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Pollution in Sydney Harbour: sewage, toxic chemicals and microplastics

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SUMMARY

Sydney Harbour is a paradox. On the one hand, it is known as one of the most beautiful harbours in the world; on the other, few other estuaries are as modified and polluted. This paper deals primarily with the *what* and *where* of pollution in the Harbour, briefly noting at several points the environmental impacts of the pollution. A description of the Harbour and brief history of how it became polluted precede coverage of pollution in the Harbour today, with particular reference to water quality, dioxins, heavy metals and sediment toxicity, and microplastics. A timeline of relevant regulatory and parliamentary events is attached as an appendix. No research was found on the social and economic impacts of the pollution.

Sydney Harbour

Sydney Harbour is a tide dominated, drowned valley estuary, formed approximately 10,000 years ago when the sea level rose. It is 30km long, 2km wide, occupies about $48km^2$ and has a volume of 540,600ML. Its catchment of $480km^2$ extends across to Blacktown in the west, Terrey Hills and Normanhurst in the north, and Bankstown and Dulwich Hill in the south. For the purposes of this paper, from the entrance between North and South heads, Sydney Harbour opens into **Port Jackson** and its three main branches – **Middle Harbour**, **Parramatta River** and **Lane Cove River**. **[2.1]**

Sydney Harbour supports a diversity of organisms rarely matched elsewhere. It is also home to a number of endangered species and ecological communities. Leading up to the 2015 NSW general election, several parties and key stakeholders have come out in support of establishing a Sydney Marine Park including the Labor Party, The Greens NSW, Alex Greenwich, the Independent Member for Sydney, and the National Parks Association of NSW. In December 2014, the NSW Government announced a year-long study that would inform any decision about the creation of an integrated marine protected area along the metropolitan coast by 2016. **[2.1.2]**

Sydney Harbour is a major economic driver of the city. As a port, it has three main functions: cruise ship destination; the importation of bulk products; and hosting a naval base. These functions are expected to increase in importance into the future. **[2.1.3]**

Modification of the estuary and its catchment

Sydney Harbour's depth and sheltered waters made it an ideal location for European settlement. The expansion of Sydney has substantially changed the Harbour. Due to reclamation, 77 km of the original 322km of shoreline and $11.5km^2$ (22%) of the total $48km^2$ of the estuary have been lost, mostly upstream of Sydney Harbour Bridge. The Sydney Harbour catchment has similarly been substantially modified, with approximately 80% being urbanised or industrialised. **[2.1]**

Sydney Harbour, its tributaries and catchment, were polluted within years of European settlement. Industries were first established on the banks of Darling

Harbour in 1800, from where they gradually spread along the southern shore of the Parramatta River. Small-scale industry also polluted the waters of the Lane Cove River and Middle Harbour. While regulatory reforms were introduced in the 1940s and 1950s to address pollution of the Harbour, it wasn't until the *Clean Waters Act 1970* that pollution levels entering the Harbour began to decline. **[3.0]**

Pollution in Sydney Harbour

Threats remain to the biodiversity and ecosystems of the Harbour. Six key threats have been identified, the first two of which are discussed in depth in this paper: heavy metal and toxic chemical contamination; nutrients and turbidity; invasive species; habitat modification; fishing and aquaculture; and climate change. This paper also deals with an emerging problem – microplastics.

Water quality

A 2011 report averaged Sydney Water data for several water quality parameters in the Lane Cove River (3 sites), Middle Harbour (3 sites), Parramatta River (5 sites) and Port Jackson (3 sites). For dissolved oxygen, 9 of 14 sites in the Harbour met guidelines on average. For four other indicators (total nitrogen, total phosphorus, chlorophyll-a and enterococci), only three sites met guidelines on average – Quakers Hat Bay in Middle Harbour, and Little Sirius Cove and Rushcutters Bay in Port Jackson.

Water quality parameters in Sydney Harbour (2011)

Water quality indicator	Number of sites which met guidelines (14 sites in total)
Dissolved oxygen	Lane Cove River (1 site) Middle Harbour (2 sites) Port Jackson (3 sites) Parramatta River (3 sites)
Total nitrogen	Middle Harbour (1 site) Port Jackson (2 sites)
Total phosphorus	Middle Harbour (1 site) Port Jackson (2 sites)
Chlorophyll-a	Middle Harbour (1 site) Port Jackson (2 sites)
Enterococci	Middle Harbour (1 site) Port Jackson (2 sites)

The number of enterococci is the preferred faecal indicator for marine waters. Enterococci counts are monitored at swimming beaches in the Harbour, where they have significantly improved since the late 1990s. In 2013-14, 76% of beaches were graded good or very good, up from 68% in 2009-10. **[4.1 & 4.2]**

Dioxins

The name "dioxins" often refers to three families of compounds, the first two of which are structurally and chemically related: PCDDs or dioxins; PCDFs or furans; and dioxin-like polychlorinated biphenyls (PCBs). Each of these three families of compounds has a number of variants; of 419, 29 have high toxic potential. The most toxic of these, and one of the most toxic chemicals ever tested, is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). The presence of toxic dioxins in seafood, water or sediment is measured in a single toxicity value, the 2,3,7,8-TCDD Toxicity Equivalence Concentration (TEQ).

Dioxins are one of 23 persistent organic pollutants (POPs) listed in the 2001 Stockholm Convention to which Australia is a signatory. Short-term exposure of humans to high levels of dioxins may result in lesions and altered liver function. Long-term exposure has been linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. 2,3,7,8-TCDD has also been classified as a “known human carcinogen”. Signatories to the Convention are required to take measures to reduce the unintentional releases of dioxins with the goal of continuing minimization and, where feasible, ultimate elimination. **[5.1]**

Between 1928 and 1985, Timbrol (later known as Union Carbide) manufactured a variety of chemicals on the Rhodes Peninsula. Dioxins, including 2,3,7,8-TCDD, were released in industrial effluent disposed of in part in Homebush Bay. The Timbrol site on Rhodes Peninsula and adjacent Homebush Bay sediments were remediated between 2005 and 2011, at a cost of $21 million. Only the most contaminated sediments of the Bay were remediated by removal of the upper 0.5m of sediment and replacement with clean fill. As of 2014, the effectiveness of the remediation program was unknown. **[5.2]**

International dioxin sediment quality guidelines range from 0.0011 to 210pg TEQ/g, depending on factors such as the level of effects expected at a certain concentration. **[5.4.1]**

The 2002 Environmental Impact Statement (EIS) conducted prior to the remediation of the Timbrol site and parts of Homebush Bay found surface sediment dioxin concentrations ranging from 90 to 154,000pg I-TEQ/g, with a mean of 7,600pg I-TEQ/g. The estimated bay-wide average dioxin sediment concentration was 3,014pg I-TEQ/g. The remediation was expected to reduce the bay-wide average to 2,033pg I-TEQ/g.

Dioxin sediment concentrations in the part of Homebush Bay adjacent to the Timbrol site (pg I-TEQ/g) (2002)

Sediment depth	Minimum	Maximum	Mean
Surface (0-100mm)	90	154,000	7,600
Subsurface (400-500mm)	20	380,000	7,930
Subsurface (900-1,000mm)	50	238,000	25,680

The EIS contained several readings of water dioxin levels taken in the eastern part of the Bay, all of which significantly exceeded the value set in the Canadian Water Quality Guidelines for the Protection of Aquatic Life of 10pg TEQ/L.

Dioxin water concentrations in Homebush Bay (pg TEQ/L) (2002)

Weather	Site		
	WQ1	WQ2	WQ3
Wet weather	690	12,100	815
Dry weather	3,080	652	445

Five groundwater readings for the Lednez site are presented in the EIS. These range from 4 to 157pg TEQ/L, with no mean provided. It appears therefore that groundwater dioxin concentrations also generally exceeded known guidelines, when comparing the findings to the Canadian value of 10pg TEQ/L. **[5.4.2]**

2007 and 2008 studies made the following area-specific findings: **[5.4.3 & 5.4.4]**

Sydney Harbour dioxin sediment concentrations (pg TEQ/g) (2007 study)

Area	Minimum	Maximum	Mean
Homebush Bay	667.8	4,352.5	2,094.0
Stormwater discharge points in Hen and Chicken Bay, Iron Cove, Rozelle Bay and Long Bay	75.9	226.4	124.5
Industrial and urban areas in Parramatta River	81.1	367.2	230.0
Background values in Middle Harbour and Lane Cove River	31.5	49.5	39.5
Sydney Harbour	31.5	4,352.5	711.5

Sydney Harbour dioxin sediment concentrations (pg TEQ/g) (2008 study)

Area	Minimum	Maximum
West of the Harbour Bridge	56	610
Port Jackson	14	110
Middle Harbour	1.5	4
Sydney Harbour	1.5	610

Fin fishing was first banned in Homebush Bay in 1989 due dioxin contamination. In February 2006, a permanent ban on commercial fishing in Sydney Harbour was introduced. Consumer dietary advice for recreational fishers recommends that no seafood caught west of the Sydney Harbour Bridge be consumed, and that generally no more than 150 grams per month of seafood caught east of the Bridge be consumed. Despite this advice, it appears that some recreational fishers still eat fish caught west of the Bridge. **[5.3]**

While remediation of some of the most contaminated areas in Homebush Bay has taken place, it appears technically and financially impractical to conduct any large-scale remediation projects of dioxin-contaminated sediments. At this stage, because the area contaminated with dioxins is too extensive, the only way to address the problem is to wait until sediments cover the contaminated layer so that dioxins cannot be absorbed by fish and small invertebrates. In the meantime, a recent academic paper recommended continued long-term monitoring of dioxin levels in fish, sediments and water in order to best manage potential human health and ecological health impacts and to develop appropriate guidelines for dioxin concentrations. **[5.4.5]**

Heavy metals in Sydney Harbour

Sydney Harbour has been classified as very severely modified by heavy metal contamination. In total, 1,900 tonnes of copper, 3,500 tonnes of lead and 7,300 tonnes of zinc have been found in Sydney Harbour sediments. Approximately 20% of all three metals can be found in four embayments: Iron Cove, Rozelle & Blackwattle Bays, Homebush Bay, and Hen and Chicken Bay. These bays represent only 5% of the total Sydney Harbour area. Metal concentrations in surficial sediments of Rozelle & Blackwattle Bays, Iron Cove, Hen and Chicken Bay and Homebush Bay have generally declined over the past few decades. In the Lane Cove Estuary, heavy metal concentrations have either generally remained stable or increased. In Middle Harbour, heavy metal concentrations have generally remained stable or decreased. **[6.1.1]**

Stormwater is the most significant contemporary source of heavy metal contamination in Sydney Harbour. It has been estimated that Sydney Harbour receives an average annual loading of arsenic, cadmium, chromium, copper, nickel, lead and zinc of 0.8, 0.5, 1.7, 3.2, 1.1, 3.6 and 17.7 tonnes respectively (28.6 tonnes in total). Copper concentrations in stormwater almost always exceed the guidelines, zinc concentrations frequently exceed guidelines and arsenic, chromium and lead concentrations exceed guidelines on occasion. Nickel concentrations never exceed guidelines. **[6.1.2]**

Researchers have modelled the length of time it would take for heavy metal concentrations to decrease to two times pre-anthropogenic concentrations based on recent trends. The time taken for particular metals to decline to two times background concentrations ranged from 2 to 92 years. However, this is optimistic given sediment concentrations cannot decrease below the levels found in stormwater entering the Harbour, which is up to 10-20 times background levels in some locations. **[6.1.3]**

Sediment quality and toxicity

Researchers from the University of Sydney's School of Geosciences have investigated the quality and toxicity of sediment in Sydney Harbour, examining in particular concentrations of heavy metals, organochlorine pesticides (e.g. DDT), total polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). The highest priority Sydney Harbour sediments (16% of the Harbour) were subject to ecotoxicological tests. This data was combined with chemical data to produce a sediment chemistry and toxicity score. All the sediment in the areas tested was found to be either highly toxic (17%), moderately toxic (52%) or slightly toxic (31%). **[6.2]**

Microplastics

The term microplastics was first coined in 2004 as researchers attempted to account for all the plastic in the ocean. Microplastics are tiny plastic fragments, fibres and granules generally smaller than 5mm in diameter. A wide-ranging study into microplastics published in 2011 concluded that microplastic particles in the marine environment are mainly derived from sewage via washing clothes, rather than fragmentation of larger pieces or cleaning products. **[7.1]**

In 2014, researchers from the Sydney Institute of Marine Science found "alarming" levels of microplastic pollution in Sydney Harbour. Sediment samples taken at 27 sites across the Harbour found concentrations of microplastics ranged from 0-10 to a high of 61-100 particles per 100ml of sediment in Middle Harbour. In August 2014, Rob Stokes, the NSW Minister for the Environment, announced that he had convened a working group to work towards phasing out microbeads by 2016 through voluntary means. Rob Stokes also called for a national ban on the sale and production of shampoos and other products containing microbeads.

Australian and international comparisons

A summary of Australian and international comparisons for water quality, dioxins, heavy metals, sediment toxicity and microplastics is contained in the Tables below. The data was sourced from Tables 5, 10, 12 to 14, 16, 20 and 21, and Figure 21 of this paper. Note that the maximum dioxin reading for Sydney Harbour was taken prior to remediation; the current maximum is likely to be in the vicinity of the maximum found by a 2007 study of 4,352.5pg TEQ/g.

Stormwater quality

	Total nitrogen yield (kg/km/year)	Total phosphorus yield (kg/km/year)	Total suspended solids (kg/km/year)	% of catchment developed
Sydney Harbour	990	132	71,384	86
Australian estuaries	282–460	49–65	na	na
NW Europe	1,300	101	na	na
NE USA	1,070	139	na	na
Danish estuaries	2,400	112	na	10
NE Canada	76	4.5	na	na

Dioxins (pg TEQ/g)

	Minimum	Mean	Maximum
Sydney Harbour	31.5	711.5	154,000
Australian estuaries	0.89	na	35
Finland	na	na	80,000
Norway	6,234	na	19,444
Venice Lagoon, Italy	427	na	2,857
St. Laurensharbour, Netherlands	352	na	1,849
Passaic River, USA	310	na	1,400
Hong Kong Harbour	4	na	33
Tokyo Bay	3.3	na	52

Stormwater heavy metal yields (grams per hectare per year)

	Chromium	Copper	Nickel	Lead	Zinc
Sydney Harbour	41	72	23	82	378
Yarra River, Vic	na	7.7–11	na	5.7–31	23–190
Four US urban catchments	12	0.4–40	11	0.0–31	18–398

Heavy metal concentrations in surficial sediments (mg/kg)

		Cadmium	Copper	Nickel	Lead	Zinc
Sydney Harbour	Mean	0.8	188	21.7	364	651
	Range	0–24.3	9–1,053	5–245	38–3,604	108–7,622
Five Australian urbanised estuaries	Means	na	13–87	na	30–172	134–393
	Range	na	1–596	na	1–924	13–2,641
Australian non-urbanised estuary	Mean	na	5	na	19	49
	Range	na	2–9	na	5–28	12–82
Six international estuaries	Means	0.21–1.22	39–183	14–37	22–189	65–391
	Range	0.1–5.3	1–4,000	5–447	9–589	17–1,133
ANZECC guidelines	ISQG-Low	1.5	65	21	50	200
	ISQG-High	10	270	52	220	410

Sediment toxicity

	No chemicals exceeded an ERL value	At least one chemical exceeded an ERL value, but not an ERM value	At least one chemical exceeded an ERM value
Sydney Harbour	8%	45%	46%
US estuaries	31%	42%	27%

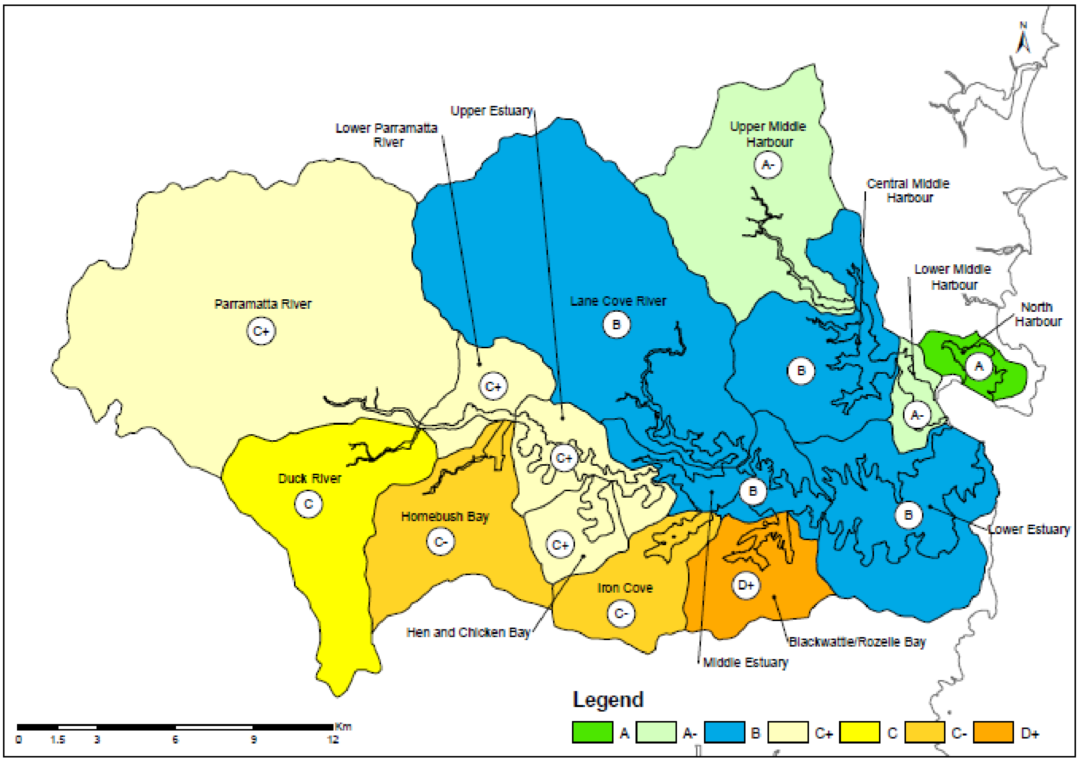
Microplastics

	Particles per 100ml sediment
Sydney Harbour	0-10 to 61-100
Western Australia, beach	0.8
International estuaries	2 to 24
International beaches	0.8 to 12.4
Deep sea sediments	26.8

A Sydney Harbour report card

Research completed at Sydney University in 2014 assessed the condition of Sydney Harbour and its sub-catchments and sub-estuaries. Three indicators were graded – catchment pressures, water quality and sediment quality – and their grades were combined into an overall grade. Management priorities were allocated to each sub-catchment/sub-estuary according to their condition. Note that this research did not include some pollutants, including dioxins. The research is therefore *indicative* of the state of the Harbour and its sub-catchments. **[8.0]**

Final assessment grade for Sydney Harbour[1]



Management priorities for Sydney Harbour

Sub-catchment/ sub-estuary	Overall priority	Sediment quality priority	Water quality priority
Blackwattle/Rozelle Bay	High	High	Medium Low
Iron Cove	High	High	Medium Low
Homebush Bay	High	Medium High	High
Duck River	High	Medium High	High
Hen and Chicken Bay	Medium High	High	Medium Low
Upper Estuary	Medium High	Medium High	Medium High
Lower Parramatta River	Medium High	Medium Low	High
Parramatta River	Medium High	Low	High
Lower Estuary	Medium Low	Low	Low
Middle Estuary	Medium Low	Medium Low	Low
Lane Cove River	Medium Low	Low	Medium High
Central Middle Harbour	Medium Low	Medium High	Low
Lower Middle Harbour	Low	Low	Low
Upper Middle Harbour	Low	Low	Medium Low
North Harbour	Low	Low	Low

[1] Gunns, T., *The development and implementation of a hierarchical assessment scheme for the management of estuaries in New South Wales*, unpublished Masters Thesis, University of Sydney, 2014, p.80

LIST OF ABBREVIATIONS

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin, one of the most toxic chemicals ever tested
2,4,5-T	2,4,5-trichlorophenoxyacetic acid, a herbicide used in Agent Orange
2,4-D	2,4-dichlorophenoxyacetic acid, a herbicide used in Agent Orange
DDT	Dichlorodiphenyltrichloroethane, a banned organochlorine pesticide
EIS	Environmental Impact Statement
ERL	Effects Range Low, the value below which adverse biological effects are seldom observed
ERM	Effects Range Median, the value above which adverse biological effects are expected to occur frequently
HpCDD	1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin, a toxic dioxin
ISQG-Low	Interim Sediment Quality Guidelines-Low, the value below which adverse biological effects are seldom observed
ISQG-High	Interim Sediment Quality Guidelines-High, the value above which adverse biological effects are expected to occur frequently
I-TEQ	2,3,7,8-TCDD Toxicity Equivalence Concentration, using NATO/CCMS-assigned dioxin toxicity factors
MEQ	Mean Enrichment Quotient, a measure of heavy metal enrichment of sediments
MERMQ	Mean Effects Range Median Quotient
OCDD	1,2,3,4,6,7,8,9 octachlorodibenzo-*p*-dioxin, a toxic dioxin
PCB	Polychlorinated biphenyl, a chemical, some types of which have toxic properties similar to dioxins
PCDD	Polychlorinated dibenzo-*p*-dioxins (dioxins)
PCDF	Polychlorinated dibenzofurans (furans)
PCP	Pentachlorophenol, a chemical used in the production of pesticides
pg	Picograms, 10^{-12} grams or one trillionth of a gram
POP	Persistent Organic Pollutant
TEQ	2,3,7,8-TCDD Toxicity Equivalence Concentration
WHO-TEQ	2,3,7,8-TCDD Toxicity Equivalence Concentration, using WHO-assigned dioxin toxicity factors

1. INTRODUCTION

Sydney Harbour is one of the most beautiful harbours in the world (Figure 1). For the people of NSW and Australia it possesses significant cultural, historic, spiritual, environmental and economic value. In 2013, Sydney Harbour became Australia's 16th National Landscape as part of the Australian National Landscapes Program, which selects areas of outstanding natural beauty and cultural significance. As described by Tourism Australia:

> Hugging the shores of one of the world's most cosmopolitan cities, the beguiling waters of Sydney Harbour are a blue-green wonderland of sparkling, yacht-studded bays, secluded beaches and coastline framed by parks and native bushland. The green heart is the great expanse of Sydney Harbour National Park, encircling the headlands and entrance to Port Jackson. It is the gateway to a region of natural beauty, rich with Aboriginal and convict history, World Heritage sites and even wildlife on the doorstep. Humpback whales have been known to seek shelter in the harbour's coves, while a colony of little penguins have made themselves at home on Manly's foreshore.
>
> Most visitors will get their first glimpse of the harbour while exploring The Rocks, parks like the Royal Botanic Gardens and coastal walkways that snake around the foreshore. With unmistakable icons like the Sydney Harbour Bridge and Sydney Opera House, it's an enticing view from any vantage point.[2]

Sadly, the history of Sydney Harbour since European settlement is marked by anything but respect for its values, research having found it to be one of the most modified and polluted estuaries in the world. Since its early days as cesspit for the colony, at various times Sydney Harbour has been subject to a stream of sewage, rubbish, industrial effluent and pollutant-laden stormwater. Today the Harbour has some of the highest concentrations of heavy metals and dioxins in the world, as well as being contaminated by organochlorine pesticides (e.g. DDT), other toxic chemicals, and microplastics. While many of the practices that disposed of these pollutants into the Harbour have ceased, there remains a legacy of sediment contamination that will take centuries to dissipate.[3]

Leading up to the 2015 NSW general election, several parties and key stakeholders have come out in support of establishing a Sydney Harbour Marine Park. In September 2014, the Labor Party announced that, if elected, it would create a Sydney Marine Park which would incorporate Sydney Harbour, Pittwater, Narrabeen Lakes, Dee Why Lagoon, Botany Bay and Port Hacking. The purpose would be to protect Sydney's marine environment while maintaining the Harbour's functions as a working harbour and well-loved and used recreational resource. The Greens NSW and Alex Greenwich, the Independent Member for Sydney, have similar positions, and the National Parks

[2] Tourism Australia, *Natural Australia: Sydney Harbour*, no date [online – accessed 12/11/2014]

[3] Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p

Association of NSW is also campaigning for a Sydney Marine Park.

In December 2014, the NSW Government announced a year-long study into new conservation areas for the Sydney region, which would examine in part the Hawkesbury Shelf marine bioregion which stretches from Newcastle to Wollongong. The NSW Environment Minister, Rob Stokes, stated that the study, due to commence at the beginning of 2015, would “inform decision making about the creation of an integrated marine protected area along the metro coast by 2016”.

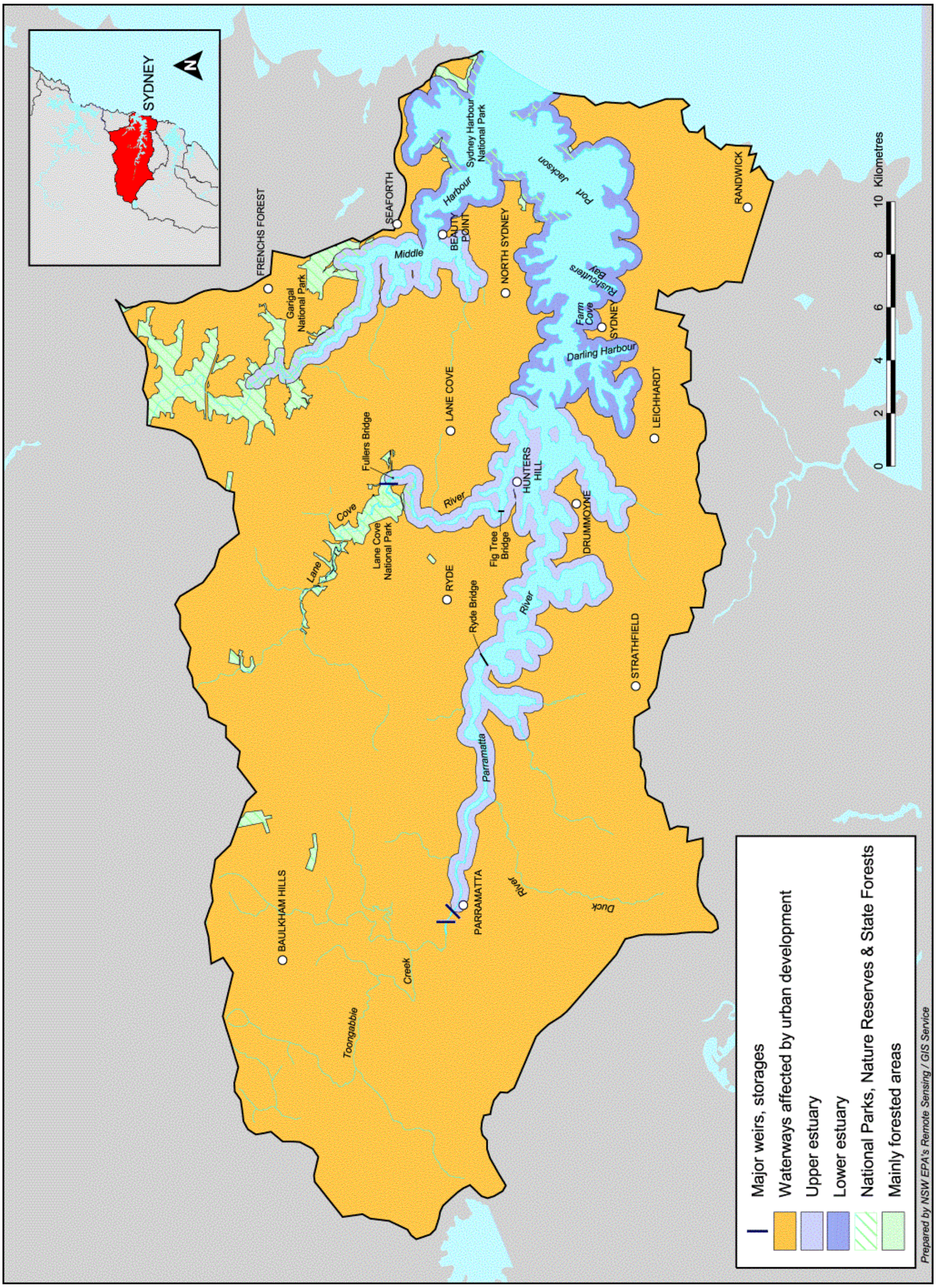
A related development was the launch in December 2014 of the Parramatta River Catchment Group’s Our Living River campaign. Their mission is to make Parramatta River swimmable again by 2025. At present, the upper and middle reaches of the River are too polluted for swimming and related activities.

This paper deals primarily with the *what* and *where* of pollution in the Harbour, briefly noting at several points the environmental impacts of the pollution.[4] No research was found on the social and economic impacts of the pollution. Other than brief mentions in Chapter 3 and a timeline in Appendix 1, the paper generally does not deal with the regulatory framework that applies to the Harbour.

Part One of the paper describes the Harbour and its sub-catchments with reference to its environmental features, economic functions and the use of the waters and surrounding catchment. A short history of pollution is also set out. Part Two covers the findings of an expanding body of research into pollution in the Harbour. The first four chapters deal with water quality, dioxins, heavy metals and sediment toxicity, and microplastics. The last presents a report card of the Harbour and its sub-catchments.

[4] For a summary of the environmental effects of pollution in the Harbour, an area which is under-researched, see: Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p

Figure 1: Sydney Harbour and its catchment[5]



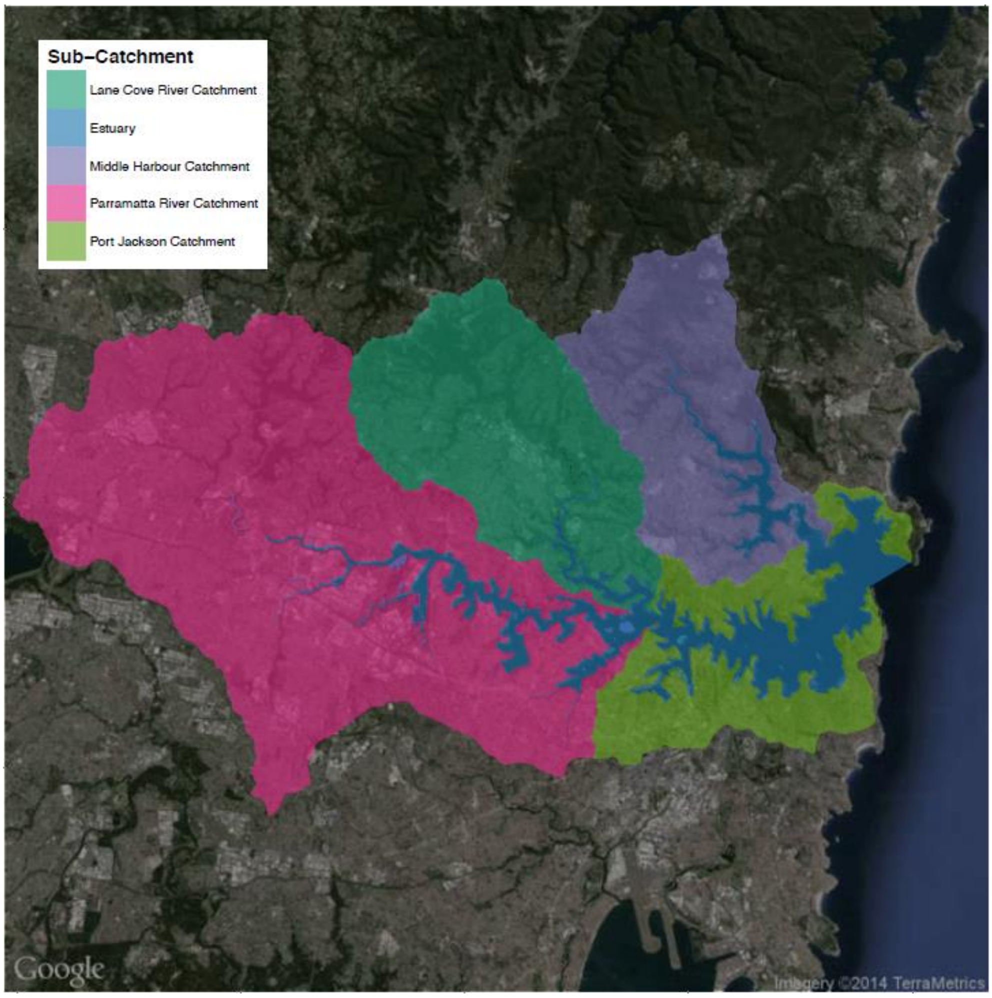
5 Amended from: NSW Department of Environment, Climate Change and Water, NSW Water Quality and River Flow Objectives: Sydney Harbour and Parramatta River, 1 May 2006 [online – accessed 12/11/2014]

PART ONE – BACKGROUND AND HISTORY

2. SYDNEY HARBOUR AND ITS CATCHMENT

This chapter describes some of Sydney Harbour's environmental, social and economic characteristics. Sydney Harbour and its components are variously defined.[6] For the purposes of this paper, from the entrance between North and South heads, Sydney Harbour opens into **Port Jackson** and its three main branches – **Middle Harbour**, **Parramatta River** and **Lane Cove River** (Figure 2).[7] The chapter finishes by identifying threats to the Harbour's environment.

Figure 2: Sydney Harbour sub-catchments[8]



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6 Birch, G., A short geological and environmental history of the Sydney estuary, Australia, pp217-246; In: Birch, G (ed), *Water, Wind, Art and Debate*, 2007. Sydney University Press, Sydney, 433p

7 Sydney Institute of Marine Science, *About Sydney Harbour*, no date [online – accessed 12/11/2014]. In contrast, the Geographical Names Board of NSW describes Port Jackson as "A harbour which comprises of all the waters within an imaginary line joining North Head and South Head. Within this harbour lies North Harbour, Middle Harbour and Sydney Harbour".

