ug/L	Nd ug/L	Sm ug/L	Eu ug/L	Gd ug/L	Dy ug/L	Er ug/L	Tm ug/L	Yb ug/L
2.3	<0.1	2.3	4436.1	<0.1	<0.1	6.7	0.6	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3.1	<0.1	2.5	4354.7	<0.1	<0.1	7.1	0.7	0.7	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	6.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	6.5	3146.9	<0.1	<0.1	5.1	0.4	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	6.0	3347.8	<0.1	<0.1	6.2	0.5	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.7	8.8	4.4	855.6	<0.1	<0.1	9.6	<0.1	0.2	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	2.3	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	3.8	3679.0	<0.1	<0.1	4.8	0.5	0.4	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	11.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	5.2	3522.0	<0.1	<0.1	4.7	0.5	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	12.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	10.9	2069.2	<0.1	<0.1	5.7	0.3	0.3	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	14.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	6.8	3713.0	<0.1	<0.1	6.1	0.6	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	7.3	4214.4	<0.1	<0.1	6.6	0.8	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	8.7	4144.0	<0.1	<0.1	7.0	0.7	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	9.7	3766.5	<0.1	<0.1	6.2	0.6	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	7.6	2037.0	<0.1	<0.1	2.8	0.3	0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	11.0	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0.7	1.1	6.3	1490.1	<0.1	<0.1	2.2	0.2	0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	12.8	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.7	12.3	1.4	69.7	<0.1	<0.1	11.4	<0.1	0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	1.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	14.4	3486.4	<0.1	<0.1	6.9	0.7	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	12.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	12.5	3644.1	<0.1	<0.1	6.7	0.7	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.0	<0.1	12.4	3641.6	<0.1	<0.1	6.1	0.7	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	24.1	2533.5	<0.1	<0.1	10.5	0.5	0.3	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	26.9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0.2	3.6	44.9	464.3	<0.1	<0.1	18.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	85.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	12.2	3353.0	<0.1	<0.1	5.5	0.6	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3.5	<0.1	36.5	1541.9	<0.1	<0.1	22.4	0.2	0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	14.8	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	7.3	<0.1	0.9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.0	<0.1	<0.1	1.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	17.4	3784.7	<0.1	<0.1	9.0	0.9	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.3	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	17.1	3726.3	<0.1	<0.1	9.0	0.8	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.0	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	15.7	2813.8	<0.1	<0.1	7.3	0.5	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10.4	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	15.3	2994.4	<0.1	<0.1	7.9	0.6	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.6	4.1	6.2	765.3	<0.1	<0.1	13.2	<0.1	0.2	<0.1	0.6	<0.1	<0.1	<0.1	<0.1	7.5	1.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	12.8	3139.4	<0.1	<0.1	5.7	0.7	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	12.2	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	13.4	3095.2	<0.1	<0.1	6.1	0.6	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	13.7	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.6	<0.1	15.6	1790.4	<0.1	<0.1	6.7	0.3	0.3	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	15.9	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	14.3	3307.1	<0.1	<0.1	7.0	0.7	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	9.4	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	15.0	3801.3	<0.1	<0.1	7.6	0.8	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6.4	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	16.3	3844.3	<0.1	<0.1	7.5	0.8	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5.5	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	15.5	3538.7	<0.1	<0.1	6.8	0.8	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7.6	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2.4	<0.1	9.0	1839.8	<0.1	2.3	5.9	0.3	1.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	12.6	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.7	<0.1	8.5	1359.4	<0.1	2.1	5.8	<0.1	1.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	15.8	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2.3	<0.1	7.6	61.0	<0.1	2.5	17.0	<0.1	0.5	<0.1	0.8	<0.1	<0.1	<0.1	<0.1	10.5	1.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	13.0	3073.1	<0.1	1.3	9.0	0.6	1.6	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	15.3	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	11.2	3035.9	<0.1	0.8	7.6	0.8	1.5	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	10.9	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	11.0	2935.1	<0.1	0.5	7.3	0.6	1.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	9.0	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	19.6	2078.8	<0.1	0.4	11.0	0.4	0.9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	29.0	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
7.4	<0.1	37.1	292.5	<0.1	<0.1	17.6	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	73.0	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	11.8	2719.5	<0.1	<0.1	6.5	0.6	1.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0.3	<0.1	27.9	1266.8	<0.1	<0.1	20.4	<0.1	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	14.9	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	3.8	4.6	<0.1	<0.1	0.5	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	3.6	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Lu ug/L	Hf ug/L	Ta ug/L	Re ug/L	Ir ug/L	Pt ug/L	Au ug/L	Hg ug/L	Tl ug/L	Pb ug/L	Bi ug/L	Th ug/L	U ug/L
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	1.1	1.5
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.6	1.5
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	1.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.6	0.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	0.9
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	1.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	0.3	1.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
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<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.3
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<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	0.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
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<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	4.8	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	2.3	0.2
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.0	<0.1	0.4	0.4
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.0	<0.1	0.5	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.8	<0.1	0.4	5.5
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1
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<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.6	<0.1	0.2	0.7
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.1	<0.1	3.0	1.0
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.5	<0.1	2.0	0.8
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.2	<0.1	2.3	8.9
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	1.1	1.8
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	0.8	1.8
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.6	1.8
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.7	<0.1	0.4	1.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.3
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	1.6
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	0.1	0.9
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

APPENDIX G

Table of Terms and Abbreviations

GLOSSARY

Term	Definition
Acid Sulfate Soil	Acid sulfate soils are natural sediments that contain iron sulfides. When disturbed or exposed to air these soils can release acid, damaging built structures and harming or killing animals and plants. Because of their estuarine origin, they are usually found at elevations less than 1 metre above sea level.
Analyte	The specific component or element measured in chemical analysis.
Anthropogenic	Coming from or having been caused by man.
Aquatic	Growing, living in or frequenting water, occurring or situated in or on water.
Aquifer	Stratum or zone below the surface of the earth capable of producing water as from a well.
Aromatic Compounds	Contain ring structure formed from closed loops of carbon chains (most often containing C-atoms) where carbons in the ring have resonant double bonds. Aromatic compounds include compounds such as benzene, toluene, ethylbenzene and xylene (BTEX), as well as polyaromatic compounds such as naphthalene. Because of the double bonding between carbon atoms, the molecules are not saturated with hydrogen atoms (as with un-saturated hydrocarbons).
Background	An area not influenced by chemicals released from the site under evaluation or other impacts created by the activity on the site under evaluation.
BioNet	NSW BioNet is the repository for biodiversity data products managed by the Office of Environment and Heritage (OEH).
Contaminant	A general term referring to any chemical compound added to a receiving environment in excess of natural conditions. The term includes chemicals or effects not generally regarded as “toxic”, such as nutrients, salts and colour.
Contamination	The condition or state of soil, water or air caused by a substance release or escape which results in an impairment of, or damage to, the environment, human health, safety, or property.
Environmental Health	The study of the protection of human populations from biological, chemical and physical hazards in their environment.
Exposure Assessment	The process of estimating the amount (concentration or dose) of a chemical that is taken up by a receptor from the environment.
Exposure Pathway	The route by which an organism comes into contact with a contaminant.
Guideline	A basis for determining a course of action. An environmental guideline can be either procedural (directing a course of action) or numerical (providing a numerical value that is generally recommended to support and maintain a specified use.
Petroleum	A naturally occurring mixture of hydrocarbons in gaseous, liquid or solid form.

Receptor	The person or organism subjected to exposure to chemicals or physical agents.
Remediation	The removal, reduction or neutralisation of substances, wastes or hazardous material from a site so as to prevent or minimise any adverse effects on the environment now or in the future.
Sediment	Soil material, both mineral or organic, that is in suspension, is being transported, or has been moved from its surface of origin by air, water, gravity or ice and has come to rest on the earth’s surface either above or below sea level.