8 Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, p.17

2.1 Sydney Harbour

2.1.1 Description

Sydney Harbour is a tide dominated, drowned valley estuary, formed approximately 10,000 years ago when the sea level rose. Characterized by steep sided banks carved into Sydney sandstone, the estuary is 30km long, 2km wide, occupies about 48km^2 and has a volume of 540,600ML (Table 1). Its catchment of 480km^2 extends across to Blacktown in the west, Terrey Hills and Normanhurst in the north, and Bankstown and Dulwich Hill in the south.[9]

Table 1: Sydney Harbour – area, volume and average depth[10]

	Catchment area (km^2)	Estuary area (km^2)	Estuary volume (ML)	Average depth (m)
Lane Cove River	95.4	3	12,600	4.2
Middle Harbour	77	6.1	81,900	13.4
Parramatta River	252.4	13.7	69,700	5.1
Port Jackson	55.7	29.1	376,400	13
Sydney Harbour	480.5	51.9	540,600	n/a

2.1.2 Zoning and environmental protection

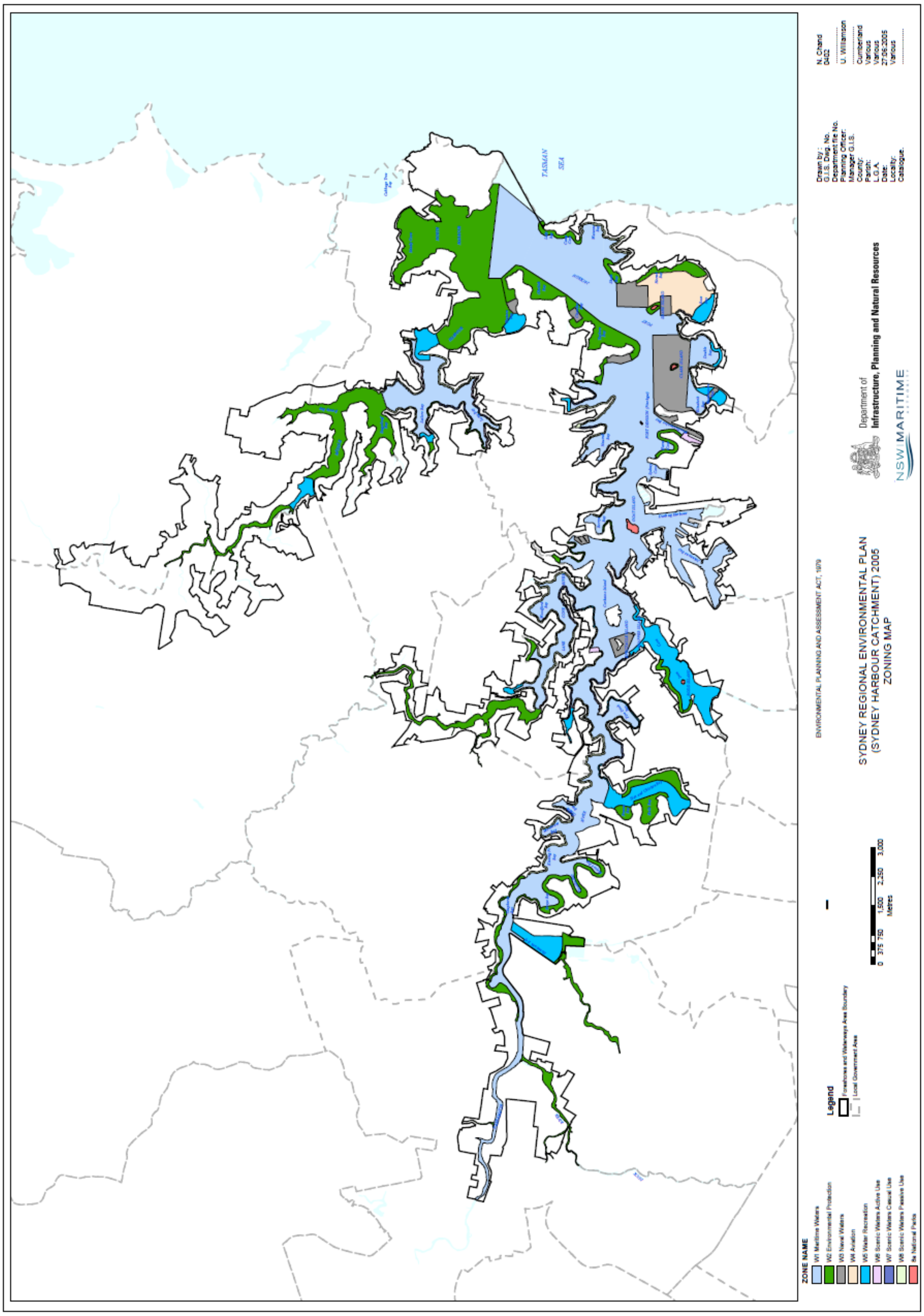
The waters of Sydney Harbour are zoned for different uses under the Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 (Harbour REP). 9 zones are established under Part 3 of the Regulation (Figure 3):

- Zone No W1—Maritime Waters
- Zone No W2—Environment Protection
- Zone No W3—Naval Waters
- Zone No W4—Aviation
- Zone No W5—Water Recreation
- Zone No W6—Scenic Waters: Active Use
- Zone No W7—Scenic Waters: Casual Use
- Zone No W8—Scenic Waters: Passive Use
- Zone No 8 (a)—National Parks

[9] Birch, G., op. cit.; Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p

[10] Sources: Office of Environment & Heritage, *Lane Cove River*, 26 April 2012 [online – accessed 11/11/2014]; Office of Environment & Heritage, *Middle Harbour Creek*, 27 April 2012 [online – accessed 11/11/2014]; Office of Environment & Heritage, *Parramatta River*, 27 April 2012 [online – accessed 11/11/2014]; Office of Environment & Heritage, *Port Jackson*, 27 April 2012 [online – accessed 11/11/2014]

Figure 3: Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 – Zoning Map



The Maritime Waters zone covers the main navigation channels, public transport, port and maritime industry activities of the Harbour and permits a wide range of waterway activities and facilities. The zone includes the important marine precincts and transport nodes of Sydney Cove, Darling Harbour, White Bay, Rozelle Bay, Blackwattle Bay, Mort Bay, Breakfast Point, Berrys Bay and parts of Balls Head Bay, Neutral Bay and Gore Cove. The main navigation channels from the Heads to Parramatta are also included in the zone.[11]

In order to effectively implement the *Control of Naval Waters Act 1918* (Cth), the Naval Waters zone restricts the use of the waterway incompatible with naval interests. The zone applies to waters around Garden Island, Clark Island, Shark Island, Steel Point, Rushcutters Bay, Bradleys Head, Chowder Bay, Hunters Bay, Spectacle Island and Balls Head Bay.[12]

The Water Recreation zone gives priority to public use and access to the water through appropriate water recreation facilities, including charter and tourism facilities and commercial marinas. Generally, the adjoining land is in public ownership and is intensively used by the public (e.g. parks). The zone includes important public beaches (e.g. Balmoral Beach), commercial marina precincts (e.g. The Spit) and bays containing existing water recreation facilities and activities (e.g. parts of Hen and Chicken Bay and Canada Bay).[13]

The Harbour REP protects important environmental areas of the Harbour in two ways. The Environment Protection zone provides for the protection, rehabilitation and long term management of the natural and cultural values of the waterways and adjoining foreshores. The zone covers a range of areas including significant estuarine ecosystems and habitats in parts of Manly Cove and Middle Harbour, estuarine and wetlands habitats along the Parramatta River, and significant riverine environments of the Lane Cove River and Duck Creek.[14]

Part 6 of the Harbour REP provides for Wetland Protection Areas.[15] These comprise mangroves, seagrasses, saltmarshes, sedgelands, wet meadows and mudflats and a 40m buffer zone to address movement, growth and seasonal variation. Development consent is required for certain types of development on land within a wetlands protection area that may have a detrimental impact on a wetland.

Important environmental areas of the Harbour are also protected under the Fisheries Management (General) Regulation 2010 and the *Marine Estate Management Act 2014*. Under the Regulation, the entire Sydney Harbour shoreline is an intertidal protected area (IPA), excluding the shoreline of North

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[11] Department of Infrastructure, Planning and Natural Resources, *Sydney Harbour Catchment: Sydney Regional Environmental Plan 2005*, June 2004, 11p

[12] Ibid.

[13] Ibid.

[14] Ibid.

[15] These Areas are identified on a map split into 16 sheets published by the NSW Department of Planning and Environment.

Harbour from Manly Point to the southern end of Forty Baskets Beach. The IPA extends from the mean high water mark to 10m seaward from the mean low water mark. Collecting seashore animals such as crabs, snails, octopus, sea urchins, pipis, mussels and oysters is prohibited, as are all fishing methods.[16]

The Sydney Harbour shoreline between Manly Point and the southern end of Forty Baskets Beach falls within the North Harbour aquatic reserve, established under the *Marine Estate Management Act 2014*. The reserve was set up to conserve important habitat and nursery areas for protected species. Line fishing for fin fish, and the use of landing nets, lobster traps and bait traps are permitted within the reserve. The collection or disturbance of habitat or all other marine life is prohibited, including collecting shellfish, pumping for worms, spearfishing and collecting dead or empty shells.[17]

As a drowned river valley, Sydney Harbour hosts a wide variety of habitats. These include saltmarsh, seagrass beds, mangroves, rocky reefs, rockpools, beaches and open water systems. These habitats support a diversity of organisms rarely matched in estuaries anywhere else in the world. For example, 586 species of fish have been identified in Sydney Harbour, several of which are endemic to the Harbour. In comparison, the entire coast of the United Kingdom is home to approximately 200 species.[18]

A number of endangered species and ecological communities are found within Sydney Harbour and its catchment. Table 2 lists those found within Sydney Harbour.[19] Bicentennial Park and Newington wetlands are located in Homebush on the Parramatta River, and are listed on the Directory of Important Wetlands in Australia. The Endangered Ecological Communities and Endangered population of little penguins are listed under the *Threatened Species Conservation Act 1995*. The habitat of the little penguin is listed as critical habitat under the Threatened Species Conservation Regulation 2010.

[16] NSW Department of Primary Industries, *Factsheet: Sydney Harbour and northern beaches recreational fishing guide*, March 2012, 8p; Fishing Management (General) Regulation 2010

[17] Ibid.

[18] Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p; Booth, D., Natural history of Sydney's Marine Fishes: where south meets north, pp143-153; In: Lunney, D., Hutchings, P., and Hochuli, D. (eds) *The Natural History of Sydney*, 2010. Royal Zoological Society of NSW, Mosman, NSW, Australia, 438p

[19] For more detail on the environmental features of Sydney Harbour, see: Sydney Metropolitan Catchment Management Authority, *Sydney Metropolitan Catchment Management Authority Catchment Action Plan*, 2009, 224p; Hedge, L.H. et al., *Sydney Harbour background report 2014*, Report prepared for NSW Department of Primary Industries by the Sydney Harbour Research Program at the Sydney Institute of Marine Science, April 2014, Sydney, 105p

Table 2: Significant environmental features of Sydney Harbour[20]

Type	Features	Location
Important Wetlands	• Bicentennial Park • Newington wetlands	• Parramatta River • Parramatta River
Endangered Ecological Communities	• NSW Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions • Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner Bioregions • Sydney Turpentine-Ironbark Forest[21]	• Lane Cove River, Middle Harbour & Parramatta River • Lane Cove River & Parramatta River • Parramatta River
Endangered population	• Little penguin population in the Manly point area, together with its critical habitat	• Port Jackson

2.1.3 Economic functions

NSW's ports are significant trade gateways and critical links between the landside and seaside elements of the supply chain. NSW has four major ports (Port Jackson, Port Botany, Port Kembla and the Port of Newcastle), two regional ports (Eden and Yamba) and 23 coastal harbours. Half of all annual ship visits to NSW arrive in Port Jackson and Port Botany.[22]

As a port, Sydney Harbour has three main functions: cruise ship destination; the importation of bulk products; and hosting a naval base. The number of cruise ships coming to Sydney has more than doubled in the last four years, from 119 in 2009-10 to 259 scheduled for 2013-14.[23] To cater for increased cruise ship numbers, the domestic cruise passenger terminal at White Bay was recently upgraded. An upgrade of the Overseas Passenger Terminal in Circular Quay is currently underway.[24]

Bulk product facilities are located at Glebe Island/White Bay and Gore Cove, Greenwich. The Shell terminal at Gore Cove, Greenwich, receives petroleum products.[25] The Glebe Island/White Bay precinct contains eight working berths for the discharge of dry bulk cargo (e.g. cement, gypsum and sugar) and bulk liquids (e.g. oils and tallow). Sydney Harbour is an ideal port for the import of

[20] Sources: Environment Australia, *A Directory of Important Wetlands in Australia*, 3rd edition, 2001. Environment Australia, Canberra; Sydney Metropolitan Catchment Management Authority, op. cit.

[21] This is also listed as a critically Endangered Ecological Community under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth).

[22] NSW Government, *NSW Freight and Ports Strategy*, November 2013, 236p

[23] Port Authority of NSW, *Cruising*, no date [online – accessed 19/11/2014]

[24] NSW Government, op. cit.

[25] Sydney Ports Corporation, *Commercial shipping in Sydney Harbour: past, present and future*, Presentation by Marika Calfas, General Manager Planning Sydney Ports Corporation, 20 August 2012. This presentation charts the rise and decline in the number of port facilities located in Sydney Harbour from 1901 to 2012.

low value, dry bulk products as it minimises the transport costs associated with their distribution throughout Sydney. Consolidation of existing and future dry bulk trade is expected to occur at Glebe Island.[26]

The Royal Australian Navy Fleet Base East is located at Garden Island, located to the east of the CBD on the southern side of Sydney Harbour. Fleet Base East is primarily used for ship maintenance and repair. Significant Navy future plans for Fleet Base East and Garden Island include initial home-porting with the associated System Program Offices of three new Air Warfare Destroyers and two new Landing Helicopter Dock amphibious vessels.[27]

The Draft Metropolitan Strategy for Sydney has nominated Sydney Harbour as one of nine key 'city shapers' that:

> … have been identified because of their size and scale and the opportunities they present for the change and investment that are critical for the growth of Sydney. They will shape how our city functions and are critical in delivering the vision for Sydney.[28]

The Strategy describes the Harbour as:

> … the defining feature of Sydney and one of our biggest economic advantages. It has influenced where and how Sydney has grown and attracts considerable investment from both public and private sectors.
>
> Over the next 20 years, Sydney Harbour and its surroundings will continue to be the major economic driver for our city. It is the site of a nationally significant working port complementing Port Botany, a national and international tourist attraction, a destination of cruise ship companies and a sought-after location for investment in housing and commerce.[29]

Several priorities were identified for Sydney Harbour:

- Protect Port Jackson and support its function as a major working port;
- Recognise and protect Glebe Island and White Bay for their maritime and working harbour role and investigate the long-term future of the area with the community;
- Promote the arts and culture venues around Sydney Harbour and Sydney CBD;
- Develop long-term options for expanding cruise ship terminal space;
- Increase opportunities for recreational access to the foreshore and waters, including those offered through harbourside property

[26] NSW Government, op. cit.

[27] Ibid.

[28] NSW Department of Planning & Infrastructure, *Draft Metropolitan Strategy for Sydney to 2013*, March 2013, p.18

[29] Ibid., p.21

regeneration;

- Improve water quality and protect biodiversity;
- Provide a new pedestrian connection between Wynyard and Barangaroo;
- Improve and expand ferry services throughout Sydney Harbour and along Parramatta River; and
- Provide opportunities for sustainable visitor and tourism experiences on the islands and foreshores of Sydney Harbour National Park.[30]

2.1.4 Modification of the estuary and its catchment

Sydney Harbour's depth and sheltered waters made it an ideal location for European settlement. The expansion of Sydney has brought about substantial change to the Harbour. Of the original 322km of shoreline, 77km have been lost due to reclamation and infilling of intertidal areas. Approximately 49% of the shoreline has been replaced by seawalls. Natural habitat accounts for 51.1%; of this amount, mangroves account for 17.5%, horizontal rock platform for 10.5% and cobbles/boulders for 10.4%.[31]

11.5km^2 (22%) of the total 48km^2 of the estuary have been reclaimed for industrial, recreational and residential uses, mostly upstream of Sydney Harbour Bridge.[32] While reclamation activities took place from European settlement up to 2002, the majority occurred in the periods 1922-55 (5.74km^2), 1889-1922 (2.08km^2) and 1955-78 (2.03km^2).[33] Approximately 100 Megatonnes of garbage, industrial waste and contaminated estuarine sediments were used throughout the Harbour for reclamation.[34]

The Sydney Harbour catchment has similarly been substantially modified, with approximately 80% being urbanised or industrialised (Table 4). Key land uses include residential (47.0%), roads (18.5%), commercial (8.5%) and industrial (3.9%). 15% of the catchment is made up of undisturbed forest, preserved in areas like Lane Cove National Park and Sydney Harbour National Park (Figure 4). Population density in the catchment increased from 2,392 persons/km^2 in 1996 to 2,629 persons/km^2 in 2006 (Table 3). In 2011, approximately 1.2 million people lived in the catchment.[35]

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[30] Ibid., p.21

[31] Creese, R. et al., *Mapping the habitats of NSW estuaries*, Report to the Hunter Central Rivers Catchment Management Authority, Industry & Investment NSW – Fisheries Final Report Series No. 113, September 2009, 95p

[32] Birch, G., op. cit.

[33] Birch, G. et al., Reclamation in Sydney Estuary, 1788-2002, *Australian Geographer*, 2009, Vol 40(30): 347-368

[34] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

[35] Raynor, D. et al., *Sydney Harbour Catchment Water Quality Improvement Plan: data compilation and review*, WRL Technical Report 2011/07, prepared for the Sydney

Table 3: Land use in the Sydney Harbour catchment[36]

Land use	Area (km^2)	Area (%)
Bushland	30.25	6.3%
Parkland	67.91	14.0%
Residential	227.33	47.0%
Roads	89.47	18.5%
Railway	4.08	0.8%
Industrial	18.96	3.9%
Commercial	41.08	8.5%
Water	2.97	0.6%
Rural	1.6	0.3%
Sewer	0.04	0.01%
Total	483.69	100.0%

Table 4: Land use and population density in the Sydney Harbour sub-catchments[37]

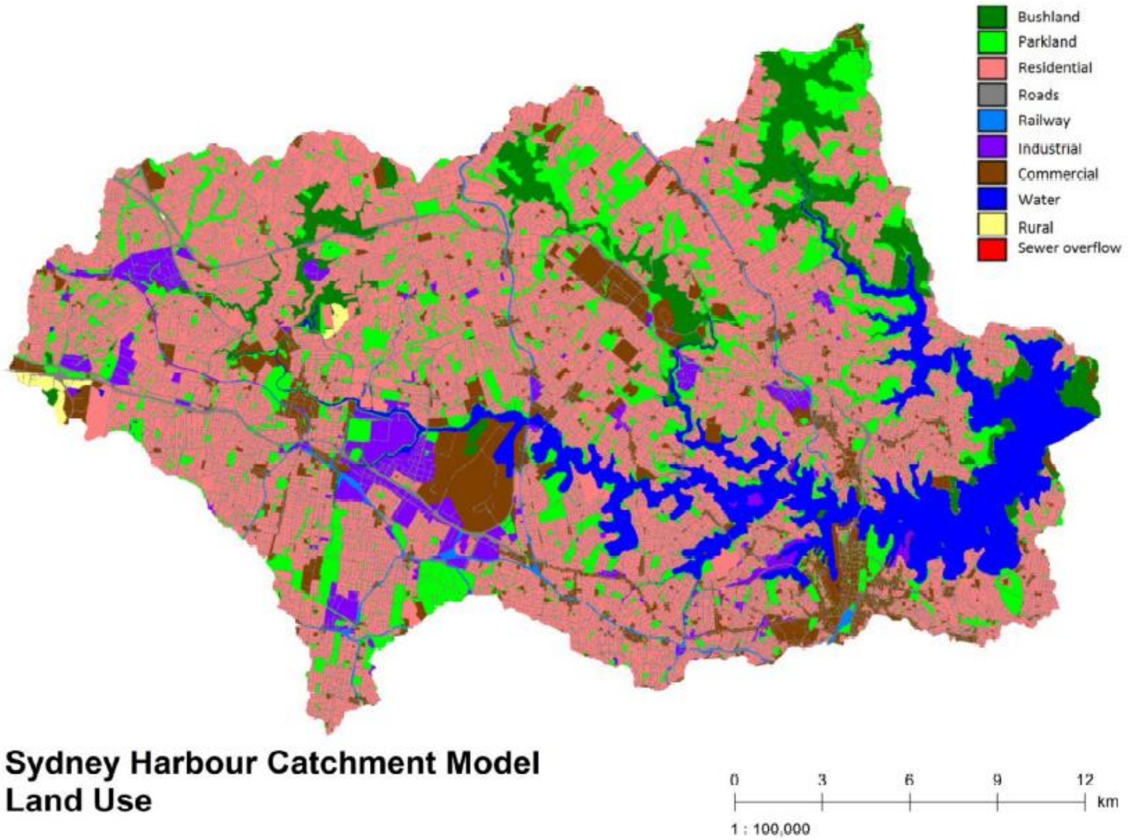
Catchment	Land use				Population density (persons/km^2) (2006)
	Undisturbed forest	Disturbed	Other	Total area	
Lane Cove River (km^2)	22.3	73.4	2.4	98.1	1,949
(% of catchment total)	23%	75%	2%	100%	-
Middle Harbour (km^2)	21.7	55.0	3.6	80.3	1,783
(% of catchment total)	27%	68%	5%	100%	-
Parramatta River (km^2)	26.0	228.6	11.0	265.6	2,584
(% of catchment total)	10%	86%	4%	100%	-
Port Jackson (km^2)	6.1	43.8	3.6	53.6	5,164
(% of catchment total)	11%	82%	7%	100%	-
Sydney Harbour (km^2)	76.1	400.7	20.7	497.5	2,629
(% of catchment total)	15%	81%	4%	100%	-

Metropolitan Catchment Management Authority, August 2011, 77p.

36 Freewater, P. et al., *Sydney Harbour Catchment Water Quality Improvement Plan*, 23rd NSW Coastal Conference 2014, Ulladulla, NSW, 11-14 November 2014, p.10

37 Roper, T. et al., *Assessing the condition of estuaries and coastal lake ecosystems in NSW*, Monitoring, reporting and evaluation program, Technical report series, Office of Environment and Heritage, Sydney, June 2012, 270p. Note that the totals do not equate with the figures in Tables 1 and 3. In part, this is due to the use of different mapping methods and incomplete land-use maps.

Figure 4: Land use in the Sydney Harbour catchment[38]



2.2 Lane Cove River

The Lane Cove River is a 24km long tributary of the Parramatta River, which it meets at Hunters Hill, and the smallest tributary of the Harbour in terms of estuary area (3km^2) and volume (12,600ML).[39] It has been substantially modified since European settlement. A weir was constructed in 1938 to provide a freshwater lake at one of Sydney's most popular picnicking spots in Lane Cove National Park.[40] Dredging has removed most of the River's sandy spits and beaches. The shoreline has been significantly modified in some areas, particularly through infilling swamps. A number of swampy areas were filled as municipal garbage dumps.[41]

[38] Freewater, P. et al., op. cit., p.11

[39] Geographical Names Board of New South Wales, Lane Cove River, 14 November 2014 [online – accessed 14/11/2014]; Butler, R., and Jha, S., Lane Cove River Coastal Zone Management Plan, Final Report, Prepared for Lane Cove River Estuary Management Committee, Hunters Hill Council, Lane Cove Council, Ryde Council and Willoughby Council by BMT WBM Pty Ltd, September 2012, Sydney, 115p

[40] NSW Department of Primary Industries, Reducing the impact of weirs on aquatic habitat: NSW detailed weir review, Report to the New South Wales Environmental Trust, Sydney Metropolitan CMA Region, 2006

[41] McLoughlin, L. and Wyatt, M., *The Upper Lane Cove: history, heritage, bibliography*, 1993. Graduate School of the Environment, Macquarie University, 204p; McLoughlin, L., Shaping Sydney Harbour: sedimentation, dredging and reclamation 1788-1990s, *Australian*

Covering 95km^2, the River's catchment includes seven local government areas, either wholly or partially: Lane Cove, Hornsby (partial), Hunters Hill, Ku-ring-gai (partial), Parramatta (partial), Ryde and Willoughby. Three quarters of the catchment is urbanised; undisturbed forest makes up the remainder (Table 4). Despite considerable modification to the River and its catchment, large sections of the estuary and its shoreline still remain important natural remnants. One of the most significant natural areas is Lane Cove National Park, which covers 6 km^2 (7%) of the catchment.[42] Other significant environmental features include mangrove, NSW Coastal Saltmarsh and Swamp Oak communities.[43]

2.3 Middle Harbour

Middle Harbour is a 12km long tributary of Sydney Harbour, which it meets between Grotto Point and Middle Head.[44] It is perhaps the least modified tributary of Sydney Harbour, having never had a significant role as a commercial port. Instead, it has generally provided for sheltered recreational boating and fishing areas for the adjacent residential suburbs.[45] Nevertheless, some modification has occurred: sand mining within the river took place between 1955 and 1982 near Roseville bridge,[46] and some areas of the estuary have been reclaimed using landfill.[47]

Six LGAs are partially located in Middle Harbour's catchment: Ku-ring-gai; Manly; Mosman; North Sydney; Warringah; and Willoughby. Middle Harbour has the least urbanised catchment (68%), with 21.7km^2 (27%) of the total 77km^2 being undisturbed forest (Table 4). Much of this forest is preserved within Garigal National Park. Other significant environmental features include subtidal reefs, mangroves, seagrass meadows and NSW Coastal Saltmarsh.[48]

2.4 Parramatta River

The Parramatta River is a 19km tributary of Sydney Harbour, which it meets at Balmain. It has several significant tributaries, including the Duck River, Haslams Creek and Iron Cove Creek. The river has been significantly modified since European settlement. Five weirs are situated on the river or one of its

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Geographer, 2000. Vol 31(2), pp.183-208

42 Butler, R., and Jha, S., op. cit.

43 Sydney Metropolitan Catchment Management Authority, op. cit.

44 Manly Council, *Clontarf/Bantry Bay data compilation & estuary processes study*, Final Report, August 2007

45 Godden Mackay, *Sydney and Middle Harbours Heritage Study*, Final Report, Report prepared for NSW Department of Planning, July 1991

46 Souter, G., *Times & Tides: A Middle Harbour Memoir*, 2004. Simon & Schuster, Pymble, 278p.; McLoughlin, L., Shaping Sydney Harbour: sedimentation, dredging and reclamation 1788-1990s, *Australian Geographer*, 2000. Vol 31(2), pp.183-208

47 Birch, G., op. cit.

48 Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p

tributaries.[49] The river has been dredged on a number of occasions, primarily to make the river amenable to industrial activity.[50] Approximately 2.9km^2 of the estuary are estimated to have been reclaimed.[51] This includes the largest reclamation project in Sydney Harbour at Homebush Bay, where land was reclaimed for industrial purposes using, in part, waste materials from a variety of sources.[52]

At 252.4 km^2, the Parramatta River has the largest catchment of the Harbour tributaries. Thirteen LGAs are located at least in part in the catchment: Ashfield; Auburn; Bankstown; Blacktown; Burwood; Canada Bay; The Hills; Holroyd; Hunters Hill; Leichhardt; Parramatta; Ryde; and Strathfield. The river also has the most urbanised catchment, with 86% being classified as disturbed and only 10% as undisturbed forest (Table 4). Important environmental features include mangroves, seagrass meadows, NSW Coastal Saltmarsh, Swamp Oak and Sydney Turpentine-Ironbark Forest communities.

2.5 Port Jackson

Port Jackson is 11km long and the largest part of Sydney Harbour in terms of estuary area (29.1km^2) and volume (376,400ML). Dredging took place throughout most of the 19th and 20th centuries in bays such as Sydney Cove, Darling Harbour and Woolloomooloo Bay, and out to the Heads. Dredged material was often used in reclamation projects in areas including Woolloomooloo Bay, Sydney Cove, Farm Cove, Darling Harbour, White Bay, Blackwattle Bay and Rushcutters Bay. Most of the areas of the estuary which were reclaimed were mudflats, in part because they had become 'unhealthy', having been filled with sewage, dead animals and offal from abattoirs.[53]

Port Jackson has the smallest catchment area (55.7km^2) in the Harbour. Eight LGAs are partially located in its catchment: Leichhardt; Manly; Marrickville; Mosman; North Sydney; Sydney; Waverley; and Woollahra. 82% of the catchment is urbanised. This includes the City of Sydney CBD and significant current and proposed urban development projects such as Barangaroo and the Bays Precinct Urban Renewal Program. Important environmental features include seagrass meadows and subtidal rocky reefs.

2.6 Threats facing the Harbour

In light of a 2014 systematic review of the science on Sydney Harbour, the Sydney Institute for Marine Science (SIMS) identified six key threats to the

[49] Cardno, *Parramatta River Estuary Coastal Zone Management Plan*, Prepared for the Parramatta River Estuary Management Committee, 24 June 2013, 296p

[50] McLoughlin, L., Shaping Sydney Harbour: sedimentation, dredging and reclamation 1788-1990s, *Australian Geographer*, 2000. Vol 31(2), pp.183-208

[51] Cardno, op. cit.

[52] McLoughlin, L., Shaping Sydney Harbour: sedimentation, dredging and reclamation 1788-1990s, *Australian Geographer*, 2000. Vol 31(2), pp.183-208

[53] Ibid.

biodiversity and ecosystems of the Harbour:

- Metalloids, organo-metallic and metallic contamination;
- Nutrients and turbidity;
- Neo biota: non indigenous and novel species in Sydney Harbour;
- Habitat modification;
- Fishing and aquaculture; and
- Climate change.[54]

The first two are discussed in depth in Chapters 6 and 4 respectively; the other four are briefly summarised below. Note that these threats overlap in space and time and act simultaneously. For example:

- Non indigenous species interact with increased metal contamination to reduce the abundance of native species in the Harbour;
- Nutrient enrichment ameliorates the effect of metal contamination. This may be masking potential effects of metals on natural systems above those currently observed; and
- Climate change effects are broad scale and generally synergistic. Increased pH, for example, increases the toxicity of a variety of common contaminants.[55]

Further research is required to understand how these threats may *interact* when impacting Sydney Harbour's natural systems.

2.6.1 Neo biota: non indigenous and novel species in Sydney Harbour

Many non-indigenous species (NIS) have become established in Sydney Harbour, including the tunicate, Pacific oyster and the green alga, *Caulerpa taxifolia*.[56] Several other high profile marine pests, such as the Asian shore clam, Chinese mitten crab and brown mussel, are not yet established in Australia. Singapore, Auckland, Port Villa, Tauranga and Napier are ports from which there is a high likelihood that these or other NIS may be introduced.

The ecological and economic impacts of NIS are poorly understood. Impacts may include competition with native species, modification of habitat and negative effects on sediment and water column properties. Further research is also required into issues like the role of unregulated recreational vessels in

[54] Coastal Zone Management Plans for the Lane Cove River and Parramatta River identify threats particular to those tributaries. A Coastal Zone Management Plan for Middle Harbour and Port Jackson is under development.

[55] Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, p.50

[56] See also: Hedge, L.H. et al., *Sydney Harbour background report 2014*, Report prepared for NSW Department of Primary Industries by the Sydney Harbour Research Program at the Sydney Institute of Marine Science, April 2014, Sydney, 105p

distributing NIS and the local conditions which promote the establishment and spread of these species.

2.6.2 Habitat modification

As noted earlier in this chapter, Sydney Harbour has been extensively modified by reclamation and the construction of artificial structures such as seawalls and marinas. Unfragmented natural shores support greater biodiversity than habitats fragmented by artificial structures. The make-up of flora and fauna populations found on artificial structures is dramatically different to natural habitats. These structures are also home to many non-indigenous species. Further research is required into the effects of habitat modification on biodiversity.

2.6.3 Fishing and aquaculture

Commercial fishing in Sydney Harbour was banned in 2006 due to high levels of dioxins in fish. While data on recreational fishing in NSW is limited, on-site surveys suggest that estuaries in the Sydney region, including Sydney Harbour, experience approximately twice the effort and catch of other estuaries in the State. Data on fishing in Sydney Harbour suggest a relatively healthy fishery, based on catch per effort, but it does have a higher proportion of undersized catch than other estuaries. Several species (mulloway, kingfish and snapper) listed as overfished or 'growth overfished' by the Department of Primary Industries are commonly caught in Sydney.[57] Topics for further research include the impacts of recreational fishing and the impacts of organic pollutants on food webs, including human consumption.

2.6.4 Climate change

According to SIMS, Sydney Harbour is located in a part of the world warming faster than the global average. A number of potential impacts are likely:

- Sea surface temperature rise – a rise of 3 degrees Celsius is predicted in the waters off Sydney by 2070 which could contribute to increasing water temperatures in the estuary;
- Acidification – elevated atmospheric CO_2 concentrations and increased CO_2 dissolution into the surface ocean changes the ocean's chemistry, including by increasing the acidity of the ocean's surface layer;
- Changes in hydrology and ocean circulation – water entering the estuary at the seaward end is becoming warmer as well as less productive, with potential implications for recruitment of organisms into the harbour and other processes;
- Sealevel rise – waters along Australia's eastern seaboard are rising in line with global averages (1.7mm per year); potential impacts include a

[57] Department of Primary Industries, *Status of fisheries resources in NSW 2011-12*, Summary, May 2014, 10p

reduction in saltmarsh habitats; and

- Increased storm surge and severe weather – estuaries with significant coastal infrastructure like Sydney Harbour are at risk of damage from severe weather events. Mangrove and seagrass habitats, which play a role in buffering coastal settlements from erosion, will become more important to maintain.