ABBREVIATIONS

Acronym	Definition
ABN	Australian Business Number
ABS	Australian Bureau of Statistics
ACM	Asbestos Containing Material
APVMA	Australian Pesticides and Veterinary Medicines Authority
AF/FA	Asbestos Fines / Fibrous Asbestos
AHD	Australian Height Datum
ANOVA	Analysis of Variance
ANZAST	Australian New Zealand Guidelines for Water Quality (2018)
ANZECC	Australian New Zealand Environment Conservation Council
ANZG	Australian and New Zealand Governments
ASC	Assessment of Site Contamination
ASS	Acid Sulfate Soil
BC Act 2016	Biodiversity Conservation Act 2016
B(a)P	Benzo(a)pyrene
BH	Borehole
BOD	Biological Oxygen Demand
BTEXN	Benzene, Toluene, Ethylbenzene, Xylene and Naphthalene
$CaCO_3$	Calcium Carbonate
CEMP	Construction Environmental Management Plan
CLM Act	*Contaminated Land Management Act (1997)*
cm	*Centimetre*
CoPC	Contaminants of Potential Concern
CPS	Critical components, processes and services
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Conceptual Site Model
DECC	Department of the Environment and Climate Change
DEWHA	Department of the Environment, Water, Heritage and the Arts
DoE	Department of the Environment
DoEE	Department of the Environment and Energy
DO	Dissolved Oxygen
DWE	Department of Water and Energy
EAAF	East Asian Australasian Flyway
ECD	Ecological Character Description
EEC	Endangered Ecological Communities
EMP	Environmental Management Plan
EPBC Act 1999	*Environment Protection and Biodiversity Conservation Act 1999*
EP&A Act	*Environmental Planning and Assessment Act 1979*

Acronym	Definition
EP&A Regulation	Environmental Planning and Assessment Regulation 2000
EPA	Environment Protection Authority
EPL	Environment Protection Licence
ERA	Ecological Risk Assessment
ESA	Environmental Site Assessment
HBOC	Hunter Bird Observers Club
HLLS	Hunter Local Land Service
HEPA	Heads of EPAs Australia and New Zealand
ha	Hectare
ICOLLS	Intermittently Closed and Open Lakes and Lagoons
IUCN	International Union for Conservation of Nature
km	kilometres
KWRP	Kooragang Wetland Rehabilitation Project
LAC	Limits of Acceptable Change
LC50	Median lethal dose Lethal Concentration 50
LDPE	Low-density Polyethylene
LEP	Local Environmental Plan
LGA	Local Government Area
LOR	Limit or Reporting
m	metres
m bgs	Metres below ground surface
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
mm	Millimetres
mS/cm	micro siemens per centimetre
NARCLiM	NSW and ACT Regional Climate Modelling
NCCARF	National Climate Change Adaptation Research Facility
NEPM/NEPC	National Environment Protection Measure (2013) / National Environment Protection Council
NEMP	National Environmental Plan
NOAEL / LOAEL	No-observed-adverse-effect level Lowest-observed-adverse-effect level
NOW	NSW Office of Water
NPWS	National Parks and Wildlife Service
NSW	New South Wales
NSW EPA	New South Wales Environment Protection Authority
NTU	Nephelometric turbidity
^{o}C	Degrees Celsius
OCP & OPP	Organochlorine & Organophosphorus Pesticides

Acronym	Definition
OEH	Office of Environment and Heritage
PAH	Polycyclic Aromatic Hydrocarbon
PFAS / PFOS / PFHxS / PFHxA / PFHpA / PFDS / PFPeA / PFDcA / PFHpA / PFNA / PFBuA	Per and Poly-fluorinated Alkyl Substances / Perfluorohexane sulfonate / Perfluorohexanoic acid / Perfluoroheptanoic acid / Perfluorodecane sulphonic acid / Perfluoro-n-pentanoic acid / Perfluorodecanoic acid / Perfluoroheptanoic acid / Perfluorononanoic acid / Perfluoro-n-butanoic acid
PPM	Parts Per Million
PPT	Parts Per Trillion
POEO Act	Protection of the Environment (Operations) Act 1997
PQL	Practical Quantitation Limits
RAAF	Royal Australian Air Force
SSD	Species Sensitivity Distribution
SWMs	Safe Work Method Statement
TOC	Total Organic Carbon
TPH/TRH	Total Petroleum Hydrocarbons / Total Recoverable Hydrocarbons
UCL	Upper Control Limit
µg/L	micrograms per litre
UNSW	University of NSW
%	Percent

ARCADIS Design & Consultancy for natural and built assets

umwelt Environmental & Social Consultants