Topics for future research include harbour organism responses to elevated temperatures and changing temperature dynamics, and ocean and atmospheric linkages that influence coastal oceanography as well as watershed hydrology.

3. HISTORY OF POLLUTION IN SYDNEY HARBOUR

Since European settlement, industry has generally gravitated towards Sydney Harbour for at least one of two reasons: the use of the waterways for transport; or for access to water needed in the industrial process.[58] Together with the progressive urbanisation of the catchment, the spread of industry upriver from central Sydney eventually polluted all parts of the Harbour. This chapter charts the history of pollution in Sydney Harbour, from being a receptacle of sewage, abattoir waste and industrial effluent through to the last few decades when four sources of pollution remain: contaminated sediment in the Harbour; leachate from reclaimed land; stormwater; and sewage overflows.

3.1 1788 to 1860s: Waste receptacle

Sydney Harbour, its tributaries and catchment, were polluted within years of European settlement. At first, the waters of the Harbour were the receptacle of rubbish and sewage, and its banks were stripped of natural cover.[59] Industries sprang up at different points on the Harbour from the 1800s onwards.

In Port Jackson, industries were first established on the banks of Darling Harbour in about 1800. From there, they spread to Cockle, Rozelle and Blackwattle Bays. Metal foundries were the first to be set up, followed closely by tanneries.[60] Whale oil processing was consigned to the north shore of the Port, due to the noxious smell. Other industries located on the north shore that required isolation included a sugar works and distillery, a kerosene refinery, and a wool washing plant.[61]

Balmain and Pyrmont were the peninsulas that hosted the majority of Sydney Harbour's waterfront industry. The onset of heavy metal sediment contamination in Blackwattle Bay occurred between 1866 and 1876 – a period when metal usage in the area rapidly increased.[62] Industries in the area included coppersmiths, paint manufacturers, the first Sydney Gasworks, engineering works, sawmills, breweries, a distillery, coal depots, and a boiling down works.[63] The Glebe Island abattoirs were the biggest water and air polluters in the city. Built in 1860 to replace dozens of unregulated fellmongers, the abattoirs were intended to end the practice of backyard disposal of blood

[58] Godden Mackay, op. cit.

[59] Powell, C., *A River Revived: The Parramatta*, 1987. New South Wales University Press, Kensington, 102p.

[60] Birch, G., op. cit.

[61] Godden Mackay, op. cit.

[62] Taylor, S. et al., Historical catchment changes and temporal impact on the sediment of the receiving basin, Port Jackson, New South Wales, *Australian Journal of Earth Sciences*, 2004. Vol 51(2): 233-246.

[63] Godden Mackay, op. cit.; Coltheart, L., *Between wind & water: A history of the ports and coastal waterways of New South Wales*, 1997. NSW Department of Public Works and Services, Hale & Iremonger, Sydney, 208p.; Hoskins, I., *Sydney Harbour: A history*, 2009. UNSW Press, Sydney, 359p.

and offal down drains and sewers. Not only did it fail to do so, it compounded the problem with its own flood of effluent.[64]

The Lane Cove River and Middle Harbour were relatively unpolluted by the mid-1800s. Agriculture was the primary land use, together with a small timber industry and, in the case of the Lane Cove River, tanneries and small-scale sand mining.[65] In contrast, it appears that the Parramatta River had become significantly polluted; the upper reaches received waste from slaughter-houses, the mental hospital, raw sewage, domestic rubbish, and drainage from farmlands. In 1849, a newspaper report described the river as follows:

> The abominable filthy state of this common cesspool was reported a short time since, and the stubborn facts which were then related in connection with this public and dangerous nuisance are of too filthy a nature to be repeated. The state of the water is such at present as to destroy the fish which are floating ashore to add to the numerous dead bodies, in a state of decomposition, impregnating the air and endangering the health of the inhabitants.[66]

Several attempts were made to address pollution of the Harbour (see Appendix 1 for a timeline of relevant regulatory and parliamentary events). The *Harbours Act 1832* prohibited the disposal from a ship of any ballast, rubbish, gravel, earth, stone, wreck or filth into the Harbour; these materials were only to be disposed of upon land where tidal water never flowed.[67] In the following year, the *Sydney Police Act 1833* prohibited the disposal of filth or rubbish into any watercourse, and any dead animal into any part of Sydney Cove or Darling Harbour, or their foreshores.[68] And in 1849, the *Sydney Slaughter-houses Act 1849* removed polluting industries (tanneries, curriers, soap boilers, tallow melters and tripe boilers) from central Sydney,[69] from which the Harbour benefitted incidentally.[70] Tanneries relocated to Botany, Willoughby and Parramatta.[71]

Despite these attempts, a Commission was appointed in 1865 to inquire into the condition of Port Jackson, with particular regard to the causes of shoaling and the effect produced by disposal of the city's sewerage.[72] The Commission criticized the City Corporation for turning the Harbour into a cesspit due to the

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[64] Hoskins, I., op. cit.

[65] State Pollution Control Commission, *Lane Cove River: The north-west passage*, Paper from Environmental Education Seminar – Man and His Environment, 8 August 1978, 6p.; McLoughlin, L. and Wyatt, M., op. cit.; Souter, G., op. cit.

[66] Quoted in: State Pollution Control Commission, *A River Reviving: Parramatta River*, Papers from Environmental Education Seminar – Man and His Environment, organized by National Trust of Australia (NSW), 20 & 28 April 1979, p.9

[67] Section 2

[68] Sections 13 and 37

[69] Section 7

[70] Powell, C., op. cit.

[71] Taylor, S. et al., op. cit.

[72] Broadbent, J., *Transformations: Ecology of Pyrmont peninsula 1788 – 2008*, 2010. Sydney, 732p.

indiscriminate discharge of sewage:

> In getting rid of the street matter in the cheapest manner, they have found a convenient receptacle in the harbour and have, as it were, converted it into a large cesspit, thus doing enormous injury to that which is the most valuable possession of the citizens.[73]

It recommended the construction of more efficient silt traps and two large subsiding tanks on the main sewer to intercept sand and other solid matter.[74]

3.2 1870s to 1910s: Industrial expansion

Sydney spread rapidly westward between 1870 and 1920. Industry gradually replaced agriculture, taking advantage of large areas of flat land on the southern shores of the Harbour, and multiple transport modes including the river, tramways and railways. By 1900, industries were located along almost all southern shores of the lower Parramatta River. From Iron Cove to Homebush Bay, industries established during this time included chemical industries, metal working, dye use, electrical and glass manufacturing, a large base metal foundry and smelter, and brickworks.[75] Closer to the CBD, while some new industries were founded, such as the White Bay Power Station in the early 1900s,[76] others such as the gasworks moved upriver.[77]

Sewage remained a problem for Port Jackson and the Parramatta River during this period. In 1877, it was reported that sewers had deposited “all the filth of the city in the harbour, rendering all business occupations upon its shores disgustingly offensive”.[78] In 1892, Hen and Chicken Bay was described as a “cess pan for the drainage of Burwood and Croydon”,[79] and four years later the Engineer-in-Chief of the Public Works Department described the river near Parramatta in the following terms:

> The wind at the time caused filthy scum to accumulate in large quantities on the surface of the water. Moreover, putrid matter had been deposited along the bank so that with the nauseous scum and black filthy deposit, it is scarcely possible to imagine anything worse. Fermentation then takes place under the action of the sun and noxious gases are emitted which must be most injurious

[73] Commission appointed to inquire into the condition of the harbour of Port Jackson, Report into the Condition of the Harbour of Port Jackson, 19 April 1866, p.8; quoted in Hoskins, I., op. cit., p.177

[74] Borchardt, D., *Checklist of Royal Commissions, Select Committees of Parliament and Boards of Inquiry*, Part IV New South Wales 1855 – 1960, 1975, 394p.

[75] Department of Environment and Planning, *Parramatta River Regional Environmental Study: Open Space and Recreation, Heritage Study*, 1986, Sydney, 161p.; Taylor, S. et al., op. cit.; Birch, G., op. cit.

[76] Broadbent, J., op. cit.

[77] Hoskins, I., op. cit.

[78] Quoted in: Broadbent, J., op. cit., p.444

[79] Quoted in: Powell, C., op. cit., p.37

to the health.[80]

The impacts of sewage disposal on the Harbour were compounded by the continued operation of the Glebe Island Abattoirs. Algal blooms and toxic fish kills were common, and Blackwattle Bay was described as being coloured 'blood red'.[81]

Five inquiries were held between 1875 and 1887 on sewage and/or the abattoirs and their impacts (see Appendix 1). While recommendations on managing and limiting sewage disposal in the Harbour were made by the 1875 inquiry,[82] it wasn't until 1889 that the central city was connected to the Bondi Ocean Outfall. Balmain, Annandale, Leichhardt and Glebe were soon added, and the suburbs between Haberfield and Lidcombe were progressively added to the Southern (Malabar) System after its completion in 1889. Parramatta built a septic-tank system in 1910.[83]

The sewage problem was not immediately resolved upon connection of the city to the Bondi Ocean Outfall. Sydney's bubonic plague of 1899-1900 was caused in part by "raw sewage running into the bay at Darling Harbour".[84] The Sydney Harbour Trust was established under the *Sydney Harbour Trust Act 1901* to prevent the plague re-occurring. The Act also prohibited the disposal of any rubbish, earth, ashes, dirt, mud, soil, or offensive matter into the port or upon its shores.[85]

A series of newspaper exposés in 1879 led to the first parliamentary inquiry into the Glebe Island abattoirs.[86] This inquiry recommended improved management of the abattoirs; 1882 and 1887 inquiries recommended its removal further from the city.[87] In 1916, the abattoirs were moved to Homebush.[88]

The Lane Cove River and Middle Harbour were gradually exposed to more pollution during this period, in part due to increased urbanisation. Between 1902 and 1918, concentrations of heavy metals began to increase in the Lane Cove

[80] Quoted in: State Pollution Control Commission, *A River Reviving: Parramatta River*, Papers from Environmental Education Seminar – Man and His Environment, organized by National Trust of Australia (NSW), 20 & 28 April 1979, p.9

[81] Hoskins, I., op. cit.; Broadbent, J., op. cit.

[82] Borchardt, D., op. cit.

[83] State Pollution Control Commission, *A River Reviving: Parramatta River*, Papers from Environmental Education Seminar – Man and His Environment, organized by National Trust of Australia (NSW), 20 & 28 April 1979, 12p.

[84] Andrews, G., *Port Jackson 200*, 1986, Frenchs Forest, Reed, p.72, quoted in: Broadbent, J., op. cit., p.556

[85] Section 86. The note attached to this section in the Act states that the section provides for penalties "on throwing ballast out of vessels into the port", rather than dealing with all pollution sources.

[86] Hoskins, I., op. cit.

[87] Borchardt, D., op. cit.

[88] Birch, G., op. cit.

River.[89] Boiling down works, a bone mill, a corn/starch factory and tanneries were operating in the catchment by this time.[90]

Heavy metal contaminants in Middle Harbour sediments are present in the earliest available samples, dated at 1907.[91] Together with sewage farms, industries such as tanneries, an abattoir, plaster works, boiling down works, and other factories were established from 1876 onwards. Tips were also set up adjacent to waterways, from which leachate carried contaminants into the Harbour.[92]

3.3 1920s to 1960s: The forgotten river

Up until the 1920s, the Parramatta River used to be a popular holiday destination. It had also been a significant transport corridor. In 1928, ferry services ceased beyond Hunters Hill. These changes were due in part to technological and social changes, and in part to industrial pollution. While newspaper articles describing the polluted state of the river began to appear regularly during the 1930s, the Department of Environment and Planning argues that it henceforth became 'The Forgotten River':

> … little attention was paid to the River despite, or perhaps because of, increasing pollution which continued to degrade its quality. Running through the heart of the metropolis the river disappeared from the public mind until the effects of pollution could no longer be ignored.[93]

In the 1940s, the *Sydney Morning Herald* published no articles on the river. Media coverage increased during the 1950s and 1960s, and in 1972-73 the *Sydney Morning Herald* published a series of articles on 'The Forgotten River'.[94]

During this period, sewage disposal in the Harbour gradually declined with the completion of the Northern Suburbs Ocean Outfall Sewer out to Parramatta in 1930; all suburbs on the southern side were connected to ocean outfalls by the 1950s.[95] However, industrial pollution of the Harbour increased substantially. Between the World Wars, large-scale manufacturing of heavy electrical equipment, large oil refineries and power supply stations were constructed

[89] Taylor, S. et al., op. cit.

[90] McLoughlin, L., Mangroves and grass swamps: changes in the shoreline vegetation of the Middle Lane Cove River, Sydney, 1780's – 1880's, *Wetlands (Australia)*, 1987, Vol 7(1): 13-24.; Patterson Britton & Partners Pty Ltd in association with W.S. Rooney & Associates, *Lane Cove River Estuary Processes Study*, Report for Lane Cove Council, Hunters Hill Council, Ryde City Council, Willoughby Council and the Department of Land and Water Conservation, October 2000, 103p.

[91] Taylor, S. et al., op. cit.

[92] Souter, G., op. cit.; Taylor, S. et al., op. cit.

[93] Department of Environment and Planning, op. cit., p.43

[94] Ibid., 161p.

[95] State Pollution Control Commission, *A River Reviving: Parramatta River*, Papers from Environmental Education Seminar – Man and His Environment, organized by National Trust of Australia (NSW), 20 & 28 April 1979, 12p.

close to the estuary, primarily along the Parramatta River.[96] Companies included Shell, Plessey, Petroleum and Chemical Corporation (PACCAL), James Hardie and Orica. Timbrol (which later became Union Carbide), the primary source of the dioxins now contaminating the Harbour, commenced operations in 1928.[97]

The waters of the Parramatta River offered a no cost waste disposal solution, a key incentive that drew and retained industries in the area.[98] Attempts were made to address pollution of the River in the 1940s and 1950s. The Pollution of Navigable Waters Regulations 1941[99] prohibited the dumping of animals into any navigable waterways or on their shores and the disposal of 'refuse matter', by owners or occupants of industrial establishments, into navigable waterways near a city, town or municipality.[100] These were replaced by the Navigable Waters (Anti-Pollution) Regulations 1955. The regulations prohibited disposal of any inflammable liquid, dangerous goods, oil, tar, liquid derived from petroleum, shale or coal, or any toxic substance including pesticides.[101] Maximum effluent standards were set for biochemical oxygen demand, acidity, alkalinity, sulphur, ammonia and heavy metal concentrations.[102] The Maritime Services Board could set stricter standards[103] or relax the standards.[104] Standards could be relaxed if they could only be implemented with the utmost difficulty or at inordinate inconvenience and expense, or if the waterway would not be unduly affected, after taking into consideration the comfort, convenience and health of water users and any potential environmental impact.[105]

These regulations appear to have had little effect on minimising industrial effluent entering the Harbour. Heavy metal concentrations in the sediment of Parramatta River generally reached maximum concentrations by approximately 1970, after which they gradually declined.[106] Media coverage gradually revived interest in the River. According to media reports, in the 1950s thick black sludge blanketed ten miles of the foreshore and in the 1960s the river was covered with green slime. Fishing was prohibited above Gladesville in 1951, fish kills were reported during the 1950s and 1960s, and swimming in the River became dangerous to human health.[107] Although the waters of the River were declared

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[96] Birch, G., op. cit.

[97] Powell, C., op. cit.; Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW.

[98] Beder, S., *From pipe dreams to tunnel vision: engineering decision-making and Sydney's sewerage system*, unpublished PhD Thesis, 1989, University of New South Wales, 423p.

[99] *NSW Government Gazette*, 24 December 1941, p.4450

[100] Provision for regulations of this sort were included in the *Navigation Act 1901* as made.

[101] Clause 3(1)(a)

[102] Clause 3(3)

[103] Clause 4

[104] Clause 7

[105] Clause 7

[106] Taylor, S. et al., op. cit.

[107] Powell, C., op. cit.; Beder, S., op. cit.

to be 'virtually dead',[108] a Maritime Services Board spokesman:

> … emphasised the need for being realistic. He had argued that [the] Maritime Services Board couldn't expect businesses to shut their factories and send their workers home just because they were putting some pollutants in the water.[109]

Pollutants entering the Parramatta River during this period included heavy metals, petroleum hydrocarbons, asbestos, chlorinated pesticides, chlorinated benzenes, polycyclic aromatic hydrocarbons and dioxins. Some of these entered the Harbour waters directly as effluent; others via leachate from land reclaimed using contaminated materials and tips sited next to the estuary.[110]

Pollution of Middle Harbour and the Lane Cove River also substantially increased between the 1920s and 1960s. Tips were located in or adjacent to minor tributaries, via which leachate carried pollutants directly into the Harbour and River.[111] The construction of a weir on the Lane Cove River in 1938 exacerbated the effect of pollution from tips, industry and sewage; severe and persistent deoxygenation resulted in frequent fish kills and hydrogen sulphide (rotten egg) gas blackened metal and lead paintwork on nearby homes. Redirection of industrial effluent to the sewerage system helped ameliorate these problems.[112]

3.4 1970 to present: A river reviving

In May 1968, a Senate Select committee began an investigation into water pollution across Australia.[113] Completed in June 1970, their report drew further attention to the polluted state of the nation's rivers, finding that some waterways were so bad that they could no longer be used except as sewers. Three main causes of pollution were identified: sewage, industrial effluents and salinity. The Senate Select committee criticised the regulation of water pollution, arguing that it bordered on the chaotic.[114] The report was followed by a spate of State legislation, including the NSW *Clean Waters Act 1970*.[115]

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[108] Department of Environment and Planning, op. cit., p.72

[109] Beder, S., op. cit., p.173

[110] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW.; Blaxell, G., *The River: Sydney Cove to Parramatta*, 2004, Eastwood, Brush Farm Historical Society, 294p.; Suh, J-Y. et al., Spatial distribution and source of heavy metals in reclaimed lands of Homebush Bay: the venue of the 2000 Olympic Games, Sydney, New South Wales, *Australian Journal of Earth Sciences*, 2004, Vol 51(1): 53-66

[111] Sinclair Knight Merz, *Lane Cove River estuary data compilation study*, for the Lane Cove River Estuary Management Committee, November 1997, 59p.; Souter, G., op. cit.

[112] State Pollution Control Commission, *Interim report on the impact of wet-weather conditions on the quality of waters in Lane Cove River*, 1977, Sydney, 55p.; McLoughlin, L. and Wyatt, M., op. cit.

[113] Staib, R., *Solving major pollution problems: a new process model*, unpublished PhD Thesis, 1997, Macquarie University, Graduate School of the Environment, 189p.

[114] Beder, S., op. cit.

[115] Wegner, J., Sludge on tap: Queensland's first water pollution legislation, 1944-1985,

Under development throughout the 1960s, the *Clean Waters Act 1970* came into force at the end of 1972 together with its regulations. It was administered by the State Pollution Control Commission (SPCC), which was established in June 1971.[116] At first, a waterway had to be classified by the Clean Waters Advisory Committee before a licence could be issued regulating disposal of pollution into the waterway. Prior to classification, disposal of pollutants into a waterway was not prohibited. This changed in 1975 with new regulations which made it an offence to discharge wastes into waters without a licence whether or not those waters were classified.[117] It has been argued that initial implementation of the legislation and administrative structure was compromised; the government of the day:

> … in aiming to clean up waterways without harming industry, was careful to minimise the economic penalty that would be suffered by industry and was unwilling to set down hard and fast standards for effluents that industries might not be able to meet using cheap and readily available technologies.[118]

While implementation of the Clean Waters Act forced some industries to install rudimentary pretreatment equipment, the primary accomplishment was to divert industrial wastes from Sydney Harbour into the ocean via the sewerage system.[119]

According to the State Pollution Control Commission, before 1970 there were approximately 210 sites from which poorly-treated or untreated industrial wastewater was discharged into the Parramatta River. By 1985, this number had fallen to 19 licensed sites. Disposal of untreated wastes into Port Jackson was eliminated or controlled and only three licensed discharges into the Lane Cove River remained. Water quality in Middle Harbour improved as septic tanks were replaced by reticulated sewerage.[120] In order to compel industry to recycle waste or relocate away from the River, the SPCC usually withdrew licences for discharge into the Harbour as they came up for review.[121]

Beginning in 1985, a number of investigations were made concerning pollution in Homebush Bay – one of the most contaminated parts of Sydney Harbour. Homebush Bay was the site of a significant amount of industry and the largest reclamation project in the Harbour. Of the 11.35km^2 of the Harbour reclaimed, just under a third (3.72 km^2) are located at Homebush Bay.

Environment and History, 2009, Vol 15(2): 199-216

[116] The State Pollution Control Commission was established under the *State Pollution Control Commission Act 1970*.

[117] Beder, S., op. cit.

[118] Ibid., p.205

[119] Ibid. Over 6,000 factories were connected to the sewerage system between 1972 and 1978.

[120] State Pollution Control Commission, *Pollution control in Sydney's waterways*, 1986, 4p.

[121] State Pollution Control Commission, *A River Reviving: Parramatta River*, Papers from Environmental Education Seminar – Man and His Environment, organized by National Trust of Australia (NSW), 20 & 28 April 1979, 12p.

Two large scale clean-ups of the land and/or sediment around Homebush Bay have been undertaken in the past twenty years, at Olympic Park and on the Rhodes peninsula adjacent to Homebush Bay. The clean-up of Olympic Park prior to the 2000 Sydney Olympics dealt with 400 tonnes of hazardous waste, which included heavy metals, asbestos, dioxins, and organochlorine pesticides. At a cost of $137 million, it was one of the largest remediation projects carried out in Australia.[122] 82,000 tonnes of material were treated in the remediation of the Rhodes peninsula, extracted from approximately 900,000 tonnes of soil and 50,000 tonnes of sediment from Homebush Bay.[123] A similar set of pollutants were found on the Rhodes peninsula.[124]

Since the introduction of the *Clean Waters Act 1970*, water quality in Sydney Harbour has improved markedly. Industrial effluents have been eliminated as a source of pollution. However, four other sources of pollution remain: contaminated sediment in the Harbour; leachate from reclaimed land; stormwater; and sewage overflows.[125]

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[122] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

[123] Thiess Services, *Former Lednez/Union Carbide site & Homebush Bay remediation*, no date [online – accessed 19 December 2014]

[124] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW.

[125] State Pollution Control Commission, *A River Reviving: Parramatta River*, Papers from Environmental Education Seminar – Man and His Environment, organized by National Trust of Australia (NSW), 20 & 28 April 1979, 12p.; Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

PART TWO – POLLUTION IN SYDNEY HARBOUR

Sydney Harbour has been significantly affected by human activities. A 2014 study of 38 NSW estuaries within 300km of the Sydney CBD categorised the Harbour as one of four 'severely modified' estuaries.[126] The five chapters in part two of this paper set out the contemporary picture of pollution in Sydney Harbour, showing in many cases how Sydney Harbour is not only one of the most polluted estuaries in Australia but also on an international scale. Water quality issues are dealt with briefly in the first chapter. Chapters 5 to 7 deal with some of the key pollutants of concern: dioxins; heavy metals; and microplastics. The last chapter presents a report card on the state of Sydney Harbour.

4. WATER QUALITY

Water quality parameters can be divided between those which have direct toxic effects on animals and plants (e.g. pesticides and heavy metals) and those that indirectly affect ecosystems causing a problem for a specified environmental value (e.g. nutrients, turbidity and enrichment with organic matter).[127] This section briefly deals with the following parameters:

- Dissolved oxygen;
- Total nitrogen;
- Total phosphorus;
- Enterococci;
- Chlorophyll-a; and
- Total suspended solids (TSS).[128]

Where possible, the data on these parameters are compared with ANZECC (2000) guidelines for water quality.

4.1 Sydney Water data

A 2011 report averaged Sydney Water data for several parameters at different sites in Sydney Harbour (Figures 5 to 9). The averaged data covered the time period of 2005 to 2008 for every site except Lane Cove Weir and Parramatta Weir, for which data was available up to 2011. Listed by sub-catchment, the

[126] The other three estuaries were the Cooks River, Curl Curl Lagoon and Manly Lagoon. Factors used in categorising the estuaries included the amount of key heavy metals in the catchment and their potential toxicity, the amount of the catchment that was urbanised, and population density. Gunns, T., *The development and implementation of a hierarchical assessment scheme for the management of estuaries in New South Wales*, unpublished Masters Thesis, University of Sydney, 2014, 115p.

[127] ANZECC & ARMCANZ, *Australian and New Zealand guidelines for fresh and marine water quality*, Volume 1 – The guidelines, National Water Quality Management Strategy Paper No.4, October 2000, 314pp.

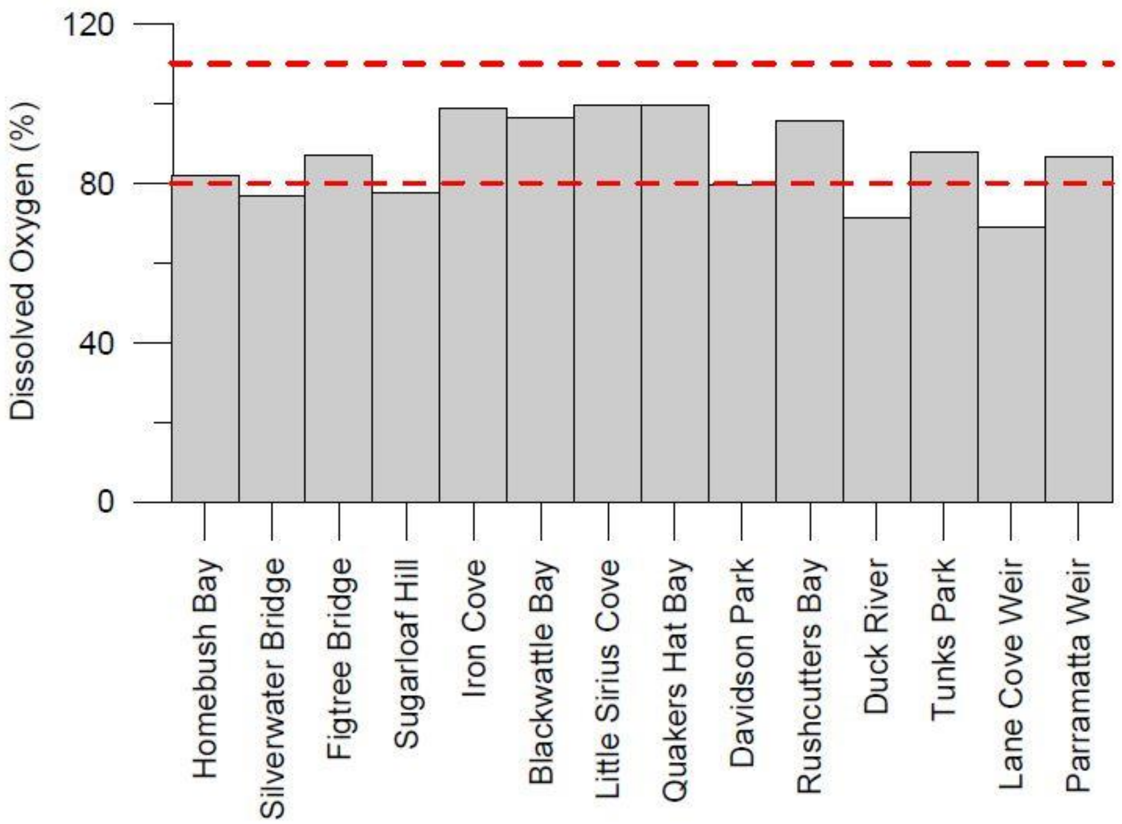
[128] Note that these parameters are used, together with other indicators, to put together the Sydney Harbour report card in chapter 8 of this paper

sites are as follows:

- Lane Cove River – Figtree Bridge, Sugarloaf Hill, Lane Cove Weir;
- Middle Harbour – Quakers Hat Bay, Davidson Park, Tunks Park;
- Parramatta River – Homebush Bay, Silverwater Bridge, Iron Cove, Duck River, Parramatta Weir; and
- Port Jackson – Blackwattle Bay, Little Sirius Cove, Rushcutters Bay.

Low levels of dissolved oxygen have an adverse effect on aquatic organisms which depend on dissolved oxygen for efficient functioning. It may also produce conditions that cause sediments to release previously-bound nutrients and toxicants into the water column.[129] All sites in Port Jackson had good levels of dissolved oxygen (Figure 5), while the other three sub-catchments had at least one site with dissolved oxygen levels below or just on the lower ANZECC (2000) guideline.

Figure 5: Average dissolved oxygen saturation for selected sites in Sydney Harbour compared to upper and lower ANZECC (2000) guidelines[130]

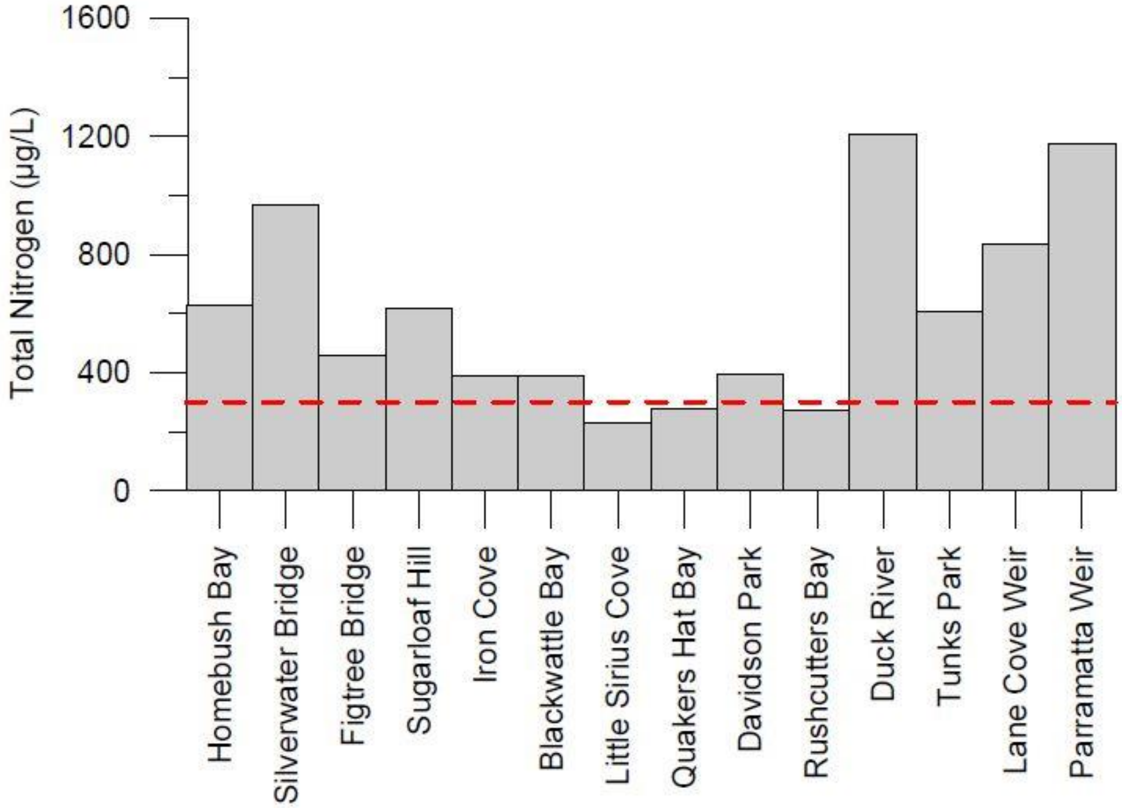


High levels of nutrients, particularly nitrogen and phosphorus, can result in

[129] ANZECC & ARMCANZ, op. cit.
[130] Raynor, D. et al., op. cit., p.25

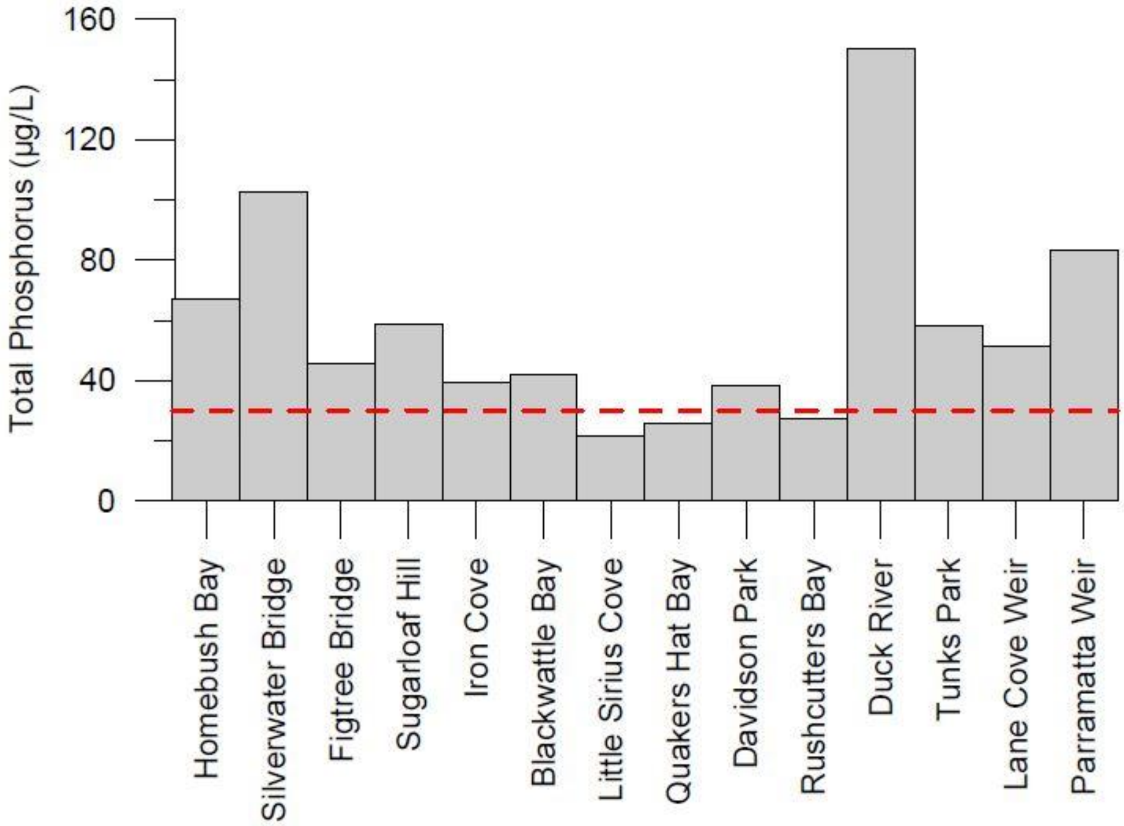
excessive growth of aquatic plants. This may lead to problems such as toxic effects, reduction in dissolved oxygen, and changes in biodiversity.[131] The ANZECC (2000) guideline of 300 micrograms per litre (µg/L) was exceeded on average by every site in Sydney Harbour bar three – Little Sirius Cove and Rushcutters Bay in Port Jackson, and Quakers Hat Bay in Middle Harbour (Figure 6). The worst sites were in the Parramatta River – Silverwater Bridge, Duck River and Parramatta Weir. This pattern of compliance with guidelines and the worst performing sites was repeated for total phosphorus, chlorophyll-a and enterococci counts (Figures 7 to 9), except in the case of chlorophyll-a where Lane Cove Weir was slightly worse than the Duck River (Figure 8).

Figure 6: Average total nitrogen concentration for selected sites in Sydney Harbour compared to ANZECC (2000) guidelines[132]



[131] ANZECC & ARMCANZ, op. cit.
[132] Raynor, D. et al., op. cit., p.28

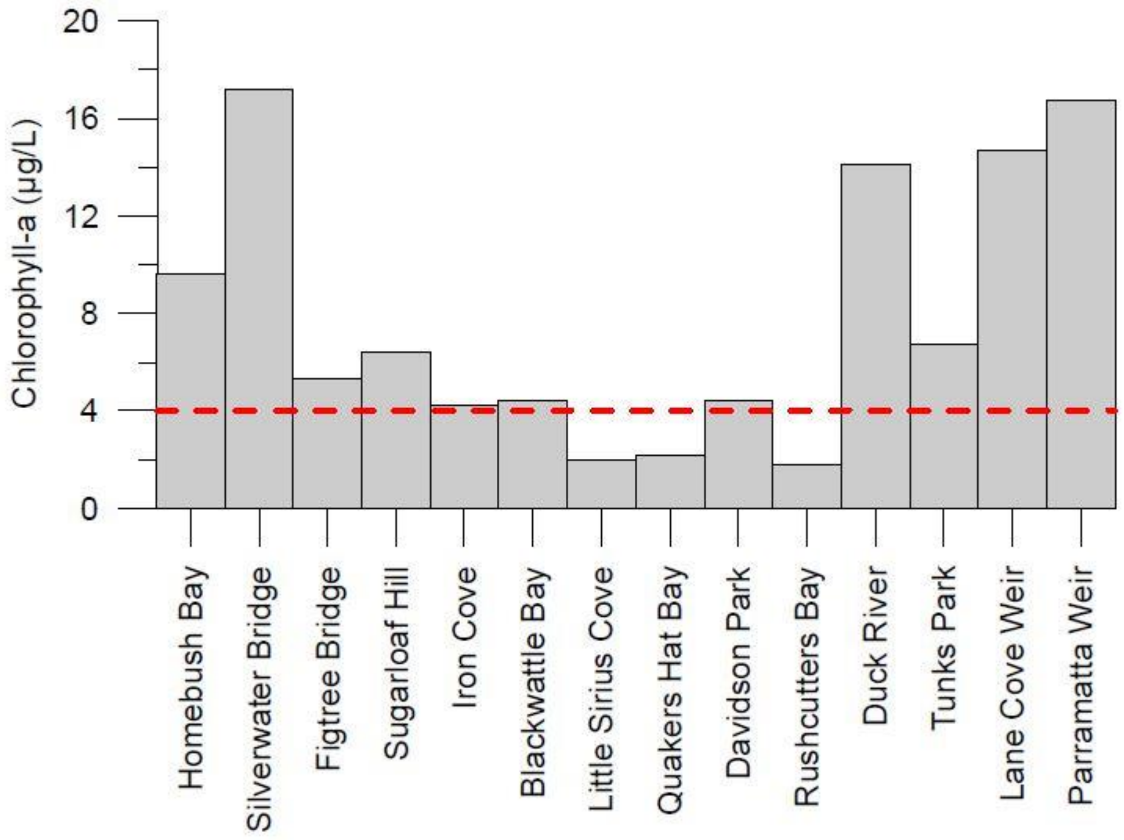
Figure 7: Average total phosphorus for selected sites in Sydney Harbour compared to ANZECC (2000) guidelines[133]



Chlorophyll-a is a general indicator of plant biomass. Increased levels of chlorophyll-a may indicate excessive growth of aquatic plants. On average, sites in Sydney Harbour generally exceeded the ANZECC (2000) guideline of 4 micrograms per litre (µg/L) (Figure 8).

133 Ibid., p.29

Figure 8: Average chlorophyll-a concentration for selected sites in Sydney Harbour compared to ANZECC (2000) guidelines[134]

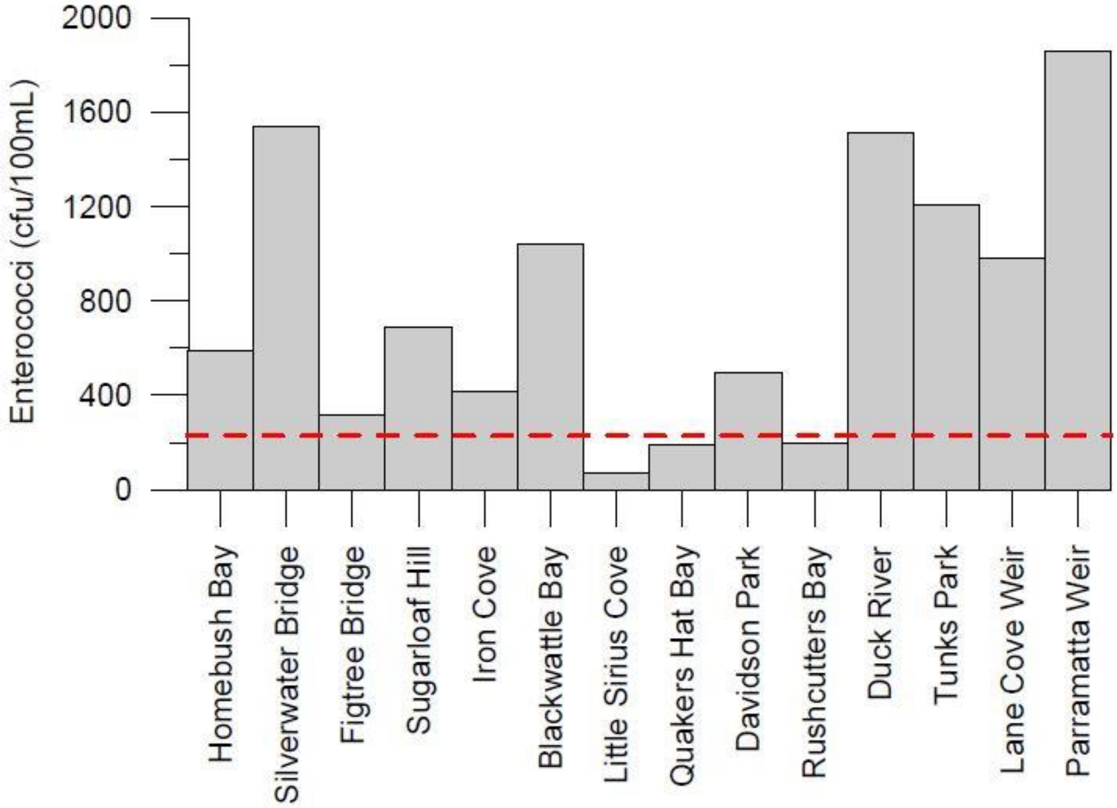


The World Health Organization recommends the use of enterococci as the single preferred faecal indicator in marine waters. These bacteria are excreted in faeces and are rarely present in unpolluted waters.[135] All but three sites in Sydney Harbour exceeded the ANZECC (2000) guideline of 230 colony forming units per 100mL (cfu/100mL) for secondary contact, where secondary contact refers to sports that generally have less-frequent body contact with water, for example, boating or fishing. Primary contact refers to sports where the user comes into frequent contact with water, such as swimming or surfing. The ANZECC (2000) guideline for primary contact is 35 cfu/100mL.

[134] Ibid., p.31

[135] National Health and Medical Research Council, *Guidelines for managing risks in recreational water*, February 2008, 215pp.; NSW Office of Environment & Heritage, *State of the Beaches 2013-14 – Summary and how to read this report*, October 2014, 21pp.

Figure 9: Average enterococci count for selected sites in Sydney Harbour compared to ANZECC (2000) guidelines[136]



4.2 Water quality at Sydney Harbour beaches

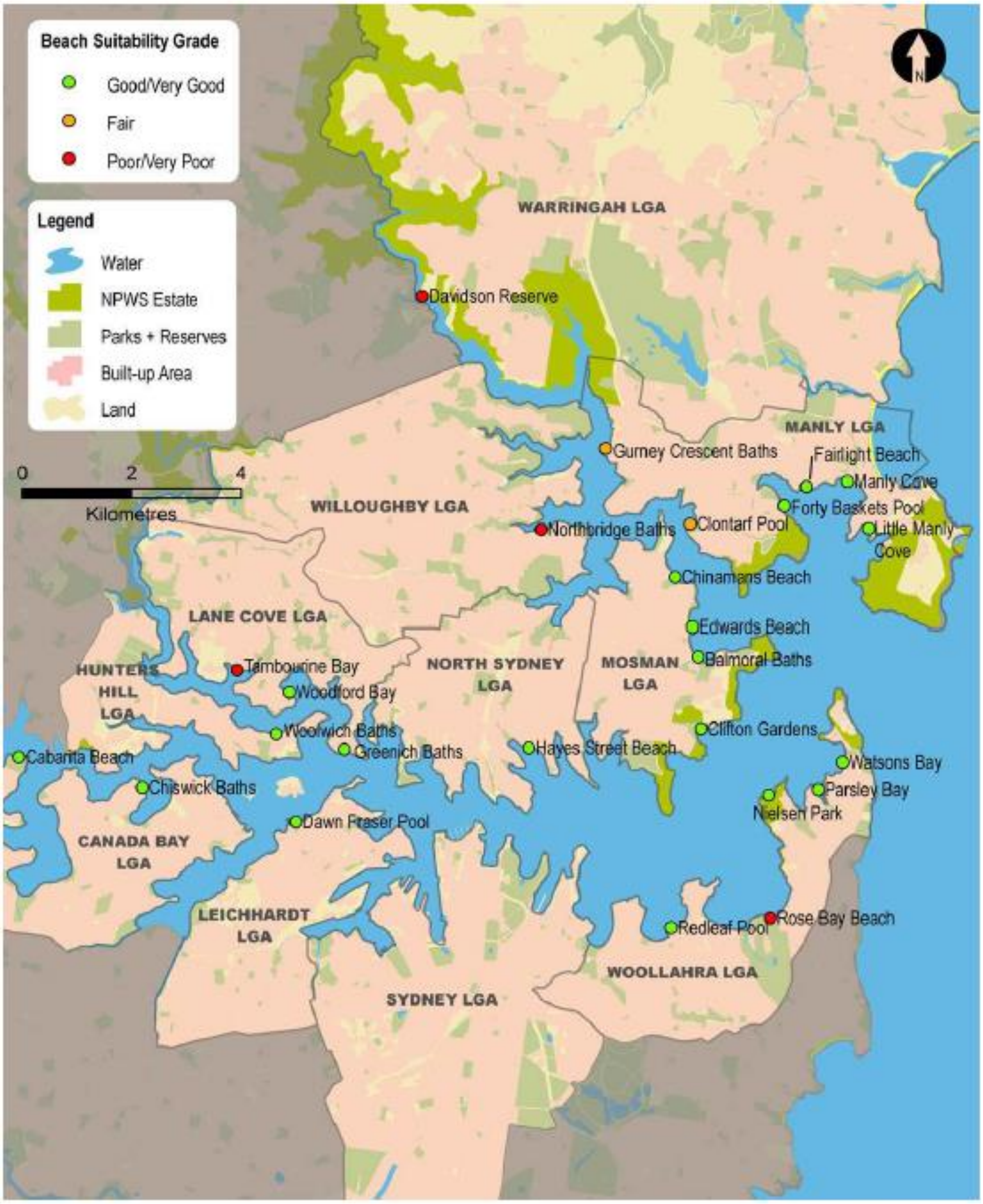
Enterococci counts are also monitored by the NSW Office of Environment & Heritage, the results of which are presented in the annual State of the Beaches report. The report grades beaches from very good to very poor based on a combination of sanitary inspection (identification and rating of potential pollution sources at a beach) and microbial assessment (water quality measurements gathered over previous years). The microbial assessment uses four categories:

- Category A: ≤40 cfu/100mL
- Category B: 40-200 cfu/100mL
- Category C: 201-500 cfu/100mL
- Category D: >500 cfu/mL.[137]

[136] Raynor, D. et al., op. cit., p.30. Note that the data included in this figure is all post-2005, while the other data dates back to 1995. The report authors only included post-2005 data for enterococci counts in order to present likely “existing” conditions. This is because Sydney Water Corporation implemented a Sewer Fix program in 2001 (see page 32 of the report).

[137] NSW Office of Environment & Heritage, *State of the Beaches 2013-14 – Sydney Region New South Wales*, October 2014, p.117

Figure 10: Sampling sites and Beach Suitability Grades in Sydney Harbour[138]



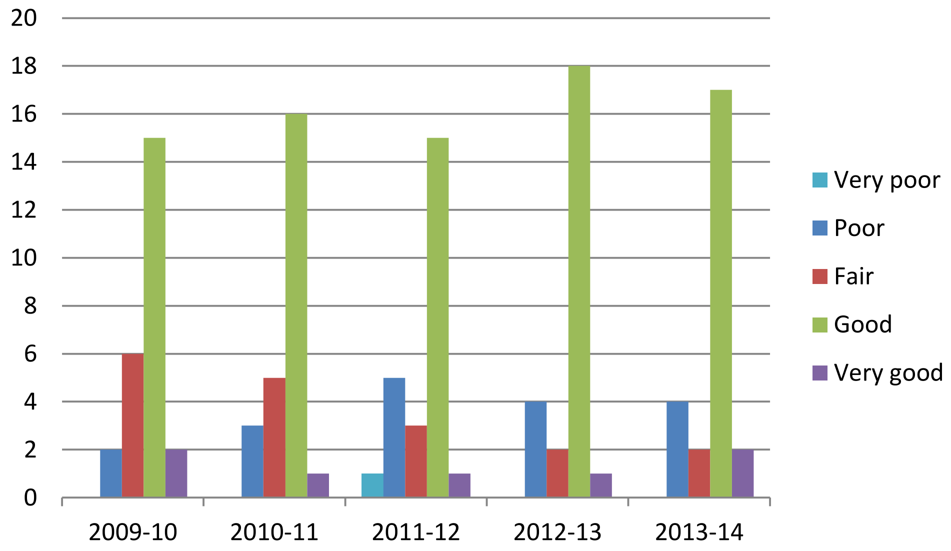
In 2013-14, of 25 swimming locations in Sydney Harbour, 2 were rated very good (Nielsen Park and Watsons Bay), 17 were good, 2 were fair and 4 were poor (Figure 10). The report notes that, as a precaution, swimming should be avoided at Sydney Harbour swimming sites during and for up to three days following rainfall or if there are signs of stormwater pollution such as discoloured water or floating debris. Sources of enterococci include boats, stormwater,

138 Ibid., p.45

sewage overflows, toilet facilities and bathers.[139] Recent research has found that sewage overflows are a relatively small source, contributing approximately 2% of total enterococci despite there being over 550 sewer overflows located across the catchment.[140]

Since 2009-10, grades for the quality of Sydney Harbour beaches have improved slightly (Figure 11). In 2009-10, 68% of beaches were graded good or very good; this rose to 76% in 2012-13 and 2013-14.

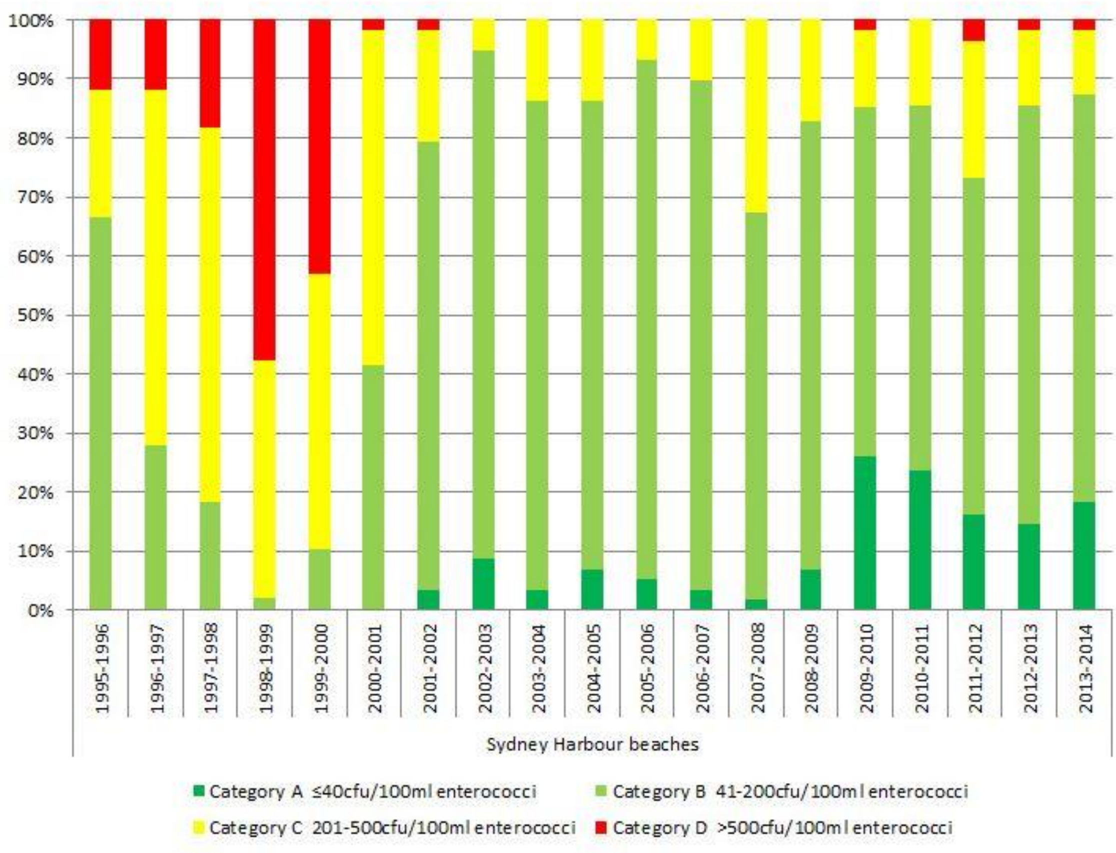
Figure 11: Beach grades for Sydney Harbour: 2009-10 to 2013-14[141]



While not directly comparable to Figure 11, Figure 12 demonstrates that faecal contamination of Sydney Harbour has improved in the last 20 years, with a marked improvement from 2001-02 onwards.

139 Ibid.
140 Freewater, P. et al., op. cit.
141 Sources: State of the Beaches annual reports 2009-10 to 2013-14

Figure 12: Historical trends in water quality for Sydney Harbour beaches[142]



The beaches covered by the State of the Beaches reports do not include most beaches in the Parramatta River. At the end of 2014, the Parramatta River Catchment Group launched its Our Living River campaign. The mission is to make the Parramatta River swimmable again by 2025 (Figure 13). As of the end of 2014, swimming was not recommended at the majority of beaches on the Parramatta River.

142 NSW Office of Environment & Heritage, *Historical trends in water quality*, 26 February 2015 [online – accessed 9 March 2015]

Figure 13: Swimming in the Parramatta River[143]

4.3 Nutrients and total suspended solids in stormwater entering the Harbour

Research published in 2010 modelled the amount of nutrients and suspended sediment entering Sydney Harbour. On average, every year 475 tonnes of total nitrogen, 63.5 tonnes of total phosphorus and 34,300 tonnes of total suspended solids enter Sydney Harbour via stormwater.[144] This is equivalent to a rate of kg per km^2 per year of 990, 132 and 71,384 respectively (Table 5). Sydney Harbour has substantially higher nutrient yields than other Australian urban areas, most probably due to the high level of urbanisation (86%). Sydney Harbour generally receives less nutrients per year than catchments in Europe and the USA.

[143] Parramatta River Catchment Group, *Locations*, 2014 [online – accessed 21 January 2015]

[144] Birch, G. et al., Modelling nutrient loads to Sydney estuary (Australia), *Environmental Monitoring & Assessment*, 2010, Vol 167(1-4): 333-348

Table 5: Nutrient and total suspended solids entering Sydney Harbour, comparison with Australian and international catchments[145]

Catchment	Total nitrogen yield (kg/km/year)	Total phosphorus yield (kg/km/year)	Total suspended solids (kg/km/year)	% of catchment developed
Australian estuaries				
Sydney Harbour	990	132	71,384	86
Port Phillip Bay	282/289*	65/53*	na	11
Botany Bay	460	49	na	40
Regional zones				
North Sea	1,450	117	na	na
NW Europe	1,300	101	na	na
NE coast USA	1,070	139	na	na
NE Canadian	76	4.5	na	na
47 Danish estuaries	2,400	112	na	10
Selected international estuaries				
River Tamar, UK	3,890	140	na	minor
Charlotte Harbour, USA	230	na	na	7
Isle of Wight Bay, USA	740	na	na	52
Neuse, USA	1,950	211	na	9
St Martin River, USA	3,400	na	na	na
Scheldt, France	17,220	na	na	46

* The two Port Phillip Bay figures have been sourced from two different studies.

Most pristine catchments are considered to have a total nitrogen (TN) yield of 80–200 kg/km/year, moderately modified catchments have 500–2,000 kg/km/year and heavily influenced catchment have >10,000 kg/km/year, whereas the average total phosphorus (TP) yield for the UK is 152 kg/km/year. Sydney Harbour is therefore moderately influenced by TN discharge and receives a below average TP discharge.[146]

Nutrient load into Sydney Harbour was divided into three categories according to rainfall levels: base flow (<5 mm per day); moderate flow (5-50 mm per day); and high flow (>50 mm per day). The majority (60%) of the annual pollutant load is delivered during moderate flow conditions (5-50 mm per day), and only 2% of the annual load enters the Harbour during base flow conditions (<5 mm per day).[147]

[145] Table adapted from: Ibid. p.344
[146] Ibid.
[147] Ibid.

5. DIOXINS

5.1 What are dioxins? Types, measurement, toxicity and sources

The name “dioxins” often refers to three families of compounds, the first two of which are structurally and chemically related:

- Polychlorinated dibenzo-*p*-dioxins (PCDDs or dioxins);
- Polychlorinated dibenzofurans (PCDFs or furans); and
- Certain dioxin-like polychlorinated biphenyls (PCBs) with toxic properties similar to dioxins.

Each of these three families of compounds has a number of variants, or congeners – chemical substances related to each other by origin, structure or function. PCDDs consist of 75 congeners, of which 7 have high toxic potential; PCDFs consist of 135 congeners, of which 10 have high toxic potential; and PCBs consist of 209 congeners, 12 of which have high toxic potential.[148] The most toxic of these, and one of the most toxic chemicals ever tested, is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD).[149]

2,3,7,8-TCDD is used as a toxicity reference compound, being given a toxicity value of 1. The other 28 toxic dioxins are each assigned a toxicity value relative to that of 2,3,7,8-TCDD. This allows for combinations of dioxins in seafood, sediment or water to be expressed in a single toxicity value, the 2,3,7,8-TCDD Toxicity Equivalence Concentration (TEQ).[150] TEQs have been through several iterations. Prior to 1998, toxic equivalence was expressed using criteria from the North Atlantic Treaty Organization and Committee on the Challenges of Modern Society (NATO/CCMS) toxicity factors (I-TEQ). After 1998, the World Health Organization toxicity factors have generally been adopted (WHO-TEQ). The WHO-TEQ changed the toxicity value of 4 of the 17 PCDDs (dioxins) and PCDFs (furans), and took into account the toxicity of the 12 dioxin-like PCBs.[151] 2 of the PCDDs with modified toxicity values comprise a substantial proportion of the dioxins found in Sydney Harbour – 1,2,3,4,6,7,8,9 octachlorodibenzo-*p*-

[148] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308; World Health Organization, *Dioxins and their effects on human health*, Fact sheet N^{o}225, Updated June 2014, [online – accessed 23 January 2015]

[149] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

[150] Gatehouse, R., *Ecological risk assessment of dioxins in Australia*, National Dioxins Program Technical Report No. 11, Australian Government Department of the Environment and Heritage, 2004, Canberra, 146p.

[151] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 5 – Detailed human health and ecological risk assessment of Homebush Bay sediments*, December 2002, Rhodes, NSW, p.97

dioxin (OCDD) and 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin (HpCDD).[152] Their toxicity values were revised downwards from 0.001 to 0.0001 and 0.1 to 0.01 respectively. A 2005 updated version of the WHO-TEQ slightly modified the toxicity value of 14 of the 29 dioxins. In this paper, all TEQ values are 1998 WHO-TEQ values unless otherwise stated.

Dioxins are one of 23 persistent organic pollutants (POPs) listed in the 2001 Stockholm Convention to which Australia is a signatory. Others include chemicals also found in Sydney Harbour such as DDT (see further chapter 6.2 of this paper). Dioxins are listed under Annex C of the Convention, under which signatories are required to take measures to reduce the unintentional releases of dioxins with the goal of continuing minimization and, where feasible, ultimate elimination.

Dioxins are chemically stable, resist metabolism and are fat soluble, accumulating in fatty tissue. The release of stored dioxins from fatty tissue into the body's circulation is extremely slow, and limits the rate of metabolism by the liver and subsequent excretion. Environmental persistence is a key characteristic of dioxins, persistence being defined as resistance to biological and chemical breakdown in the atmospheric, aquatic or terrestrial environment. Persistence is most commonly measured in half-life time – the time it takes for half of the chemical to be degraded. The average half-life of dioxins is 7 years, the shortest being 3.7 years and the longest 50 years.[153]

Short-term exposure of humans to high levels of dioxins may result in lesions and altered liver function. Long-term exposure has been linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. 2,3,7,8-TCDD has also been classified as a "known human carcinogen".[154] Studies on animals have found that, depending on the duration of exposure, dose and type of animal, adverse responses include:

- Acute lethality;
- Reproductive impairment;
- Developmental abnormalities in young;
- Endocrine and immune dysfunction;
- Neurological dysfunction;
- Wasting syndrome; and

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[152] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308

[153] Legislative Council Standing Committee on State Development, *Redevelopment and remediation of the Rhodes Peninsula*, June 2002, 138pp. Note that half-life figures also depend on the environment in which the dioxin is located. For example, estimates of the half-life of 2,3,7,8-TCDD on the soil surface range from 9 to 15 years, whereas the half-life in subsurface soil may range from 25 to 100 years. Source: Gatehouse, R., op. cit.

[154] World Health Organization, op. cit.

- Edema and haemorrhaging.[155]

PCDDs and PCDFs are unintentional by-products of combustion (both natural such as bushfires and anthropogenic such as waste or fuel incineration and operation of the internal combustion engine) and certain types of chemical manufacturing and industrial processes. These include the manufacture of industrial and agricultural chemicals containing chlorinated phenols (e.g. wood preservatives and pesticides) and during combustion of materials treated with chlorophenols. Elemental chlorine bleaching of pulp and paper is another type of industrial process that may also produce PCDDs and PCDFs.[156]

Up until the 1970s, PCBs were produced for use in a range of industrial and commercial applications because of their low flammability, chemical stability, high boiling point and electrical insulating properties. These applications included; use in electrical, heat transfer, and hydraulic equipment; as plasticisers in paints, plastics and rubber products; and in pigments, dyes and carbonless copy paper.[157]

In aquatic environments, dioxins adsorb strongly to dissolved or particulate organic carbon suspended in the water column. Dioxins adsorbed to particulate matter tend to rapidly redistribute by settling out to bottom sediments. Dioxins adsorbed to organic matter in soil may enter aquatic environments via runoff and soil erosion.[158]

5.2 History of dioxins in Sydney Harbour: Agent Orange manufacturing in Rhodes and fishing bans

In 1928, Timbrol began manufacturing timber preservatives on the Rhodes Peninsula. In 1957, Timbrol was acquired by Union Carbide Australia, which was renamed Zendel Industries in 1988 and Lednez Industries in 1991.[159] The name changes followed the Bhopal gas disaster at the Union Carbide India pesticide plant in 1984.[160]

A variety of chemicals were manufactured by Timbrol/Union Carbide between 1928 and 1985, when production ceased (Table 6). Research has shown that the dioxins in Sydney Harbour are primarily by-products of the production of two chemicals: pentachlorophenol (PCP) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). PCP was used in the manufacture of pesticides and as a wood preservative by the timber industry. PCP typically contains elevated levels of

[155] Gatehouse, R., op. cit.
[156] Ibid.
[157] Ibid.
[158] Ibid.
[159] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW
[160] McGrath, C., Mending holes in the green safety net, *Precedent*, November/December 2012, Issue 113: 4-8

two dioxins – OCDD and HpCDD.[161]

Table 6: Chemicals manufactured at the Union Carbide/Lednez site[162]

Years	Chemicals
1928-1986	Timber products: koppers and coal tars
1932-1985	Xanthates
1940-1961	Aniline and nitrobenzene
1942-1971	Synthetic phenol
1947-1985	Chlorophenol and chlorobenzenes
1949-1976	2,4,5-T and 2,4-D herbicides
1952-1976	Chlorine gas
1955-1968	DDT and DDD insecticides
1960-1976	Bisphenol-A (DPP)
1964-1976	Phenol-formaldehyde resins and moulding components

Between 1949 and 1976, Union Carbide manufactured 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and 2,4-dichlorophenoxyacetic acid (2,4-D) herbicides, the two ingredients for Agent Orange that was used as a defoliant during the Vietnam War. 2,4,5-T herbicide production is characterised by elevated levels of 2,3,7,8-TCDD, the most toxic dioxin.[163]

Prior to 1970, waste including dioxins from Union Carbide chemical manufacturing was disposed at a landfill in Homebush.[164] Contaminated soils were also used during several stages of land reclamation in Homebush Bay. Dioxins entered the waters and sediment of Homebush Bay via overflow during reclamation, stormwater and factory wastewater. After 1970, wastewater was intercepted to comply with the *Clean Waters Act 1970*.[165]

A number of studies have been conducted into the dioxin contamination of the soils and sediments of Homebush Bay.[166] As a result of the first studies

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[161] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308

[162] Adapted from: Ibid. p306. For a substantial timeline of the industrial and remediation history of Rhodes Peninsula, see: City of Canada Bay, *The industrial and remediation history of the Rhodes Peninsula 1911-2012*, 11 September 2014 [online – accessed 23 January 2015]

[163] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308

[164] Sydney Olympic Park Authority, *Treatment of hazardous chemical wastes, Sydney Olympic Park*, Project Summary Report to NSW Environment Protection Authority, May 2003, 267pp.

[165] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: site history*, Technical Paper 2, December 2002, Rhodes, NSW.

[166] See: Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW;

conducted in the late 1980s, the State Pollution Control Commission implemented a total fin fishing ban in Homebush Bay in 1989. This was extended to a commercial fishing ban upstream of the Gladesville Bridge in 1990.

In 1997, the NSW Government committed to remediating dioxin contamination in Homebush Bay. The Government acquired the Union Carbide/Lednez site and commissioned an Environmental Impact Statement (the Lednez EIS). The proposed remediation of the Union Carbide/Lednez site, parts of Homebush Bay and the adjacent Allied Feeds site was subject to a Parliamentary Inquiry and a Commission of Inquiry.[167] The remediation projects went ahead in 2005 and were completed in March 2011.[168]

The remediation of the Union Carbide/Lednez site and parts of Homebush involved excavation of approximately 450,000 of fill and treatment of up to 200,000 m^3 of soil on the Rhodes Peninsula. 27,000 m^3 of sediment was excavated from Homebush Bay, 10,000 m^3 of which was treated. Only the most contaminated sediments of the Bay were remediated by removal of the upper 0.5m of sediment and replacement with clean fill.[169] Completed at the cost of $21 million,[170] as of 2014 the effectiveness of the remediation program was unknown.[171]

5.3 Dioxins in fish

Following a preliminary study into dioxins in prawns caught in Parramatta River at the end of 2005, a full ban on commercial fishing in all of Sydney Harbour was introduced in February 2006 (Table 7).[172] The preliminary study was followed by further prawn sampling as well as tests on bream as a representative of a bottom feeding finish species likely to contain higher levels

Department of the Environment, *National Dioxins Program* series of reports, 2004-2005 [online – accessed 23 January 2015]; Birch, G. et al., Modelling nutrient loads to Sydney estuary (Australia), *Environmental Monitoring & Assessment*, 2010, Vol 167(1-4): 333-348.

[167] Cleland, K., *Proposed remediation of the former Allied Feeds site*, Rhodes, Report to the Honourable Craig Knowles, by the Commissioners of Inquiry for Environment and Planning, July 2003, 123pp.

[168] Thiess Services, *Rhodes Remediation Projects: Project timelines*, no date [online – accessed 23 January 2015]

[169] Birch, G. et al., Modelling nutrient loads to Sydney estuary (Australia), *Environmental Monitoring & Assessment*, 2010, Vol 167(1-4): 333-348

[170] Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: 542-561

[171] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p

[172] See the following for a brief overview of commercial fishing in Sydney Harbour prior to the ban: Hedge, L.H. et al., *Sydney Harbour background report 2014*, Report prepared for NSW Department of Primary Industries by the Sydney Harbour Research Program at the Sydney Institute of Marine Science, April 2014, Sydney, 105p

of dioxins.

Table 7: Fishing bans in Sydney Harbour and public health reports[173]

Date	Event
1989	Fin fishing ban in Homebush Bay
1990	Commercial fishing ban upstream of the Gladesville Bridge
November 2005	NSW Interdepartmental Committee on Contaminants in Fish conducts study into dioxins in seafood caught in Parramatta River
3 December 2005	Temporary ban on commercial and recreational prawn fishing in Sydney Harbour
24 January 2006	Temporary three-month ban on commercial fishing in Sydney Harbour
9 February 2006	Permanent commercial fishing ban in Sydney Harbour
24 February 2006	Dioxins in seafood in Port Jackson and its tributaries (NSW Food Authority)
23 May 2006	Interim report from expert panel considering the four blood dioxin levels for Sydney Harbour fishermen and their family members reported by ABC's 7.30 report (NSW Health)
June 2006	Dioxins in prawns and fish from Sydney Harbour: An assessment of the public health and safety risk (Food Standards Australia New Zealand)
3 August 2006	Supplementary report from the expert panel considering the blood dioxin levels for Sydney Harbour fishermen and their family members (NSW Health)
9 December 2006	Dietary advice for recreational fishers in Sydney Harbour released
March 2007	Dioxins in seafood from Sydney Harbour: A revised assessment of the public health and safety risk (Food Standards Australia New Zealand)
19 December 2007	Further tests lead to changed dietary advice for recreational fishers

In 2002, the National Health and Medical Research Council adopted an Australian Tolerable Monthly Intake (TMI) of dioxins of 70pg (picograms or 1 trillionth of a gram) TEQ/kg bodyweight as an intake which should be adequately protective of the general population with respect to the effects of dioxins.[174] While there is no national Action Level[175] for dioxins in food in Australia, the NSW Food Authority applied a **temporary Action Level of 6pg**

[173] Sources: NSW Food Authority, Authority alerts Sydney Harbour fishers, *Foodwise*, March 2006, Vol 2, 8pp.; Birch, G. et al., Modelling nutrient loads to Sydney estuary (Australia), *Environmental Monitoring & Assessment*, 2010, Vol 167(1-4): 333-348.

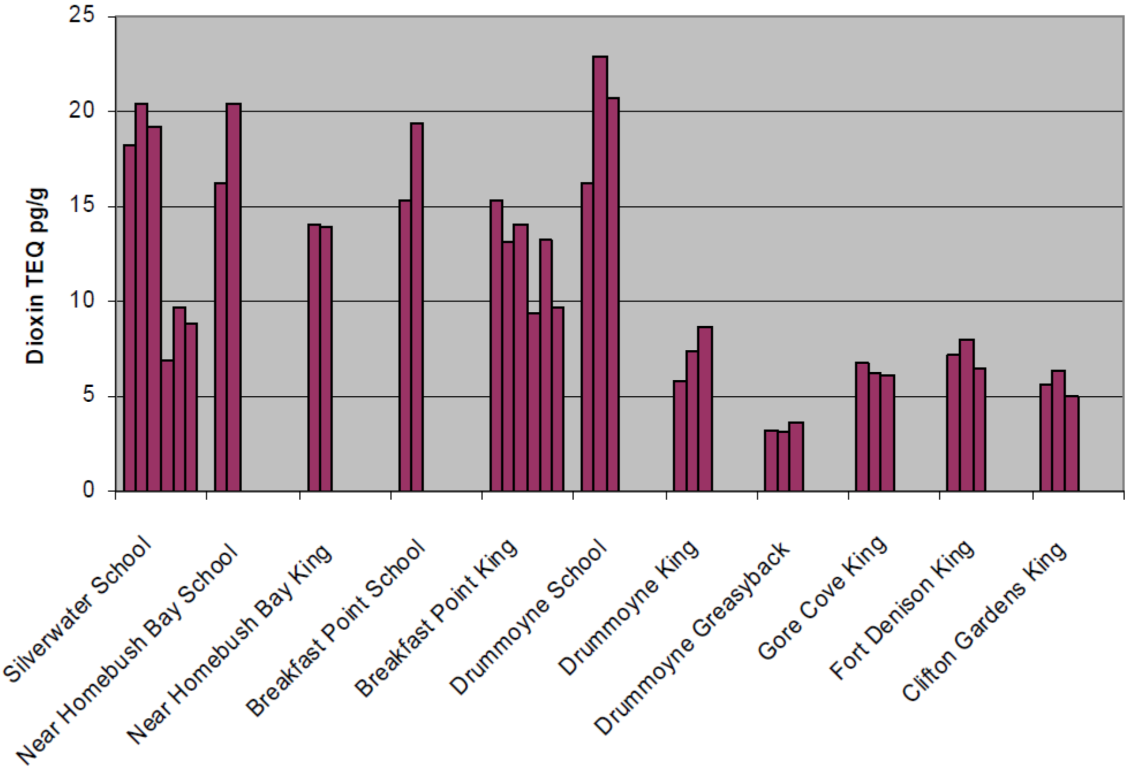
[174] This TMI was first recommended by the Joint FAO/WHO Expert Committee on Food Additives in 2001. Also in 2001, the European Union Scientific Committee on Food adopted a Tolerable Weekly Intake of 14pg/kg bodyweight, which approximates to a TMI of 60pg/kg bodyweight.

[175] The aim of an Action Level is to trigger an investigation of the reasons for high levels of dioxins. This approach, as opposed to a stringent Maximum Level approach that sets an absolute cut-off limit for consumer protection, has the advantage of focusing on product averages thus allowing enforcement agencies to take a holistic approach when a problem is identified.

TEQ/g fresh weight in seafood in its investigation.[176] This Action Level was supported by later studies conducted by Food Standards Australia New Zealand (Table 7).

As part of the NSW Food Authority's 2006 investigation, 36 composite prawn samples were taken across seven sites in Sydney Harbour (Figure 14). The content of dioxins in the samples ranged from 3.1-22.9pg TEQ/g fresh weight, with an average of 11.3pg TEQ/g fresh weight. 2,3,7,8-TCDD was the most common dioxin found. The majority of samples exceeded the temporary Action Level of 6pg TEQ/g fresh weight.

Figure 14: Levels of dioxins recorded in 36 composite prawn samples harvested from 7 different locations in Sydney Harbour[177]



[176] The NSW Food Authority noted that the European Union has a Maximum Level for fish and fish products of 4pg TEQ/g fresh weight for dioxins, excluding dioxin-like PCBs.

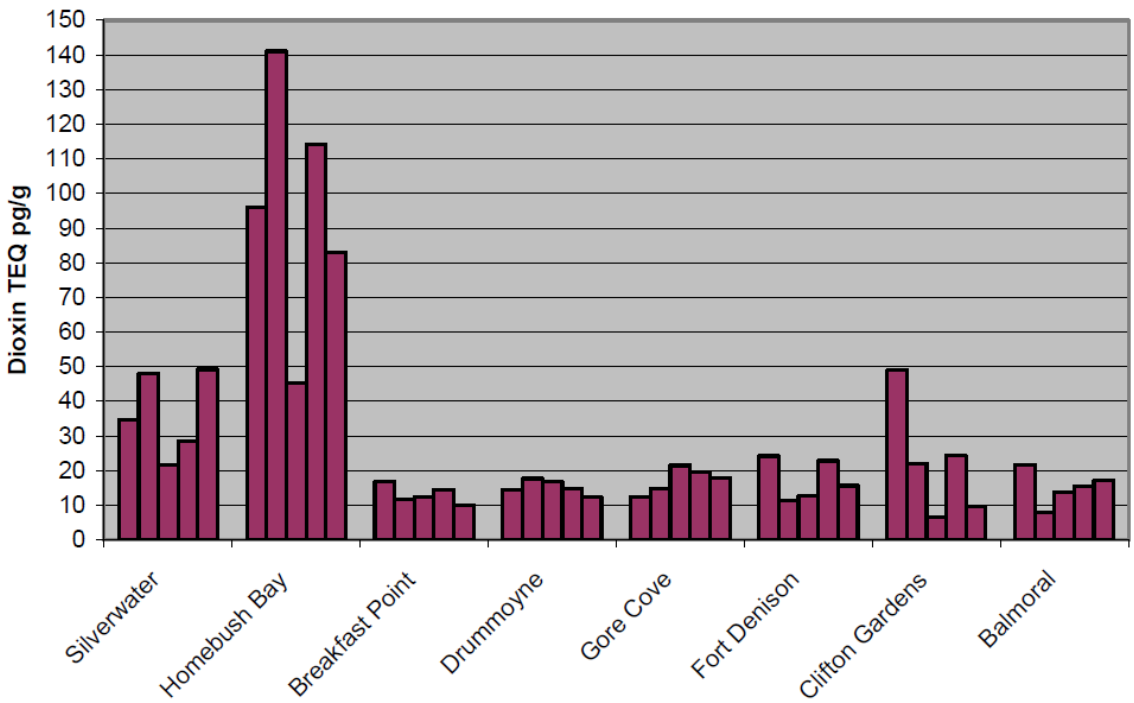
[177] NSW Food Authority, *Dioxins in seafood in Port Jackson and its tributaries*, Report of the Expert Panel, 24 February 2006, p.15

40 composite bream samples were taken from 8 sites in Sydney Harbour (Figure 15). The content of dioxins in the samples ranged from 6.6-141pg TEQ/g fresh weight, with an average of 29.1pg TEQ/g fresh weight. The average fell to 19.5pg TEQ/g fresh weight when Homebush Bay was excluded due to its high levels of contamination. 2,3,7,8-TCDD was again the most common dioxin except in one case, where a dioxin-like PCB compound was the most common toxin. All samples exceeded the temporary Action Level of 6pg TEQ/g fresh weight.

The NSW Food Authority Expert Panel concluded by noting in part that:

- The research findings suggest widespread contamination of dioxins in seafood caught in Sydney Harbour;
- Levels of dioxins in prawns and bream are equivalent to or higher than levels found in some seafood caught from other highly contaminated areas in the world; and
- On average more than one 150 gram serve per month of fish, or two 150 gram serves of prawns, from Sydney Harbour would result in consumers exceeding the recommended TMI for dioxins.

Figure 15: Levels of dioxins recorded in 40 composite bream samples harvested from 8 different locations in Sydney Harbour[178]



[178] Ibid., p.16

In the 12 months after the ban's commencement, research was conducted into the health risks of eating fish from Sydney Harbour, the level of dioxins in a number of additional seafood species, and the exposure of Sydney Harbour fishermen and their families to dioxins in seafood sourced from Sydney Harbour (Table 7). The studies on fishermen and their families found that their dioxin levels were substantially higher than south east urban Australian background levels. However, not enough research had been conducted at the time to know whether the fishermen and their families were likely to experience negative health effects.[179]

Recreational fishing is permitted in most areas of Sydney Harbour, although it is banned in the Duck River and Homebush Bay for public health reasons.[180] Consumer dietary advice for recreational fishers, last updated in December 2007, recommends that no seafood caught west of the Bridge be consumed, and that generally no more than 150 grams per month of seafood caught east of the Bridge be consumed. Based on research conducted in 2006/07, more specific dietary advice is provided on the recommended maximum consumption of popular species (Table 8). Despite the consumer dietary advice, it appears that some recreational fishers still eat fish caught in places like the Lane Cove River and east of Cockatoo Island.[181]

[179] NSW Health, *Supplementary report from the expert panel considering the blood dioxin levels for Sydney Harbour fishermen and their family members*, 3 August 2006, 9p. The first study conducted by the ABC can be found here: Symons, R. et al., Sydney Harbour fishermen and families: elevated levels of dioxins resulting from consumption of TCDD-contaminated fish, *Organohalogen Compounds*, 2006, Vol 68: 375-378. See also the NSW Health Rhodes Serum Dioxin Study, which investigated dioxin levels in people living on the Rhodes Peninsula adjacent to the area remediated due to its contamination by pollutants including dioxins. According to the final report, the remediation did not expose the local residents in the study to levels of dioxin that would be expected to impact upon their health.

[180] NSW Department of Primary Industries, *Factsheet: Sydney Harbour and northern beaches recreational fishing guide*, March 2012, 8p

[181] *ABC News*, Anglers ignoring Sydney Harbour health warnings, fishing hotspots indicate, 16 August 2014

Table 8: Recommended maximum intake of popular species and their dioxin concentration findings[182]

Seafood	Dioxin concentration (pg TEQ/g)			Recommended max. intake	
	Sydney Harbour average	West of Harbour Bridge	East of Harbour Bridge	Number of 150 gram serves	Amount per month
Crustacea	11	13	6	-	-
Prawns	12	13	6	4 per month	600g
Crabs	9	10	5	5 per month	750g
Fish	25	37	11	-	-
Bream	27	31	18	1 per month	150g
Dusky Flathead	4	5	2	12 per month	1800g
Fanbelly Leatherjacket	1	1	1	24 per month	3600g
Flounder	6	9	2	12 per month	1800g
Kingfish	2	n/a	2	12 per month	1800g
Luderick	11	19	2	12 per month	1800g
Mulloway	21	21	n/a	-	-
Sand Whiting	3	4	3	8 per month	1200g
Sea Mullet	99	108	70	1 every 3 months	50g
Silver Biddie	41	54	23	1 per month	150g
Silver Trevally	29	42	5	5 per month	750g
Tailor	38	78	24	1 per month	150g
Trumpeter Whiting	4	6	2	12 per month	1800g
Yellowtail Scad	11	29	3	8 per month	1200g
Molluscs	-	-	-	-	-
Squid	17	24	6	4 per month	600g

[182] Sources: Food Standards Australia New Zealand, *Dioxins in seafood from Sydney Harbour: A revised assessment of the public health and safety risk*, Technical Report Series No. 44, March 2007, p.6; NSW Food Authority, *Sydney Harbour seafood*, 20 September 2013 [online – accessed 29 January 2015]. Note that the advice in the table is provided where only one species is being eaten in the month. Each guideline number of serves is therefore the recommended total intake for the month. For example eating 150 grams of Bream and 600 grams of prawns in one month would exceed the recommended intake.

5.4 Dioxins in Sydney Harbour: where it is and what can be done

As noted previously, Homebush Bay is the primary source of the dioxins in Sydney Harbour.[183] Dispersal of dioxins throughout the rest of Sydney Harbour is likely attributable to three processes:

(1) Aerial deposition during the period when dioxins were produced as a by-product of combustion during pesticide production at Rhodes Peninsula;

(2) Diffuse and point source stormwater runoff generated by periods of heavy rain may transport dioxin-laden sediment from the contaminated Homebush Bay foreshore into the Bay where they travel upstream and downstream as part of the fresh-water plume on top of marine water; and

(3) Newly deposited sediments can be resuspended by wind-driven waves, after which they may be transported to other parts of the Harbour via spring tidal currents.[184]

Following identification of relevant international sediment quality guidelines for dioxins, this section summarises the three most recent studies of dioxins in Sydney Harbour before outlining what may be done to address the problem.

5.4.1 International sediment quality guidelines for dioxins

Although there are no Australian sediment quality guidelines against which dioxin concentrations in Sydney Harbour can be evaluated, international guidelines can provide benchmarks for this purpose (Table 9). Guideline values range from 0.0011 to 210pg TEQ/g, depending on factors such as the organism being exposed to the dioxins and the level of effects expected at a certain concentration. Background values ranged from 2 to 5pg TEQ/g, a finding similar to other studies.[185] Note that the guidelines use 2005 WHO-TEQ values.[186]

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[183] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308

[184] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

[185] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308

[186] US EPA, *Memorandum: Compilation and discussion of sediment quality values for dioxin, and their relevance to potential removal of dams on the Klamath River*, 13 January 2010, 10p.

Table 9: International dioxin sediment quality guidelines[187]

Basis	Country	Intent	Sediment guideline (pg TEQ/g)	Comments
Background	USA	-	2 – 5	San Francisco Bay
Background	USA	-	5.3	11 non-impacted urban and rural lakes
Risk-based	USA	Protection of recreational fishers	15	-
Risk-based	USA	Protection of human consumers	0.0011/1.1	Threshold for potential risk to subsistence consumers/ Threshold for potential risk to the general population of consumers
Effects-based	USA	Protection of ecological receptors	60/100 (fish) 2.5/25 (mammals) 21/210 (birds)	Threshold for low level risk/ Threshold for high level risk
Effects-based	USA	Protection of wildlife consumers	0.052/1.4 (mammals) 0.7/3.5 (birds)	No Observed Adverse Effect Level/Low Observed Adverse Effect Level
Effects-based	USA	Protection of fish	0.56	Level at and below which chemicals would not be expected to accumulate in tissues of fish or other aquatic organisms above acceptable levels
Effects-based	Canada	Protection of benthos[188]	0.85/21.5	Threshold Effect Level/ Probable Effect Level
Effects-based	Holland	Protection of ecosystem	13	Level at which, with reasonable certainty, at least 95% of species will not experience adverse effects

Table 9 contains three values related to different human consumers, the first two of which came from the same study: 0.0011pg TEQ/g for subsistence consumers; 1.1pg TEQ/g for the general population; and 15pg TEQ/g for recreational fishers. The last two are more relevant to Sydney Harbour. The threshold for low level risk to wildlife values range from 0.56pg TEQ/g to 60pg

[187] US EPA, *Interim report on data and methods for assessment of 2,3,7,8-tetrachlorodibenzo-p-dioxin risks to aquatic life and associated wildlife*, March 1993, 159p.; Canadian Council of Ministers of the Environment, *Canadian sediment quality guidelines for the protection of aquatic life: Polychlorinated dioxins and furans (PCDD/Fs)*, 2001, 6p.; Hurst, M.R. et al., Determination of dioxin and dioxin-like compounds in sediments from UK estuaries using a bio-analytical approach: chemical-activated luciferase expression (CALUX) assay, *Marine Pollution Bulletin*, 2004, Vol 49(7-8): 648-658; US EPA, *Memorandum: Compilation and discussion of sediment quality values for dioxin, and their relevance to potential removal of dams on the Klamath River*, 13 January 2010, 10p.

[188] The community of organisms which live on, in or near the seabed

TEQ/g; the threshold for high level risk to wildlife values range from 21.5pg TEQ/g to 210pg TEQ/g.

5.4.2 Remediation of Lednez site, Rhodes and Homebush Bay (2002)

The 2002 Environmental Impact Statement (the Lednez EIS) on the proposed remediation of the Union Carbide/Lednez site and parts of Homebush Bay published dioxin levels in the sediments and water of Homebush Bay and the groundwater under the Lednez site. The EIS uses I-TEQ values, rather than WHO-TEQ (see further section 5.1 of this paper). A Technical Paper[189] produced for the EIS by Sinclair Knight Merz appears to argue that, in this case, the I-TEQ values contained in the EIS are generally comparable with WHO-TEQ values.[190]

Sediments in Homebush Bay were tested in a grid pattern alongside the eastern shore of the Bay at three depths (Table 10; Figure 16). At the surface level, readings ranged from 90 to 154,000pg I-TEQ/g, with a mean of 7,600pg I-TEQ/g. Note that the mean value at the 900-1,000mm depth is probably skewed high, with much fewer samples taken at this depth together with two very high readings.[191] The estimated bay-wide average dioxin sediment concentration was 3,014pg I-TEQ/g.[192]

Table 10: Dioxin sediment concentrations in the part of Homebush Bay adjacent to the Lednez site (pg I-TEQ/g)[193]

Sediment depth	Minimum	Maximum	Mean
Surface (0-100mm)	90	154,000	7,600
Subsurface (400-500mm)	20	380,000	7,930
Subsurface (900-1,000mm)	50	238,000	25,680

[189] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 5 – Detailed human health and ecological risk assessment of Homebush Bay sediments*, December 2002, Rhodes, NSW, 396p

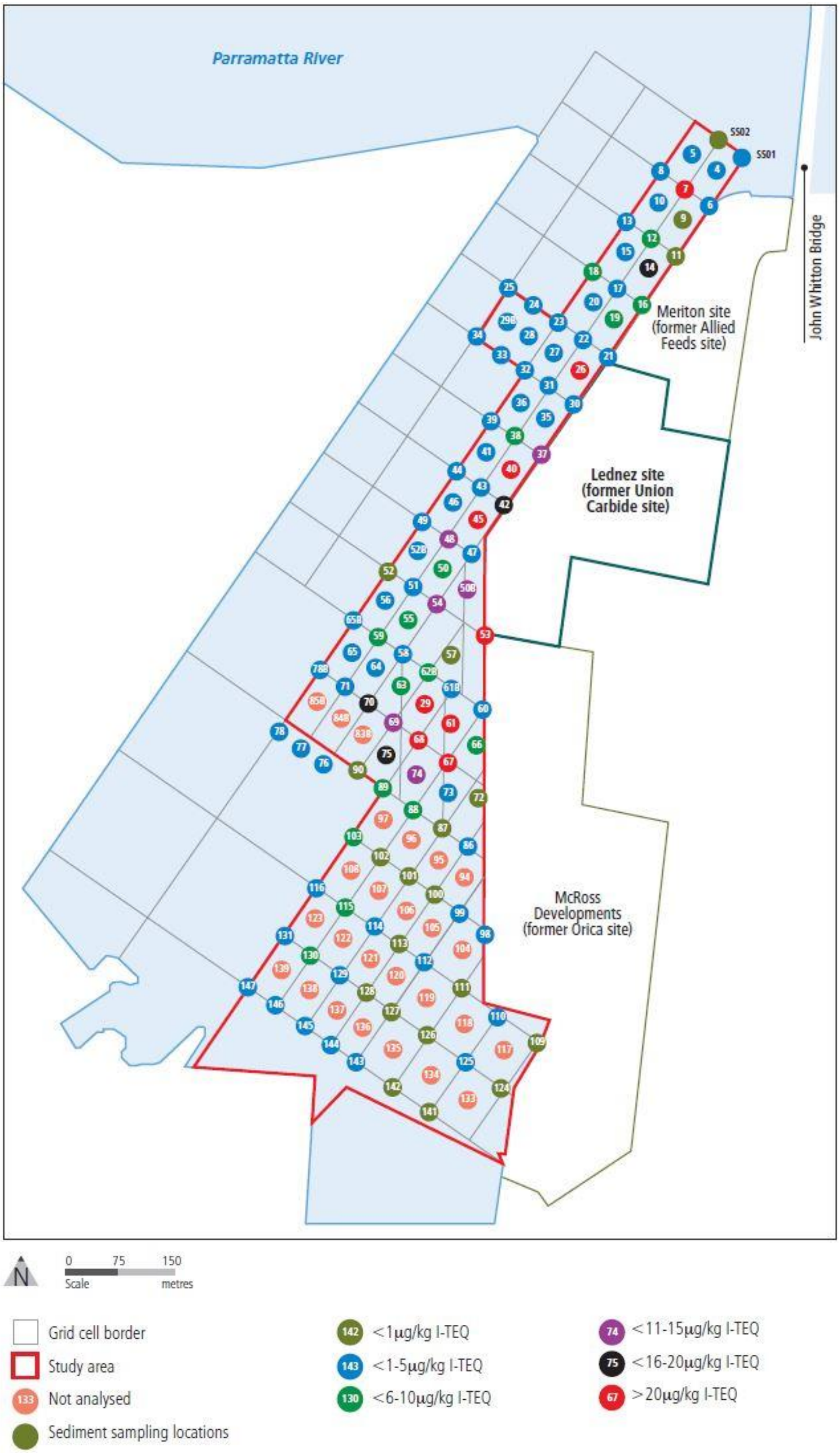
[190] Ibid., pp.66-68. This appears to be the case for two reasons. First, they note that the potential contribution of dioxin-like PCBs to the final TEQ reading is relatively low, in the order of 1%. Dioxin-like PCBs are included in WHO-TEQ values but not in I-TEQ values. Second, they appear to argue that, if anything, the I-TEQ values presented may be lower than the comparable WHO-TEQ values. They found that the 2,3,7,8-TCDD levels could be multiplied by 2.86 to provide the TEQ value to “an acceptable level of confidence”, in which case figures in the Surface (0-100mm) row of Table 10 would read as 28.6, 188,760 and 7,722 respectively.

[191] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 3 – Extent of contamination in Homebush Bay*, December 2002, Rhodes, NSW

[192] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW

[193] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 3 – Extent of contamination in Homebush Bay*, December 2002, Rhodes, NSW

Figure 16: Dioxin sediment concentrations in Homebush Bay (0-100mm)[194]



194 Ibid., p.5.32. Note that 1μg/kg = 1,000 pg/g

According to the main EIS report, the dioxin sediment concentration findings indicate that the extent of contamination was greatest at the surface of the sediments, with the size of the contamination footprint decreasing with depth. This confirmed that much of the organic contamination produced by the reclamation of the industrial sites (along the north-eastern side of the Bay) had migrated out over time into the sediments of Homebush Bay.

The EIS adopted the recommended Preferred Remediation Scenario,[195] arguing that it would have the following benefits:

- It would realise the greatest rate of reduction in dioxin levels in the bay sediments per unit area;
- As dioxin levels in fish decrease, so would impacts to human health by lowering the potential for daily intake through the food chain;
- It would ensure that future residential users of the Lednez, Meriton and Orica sites would be protected from unsafe exposure resulting from bay based recreational activities, including those involving direct contact with sediments along the foreshore;
- It would ensure the health of the ecological communities that frequent the bay by removing the most heavily contaminated sediments from the bay; and
- It would reduce the contaminant load available for future dispersion throughout the environment.[196]

According to Sinclair Knight Merz, implementation of this scenario would reduce the bay-wide average dioxin sediment concentration from 3,014pg I-TEQ/g to 2,033pg I-TEQ/g.[197] Note that the final area remediated appears to be larger than that proposed in the EIS (Figure 17).[198]

The international sediment quality guideline values for dioxins range from 0.0011 to 210pg TEQ/g, depending on a range of factors. The minimum level (90pg I-TEQ/g) found in the area of Homebush Bay adjacent to the Lednez site exceeds all but two of the identified guideline values. The surface average for this area (7,600pg I-TEQ/g), the estimated average for Homebush Bay (3,014pg

[195] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 5 – Detailed human health and ecological risk assessment of Homebush Bay sediments*, December 2002, Rhodes, NSW, 396p

[196] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW

[197] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 5 – Detailed human health and ecological risk assessment of Homebush Bay sediments*, December 2002, Rhodes, NSW, p.49 of the Supplementary Final Report

[198] For the proposed area, see page 5.6 of Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW

I-TEQ/g) and the expected bay-wide average following remediation (2,033pg I-TEQ/g) all exceed the guideline values.

Figure 17: Remediation of sediments in Homebush Bay[199]

The EIS contains several readings of dioxin levels for the waters of Homebush Bay (Table 11; Figure 18). Only six readings are reported, all of which exceed the guideline set in the Canadian Water Quality Guidelines for the Protection of Aquatic Life of 10pg TEQ/L. The ANZECC (2000) guidelines for water quality do not provide guidelines for dioxin concentrations.

Table 11: Dioxin water concentrations in Homebush Bay (pg TEQ/L)[200]

Weather	Site		
	WQ1	WQ2	WQ3
Wet weather	690	12,100	815
Dry weather	3,080	652	445

Five groundwater readings for the Lednez site are presented in the EIS. These range from 4 to 157pg TEQ/L, with no mean provided. It appears therefore that the groundwater dioxin concentrations also generally exceeded known guidelines, when comparing the findings to the Canadian guideline of 10pg TEQ/L.[201]

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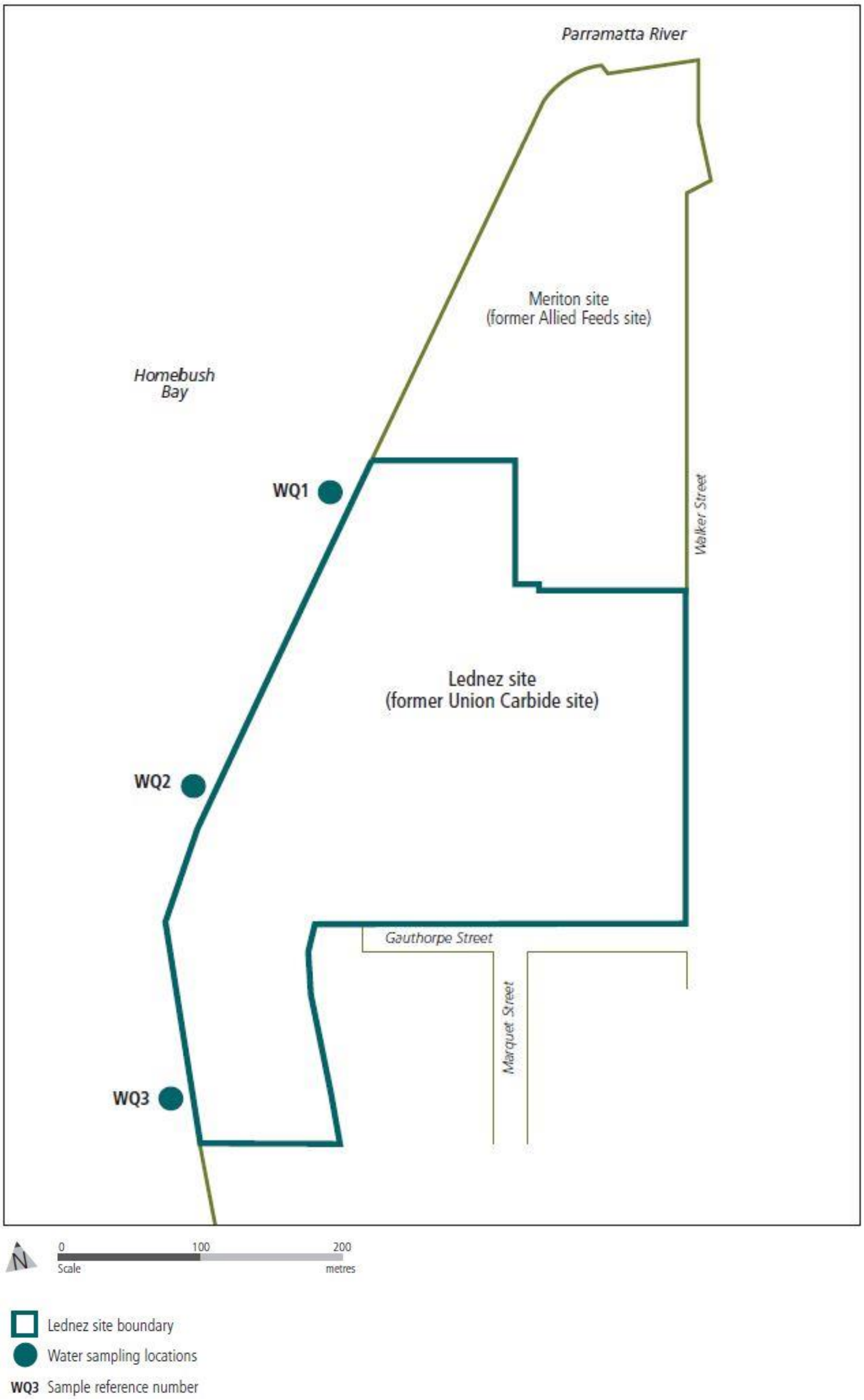
199 Thiess Services, *Rhodes Remediation Projects: Bay remediation map*, no date [online – accessed 23 January 2015]

200 Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW, p.8.20

201 Ibid., p.8.8

Figure 18: Water quality sampling locations in Homebush Bay[202]



[202] Ibid., p.8.16

It is important to note that all the dioxin findings set out in this section were recorded prior to the remediation of the most contaminated part of Homebush Bay and the Lednez site. While also conducted prior to the remediation of Homebush Bay, the following two studies provide a picture of dioxin contamination across the whole Harbour.

5.4.3 The source and distribution of dioxins in Sydney Harbour with international comparisons (2007)

A 2007 study examined the distribution of dioxins across Sydney Harbour, including within Homebush Bay. It took samples at 16 locations across the Harbour (Figures 19 and 20). Values across the Harbour ranged from 31.5 to 4,352.5pg TEQ/g with an average of 711.5pg TEQ/g, although this average is possibly biased high due to five of the samples being taken from the highly elevated sediment within Homebush Bay. Findings specific to particular areas of the Harbour include:

- Homebush Bay had an average of 2,094.0pg TEQ/g with a range of 667.8 to 4,352.5pg TEQ/g;
- Stormwater discharge points (S9 to S12) had an average of 124.5pg TEQ/g and a range of 75.9 to 226.4pg TEQ/g;
- Industrial and urban areas (S3 to S6) had an average of 230pg TEQ/g and a range of 81.1 to 367.2pg TEQ/g; and
- Background sediment samples (S1A, S1B and S2) had an average of 39.5pg TEQ/g and a range of 31.5 to 49.5pg TEQ/g.[203]

The study's Homebush Bay findings are much lower than those contained in the Lednez EIS (average of 7,600pg I-TEQ/g and range of 90 to 154,000pg I-TEQ/g in surface sediment). Given how localised the highest readings were found to be in the EIS, it is quite possible that this study, which only took five samples across the whole of Homebush Bay, missed the most contaminated parts of the Bay.

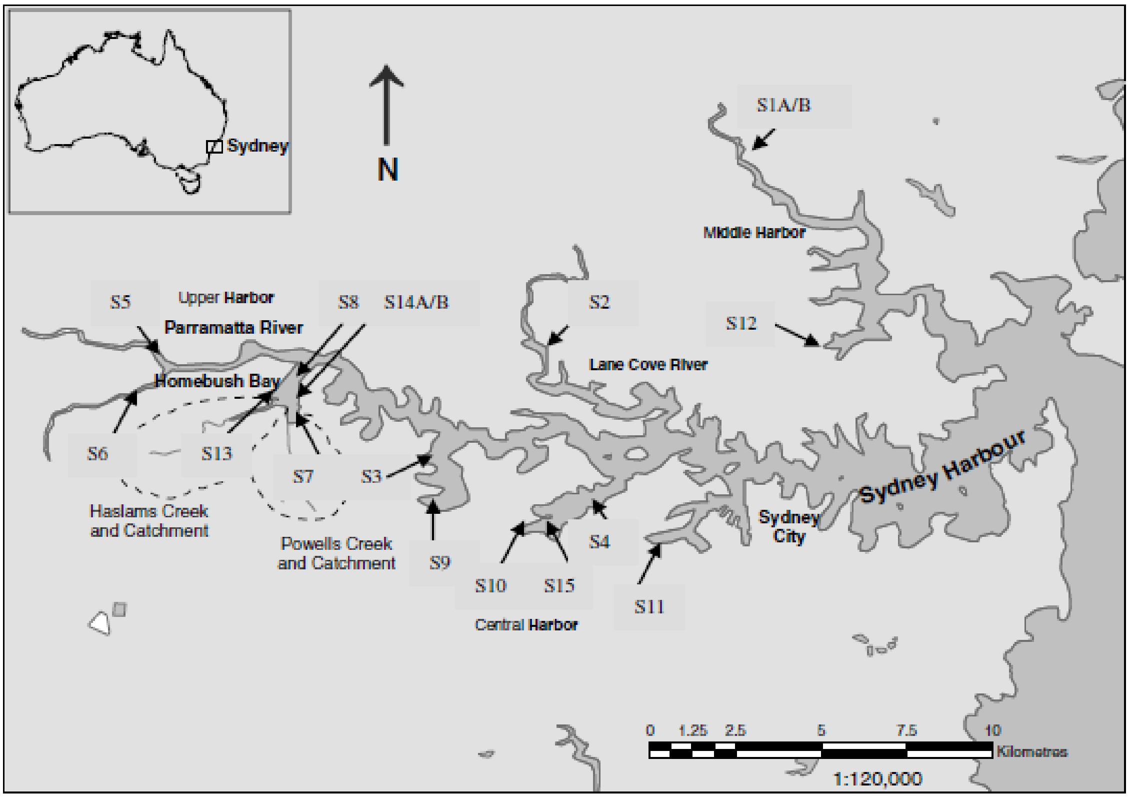
In comparison with the guidelines contained in Table 9:

- All findings, including those in the relatively uncontaminated areas of Lane Cove River and Upper Middle Harbour, exceeded the suggested guidelines for human consumers of 1.1 and 15pg TEQ/g;
- All findings other than the background sediment samples exceeded *every* low level risk guideline. The background sediment samples exceeded every low level risk guideline but one – the US low level risk guideline for fish of 60pg TEQ/g; and
- The threshold for high level risk to wildlife values range from 21.5pg

[203] Birch, G. et al., The source and distribution of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in sediments of Port Jackson, Australia, *Marine Pollution Bulletin*, 2007, Vol 54(3): 295-308

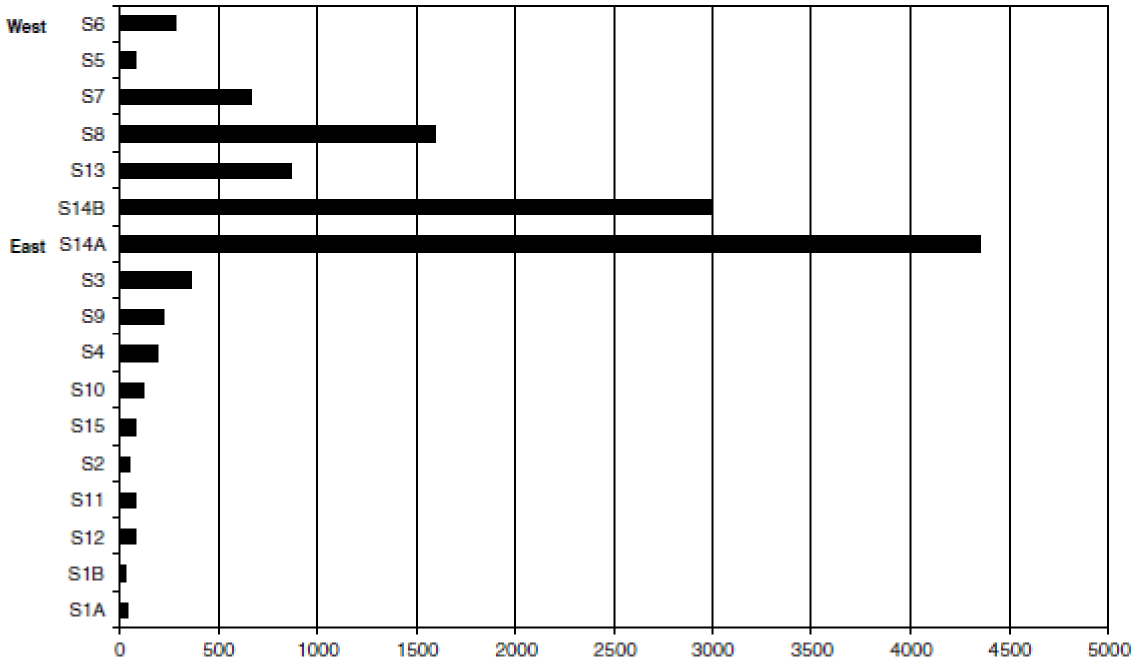
TEQ/g to 210pg TEQ/g. All findings exceeded the lowest of the guidelines for high level risk to wildlife. Almost every finding in the contaminated areas of the Harbour exceeded the US high level risk guideline for fish of 100pg TEQ/g.

Figure 19: Sample locations: 2007 study into dioxins in Sydney Harbour sediments[204]



204 Ibid. p.300

Figure 20: Dioxin concentrations in Sydney Harbour extending east and west from Homebush Bay (S7, S8, S13, S14; pg TEQ/g)[205]



This study found that dioxin readings in Sydney Harbour sediments are far higher than anywhere else in Australia (Table 12). The minimum Sydney Harbour reading of 31.5pg TEQ/g is only marginally lower than the highest reading outside of Sydney Harbour, namely 35pg TEQ/g in Botany Bay.

Table 12: Australian State and Territory dioxin sediment concentrations[206]

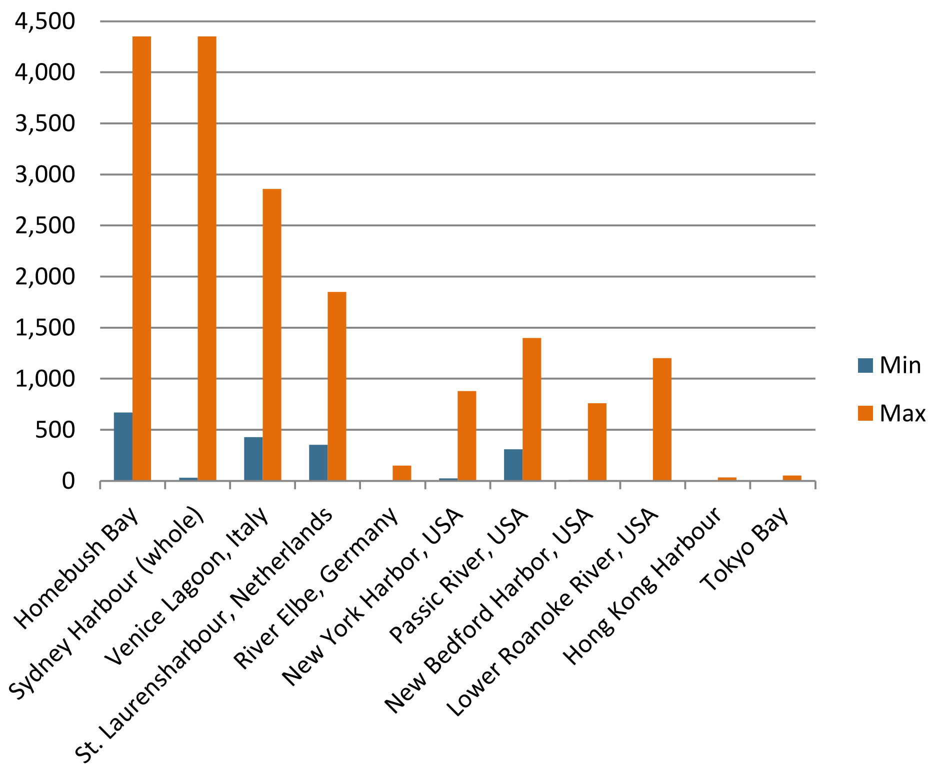
Location	Concentration (pg TEQ/g)
Port Darwin (NT)	0.89
Brisbane River (Qld)	4.9
Sydney Harbour	31.5 – 4,352.5
Botany Bay	22 – 35
Lake Illawarra	6
Yarra River (Vic)	1 – 17
Central Port Phillips (Vic)	2.5 – 3.2
Lower Derwent River (Tas)	4.9
Torrens River (SA)	1.0 – 1.5
Swan/Canning River (WA)	5.5

The two highest international dioxin sediment concentrations after those found in the Lednez EIS (154,000pg I-TEQ/g in surface sediment) were recorded in

[205] Ibid. p.300
[206] Ibid. p.298

Finland (80,000pg TEQ/g) and at Frierfjorden, Norway (6,234 to 19,444pg TEQ/g). Figure 21 provides some other international examples for comparative purposes using the Sydney Harbour findings from this study. The Sydney Harbour average of 711.5pg TEQ/g is comparable to the maximum concentrations of several industrial areas including New York Harbor (880pg TEQ/g), Passiac River (1,400pg TEQ/g), New Bedford Harbor (761pg TEQ/g) and Lower Roanoke River (1,200pg TEQ/g). However, these areas would probably have average concentrations much lower than that of Port Jackson. The Homebush Bay average (2,094.9pg TEQ/g) is comparable to the maximum values of places like Venice Lagoon, Italy (2,857pg TEQ/g) and St Laurensharbour, Netherlands (1,849pg TEQ/g).[207]

Figure 21: International dioxin concentrations (pg TEQ/g)[208]



5.4.4 Department of Environment, Climate Change and Water (2008)

A study into dioxin sediment concentrations was conducted by the Department of Environment, Climate Change and Water using data collected in 2008 (Figure 22). According to this study:[209]

- Dioxin concentrations in Sydney Harbour ranged from 1.5pg TEQ/g in Middle Harbour to 610pg TEQ/g in Parramatta River near Rhodes;

[207] Ibid.

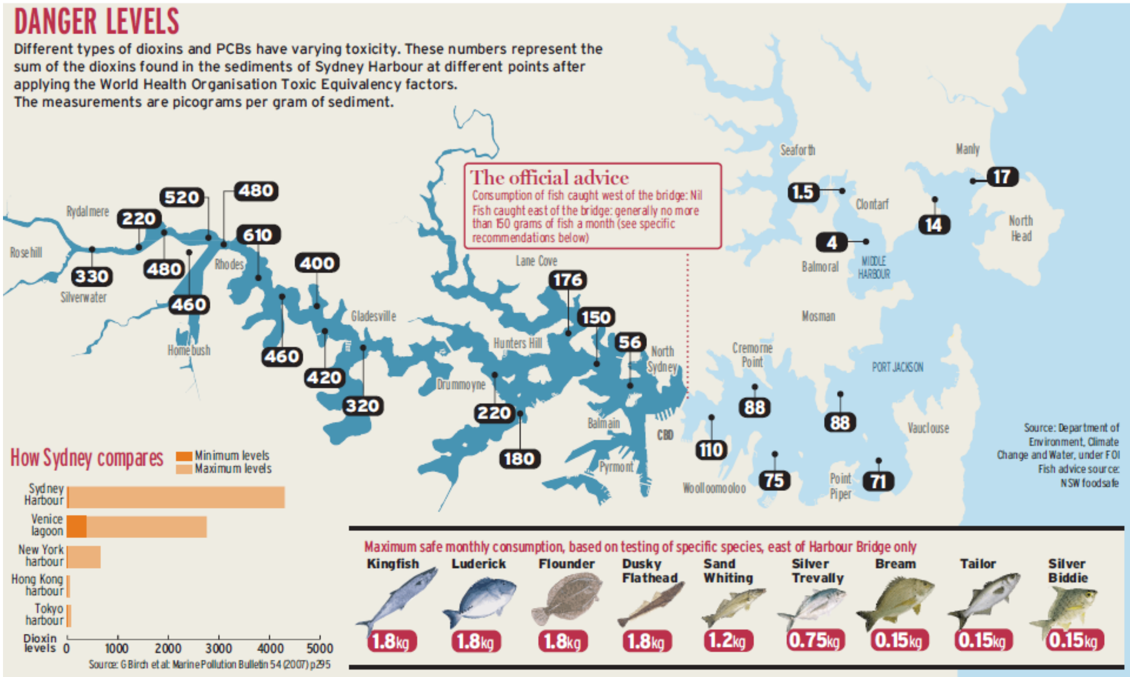
[208] Ibid.

[209] *SMH*, The poison that got away: Harbour dioxins hit critical level, 30 October 2010

- West of the Harbour Bridge, concentrations ranged from 56 to 610pg TEQ/g;
- In Port Jackson east of the Harbour Bridge, and including North Harbour, values ranged from 14 to 110pg TEQ/g; and
- In Middle Harbour, values ranged from 1.5 to 4pg TEQ/g.[210]

This study does not appear to have collected data from Homebush Bay.

Figure 22: Dioxin levels in Sydney Harbour (2008 study)[211]



In comparison with the guidelines contained in Table 9:

- All findings west of the Harbour Bridge exceeded guidelines for human consumers of 1.1 and 15pg TEQ/g. Only three findings east of the Harbour Bridge did not exceed the less strict guideline of 15pg TEQ/g – one in North Harbour, and two in Middle Harbour;
- With one exception, all findings west of the Harbour Bridge exceeded the low level risk guidelines for wildlife. The exception was the finding of 56pg TEQ/g just west of the Bridge, which was marginally under the highest low level risk guideline of 60pg TEQ/g (for fish). The findings just to the east of the Harbour Bridge (71 to 110pg TEQ/g) all exceeded the low level risk guidelines for wildlife; and
- Every finding west of the Harbour Bridge exceeded the Canadian Probable Effect Level of 21.5pg TEQ/g, and all but one exceeded the high level risk guideline for fish of 100pg TEQ/g. One finding east of the

[210] *SMH*, Harbour spots with the fish you should reject, 30 October 2010
[211] Ibid.

Bridge exceeded the high level risk guideline for fish (110pg TEQ/g just east of the Bridge) and five exceeded the Canadian Probable Effect Level.

5.4.5 What can be done?

According to the Department of Environment, Climate Change and Water, current dioxin contamination levels suggest that it will be decades before it will be safe to eat fish from west of the Sydney Harbour Bridge. While remediation of some of the most contaminated areas in Homebush Bay has taken place, it appears technically and financially impractical to conduct any large-scale remediation projects of dioxin-contaminated sediments. At this stage, because the area contaminated with dioxins is too extensive, the only way to address the problem is to wait until sediments cover the contaminated layer so that dioxins cannot be absorbed by fish and small invertebrates.[212] A recent paper on Sydney Harbour recommended that:

- With respect to the impact of dioxins on human health, long-term monitoring of fish tissue is required to determine the success of the dredging and capping program undertaken in Homebush Bay;
- Long-term monitoring of bed sediment dioxin concentrations throughout the Harbour is required to ensure the source of dioxin contamination has been effectively capped;
- Modelling investigations encompassing chemical, sediment and hydrodynamic transport would facilitate improved understanding of the long-term impact of dioxins and the potential recovery time for the Harbour with respect to these chemicals; and
- Dioxin uptake studies would further advance our understanding of their impact on estuarine species and enable appropriate guidelines for dioxin concentrations within estuary waters and bed sediments to be put in place.[213]

[212] *SMH*, The poison that got away: Harbour dioxins hit critical level, 30 October 2010

[213] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, p.28, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

6. HEAVY METALS AND SEDIMENT TOXICITY

6.1 Heavy metals

6.1.1 Distribution

Sydney Harbour has some of the highest recorded sediment concentrations of heavy metals in Australia (Table 13) and internationally (Table 14). Copper, lead and zinc mean and maximum concentrations in Sydney Harbour are higher than comparable estuaries such as Georges River/Botany Bay and Port Philip, and much higher than the relatively undisturbed Myall Lakes.[214] For comparative purposes, ANZECC (2000) sediment quality guidelines have been included at the end of the Table.

Table 13: Sydney Harbour and Australian normalised (<62.5 μm) metal concentrations (mg/kg) in surficial sediment[215]

Estuary		Copper	Lead	Zinc
Sydney Harbour	Mean	188	364	651
	Range	9 – 1,053	38 – 3,604	108 – 7,622
Pittwater	Mean	87	65	134
	Range	25 – 596	20 – 174	20 – 272
Georges River/Botany Bay	Mean	70	155	393
	Range	17 – 457	29 – 924	76 – 2,641
Hawkesbury River	Mean	47	55	135
	Range	17 – 203	19 – 174	68 – 272
Hunter River	Mean	-	172	-
	Range	35 – 193	48 – 777	31 – 1,638
Myall Lakes	Mean	5	19	49
	Range	2 – 9	5 – 28	12 – 82
Brisbane Water	Mean	30	57	157
	Range	13 – 153	26 – 362	76 – 775
Port Philip Bay	Mean	13	30	202
	Range	1 – 62	1 – 197	13 – 1,600
ANZECC sediment quality guidelines	ISQG-Low	65	50	200
	ISQG-High	270	220	410

The ISQG-Low value represents the value below which adverse biological effects are seldom observed. The ISQG-High value denotes the value above

214 Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: 542-561

215 Ibid. p.552; ANZECC & ARMCANZ, op. cit.

which adverse biological effects are expected to occur frequently. Lead and zinc mean concentrations in Sydney Harbour exceed the ISQG-High values, and the copper mean concentration lies approximately half-way between the ISQG-Low and ISQG-High values.

According to research published in 2013, in comparison with international estuaries, Sydney Harbour has the highest maximum concentration for cadmium, lead and zinc (Table 14) and the highest mean concentration for copper, lead and zinc. Only one other harbour has a higher maximum concentration for copper (Hong Kong, 4,000 mg/kg) and only one other harbour has a higher maximum concentration for nickel (Lima Estuary, Portugal, 447 mg/kg). ANZECC (2000) sediment quality guidelines have also been included in Table 14. While mean concentrations of cadmium and nickel in Sydney Harbour were either lower than or equal to the ISQG-Low value, the maximum values for each metal were substantially higher than the ISQG-High value.

Table 14: Sydney Harbour and global normalised (<62.5 µm) metal concentrations (mg/kg) in surficial sediment[216]

Estuary		Cadmium	Copper	Nickel	Lead	Zinc
Sydney Harbour	Mean	0.8	188	21.7	364	651
	Range	0–24.3	9–1,053	5–245	38–3,604	108–7,622
Hong Kong	Mean	0.33	119	25	54	148
	Range	0.1–5.3	1–4,000	5–220	9–260	17–790
Quanzhou Bay, China	Mean	0.59	71	33	68	180
	Range	0.3–0.9	25–120	16–46	34–101	106–242
Lima Estuary, Portugal	Mean	-	45	14	37	111
	Range	-	16–406	46–447	19–64	59–398
Port of Barcelona, Spain	Mean	1.22	183	25	189	391
	Range	0.4–2.8	71–531	18–34	86–589	183–1,133
San Pablo Bay, San Francisco, USA	Mean	0.21	39	37	22	65
	Range	0.1–0.4	25–49	27–45	15–27	48–79
Montevideo Harbour, Uruguay	Mean	-	89	30	85	312
	Range	-	59–135	26–34	44–128	174–491
ANZECC sediment quality guidelines	ISQG-Low	1.5	65	21	50	200
	ISQG-High	10	270	52	220	410

Research in the early 2000s quantified the amount of copper, lead and zinc in Sydney Harbour (Table 15). Approximately 20% of all copper, lead and zinc can

[216] Ibid.

be found in four embayments: Iron Cove, Rozelle & Blackwattle Bays, Homebush Bay, and Hen and Chicken Bay (473, 730 and 1,490 tonnes respectively). These bays represent only 5% of the total Sydney Harbour area. The remaining 80% of heavy metals is located in both small, highly-concentrated areas of upper parts of other tributaries and embayments in the Harbour, and in low concentrations throughout the Harbour.[217]

Table 15: Heavy metal inventories in Sydney Harbour (tonnes)[218]

Location	Copper	Lead	Zinc
Lower Harbour (east of Harbour Bridge)	600	1300	2300
Middle Harbour	200	350	580
Upper Harbour (west of Harbour Bridge)	1200	2100	4600
Iron Cove	120	250	470
Rozelle & Blackwattle Bays	100	190	350
Homebush Bay	33	80	210
Hen and Chicken Bay	220	210	460
Sydney Harbour	1900	3500	7300

Research published in 2013 evaluated the heavy metal contamination of Sydney Harbour by examining the degree to which the sediments have become enriched by heavy metals (Figures 23 to 25). Enrichment factors of 1.5–3, 3–5, 5–10 and>10 times were classified as minor, moderate, severe and very severe modification, respectively. A Mean Enrichment Quotient (MEQ) was calculated by adding enrichment factors for the most enriched metals (copper, lead and zinc) and dividing by three to provide an 'average' magnitude of human-induced change.[219]

Cobalt, chromium, copper, nickel, lead and zinc enrichment of Sydney Harbour sediments has been investigated. No area of Sydney Harbour was classified as very severely modified by contamination with cobalt, chromium or nickel (using mean enrichment factors) (Figure 23). Further, only Homebush Bay was severely modified by one of these three metals – chromium (mean enrichment factor of 5.2).[220]

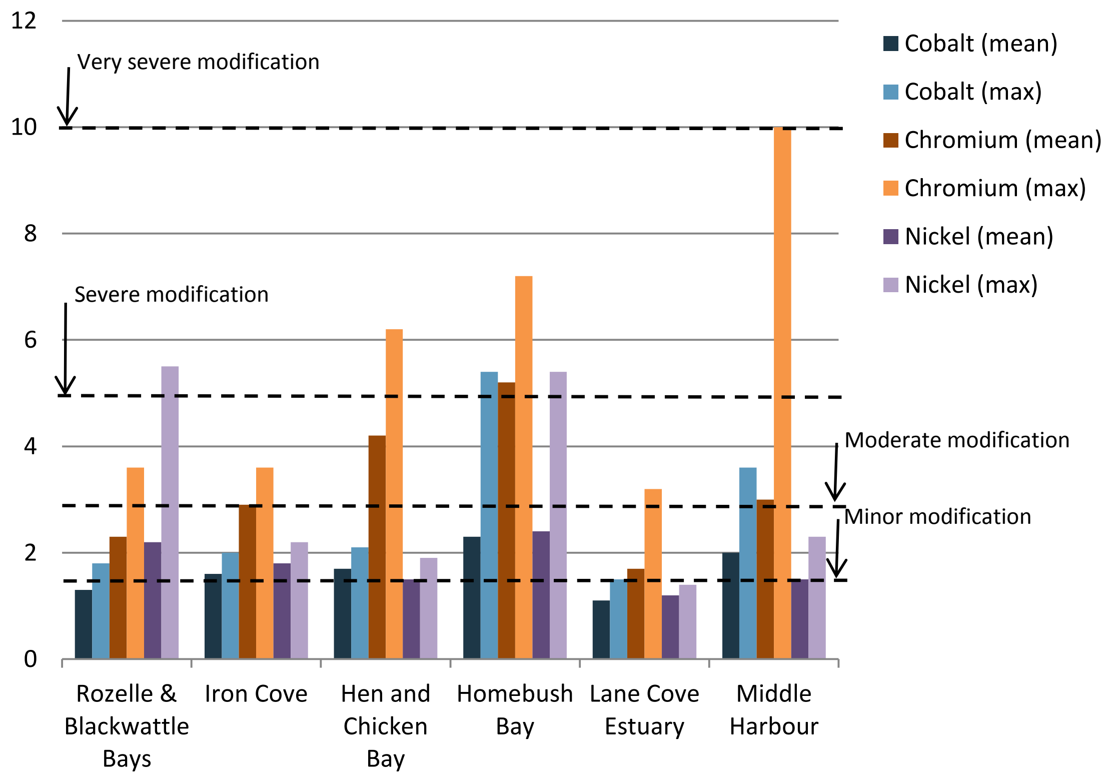
[217] Birch, G. and Taylor, S., *The contaminant status of Sydney Harbour sediments: A handbook for the public and professionals*, Environmental, Engineering and Hydrogeology Specialist Group (EEHSG) Geological Society of Australia, Public Education and Information Monograph No. 1, 2004, 100p.

[218] Modified from: Birch, G. and Taylor, S., op. cit. p.80. Note that, as copied from the source, the figures for the Lower Harbour, Middle Harbour and Upper Harbour do not add to the total amount for Sydney Harbour.

[219] Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: 542-561

[220] Ibid.

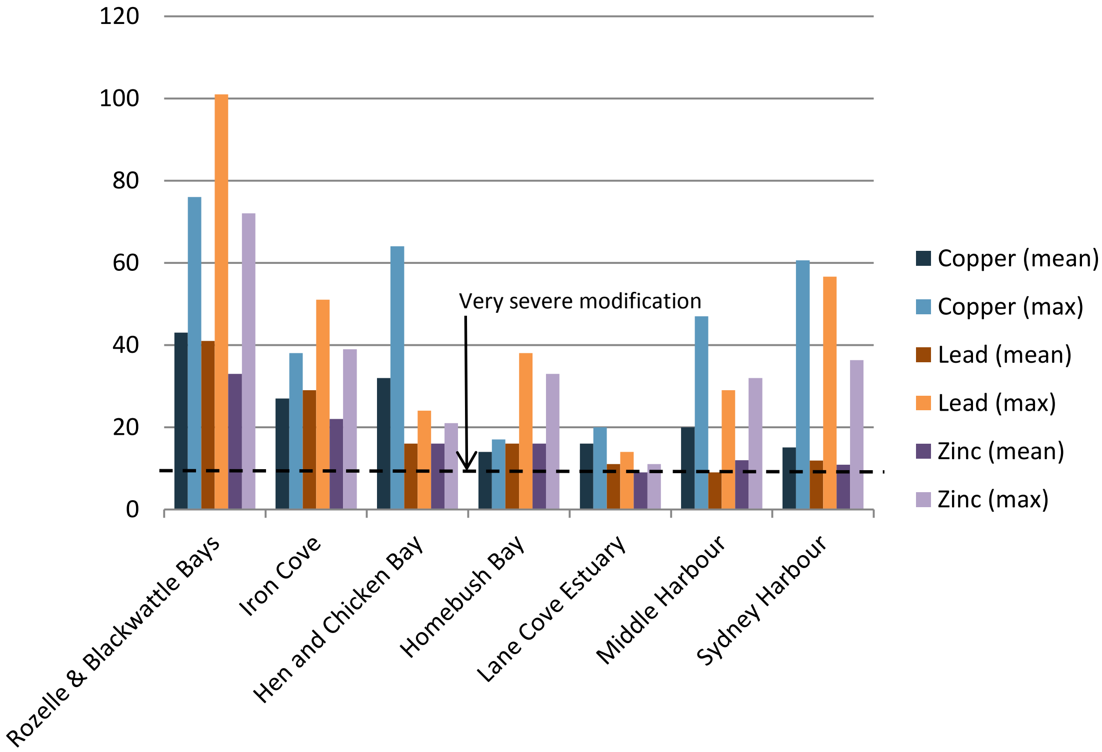
Figure 23: Cobalt, chromium and nickel enrichment in six Sydney Harbour embayments[221]



The opposite was true for copper, lead and nickel (Figure 24). All six embayments were very severely modified by copper, lead and nickel except for lead in Middle Harbour (mean enrichment factor of 9) and zinc in Lane Cove Estuary (mean enrichment factor of 9). Rozelle & Blackwattle Bays had the highest maximum enrichment factors for all three metals, copper (76), lead (101) and zinc (72).[222]

[221] Ibid. p.554
[222] Ibid.

Figure 24: Copper, lead and zinc enrichment in six Sydney Harbour embayments[223]



All six embayments, as well as Sydney Harbour as a whole, were classified as very severely modified by heavy metal contamination with Mean Enrichment Quotients (MEQ) over 10 (Figure 25). Rozelle & Blackwattle Bays (39), Iron Cove (26), and Hen and Chicken Bay (21) all had much higher MEQ values than Sydney Harbour (12.6), indicating that all three are substantially more impacted than the majority of the waterway.[224]

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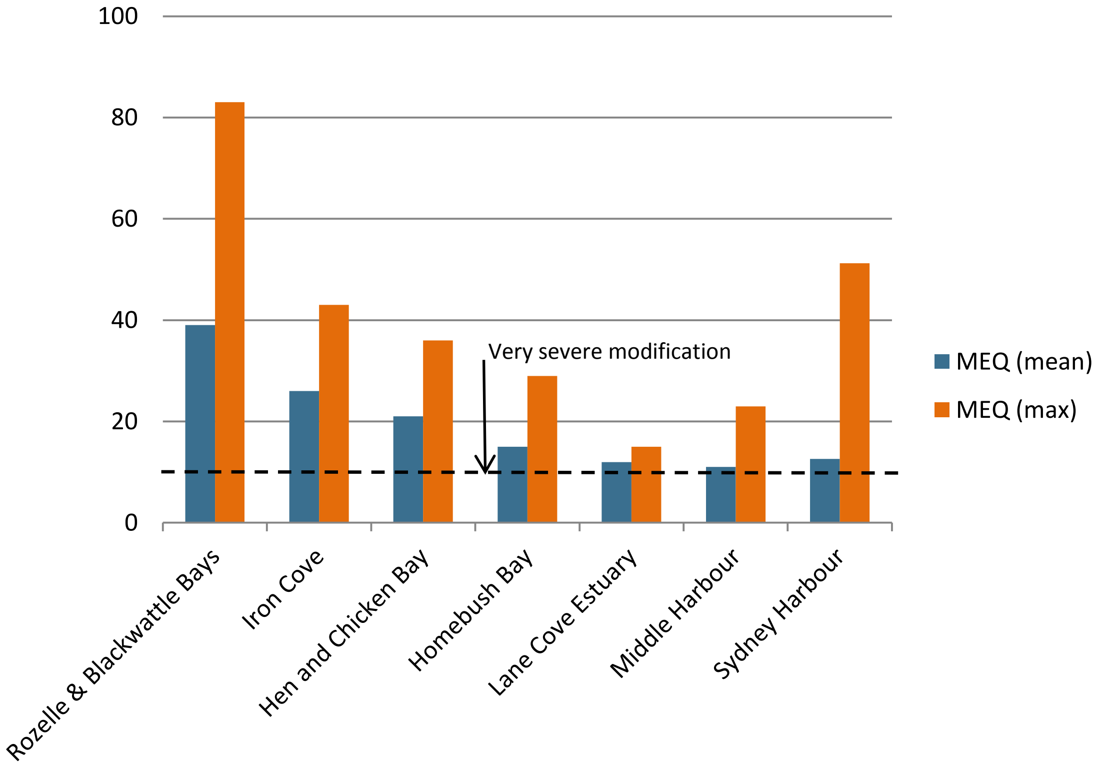
[223] Sources: Birch, G. and Olmos, M., Sediment-bound heavy metals as indicators of human influence and biological risk in coastal water bodies, *ICES Journal of Marine Science*, 2008, Vol 65(8): p.1,411; Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: p.554

[224] Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: 542-561

Figure 25: Mean Enrichment Quotient (MEQ) for heavy metals in six Sydney Harbour embayments[225]



Metal concentrations in surficial sediments of Rozelle & Blackwattle Bays, Iron Cove, Hen and Chicken Bay and Homebush Bay have generally declined over the past few decades (Figure 26). This is due in part to the movement of industry out of these catchments. Improved regulation of industrial effluents and the progressive phasing out of leaded petrol since 1985 are other contributing factors. In the Lane Cove Estuary, heavy metal concentrations have remained stable or increased except for chromium and lead in Burns Bay. In Middle Harbour, heavy metal concentrations have remained relatively stable or decreased except for copper and zinc in Sailors Bay and copper in Long Bay, which have increased.[226]

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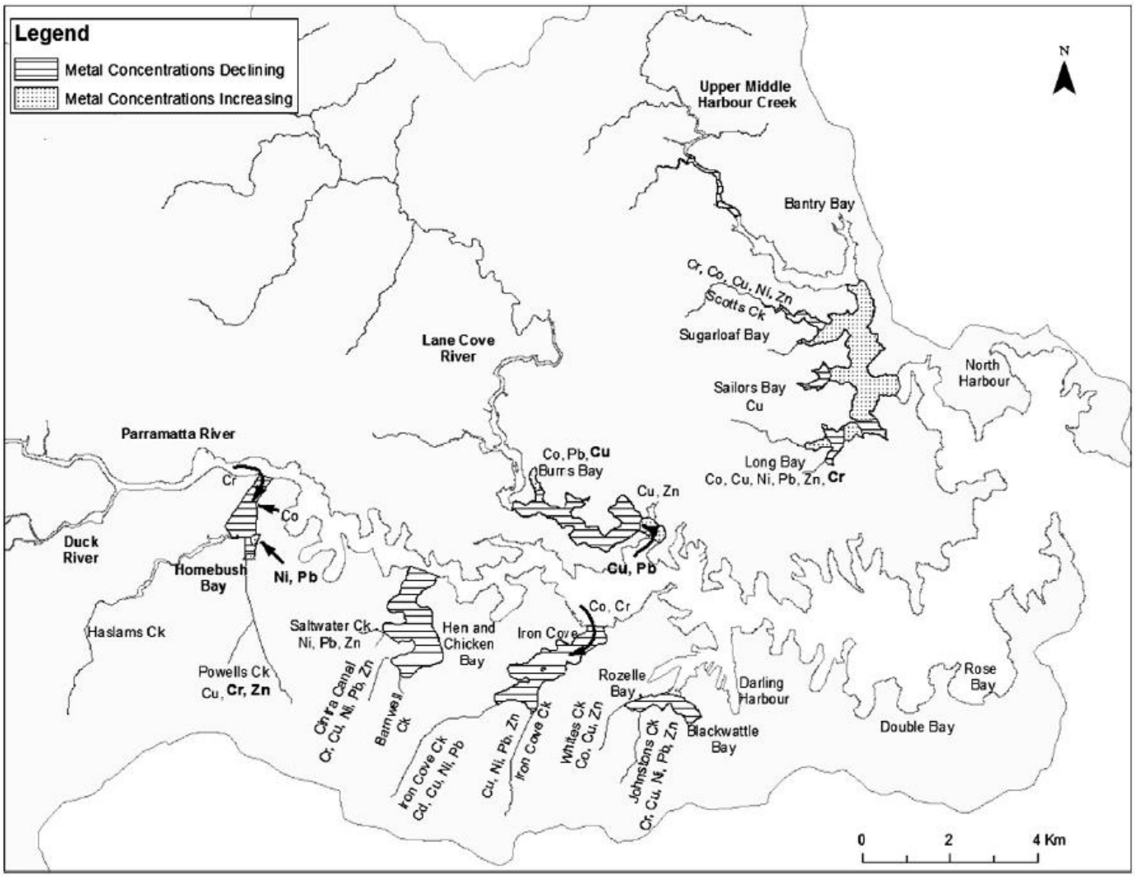
[225] Sources: Birch, G. and Olmos, M., op. cit. p.1,411; Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: p.554

[226] Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: 542-561

Figure 26: Summary of temporal trends in surficial sediment metal concentrations and sources of metals[227]



6.1.2 Heavy metals in stormwater entering Sydney Harbour

Stormwater has been identified as the most significant contemporary source of heavy metal contamination in Sydney Harbour. Other sources include the redistribution of heavy metals from the bed of the Parramatta River into embayments and throughout the Harbour, and minor contribution from industry.[228] Major sources of metals entering stormwater in urbanised catchments include road surfaces, atmospheric deposition, roof runoff, industrial activities, soil erosion, contaminated sites, sewer overflows and illegal discharges.[229] Soils in some areas of the Sydney Harbour catchment have been found to have significant levels of copper, lead and zinc contamination, with mean enrichment of soils being 14, 35 and 29 times above background levels respectively.[230]

[227] Ibid. p.559

[228] Ibid.

[229] Birch, G. and Rochford, L., Stormwater metal loading to a well-mixed/stratified estuary (Sydney Estuary, Australia) and management implications, *Environmental Monitoring and Assessment*, 2010, Vol 169(1-4): 531-551

[230] Birch, G. et al., The nature and distribution of metals in soils of the Sydney Estuary catchment, Australia, *Water, Air & Soil Pollution*, 2011, Vol 216(1-4): 581-604

It has been estimated that Sydney Harbour receives an average annual loading of arsenic, cadmium, chromium, copper, nickel, lead and zinc of 0.8, 0.5, 1.7, 3.2, 1.1, 3.6 and 17.7 tonnes respectively (28.6 tonnes in total).[231] Low-flow conditions, which contain 10% of total metal loadings, pose maximum risk to the ecosystem as all contaminants are trapped in the estuary under conditions highly favourable to their chemical and biological incorporation into sediments.[232] A proportion of the metal loadings which enter the Harbour during medium- and high-flow conditions may leave the estuary; further research is needed to quantify the fate of these contaminants.[233]

Stormwater heavy metal loadings to Sydney Harbour are much higher than comparable estuaries (Table 16). For example, 72 grams per hectare per year of copper enter the Harbour from its catchment, seven times greater than copper yields in the Yarra River. Metal yields for Sydney Harbour are about three to ten times higher than the Yarra River catchment, and between 0 to 80 times greater than comparable urban catchments in the USA. [234]

Table 16: Stormwater heavy metal yields for Australian and international urban catchments (grams per hectare per year)[235]

Location	Chromium	Copper	Nickel	Lead	Zinc
Sydney Harbour	41	72	23	82	378
Yarra River, Vic	-	7.7 – 11	-	5.7 – 31	23 – 190
Los Angeles River, USA	-	6.3 – 21	-	0.0 – 0.9	19 – 78
San Gabriel River, USA	-	0.4 – 4.2	-	0.1 – 1.4	268 – 398
San Jose Creek, USA	-	5.5 – 7.2	-	1.0 – 1.5	144 – 313
Ballona Creek, USA	12	4.6 – 40	11	1.5 – 14	18 – 21

Heavy metal concentrations in stormwater entering Sydney Harbour have been evaluated against ANZECC (2000) guidelines. The guidelines provide trigger values for dissolved metals, below which no adverse effects on the aquatic ecosystem for chronic exposures should occur. If the trigger values are exceeded, further investigation to evaluate risk to the ecosystem is recommended. Dissolved copper poses the greatest risk to the ecosystem, with between 54% and 100% of samples exceeding the trigger value for creeks discharging to Iron Cove, Hen and Chicken Bay, Homebush Bay, Parramatta River and Lane Cove River under low-flow conditions and 100% of samples for

[231] Birch, G. and Rochford, L., op. cit.

[232] Beck, H. and Birch, G., Metals, nutrients and total suspended solids discharged during different flow conditions in highly urbanised catchments, *Environmental Monitoring and Assessment*, 2012, Vol 184(2): 637-653

[233] Lee, S. and Birch, G., Utilising monitoring and modelling of estuarine environments to investigate catchment conditions responsible for stratification events in a typically well-mixed urbanised estuary, *Estuarine, Coastal and Shelf Science*, Vol 111: 1-16

[234] Birch, G. and Rochford, L., op. cit

[235] Modified from: Ibid. p.542

all creeks during medium/high flow.[236]

Dissolved zinc exceeded the trigger value for >95% of samples from creeks entering Iron Cove, Hen and Chicken Bay and Duck River, and for 33% of samples from the Lane Cove River under low-flow conditions. Under medium/high flow conditions, dissolved zinc exceeded the trigger value in >80% of samples entering Iron Cove, Duck River and Parramatta River. Dissolved arsenic and chromium trigger values were exceeded in specific sub-catchments only: Iron Cove (10-12% during low-flow) and Hen and Chicken Bay (36-53% during medium/high-flow) for arsenic, and Iron Cove (15-72% during low-flow) for chromium. Lead is poorly soluble, dissolved concentrations being less than the trigger level in >80% of samples under all conditions. Dissolved nickel trigger values were never exceeded.[237]

6.1.3 Environmental effects and modelled contamination trends

Heavy metal contamination has been linked to strong changes in the structure of infaunal assemblages, benthic larval fish assemblages and highly stressed biota.[238] These effects can be expected to be ongoing for at least the next few decades given the current level of heavy metal contamination and the modelled rates (relaxation rates) at which these concentrations will decrease (Table 17). Based on recent sediment concentration trends for several locations in Sydney Harbour, researchers modelled the length of time it would take for heavy metal concentrations to decrease to two times background concentrations (i.e. two times pre-anthropogenic concentrations), assuming that dispersion processes within the estuary and activities which supply additional metals to the Harbour remain unchanged.

The time taken for particular metals to decline to two times background concentrations ranged from 2 to 92 years. Sediment concentrations in Hen and Chicken Bay could be expected to return to two times background levels most quickly of the areas investigated, being at most 13 years (copper). In contrast, the very earliest this could occur in Sugarloaf Bay, Middle Harbour, is in 41 years (zinc); it will be 92 years until copper levels in this Bay reach two times background concentrations.[239]

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[236] Ibid.

[237] Ibid.

[238] Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p; *SMH*, Toxic estuaries in NSW making rock oysters infertile, 13 April 2014

[239] Ibid.

Table 17: Number of years for heavy metal concentrations to reach 2 times background concentrations[240]

Location	Chromium	Copper	Lead	Zinc
Blackwattle Bay	-	60	10	20
Rozelle Bay	-	23	4	19
Iron Cove (Hawthorne canal)	-	15	20	64
Iron Cove (central)	-	20	23	20
Iron Cove (entrance)	-	IT	40	66
Hen and Chicken Bay	-	13	6	2
Lane Cove River (Burns Bay)	15	IT	40	IT
Middle Harbour (Sugarloaf Bay)	76	92	73	41

Notes: IT – increasing trend at top of sediment core

The modelled times for a reduction in metal concentrations to two times background concentrations are optimistic for two reasons. The time required to achieve this objective assumes the rate of change to be constant over time. However, the rate of change will slow progressively as concentrations near the target concentration; the time to reach the target concentration will consequently increase. Sediment concentrations also cannot decrease below the levels found in stormwater entering the Harbour, which is up to 10-20 times background levels in some locations. While the high concentrations of metals that are a legacy of past industrial pollution are gradually being covered by less contaminated sediment, heavy metal contamination of Harbour sediments continues via stormwater. Improved stormwater management practices are therefore required in order to reduce sediment metal concentrations to acceptable levels.[241]

6.2 Sediment quality and toxicity

Over a number of years, researchers from the University of Sydney's School of Geosciences have investigated the quality and toxicity of sediment in Sydney Harbour. This section sets out a broad overview of their findings. Note that Homebush Bay foreshore and bay sediments with some of the highest pollutant concentrations have been remediated since the research was conducted. As of 2014, the effectiveness of the remediation program was unknown.[242]

The research summarised here does not include dioxins and furans in its analysis, although it does include total polychlorinated biphenyls (PCBs) (see

[240] Modified from: Birch, G. et al., The use of vintage surficial sediment data and sedimentary cores to determine past and future trends in estuarine metal contamination (Sydney estuary, Australia), *Science of the Total Environment*, 2013, Vol 454-455: 558

[241] Ibid.

[242] Lee, S. and Birch, G., Sydney Estuary, Australia: Geology, anthropogenic development and hydrodynamic processes/attributes, pp 17-30, In: Wolanski, E. (ed), *Estuaries of Australia in 2050 and beyond*, 2014, Springer, Dordrecht, 292p.

chapter 5 of this paper). Other toxic pollutants not included in this study that have been found in Sydney Harbour include other heavy metals (aluminium, arsenic, barium, boron, molybdenum, selenium, silver, tin and vanadium), monocyclic aromatic compounds (chlorinated benzenes and substituted phenols) and phthalates.[243] Nor does the research include emerging contaminants, a globally recognised area of concern for ecosystem health. The environmental impact of new compounds and chemicals entering the environment is unknown, as are their possible interactions with other contaminants. New contaminants include microplastics (see chapter 7 of this paper), pharmacological cosmetic products and waste products from the emerging nanotechnology field.[244]

6.2.1 Stage 1: Sediment chemistry and potential health and ecological impacts

The research into sediment quality and toxicity was conducted in three stages. The first tested for the presence of pollutants including 9 heavy metals, chlorinated hydrocarbons (many of which are listed under the 2001 Stockholm Convention, such as DDT [dichlorodiphenyltrichloroethane]), 17 polycyclic aromatic hydrocarbons[245] (PAHs) and total polychlorinated biphenyls (PCBs) (Table 18).

The chemicals tested for can all produce significant human health and ecological impacts at certain levels. For example, organochlorine pesticides (OCs), which were manufactured next to the Parramatta River during the 20th century, were deregistered by the Commonwealth Government in the 1990s due to their toxicity. Generally, OCs:

- Resist degradation by chemical, physical or biological means. They are persistent and have half-lives (the time taken for half of the quantity of pesticide to be degraded) ranging from months to years and in some cases decades;
- Are toxic to humans and other animals and are very highly toxic to most aquatic life. They can have serious short-term and long-term impacts at low concentrations. In addition, non-lethal effects such as immune system and reproductive damage of some of these pesticides may also be significant; and
- Build up in the fatty tissues of humans, plants and animals. Most of them are attracted to fatty tissues and organs and are accumulated

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[243] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement: Technical Paper 3 – Extent of contamination in Homebush Bay*, December 2002, Rhodes, NSW.

[244] Hedge, L.H. et al., *Sydney Harbour: a systematic review of the science*, 2014. Sydney Institute of Marine Science, Sydney, Australia, 80p

[245] 16 of these have been identified as being of greatest concern with regard to potential exposure and adverse health effects on humans: SA Department of Health, *Polycyclic Aromatic Hydrocarbons (PAHs): health effects*, Public health fact sheet, February 2009, 4p.

significantly in animals such as fish. This means that animals high up the food chain such as birds of prey and humans can accumulate higher levels of the pesticides than animals lower down the food chain.[246]

Table 18: Sydney Harbour sediment chemical analysis[247]

Heavy metals	Chlorinated hydrocarbons	Polycyclic aromatic hydrocarbons (PAHs)
• Cadmium • Chromium • Cobalt • Copper • Iron • Manganese • Nickel • Lead • Zinc	Organochlorine pesticides (OCs) • DDT • DDD • DDE • Chlordane • Aldrin • Heptachlor • Dieldrin • Heptachlor epoxide • Lindane A fungicide • Hexachlorobenzene (HCB) Total polychlorinated biphenyls (PCBs)	17 PAHs, including: • Benzo[*b*]fluoranthene • Fluoranthene • Pyrene

Polychlorinated biphenyls (PCBs), some of which are similar to dioxins in their toxicity:

> … have been demonstrated to cause a variety of adverse health effects. PCBs have been shown to cause cancer in animals. PCBs have also been shown to cause a number of serious non-cancer health effects in animals, including effects on the immune system, reproductive system, nervous system, endocrine system and other health effects. Studies in humans provide supportive evidence for potential carcinogenic and non-carcinogenic effects of PCBs. The different health effects of PCBs may be interrelated, as alterations in one system may have significant implications for the other systems of the body.[248]

Polycyclic aromatic compounds (PAHs) are a group of compounds formed during the incomplete burning of coal, oil, gas, wood or other organic substances. They may also be used when making dyes, plastics, and pesticides,[249] all of which have been manufactured by industries located next to Sydney Harbour. PAHs may be toxic, carcinogenic, mutagenic or teratogenic

[246] Department of the Environment, *Organochlorine pesticides (OCPs) – Trade or common use names*, Scheduled Wastes Fact Sheet Number 5 (revised), April 1997 (online – accessed 15 January 2015)

[247] Birch, G. et al., Contaminant chemistry and toxicity of sediments in Sydney Harbour, Australia: spatial extent and chemistry-toxicity relationships, *Marine Ecology Progress Series*, 2008, Vol 363, pp.71-87

[248] US EPA, *Health effects of PCBs*, 14 June 2013 [online – accessed 15 January 2015]

[249] Agency for Toxic Substances and Disease Registry, *Toxicological profile for polycyclic aromatic hydrocarbons*, U.S. Department of Health and Human Services, August 1995, 458p

(able to disturb the growth of an embryo or foetus).[250]

The first stage found that the sediments of Sydney Harbour contain some of the highest reported concentrations of a wide range of contaminants (Table 19).[251] Contaminant concentrations were highest in the upper parts of embayments in the Parramatta River and the western tributaries of Middle Harbour. The main sources of contaminants were identified as stormwater and historical dumping practices by industry.[252]

6.2.2 Stage 2: Sediment quality and probable toxicity

The second stage of the research tested chemical concentration levels across the Harbour against Sediment Quality Guidelines (SQGs). The SQGs consist of 2 values for each chemical – effects range low (ERL) and effects range median (ERM). The ERL represents the value below which adverse biological effects are seldom observed. The ERM denotes the value above which adverse biological effects are expected to occur frequently. When a chemical concentration lies between the ERL and ERM, an intermediate, often irregular biological response is expected to occur.

Table 19 presents the ERL and ERM values for the most prevalent chemicals in the Harbour. The mean concentration of many chemicals exceeded their ERM value; for example, the mean concentration of lead (390) exceeded its ERM of 218. The most prevalent contaminants in the harbour were copper, lead and zinc. Sediment in 2% of Sydney Harbour had copper levels higher than the copper ERM. The respective figures for lead and zinc were 50% and 36%. Sediment in all of the Harbour, except a small area near the entrance, exceeded ERL values for at least one heavy metal.[253]

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[250] Thiess Services and Parsons Brinckerhoff, *Remediation of Lednez site, Rhodes and Homebush Bay: environmental impact statement*, December 2002, Rhodes, NSW.

[251] For maps of the distribution of a broad range of contaminants in Sydney Harbour, see: Birch, G. and Taylor, S., op. cit.

[252] Birch, G. et al., Contaminant chemistry and toxicity of sediments in Sydney Harbour, Australia: spatial extent and chemistry-toxicity relationships, *Marine Ecology Progress Series*, 2008, Vol 363, pp.71-87.

[253] Ibid.

Table 19: Summary of sediment chemical data for the most prevalent chemicals in four classes in Sydney Harbour[254]

Chemical	Concentration			Sediment Quality Guidelines		% samples amongst ranges of SQGs		
	Min.	Max.	Mean	ERL	ERM	<ERL	ERL-ERM	>ERM
Metals (mg kg^{-1})								
Copper	20	701	210	34	270	2	75	23
Lead	78	1050	390	46.7	218	0	29	71
Zinc	75	820	900	150	410	3	18	78
PAHs (µg kg^{-1})								
Fluoranthene	121	16,200	4,300	600	5,100	11	60	29
Pyrene	161	23,300	5,100	665	2,600	11	45	45
OCs (µg kg^{-1})								
Total DDT	<0.5	5,168	150	1.58	46.1	38	34	28
Total PCB (µg kg^{-1})	<5	514	40	22.7	180	83	11	6

Concentrations are expressed as dry weight and mean values are rounded to 2 significant figures. SQGs: sediment quality guidelines, ERL: effects range low, ERM: effects range-median

Concentrations for at least one OC or PAH compound in sediments in almost all upper and middle parts of the Harbour, including Middle Harbour, exceeded ERM values. Sediments in only a small part of the Harbour had PCB concentrations above the ERM value.[255]

As contaminants rarely occur individually throughout the Harbour, the probability of sediment toxicity for mixtures of contaminants was calculated using the mean ERM quotient (MERMQ) approach.[256] Sediments in the Harbour were divided into 'priority areas' according to their MERMQ value (categories 1 to 4 from low to high; Figure 27). Category 1, 2, 3 and 4 sediment corresponding to probable toxicities of approximately 10, 25, 50 and 75% comprised 19, 54, 25 and 2% of the Harbour respectively.[257]

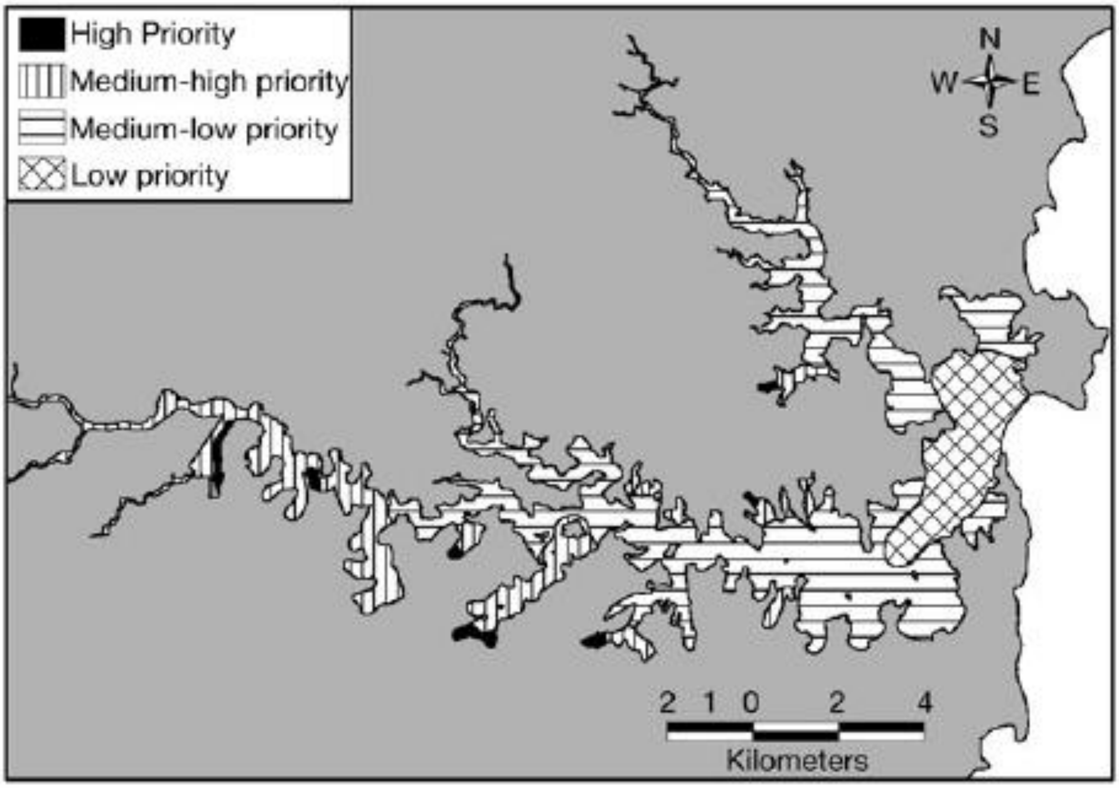
[254] Adapted from: Ibid. p.78

[255] Ibid.

[256] In this approach, contaminant concentrations at each site are normalised to (divided by) respective ERM values, the quotients are summed and then divided by the total number of contaminants.

[257] Birch, G. et al., Contaminant chemistry and toxicity of sediments in Sydney Harbour, Australia: spatial extent and chemistry-toxicity relationships, *Marine Ecology Progress Series*, 2008, Vol 363, pp.71-87

Figure 27: Four priority categories for Sydney Harbour sediments according to the probability of sediment toxicity[258]



6.2.3 Stage 3: Sediment combined chemical and toxicity scores

Stage three of the research generally focused on those areas identified as being either high priority or medium-high priority in stage 2 of the research (Figure 27). The final stage involved three ecotoxicological tests of sediments in 16% of the Harbour (Figure 28). This data was combined with the chemical data to produce a sediment chemistry and toxicity score. All the sediment in the areas tested was found to be either highly toxic (highly degraded; 17%), moderately toxic (moderately degraded; 52%) or slightly toxic (slightly degraded; 31%).

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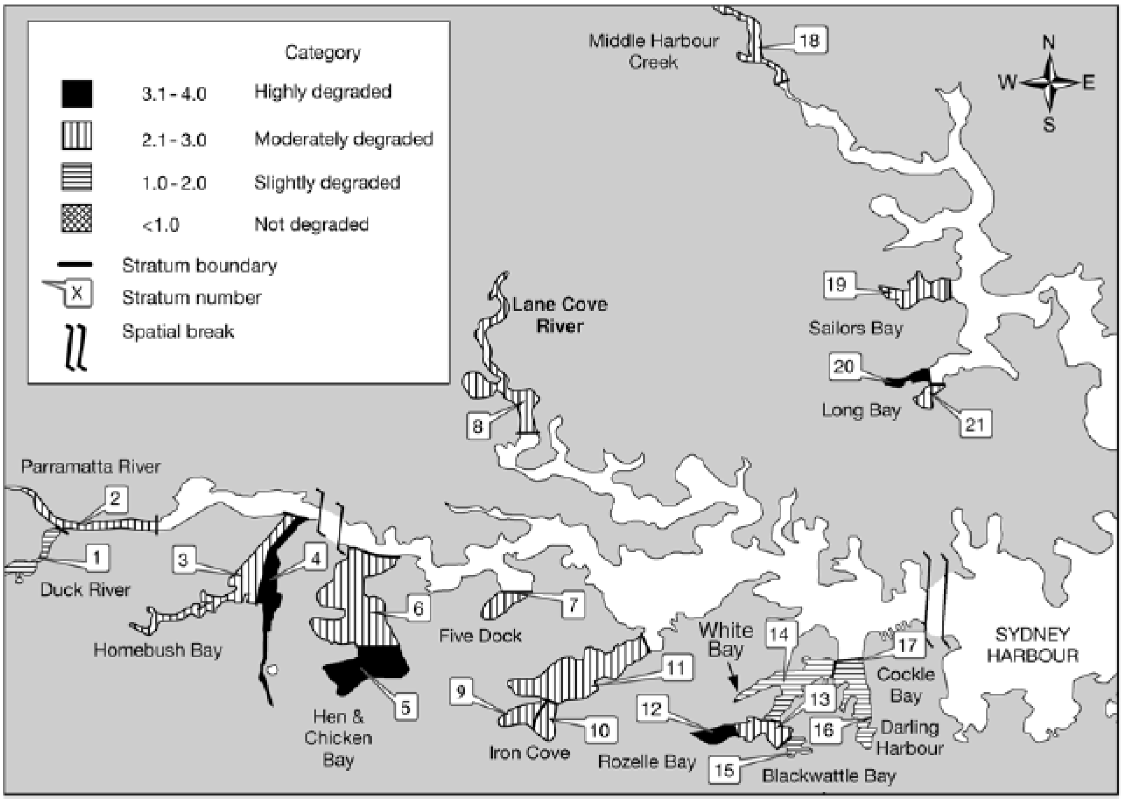
[258] Ibid. p.79

Figure 28: Combined chemistry and toxicity scores for Sydney Harbour sediments[259]



6.2.4 International comparison

The findings of the research set out above were compared with a US study, which took 1,068 estuarine samples along the 3 US coasts (Table 20). 46% of Sydney Harbour has at least one chemical which exceeds its ERM value (i.e. adverse biological effects are expected to occur frequently). In comparison, only 27% of US samples had at least one chemical which exceeded its ERM value. Further, 11% of Sydney Harbour has at least 6 chemicals which exceed their ERM value.

[259] Ibid. p.84

Table 20: Comparing sediment toxicity in Sydney Harbour and US estuaries (% of estuary)[260]

	No chemicals exceeded an ERL value	At least one chemical exceeded an ERL value, but not an ERM value	At least one chemical exceeded an ERM value
Sydney Harbour	8%	45%	46%
US estuaries	31%	42%	27%

Only 8% of Sydney Harbour has sediment in which no chemical exceeds its ERL value (i.e. the value below which adverse biological effects are seldom observed). In comparison, this was true of 31% of samples in US estuaries.

[260] Note values do not add to 100% for Sydney Harbour because of rounding. Sources: Birch, G and Taylor, S., Application of sediment quality guidelines in the assessment and management of contaminated surficial sediments in Port Jackson (Sydney Harbour), Australia, *Environmental Management*, 2002, Vol 29(6), pp. 860-870; Birch, G. et al., Contaminant chemistry and toxicity of sediments in Sydney Harbour, Australia: spatial extent and chemistry-toxicity relationships, *Marine Ecology Progress Series*, 2008, Vol 363, p.79

7. MICROPLASTICS

7.1 Plastic pollution

Plastic pollution in oceans is a global problem, negatively impacting wildlife, tourism and shipping. Research published in 2014 estimated that at least 5.25 trillion plastic particles weighing 268,940 tons are currently floating in the world's oceans, equivalent to 0.1% of world annual plastic production.[261] However, the amount of plastic *floating* in the oceans is only a fraction of the total, small particles of plastic having either been consumed by marine wildlife, frozen in sea ice or settled into sediments.[262] It has been estimated that there are up to 150 million tonnes of plastic in the oceans; in comparison, there are an estimated 800 million tonnes of fish in the ocean.[263] A February 2015 study quantified the amount of plastic entering the oceans on an annual basis at somewhere between 4.8 and 12.7 million tons.[264]

The term microplastics was first coined in 2004 as researchers attempted to account for all the plastic in the ocean.[265] Microplastics are tiny plastic fragments, fibres and granules generally smaller than 5mm in diameter. Those which are manufactured have been defined as primary microplastics, and include air-blasting media (microplastic scrubbers which are blasted at machinery, engines and boat hulls to remove rust) and microbeads used in cosmetics, shampoos and facial-cleansers.[266]

Secondary microplastics generally result from the breakdown of large plastic debris and from washing clothes in washing machines. Physical, biological and chemical processes break large plastic debris down over time. Such degradation may result in additives, designed to enhance durability and corrosion resistance, leaching out of the plastics.[267] A study of eighteen shores across six continents found that proportions of microplastics in marine sediments and sewage resembled those used for textiles (78% polyester, 9% polyamide, 7% polypropylene, 5% acrylic). The authors found that a garment can shed >1,900 fibres per wash, with garments releasing >100 fibres per litre of effluent on average. The study concluded that microplastic particles in the marine environment are mainly derived from sewage via washing clothes, rather

[261] Eriksen, M. et al., Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea, *PLoS ONE*, 2014, Vol 9(12)

[262] *The Guardian*, Drowning in plastic, 25 January 2015 [online – accessed 6 February 2015]

[263] *The Guardian*, We could end up with 'as much plastic in our oceans as fish', 27 January 2015 [online – accessed 6 February 2015]. This story included an estimate of the amount of plastic entering the oceans on an annual basis at 20 million tonnes.

[264] National Center for Ecological Analysis and Synthesis, *New in science: first estimate to quantity plastics flowing into the ocean*, 12 February 2015 [online – accessed 16 March 2015]

[265] *The Guardian*, Drowning in plastic, 25 January 2015 [online – accessed 6 February 2015]

[266] Cole, M. et al., Microplastics as contaminants in the marine environment: a review, *Marine Pollution Bulletin*, 2011, Vol 62(12): 2,588-2,597

[267] Cole, M. et al., op. cit.; *ECOS*, The science is in: the solution to pollution is not dilution, 5 May 2014, Issue 195 [online – accessed 6 February 2015]

than fragmentation or cleaning products.[268]

Plastics consist of many different polymers and, depending on their composition, density and shape, can be buoyant, neutrally-buoyant or sink. Microplastics can therefore be found throughout the water column and in sediments. Over time, buoyant and neutrally-buoyant microplastics can sink due to the accumulation of microbial biofilms, which may permit the colonisation of algae and invertebrates on the plastics' surface, or the adherence of particles.[269]

7.2 Environmental impacts

Coral has recently joined the list of marine wildlife that eats plastic floating in the ocean, other creatures including sea birds, turtles, worms, bacteria and marine plankton.[270] Humans may be consuming microplastics indirectly, and in potentially substantial quantities, insofar as they eat marine wildlife such as mussels and oysters which, when commercially grown, have been found to contain an average of 0.36 microplastic particles per gram of tissue.[271] Limited research on the health impacts of microplastics is currently available. It appears that there are three adverse impacts that may result from the ingestion of microplastics: the physical effects of ingestion; and toxic responses from (a) inherent contaminants leaching from the microplastics and (b) pollutants that have sorbed onto the microplastics. While very little research has been conducted into the physical effects of ingesting microplastics, two studies have found negative health impacts on blue mussels[272] and Japanese medaka, a widely accepted model fish species.[273]

According to the UN Globally Harmonised System, >50% of plastics are associated with hazardous monomers, additives and chemical byproducts.[274] These include polybrominated diphenyl ethers (which provide resistance to heat), nonylphenol (which reduces oxidative damage), triclosan (which reduces microbial degradation), phthalates (which soften plastic) and Bisphenol A (which is widely used in food and beverage containers). Such chemicals may interfere with biologically important processes, potentially resulting in endocrine disruption, which in turn can impact upon mobility, reproduction and

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[268] Browne, M. et al., Accumulation of microplastic on shorelines worldwide: sources and sinks, *Environmental Science & Technology*, 2011, Vol 45(21): 9,175-9,179. See also: *The Guardian*, Inside the lonely fight against the biggest environmental problem you've never heard of, 28 October 2014 [online –accessed 6 February 2015]

[269] Cole, M. et al., op. cit.; Woodall, L. et al., The deep sea is a major sink for microplastic debris, *Royal Society Open Science*, December 2014, 1: 140317

[270] *ABC News*, Coral found to be eating plastic waste in the ocean, 25 February 2015

[271] Reed, C., Dawn of the plasticene, *New Scientist*, 31 January 2015, p.32

[272] Cole, M. et al., op. cit.

[273] Rochman, C. et al., Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress, *Scientific Reports*, 2013, Vol 3:3263

[274] Ibid.

development, and carcinogenesis.[275] Some evidence has already been found that these chemicals may be released after ingestion by biota.[276]

Marine plastic debris, in particular microplastics with their large surface area to volume ratio, are susceptible to contamination by waterborne pollutants such as aqueous metals, endocrine disrupting chemicals and persistent organic pollutants (POPs), which include dioxins, polychlorinated biphenyls (PCBs) and organochlorine pesticides (e.g. DDT). Many POPs are toxic, inducing endocrine disruption, mutagenesis and/or carcinogenesis.[277] Plastics have been found to accumulate concentrations of pollutants up to a hundred times greater than those in sediments.[278] Recent research has confirmed that pollutants sorbed onto ingested microplastics are bioaccumulated by marine wildlife.[279]

7.3 Sydney Harbour

In 2014, researchers from the Sydney Institute of Marine Science found "alarming" levels of microplastic pollution in Sydney Harbour. Sediment samples were taken at 27 sites across the Harbour (Figure 29). Concentrations of microplastics ranged from 0-10 to a high of 61-100 particles per 100ml of sediment in Middle Harbour. [280] Thin plastic fibres from clothing were the most commonly found particles, outnumbering flakes or balls.[281]

Concentrations of up to 61-100 particles per 100ml of sediment are substantially higher than found elsewhere around the world (Table 21). Other studies have found concentrations of microplastics ranging from 1 to 24 particles per 100ml. The three other estuaries listed in Table 21 had concentrations of 24 (Sweden), 8 (UK, estuary) and 2 to 16 (Tamar estuary, UK) particles per 100ml of sediment.[282]

275 Cole, M. et al., op. cit.

276 Browne, M. et al., Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity, *Current Biology*, 2013, Vol 23(23): 2,388-2,392

277 Cole, M. et al., op. cit.

278 Browne, M. et al., Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity, *Current Biology*, 2013, Vol 23(23): 2,388-2,392

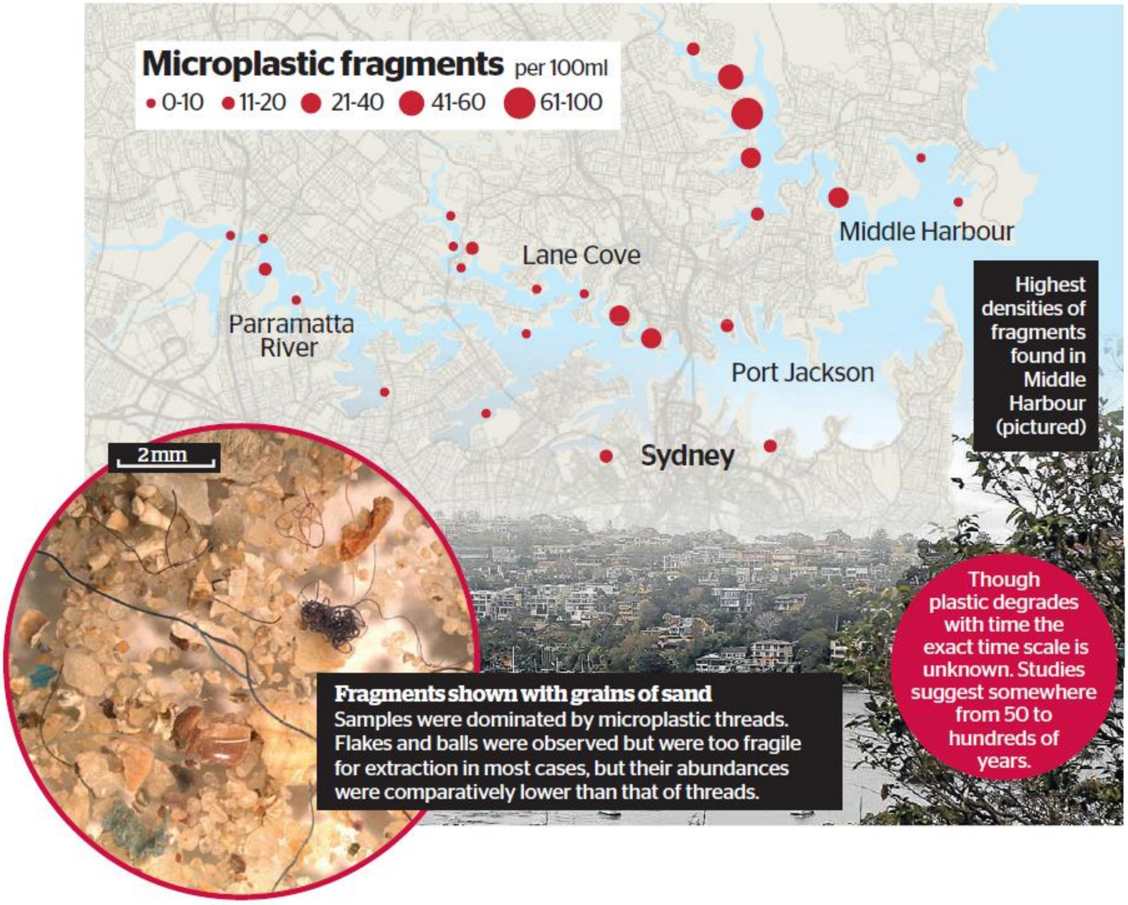
279 Cole, M. et al., op. cit.; Browne, M. et al., Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity, *Current Biology*, 2013, Vol 23(23): 2,388-2,392; Rochman, C. et al., op. cit.

280 *The Guardian*, Sydney harbour's plastic pollution at 'alarming' levels, scientists find, 25 August 2014 [online – accessed 9 February 2015]

281 *ABC News*, Invisible threat: microplastic contamination discovered on bottom of Sydney Harbour, 22 August 2014 [online – accessed 9 February 2015]

282 Note: it is unclear from some of these studies whether the values given are averages or maximums, thereby potentially limiting the comparability of these figures.

Figure 29: The distribution of microplastics in Sydney Harbour[283]



In August 2014, at the time the Sydney Harbour research findings were announced, Rob Stokes, the NSW Minister for the Environment, announced that he had convened a working group to work towards phasing out microbeads by 2016 through voluntary means.[284] He also called for a national ban on the sale and production of shampoos and other products containing microbeads.[285]

Overseas, in May 2014 the New York State Assembly passed a bill that proposes a phase-out deadline for microbeads of 2015.[286] Illinois banned the sale of cosmetics containing plastic microbeads in June 2014, with a phase out period between 2017 and 2019,[287] while a similar bill was defeated in California in August 2014.[288] In December 2014, the Netherlands, Austria, Belgium and

[283] *SMH*, Tiny threats beneath harbour, 25 August 2014

[284] *ABC News*, NSW push to phase out use of 'microplastics' in personal care products, 29 August 2014 [online – accessed 9 February 2015]; *NSW PD*, 22 October 2014, p.1,681

[285] *SMH*, NSW calls for national ban on shampoo additives that are choking the oceans, 28 August 2014 [online – accessed 9 February 2015]

[286] *Cosmetics design*, New York Senator pushes legislation to ban microbeads, 3 November 2014 [online – accessed 9 February 2015]

[287] *Time*, Know what's in your face wash: why Illinois banned microbeads, 24 June 2014 [online – accessed 9 February 2015]

[288] *Planet Experts*, California microbead ban fails to pass in State Senate, 27 August 2014

Sweden, with the support of Luxembourg, issued a joint call to ban the microplastics used in detergents and cosmetics.[289]

Table 21: International comparisons of microplastic contamination[290]

Location	Particles per 100ml sediment
Sydney Harbour	0-10 to 61-100
Sweden (harbour)	24
UK, subtidal	12
UK, estuary	8
UK, beach	1
Tamar estuary, UK	2 to 16
Chagos Archipelago, Indian Ocean, beach	9
18 shores across 6 continents	0.8 to 12.4*
Western Australia	0.8*
Portugal	12.4*
UK	12.4*
Deep sea sediments (North Atlantic Ocean, Mediterranean Sea & SW Indian Ocean)	26.8

* Converted from Browne et al (2011) study which used particles per 250ml sediment

As of 2014, Unilever, which owns the Dove brand, has announced that it will start phasing out the use of microbeads in January 2015 and finish its phase out by the end of 2015. Other companies that have stated they will phase out microbeads include L'Oreal, Johnson & Johnson, The Body Shop and Beiersdorf, which owns the Nivea brand.[291]

[online – accessed 9 February 2015]

289 *EurActiv*, Dutch rally support for microplastic ban to safeguard their mussels, 17 December 2014 [online – accessed 9 February 2015]

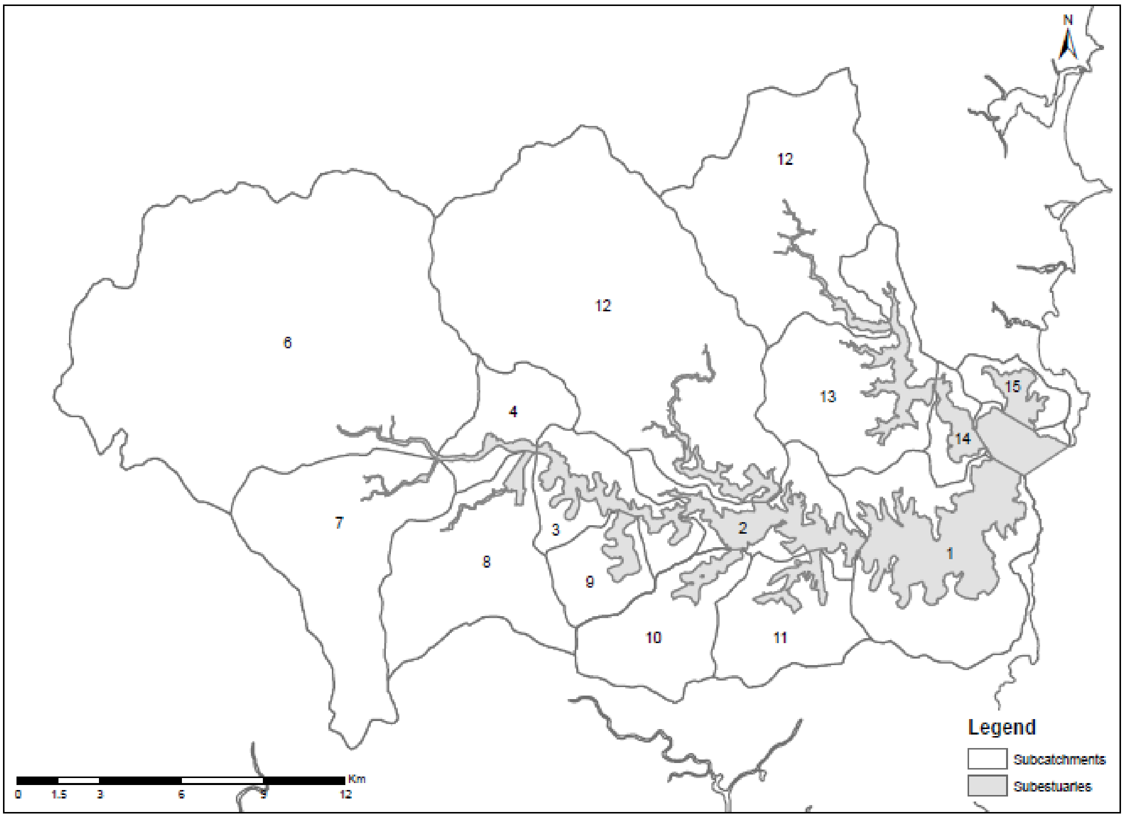
290 Sources: Browne, M. et al., Spatial patterns of plastic debris along estuarine shorelines, *Environmental Science & Technology*, 2010, Vol 44(9): 3,404-3,409; Browne, M. et al., Accumulation of microplastic on shorelines worldwide: sources and sinks, *Environmental Science & Technology*, 2011, Vol 45(21): 9,175-9,179*; The Guardian*, Sydney harbour's plastic pollution at 'alarming' levels, scientists find, 25 August 2014 [online – accessed 9 February 2015].

291 *ABC News*, NSW push to phase out use of 'microplastics' in personal care products, 29 August 2014 [online – accessed 9 February 2015]; *SMH*, Unilever says it will ban face scrub product polluting harbour in two months, 23 November 2014 [online – accessed 9 February 2015]

8. A SYDNEY HARBOUR REPORT CARD

Research completed at Sydney University in 2014 assessed the condition of Sydney Harbour and its sub-catchments and sub-estuaries (Figure 30).[292] Each sub-catchment/sub-estuary was graded on three indicators – catchment pressures, water quality and sediment quality. These grades were combined into an overall grade. Management priorities were allocated to each sub-catchment/sub-estuary according to their condition. Note that some pollutants are not taken into account in the analysis e.g. dioxins. This research is therefore *indicative* of the state of the Harbour and its sub-catchments.

Figure 30: Sub-catchment/sub-estuary systems of Sydney Harbour[293]



1. Lower Estuary	6. Parramatta River	11. Blackwattle / Rozelle Bay
2. Middle Estuary	7. Duck River	12. Upper Middle Harbour
3. Upper Estuary	8. Homebush Bay	13. Central Middle Harbour
4. Lower Parramatta River	9. Hen and Chicken Bay	14. Lower Middle Harbour
5. Lane Cove	10. Iron Cove	15. North Harbour

8.1 Catchment pressures

The catchment pressure grade assigned to each sub-catchment/sub-estuary was calculated using the following indicators:

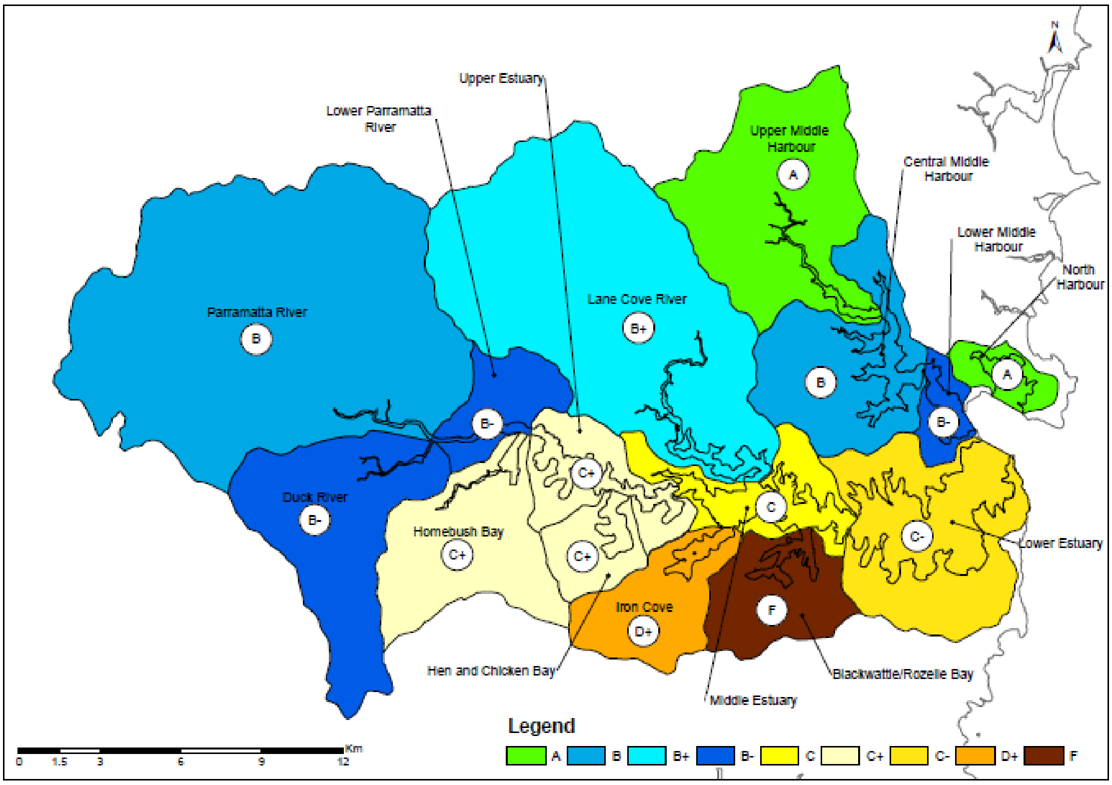
- Percentage of the catchment area which is urbanised;

[292] Gunns, T., op. cit.
[293] Ibid., p.62

- Population density;
- Percentage of the original area that has been reclaimed;
- Condition of riparian vegetation of creeks and rivers;
- Enrichment of metals in catchment soils;
- Metal yield from catchment; and
- Nutrient yield from catchment.

Blackwattle/Rozelle Bay had the highest pressure grade (Figure 31), significantly greater than the next highest sub-catchment, Iron Cove. Upper Middle Harbour and North Harbour had the lowest pressure grades.

Figure 31: Pressure grades for Sydney Harbour294



While catchment pressures were significantly correlated with sedimentary indicators, there was no correlation with water quality. This suggests that other factors such as flushing rates and estuary morphodynamics may influence water quality.

8.2 Water quality

The water quality grade assigned to each sub-catchment/sub-estuary was calculated using the following indicators:

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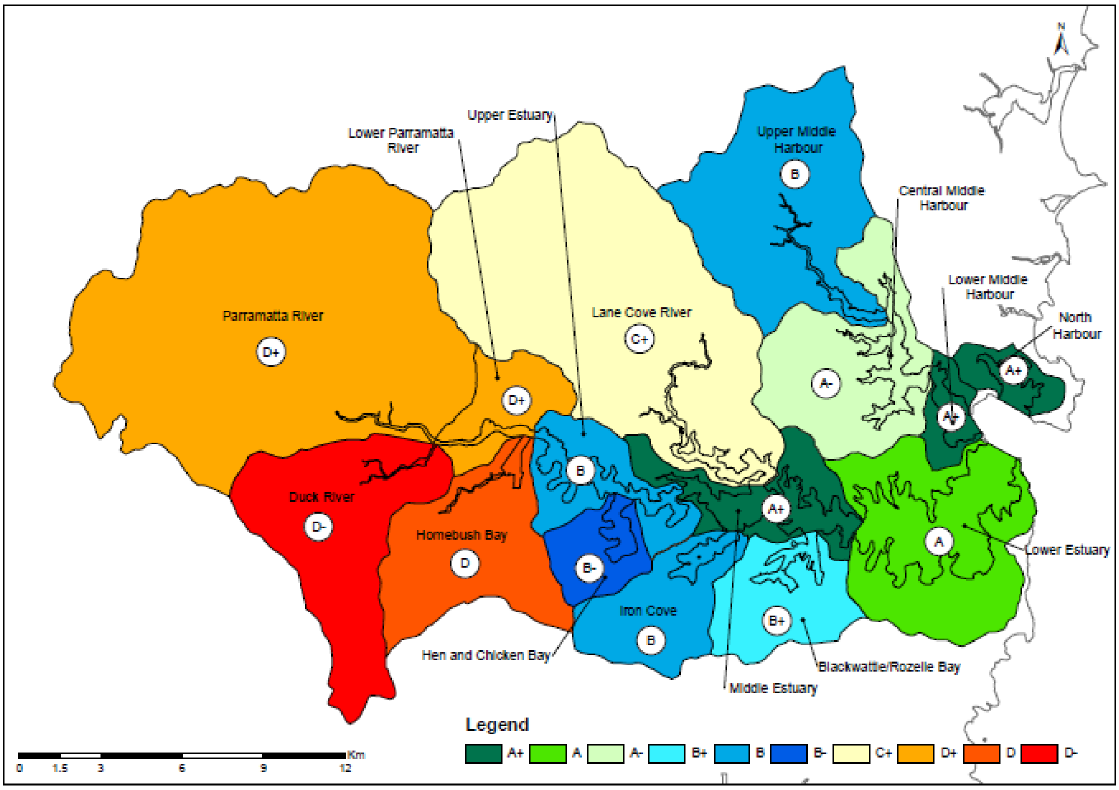
[294] Ibid., p.81

- Chlorophyll-a – a general indicator of plant biomass, increased levels of chlorophyll-a may denote eutrophication[295] of the water body;
- Dissolved oxygen – low levels can significantly affect aquatic organisms such as fish, and may increase the toxicity of pollutants such as copper, lead and zinc;
- Turbidity – significant impacts of suspended particulate matter include a reduction in light availability; and
- Nutrients (total nitrogen and total phosphorus) – excess nutrients may cause eutrophication.

The lowest water quality grades were found furthest from the Harbour mouth in the Duck River, Homebush Bay, Parramatta River and Lower Parramatta River (Figure 32). North Harbour, Lower Middle Harbour and Middle Estuary had the highest water quality.

Figure 32: Water quality grades for Sydney Harbour[296]



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295 Eutrophication is the enrichment of a water body with chemical nutrients, leading to excessive plant growth. As a result, dissolved oxygen levels decrease causing the death of other organisms such as fish.

296 Gunns, T., op. cit., p.83

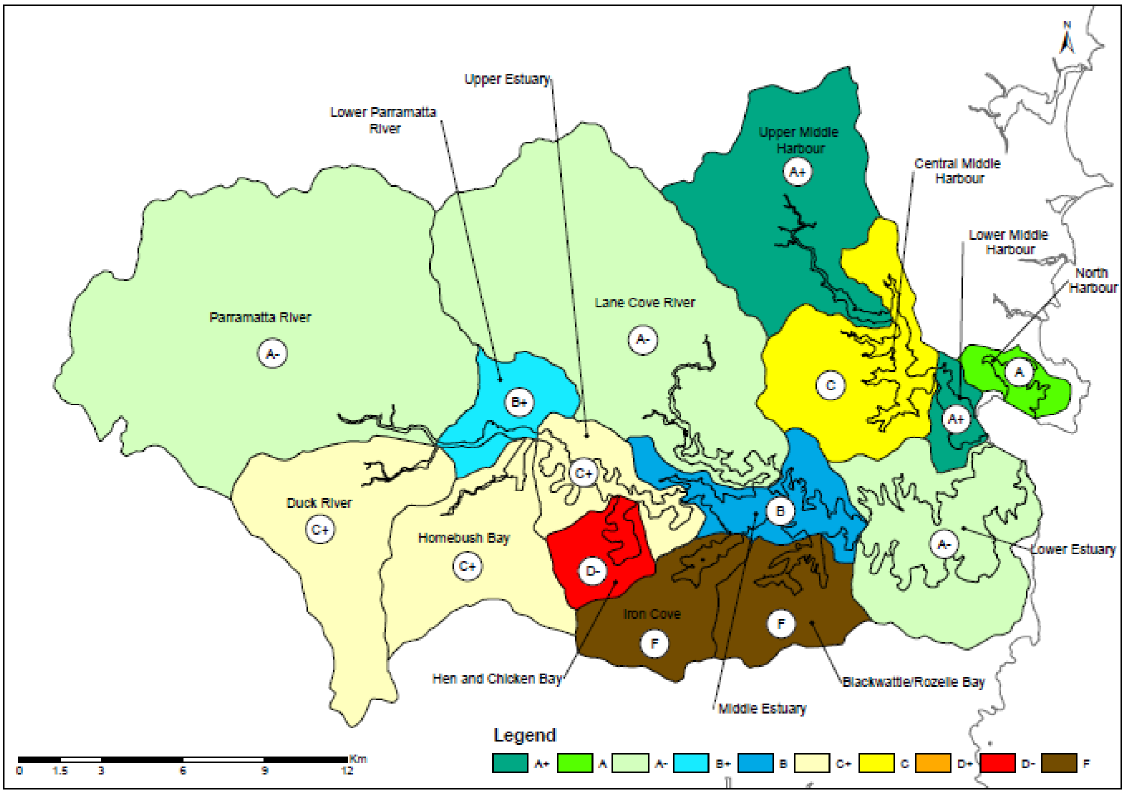
8.3 Sediment quality

Sediment quality was assessed using two indicators:

- The Human Impact Index – a measure of the increased levels of pollutants since European settlement using copper, lead and zinc as indicative pollutants; and
- The Benthic Health Index – a measure of the potential toxicity of the sediment using copper, lead and zinc as indicative pollutants.

The worst sediment quality grades were found in Blackwattle/Rozelle Bay, Iron Cove and Hen and Chicken Bay (Figure 33). Upper Middle Harbour and Lower Middle Harbour had the best sediment quality grades.

Figure 33: Sediment quality grades for Sydney Harbour[297]

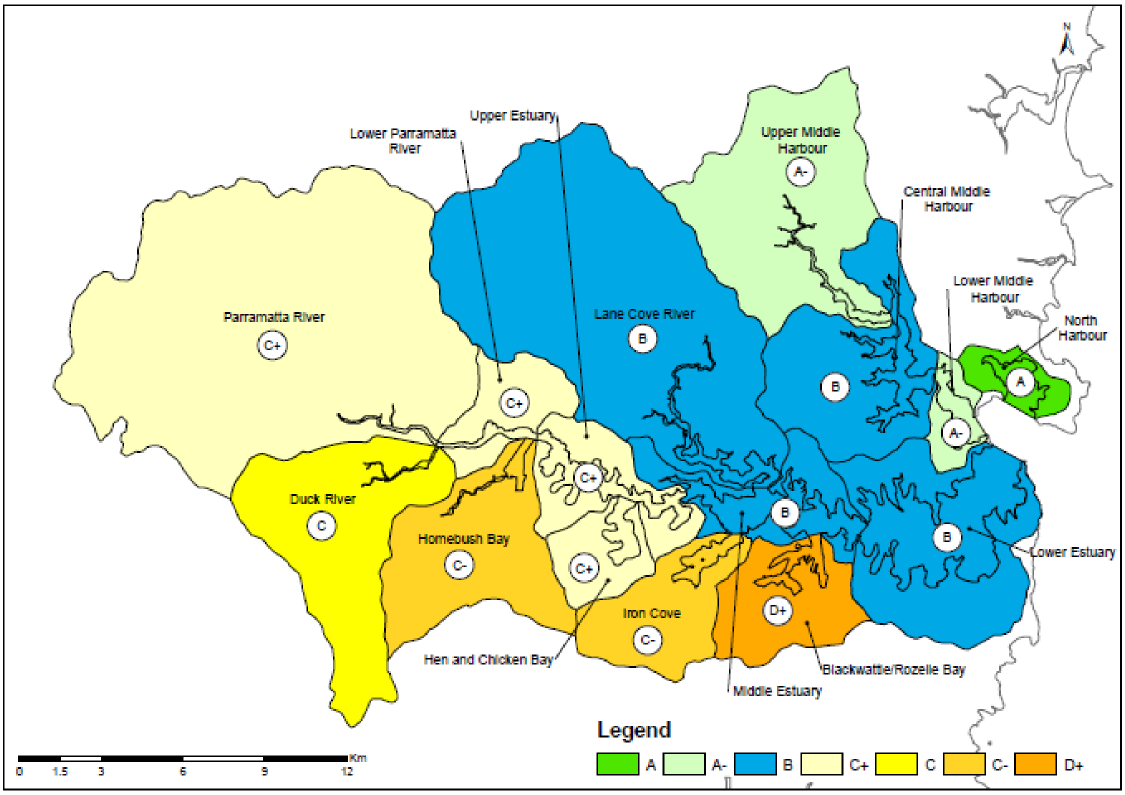


8.4 Final assessment grade and management implications

The catchment pressure, water quality and sediment quality grades were combined to give a final assessment grade for each sub-catchment/sub-estuary (Figure 34). The western and southern parts of the Harbour all received lower grades than the northern parts, with Blackwattle/Rozelle Bay, Iron Cove and Homebush Bay having the lowest grades of all. North Harbour, Upper Middle Harbour and Lower Middle Harbour had the highest grades.

297 Ibid., p.84

Figure 34: Final assessment grade for Sydney Harbour[298]



The sub-catchments of the Harbour are listed in descending order from the highest priority to the lowest priority in Table 22. Management priorities were derived from the final assessment grades. According to the author, this assessment scheme:

> … provides managers with a tool to assist in the identification of 'priority' sub-catchment/sub-estuary systems, as well as areas and issues of concern …
>
> … [the] ability to prioritise estuarine management improves the efficiency of management actions and facilitates the development of effective, appropriate and targeted long-term management strategies. An understanding of the relationships between catchment pressures and estuarine condition may also be used to identify the source and pathways of contamination to an estuary, allowing appropriate management actions to be developed.[299]

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[298] Ibid., p.80

[299] Ibid., p.94

Table 22: Management priorities for Sydney Harbour[300]

Sub-catchment/ sub-estuary	Overall priority	Sediment quality priority	Water quality priority
Blackwattle/Rozelle Bay	High	High	Medium Low
Iron Cove	High	High	Medium Low
Homebush Bay	High	Medium High	High
Duck River	High	Medium High	High
Hen and Chicken Bay	Medium High	High	Medium Low
Upper Estuary	Medium High	Medium High	Medium High
Lower Parramatta River	Medium High	Medium Low	High
Parramatta River	Medium High	Low	High
Lower Estuary	Medium Low	Low	Low
Middle Estuary	Medium Low	Medium Low	Low
Lane Cove River	Medium Low	Low	Medium High
Central Middle Harbour	Medium Low	Medium High	Low
Lower Middle Harbour	Low	Low	Low
Upper Middle Harbour	Low	Low	Medium Low
North Harbour	Low	Low	Low

[300] Adapted from: Ibid., p.94

9. CONCLUSION

While Sydney Harbour and its tributaries are visually cleaner today than they have been anytime in the past century, they are still some of the most polluted in the world when it comes to contaminants like dioxins and heavy metals. Many of these pollutants entered the Harbour as industrial effluent during a time when industrial practices were poorly regulated. While this no longer occurs, pollutants nevertheless continue to enter the Harbour, via stormwater, sewage overflows and through leachate from contaminated reclaimed land.

With regards to the pollution currently in the Harbour, it appears that remediation of polluted sediments is technically and financially impractical. It seems that the only way to address the problem is to wait until sediments cover the contaminated layer. The environmental impacts of these pollutants are expected to continue for decades, if not centuries.

On the other hand, much can be done to minimise further pollution entering the Harbour. Action is already being taken to eliminate microbeads in cosmetics, shampoos and facial-cleansers. Improved stormwater management can significantly reduce levels of heavy metals and other pollutants. Key initiatives include the soon to be released Greater Sydney Local Land Services' Sydney Harbour Catchment Water Quality Improvement Plan. Coastal Zone Management Plans are also in place for the Lane Cove River and Parramatta River, and the Sydney Harbour (Middle Harbour/Port Jackson) plan is under development.

Significant knowledge gaps remain, not least of which is an understanding of the social and economic impacts of pollution. Other research topics of particular importance include emerging contaminants, stormwater impacts on ecosystem function and any safe and efficient means for restoring or remediating polluted sediments. These and other questions, key to the future of Sydney Harbour, are progressively being addressed by stakeholders such as the Sydney Institute of Marine Science.

APPENDIX 1

Timeline of regulatory and parliamentary events

Year	Events
1832	*Harbours Act 1832*
1833	*Sydney Police Act 1833*
1849	*Sydney Slaughter-houses Act 1849*
1850	*Sydney Abattoir Act 1850*
1850	*Sydney Sewerage Act 1850*
1853	*Sydney Sewerage Act 1853*
1860	*Abattoir Road Act of 1860*
1861	*Crown Lands Alienation Act of 1861*
1864	Select Committee on Darling Harbour and Blackwattle Bay
1866	Commission appointed to inquire into the condition of the harbour of Port Jackson
1873	*Blackwattle Bay Land Reclamation Act 1873*
1875	Inquiry into Sydney city and suburban sewerage and health board
1879	Board appointed to inquire into and report upon the condition and management of the public abattoir, Glebe Island
1880	*Nuisances Prevention Act 1875*
1880	Royal Commission to inquire into and report upon the actual state and prospect of the fisheries of this Colony
1882	Royal Commission to inquire into the nature and operations of, and to classify noxious and offensive trades, within the city of Sydney and its suburbs, and to report generally on such trades
1887	Standing Committee of the Legislative Council on site for noxious trades
1892	Standing Committee on Public Works: Inquiry into the expediency of extending the railway to Darling Island, the construction of wharfage accommodation at that place, the reclamation of certain foreshores around Darling Island, and the resumption of land in connection therewith.
1901	*Sydney Harbour Trust Act 1901*
1918	Royal Commission of inquiry on the Homebush abattoirs and on the Meat Industry Act, 1915
1927	*Oil in Navigable Waters Act 1927*
1930	*Reclamation Act 1930*
1935	*Maritime Services Act 1935*
1941	Pollution of Navigable Waters Regulations 1941, under the *Navigation Act 1901*
1953	*Maritime Services (Amendment) Act 1953*
1955	Navigable Waters (Anti-Pollution) Regulations 1955, under the *Maritime Services Act 1935.* Provision for this type of regulation was introduced to the original Act by the *Maritime Services (Amendment) Act 1953*
1960	*Prevention of Oil Pollution of Navigable Water Act 1960*

1970	Water pollution in Australia [Senate Select Committee on Water Pollution]
1970	*Clean Waters Act 1970*
1970	*State Pollution Control Commission Act 1970*
June 1993	Joint Select Committee upon the Sydney Water Board: Issues Paper
April 1994	Joint Select Committee upon the Sydney Water Board
Dec 1997	Legislative Council Select Committee on the Proposed Duplication of North Head Sewerage Tunnel
April 2000	Inquiry into Oil Spills in Sydney Harbour: Interim Report [Legislative Council General Purpose Standing Committee No. 5]
May 2001	Inquiry into Oil Spills in Sydney Harbour: Final Report [Legislative Council General Purpose Standing Committee No. 5]
June 2002	Redevelopment and remediation of the Rhodes Peninsula [Legislative Council Standing Committee on State Development]
July 2003	Proposed remediation of the former Allied Feeds site, Rhodes [Commission of Inquiry]
2005	Sydney Harbour Foreshores Area Development Control Plan 2005
2005	Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005
Sept 2008	The former uranium smelter site at Hunter's Hill [Legislative Council General Purpose Standing Committee No. 5]